Annual Report

Leibniz-Institut für Kristallzüchtung

im Forschungsverbund Berlin e.V.

2023

ikz

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2023

Preface

Liebe Leserinnen und Leser,

das Jahr 2023 war für unser Institut eines der wirtschaftlich erfolgreichsten Jahre seiner Geschichte. Der Hauptgrund dafür ist der Start des IKZ Sondertatbestandes "Kristalltechnologie für Technologie-Souveränität".

Das IKZ erweitert seine Strategie in Richtung Forschung und Entwicklung (F&E) von kristallinen Prototypmaterialien für Elektronik und Photonik. Dies beinhaltet die Herstellung und Lieferung von präzisen Kristallprototypen in kleinem Maßstab an Technologiepartner zur Evaluierung und zum Benchmarking neuer Technologien.

Das IKZ erhält ab 2023 jährlich rund 2,2 Millionen € zusätzlich zu seinem Kernbudget. Diese finanziellen Mittel werden es uns ermöglichen, das IKZ als einzigartige Forschungseinrichtung in Europa und Deutschland für die Technologieentwicklung auf der Basis innovativer Kristalle zu positionieren. Um diese Strategie in die Praxis umzusetzen, haben wir im Jahr 2023 zwei große Projekte begonnen: Zum einen haben wir das IKZ Kristallprototypenlabor für Oxide & Fluoride aufgebaut. Hier wird an speziellen Wachstumsstationen das Wachstum spezifischer Kristalle von Oxiden und Fluoriden untersucht und im Hinblick auf die von den Technologiepartnern gewünschten Parameter optimiert. Zweitens wird das IKZ Kristallpräparationslabor um einen zweigeschossigen Laborbau erweitert, der in die Kristallzüchtungshalle des IKZ integriert wird. Wir benötigen diese zusätzlichen Kompetenzen in der Kristallpräparation, um unseren Technologiepartnern und Kunden hochpräzise Kristallkomponenten zu liefern.

Neben diesem strategischen Förderprogramm von Bund und Ländern war das IKZ im Jahr 2023 auch bei der Einwerbung weiterer Projektmittel erfolgreich: Insgesamt freuten sich die IKZ-Wissenschaftlerinnen und Wissenschaftler über die Bewilligung von Projektmitteln der öffentlichen Hand und der Industrie im Gesamtwert von rund 4,1 Mio. €. Diese wissenschaftlich-technischen Projekte werden auch in den kommenden Jahren im Mittelpunkt der Forschungs- und Entwicklungsaktivitäten des IKZ stehen. Zweifellos waren die gesellschaftlichen und politischen Rahmenbedingungen für Bildung, Forschung und Entwicklung in Deutschland im Jahr 2023 schwierig. Der Inflationsdruck im Jahr 2023 erhöht die Kosten auf fast allen Ebenen. Hauptkostentreiber für das IKZ im Jahr 2023 waren die gestiegenen Personalkosten in einer Größenordnung von 10 % (basierend auf den Ergebnissen des neu verhandelten öffentlichen Tarifsystems) sowie Steigerungen bei allen Arten von Verbrauchsmaterialien und Baukosten. Um wettbewerbsfähig zu bleiben, müssen wir auf diese Herausforderungen mit einem agilen Management und modernsten wissenschaftlichen und technologischen Ideen reagieren. Und das haben wir getan!

Auf der Grundlage der oben erwähnten erweiterten IKZ-Strategie und dank substanzieller Finanzierungserfolge konnten wir das IKZ im Jahr 2023 nicht nur voll funktionsfähig halten, sondern auch ein weiteres Wachstum unseres Instituts anstreben und realisieren. Wir haben neue Mitarbeiterinnen und Mitarbeiter eingestellt und unseren wissenschaftlichen und technologischen Output entsprechend erhöht. Ein wichtiges Engagement ist die Ausbildung junger Studenten im Bereich der Festkörperphysik und -chemie. Die Zahl der Promovierenden am IKZ nähert sich im Jahr 2023 der Zahl von 30 Personen, ein Wert, der dreimal so hoch ist wie die durchschnittliche Zahl der Promovierenden im vorangegangenen Evaluierungszeitraum unseres Instituts (2013-2018). Darüber hinaus wird jedes Jahr eine hohe Anzahl von Bachelor- und Masterarbeiten von unseren Wissenschaftlern betreut und abgeschlossen. Die Absolventen des IKZ haben in der Regel keine Schwierigkeiten, einen Arbeitsplatz zu finden und sind in einem breiten Spektrum von Bereichen tätig (Industrie, Wissenschaft, Beratung, Verwaltung, Bildung). Angesichts dieser verstärkten Aktivitäten in Wissenschaft und Technologie müssen wir auch unser administratives und technisches Personal aufstocken. Wir haben Ende 2023 eine Reihe von Stellen in diesen Bereichen ausgeschrieben und hoffen, diese Stellen Anfang 2024 besetzen zu können, um unsere Teams zu verstärken.

Hinsichtlich der strategischen Ausrichtung des IKZ in der EU und in Deutschland wird die vorhandene Gebäudeinfrastruktur immer mehr zum limitierenden Faktor. Seit 2018 haben wir eine große Anzahl an Baumaßnahmen durchgeführt, um die Nutzung der Gebäudeinfrastruktur zu verdichten und zu optimieren. Viele Labore wurden modernisiert und saniert. Diese Maßnahmen sind dringend notwendig, aber es gibt natürlich auch Grenzen: Die Gebäudeinfrastruktur erlaubt lediglich eine gewisse Versorgung mit Strom und technischen Medien. Darüber hinaus nähert sich das Gebäude der Grenze seiner Lebensdauer (>30 Jahre), so dass die Instandhaltungskosten steigen. Die Büroflächen sind begrenzt und nur durch eine moderne Organisation der Arbeitszeit (z.B. mobiles Arbeiten & in Zukunft nicht personalisierte Büroflächen) sehen wir eine gute Chance, unseren Mitarbeiterinnen und Mitarbeitern auch in Zukunft eine adäquate Qualität an Arbeitsplätzen zu bieten.

Mein Dank gilt allen Kolleginnen und Kollegen im IKZ, die das Institut mit ihrem täglichen Engagement unterstützen! Viel Spaß beim Lesen des IKZ-Jahresberichtes 2023 mit vielen spannenden wissenschaftlichen & technologischen Erfolgen.

Thomas Schroeder

Preface

Dear Readers,

2023 was one of the most financially successful years in the history of our institute. The main reason is given by the start of IKZ´s extraordinary item of expenditure ´Crystal Technology for Technology Sovereignty`. IKZ extends its strategy towards research & development (R&D) of crystalline prototype materials for electronics & photonics. It implies the small-scale manufacturing & delivery of precise crystal prototypes to technology partners for evaluation & benchmarking of new technologies. Since 2023, IKZ receives annually around 2.2 million € in addition to its core budget. These financial means will allow us to position IKZ as the unique R&D platform in Europe & Germany for technology development based on innovative crystals. We started two major projects to put this strategy in practice in 2023: Firstly, we built up the IKZ Crystal Prototyping Laboratory for Oxides & Fluorides. Here, on dedicated growth stations, the growth of specific crystals of oxides and fluorides is investigated and optimized with respect to parameters requested by the technology partners. Secondly, the IKZ Crystal Preparation Laboratory will be extended by a two-floor laboratory construction. This structure will be implemented into IKZ´s Crystal Growth Hall. We need these additional crystal preparation skills to deliver highly precise crystal components to technology partners & customers. Besides this strategic funding program by federal and state government bodies, IKZ was also successful on acquiring further project funds in 2023: In total, IKZ scientists were happy to receive the approval of public & industrial project funds with a total value of about 4.1 million €. These science & technology projects will be at the very heart of IKZ´s research & development activities in the coming years.

Without doubt, societal & political boundary conditions for Germany´s education & research & development were difficult in 2023. Inflation pressure raised costs on almost all levels. In 2023, main cost drivers for IKZ were the increase in staff costs on the scale of 10 % (based on the results of the newly negotiated public salary system) plus increases on all kind of consumables & construction costs. Certainly, we need to respond to these challenges by an agile management and state-of-the-art scientific & technological ideas to stay competitive. So we did! Based on the above mentioned extended IKZ strategy & substantial funding successes, we could keep IKZ not only fully operational but we targeted & realized also further growth of our institute. We hired new staff and increased accordingly our scientific & technological output. An important commitment is the education of young students in the fields of solid-state physics & chemistry. In 2023, IKZ´s number of PhD students approached about 30 persons, a value three times higher than the average number of PhD students in our institute´s previous evaluation period (2013-2018). Furthermore, a high number of B.Sc. & M.Sc. theses is supervised by our scientists and finished every year. IKZ´s alumni face no problems in general to find jobs and target a wide spectrum of activities (industry, academia, consulting, administration, education). Given these increased activities in science & technology, we also need to scale our administrative & technical staff. At the end of 2023, we announced a number of positions in these areas and hope to fill these vacancies to strengthen our teams early 2024.

The limiting factor for IKZ´s strategic role in EU & Germany becomes more & more the given building infrastructure. Since 2018, we carried out a high number of construction activities to densify & optimize the use of the building infrastructure; e.g. many laboratories were modernized and refurbished. These measures are highly necessary but there are certainly hard limits: The building infrastructure allows for a certain supply of power & media and the building is furthermore approaching its lifetime limit (>30 years) so that maintenance costs increase. Office spaces are limited and only by a modern organization of worktime (e.g. mobile work & in future non-personalized office space), we see a good chance to offer reasonable quality in work space for our employees in future.

Let me thank all our colleagues at IKZ who support the institute with their daily commitment!
Enjoy reading the IKZ Annual Report 2023 with many exciting scientific & technological achievements.

Thomas Schroeder

Content

The Institute

Photo: Sebastian Rost Fotografie

Leibniz-Institut für Kristallzüchtung im Forschungsverbund Berlin e.V.

Founded 1992
Part of Forschungsverbund Berlin e.V.
Member of the Leibniz Association

Das Leibniz-Institut für Kristallzüchtung (IKZ)

ist ein internationales Kompetenzzentrum für Wissenschaft & Technologie sowie Service & Transfer im Bereich kristalliner Materialien. Das Spektrum der Forschung und Entwicklung reicht dabei von Themen der Grundlagen- und angewandten Forschung bis hin zu vorindustriellen Forschungsaufgaben.
Kristalline Materialien sind technologische Schlüsselkomponenten zur Realisierung von elektronischen und photonischen Lösungen für gesellschaftliche Herausforderungen. Hierzu gehören künstliche Intelligenz (Kommunikation, Sensorik etc.), Energie (erneuerbare Energien, Energiewandlung etc.) und Gesundheit (medizinische Diagnostik, moderne chirurgische Operationsinstrumente etc.). Das IKZ erarbeitet Innovationen in kristallinen Materialien durch eine kombinierte Expertise im Haus, bestehend aus Anlagenbau, numerischer Simulation und Kristallzüchtung, um so kristalline Materialien höchster Qualität und mit maßgeschneiderten Eigenschaften zu erforschen.

Zusammen mit Partnern aus Instituten mit angegliederten Technologie-Plattformen sowie Industrieunternehmen treibt das Institut künftig auch verstärkt Innovationen durch kristalline Materialien voran. Diese umfassen die zuverlässigen Evaluierungen und Bewertungen innovativer kristalliner Prototypen-Materialien für disruptive Technologieansätze.

Arbeitsschwerpunkte des Institutes sind:

- Entwicklung von Züchtungs-, Bearbeitungs- und Charakterisierungsverfahren für Massivkristalle sowie kristalline Gebilde mit Abmessungen im Mikro- und Nanometerbereich sowie von materialübergreifenden Kristallzüchtungstechnologien
- Bereitstellung von Kristallen mit besonderen Spezifikationen für Forschungs- und Entwicklungszwecke
- Modellierung und Erforschung der Kristallwachstums- und Kristallzüchtungsprozesse
- Experimentelle und theoretische Untersuchungen zum Einfluss von Prozessparametern auf Kristallzüchtungsvorgänge und Kristallqualität
- Erforschung von Verfahren zur Kristallbearbeitung und der dabei ablaufenden Vorgänge

The Leibniz Institute for Crystal Growth

is an international competence center for science & technology as well as service & transfer for crystalline materials. The R&D activities cover basic and applied research up to pre-industrial development.
Crystalline materials are the key to the realization of electronic and photonic solutions to social challenges. This includes artificial intelligence (communication, sensor technology, etc.), energy (renewable energies, energy conversion etc.) and health (medical diagnostics, modern surgical instruments etc.). The IKZ develops innovations in crystalline materials by combining in-house expertise in equipment engineering, numerical simulation and crystal growth to provide highest quality crystalline materials with tailored properties.

In the future, the institute will also intensify its efforts to promote innovation by crystalline materials in cooperation with partners from technology platforms as well as industrial companies. This includes the reliable evaluation and benchmarking of innovative crystalline prototype materials for disruptive technology approaches.

The research and service tasks of the institute include:

- Development of technologies for growth, processing and characterization of bulk crystals and of crystalline structures with dimensions in the micro- and nanometer range and of comprehensive growth technologies
- Supply of crystals with non-standard specifications for research and development purposes
- Modelling and investigation of crystal growth processes
- Experimental and theoretical investigations of the influence of process parameters on crystal growth processes and crystal quality
- Development of technologies for the chemo-mechanical processing of crystalline samples and scientific investigation of related processes

The Institute

- Physikalisch-chemische Charakterisierung kristalliner Festkörper und Entwicklung geeigneter Methoden bis hin zur atomaren Ebene; Aufklärung des Zusammenhangs zwischen Struktur und Eigenschaften kristalliner Materialien

- Entwicklung und Bau von Anlagenkomponenten für die Züchtung, Bearbeitung und Charakterisierung von Kristallen

Die weitere Materialforschung in Richtung Anwendung ermöglicht verstärkt auch Innovationen durch kristalline Materialien:

- Kristall-Prototypenforschung zur zuverlässigen Bewertung innovativer, konfektionierter Kristalle für elektronische und photonische Schlüsseltechnologien

- Prototypen-Lieferfähigkeit neuartiger Kristalle bis zur Kleinserie – in der gewünschten Konfektionierung und Spezifikation – zur zuverlässigen Technologie-Forschung und Vorbereitung der Markteinführung

- Entwicklung von Wafering-Prozessen für neue Materialien, Feinbearbeitung optischer Spezialkristalle

Materialien

- Halbleiter mit großem Bandabstand (Oxide, Aluminiumnitrid) für Hochtemperatur-, Leistungs- und Optoelektronik

- Oxidische und fluoridische Kristalle für Lasertechnik, Optik, Sensorik und Akustoelektronik

- Silizium-Kristalle für Mikro- und Leistungselektronik und Photovoltaik

- Isotopenreine Halbleiter (Silizium und Germanium) für die Quantentechnologie

- Silizium/Germanium Kristalle für Strahlungsdetektoren und Beugungsgitter, kristalline Si/Ge-Schichten für thermoelektrische Anwendungen

- Ferroelektrische und halbleitende Oxidschichten für die Mikro- und Leistungselektronik, Sensoren und Datenspeicher

- Physico-chemical characterisation of crystalline solids and development of suitable methods; investigation of the correlation between crystalline structures and properties

- Development and construction of components for growth, processing and characterization of crystals

The further materials research towards applications will drive innovations by crystalline materials:

- Crystal prototypes development for the reliable benchmarking of innovative crystals with tailored properties for key technologies in electronics and photonics

- Prototype supply of innovative crystals up to small-scale batches – with tailored properties and specifications – for reliable technology research, including preparations for market introduction

- Development of wafering processes for new materials, fine processing of special optical crystals.

Materials presently in development:

- Wide band gap semiconductors (aluminium nitride, oxides) for high temperature, power- and optoelectronics

- Oxide and fluoride crystals for acousto-electronics, laser-, opto- and sensor technology

- Silicon for power electronics and photovoltaics

- Isotopically pure semiconductors (silicon and germanium) for quantum technology

- Gallium arsenide for wireless communication and in high-frequency technology

- Silicon/germanium-crystals for radiation detectors and diffraction gratings, crystalline Si/Ge layers for thermoelectric devices

- Ferroelectric and semiconducting oxide layers for micro- and power electronics, sensor applications or data storage

Das IKZ als familienfreundlicher Arbeitgeber

Das IKZ möchte seinen Beschäftigten ein offenes, kooperatives und familienfreundliches Arbeitsumfeld bieten. Das Institut unterstützt daher seine Mitarbeiterinnen und Mitarbeiter bei der Vereinbarkeit von Arbeit und Familie, z.B. durch flexible Regelungen zur täglichen Arbeitszeit oder durch variable Regelungen zu Teil- und Vollzeitbeschäftigung.
Seit 2015 ist das Institut zertifiziert durch das audit berufundfamilie. Damit verbunden hat es Ziele einer familienbewussten Personalpolitik definiert und sich verpflichtet. In den folgenden drei Jahren haben wir die in diesem Prozess definierten Maßnahmen umgesetzt. Die Zertifizierung wurde 2018, 2021 und erneut im Jahr 2024 an das Institut vergeben.

Das audit steht unter der Schirmherrschaft der Bundesfamilienministerin und des Bundeswirtschaftsministers, nähere Informationen finden sich unter
www.beruf-und-familie.de

IKZ as family-friendly employer

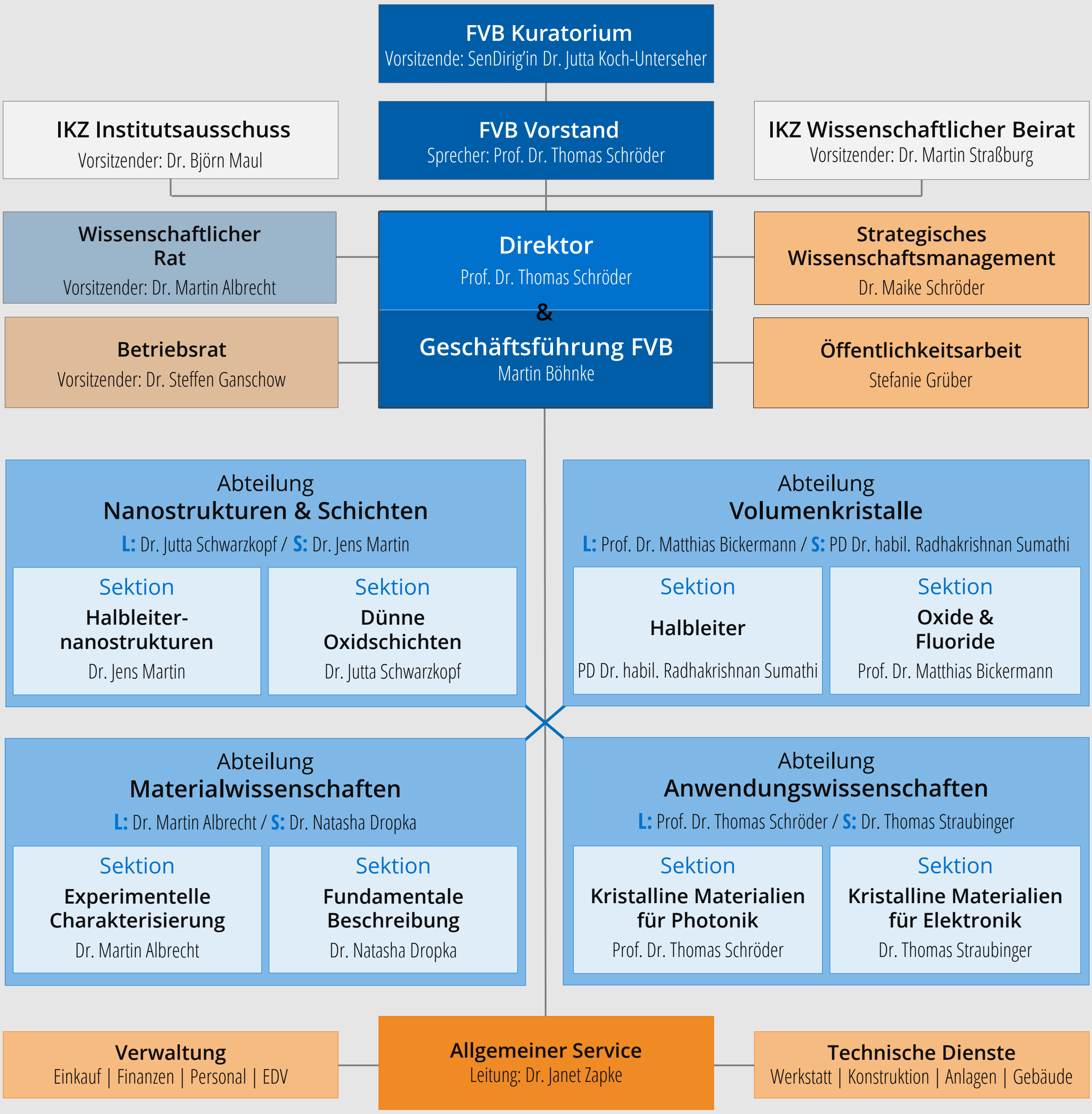
The institute intends to create a co-operative and open working environment for all employees. It places special emphasis on the reconcilability of job and family, offering flexible working time models as well as full or part-time employments. In 2015, the institute has been awarded the audit berufundfamilie certificate for its family-friendly human resources policy. During the following three years, we have been implementing the objectives defined in this process. The certification has been renewed in 2018, 2021 and in 2024.

The certificate is issued under the auspices of the German Federal Minister for Families and the German Federal Economics Minister.

More information is available under
wwww.beruf-und-familie.de

Zertifikat seit 2015
audit berufundfamilie

Organigramm
Organisation Chart
as of 30 June 2024



Wissenschaftlicher Beirat
Scientific Advisory Board
as of 30 June 2024

Beiratsvorsitzender
Chair

Dr. Martin Straßburg
ams-Osram International GmbH
Regensburg, Germany

Mitglieder
Members

Prof. Claudia Draxl
Humboldt-Universität zu Berlin
Berlin, Germany

Prof. Dr. Jan Ingo Flege
Brandenburgische Technische Universität
Cottbus- Senftenberg (BTU)
Cottbus, Germany

Dr. Martin M. Frank
IBM, Thomas J. Watson Research Center
Yorktown Heights, New York, USA

Dr. Roger Loo
Imec
Leuven, Belgium

Prof. Dr. Siddha Pimputkar
P.C. Rossin College of Engineering and Applied Science
Lehigh University
Bethlehem, PA, USA

Dipl.-Ing. Michael Rosch
Freiberger Compound Materials FCM
Freiberg, Germany

Dr. Georg Schwalb
Siltronic AG
Burghausen, Germany

Prof. Dr. Thomas Südmeyer (vice chair)
University of Neuchâtel
Physics Institute
Neuchâtel, Switzerland

Vertreter des Landes Berlin
Representative of the State of Berlin

Dr. Björn Maul
Referatsleiter Natur-, Material- und
Lebenswissenschaften
Senatsverwaltung für Wissenschaft, Gesundheit
und Pflege
Berlin, Germany

Vertreter der Bundesrepublik Deutschland
Representative of the Federal Republic of Germany

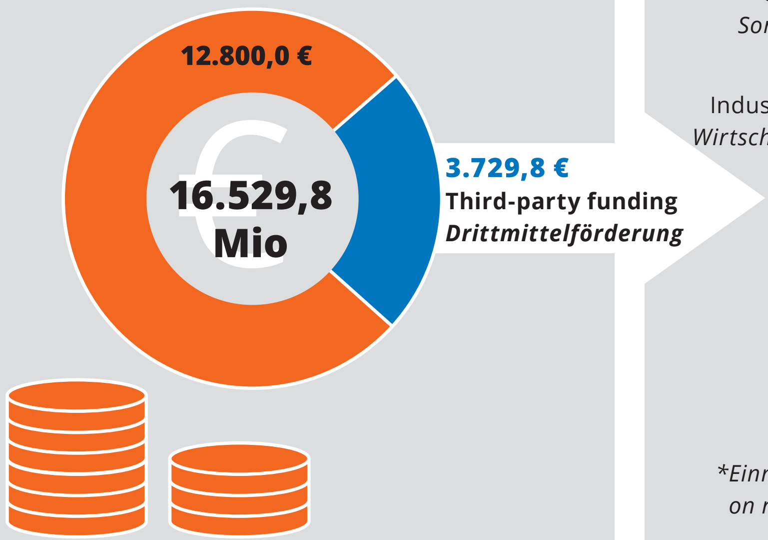
Christoph Schwickart
Bundesministerium für Bildung und Forschung BMBF
Referat 513
„Vernetzung und Sicherheit digitaler Systeme"
Bonn/Berlin, Germany

The Institute

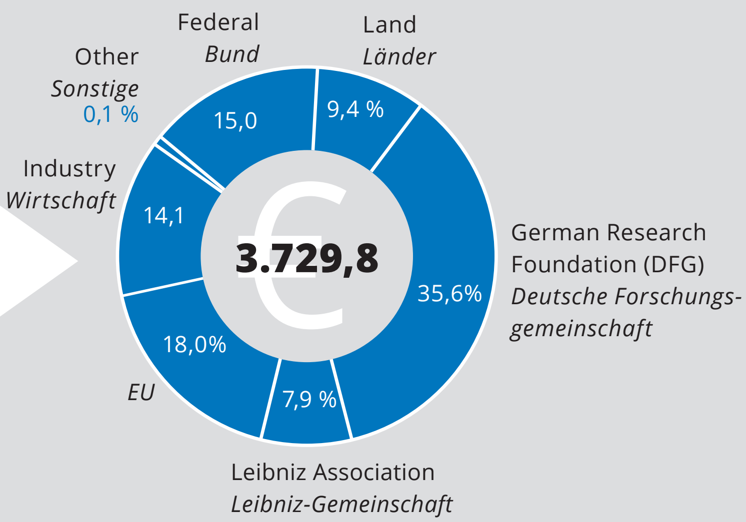
2023 in Zahlen
2023 in figures

Budget Gesamt
Total

Institutional funding
Institutionelle Förderung



Drittmittelförderung*
Third-party funding



**Einnahmen*
on revenue basis

Lehre
Education

4 Defended doctoral theses
Abgeschlossene Promotionsarbeiten

30 Ongoing dissertations
Laufende Promotionsvorhaben

8 Master theses completed
Abgeschlossene Masterarbeiten

Publikationen
Publications

89 Articles in peer-reviewed journals and book chapters
Artikel in referierten (peer-review) Journalen und Buchkapitel

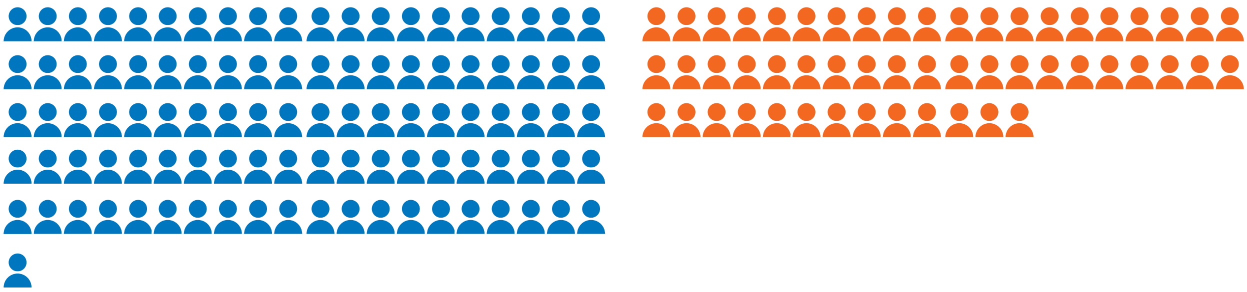
Stichtag 31.12.2023

Internationalisierung
Internationalization

Staff members from 18 countries
Beschäftigte aus 18 Ländern

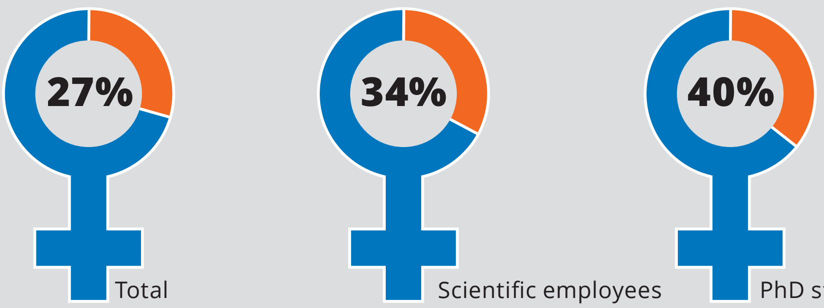
Personal gesamt
Staff total

154



101 Scientific employees
Wissenschaftliche Mitarbeiter/innen

53 Infrastructure personnel
Infrastrukturpersonal



Total
Gesamt

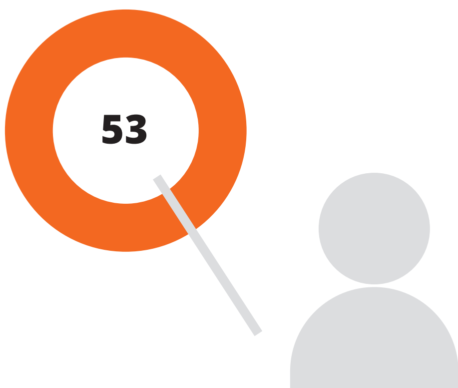
Scientific employees
Wissenschaftliche Mitarbeiterinnen

PhD students
Doktorandinnen

Frauenanteil
Female proportion

Eingeladene Beiträge
Invited Contributions

At national and international conferences, workshops, seminars
Auf nationalen und internationalen Konferenzen, Workshops, Seminaren



Technologiesouveränität
Technological Sovereignty

Kristalltechnologie zur technologischen Souveränität – ein Beitrag des Leibniz-Strategieforums „Technologische Souveränität“

Diverse Veröffentlichungen im Jahr 2023 zeigen die Bemühungen der Politik um einen breiten, partizipativen Diskurs zur Umsetzung technologischer Souveränität. Hier sind u. a. die *Zukunftsstrategie Forschung und Innovation*, die *Chinastrategie der Bundesregierung* sowie die *nationale Sicherheitsstrategie* zu nennen. Oft jedoch verfügen die Ministerien nur unzureichend über die gebührende wissenschaftliche Expertise in den notwendigen Forschungsgebieten der Schlüsseltechnologien, die zur Erreichung und Sicherung der technologischen Souveränität Deutschlands und Europas vonnöten sind.

Das Leibniz-Strategieforum ist somit die Antwort der Leibniz-Gemeinschaft, den gesellschaftlichen Transformationsprozess der technologischen Souveränität / strategischen Autonomie im Bereich der Forschung & Entwicklung & Innovation (F & E & I) mitzugestalten. Es berät dabei das Leibniz-Präsidium in enger Abstimmung. Dabei wird das Forum, getragen von den natur- und ingenieur-wissenschaftlichen Instituten, die Entwicklung von innovativen Schlüsseltechnologien von der Grundlagenforschung bis zu Prototypen zum weiteren Transfer in die Wirtschaft bereitstellen. Das Forum gliedert sich in sechs naturwissenschaftliche Cluster, in denen Leibniz-Institute führende Beiträge zur Erreichung und Sicherung der technologischen Souveränität Deutschlands und Europas liefern können: Gesundheitstechnologien, Künstliche Intelligenz, Materialien für die Digitalisierung, Quantentechnologien, Wasserstoffwirtschaft und Kommunikation & Mikroelektronik. Diese sind Teil der 2021 vom BMBF identifizierten Schlüsseltechnologien (BMBF-Dokument: „Technologisch souverän die Zukunft gestalten“). Zwecks einer holistischen Herangehensweise integriert das Strategieforum synergetisch das Wissen der Leibniz-Gemeinschaft im Bereich der Wirtschafts- und Sozialwissenschaften. Der zugehörige Cluster wurde 2023 unter der Leitung von Prof. Dirk Dohse vom IfW Kiel etabliert (Abb. 1).

Crystal technology for technological sovereignty – a contribution from the Leibniz Strategy Forum ‘Technological Sovereignty’

Various publications in 2023 show the efforts of politicians to engage in a broad, participatory discourse on the realisation of technological sovereignty. These include the Future Strategy for Research and Innovation, the Federal Government‘s China Strategy and the National Security Strategy. However, the ministries often do not have sufficient scientific expertise in the necessary research areas of key technologies that are required to achieve and secure technological sovereignty in Germany and Europe.

The Leibniz Strategy Forum is thus the Leibniz Association’s answer to helping organise the social transformation process of technological sovereignty / strategic autonomy in the field of research & development & innovation (R & D & I). It advises the Leibniz Presidium in close consultation. The Forum, driven by the scientific and engineering institutes, will provide the development of innovative key technologies from basic research to prototypes for further transfer to industry. The forum is organised into six scientific clusters in which Leibniz Institutes can contribute to the achievement and protection of technological sovereignty in Germany and Europe: Health Technologies, Artificial Intelligence, Materials for Digitalisation, Quantum Technologies, Hydrogen Economy and Communication & Microelectronics. These are part of the key technologies identified by the BMBF in 2021 (BMBF document: ‘Technologisch souverän die Zukunft gestalten’). In order to ensure a holistic approach, the strategy forum synergistically integrates the knowledge of the Leibniz Association in the field of economic and social sciences. The associated cluster was established in 2023 under the leadership of Prof Dirk Dohse from IfW Kiel (Fig. 1).

The Institute

Abb. 1:
Aufbau des Leibniz-Strategieforums „Technologische Souveränität“: Sechs Schlüsseltechnologien - Gesundheitstechnologien, Künstliche Intelligenz, Materialien für die Digitalisierung, Quantentechnologien, Wasserstoffwirtschaft und Kommunikation & Mikroelektronik – werden holistisch unter Einbezug des neu etablierten Clusters Sozial- und Wirtschaftswissenschaften betrachtet.

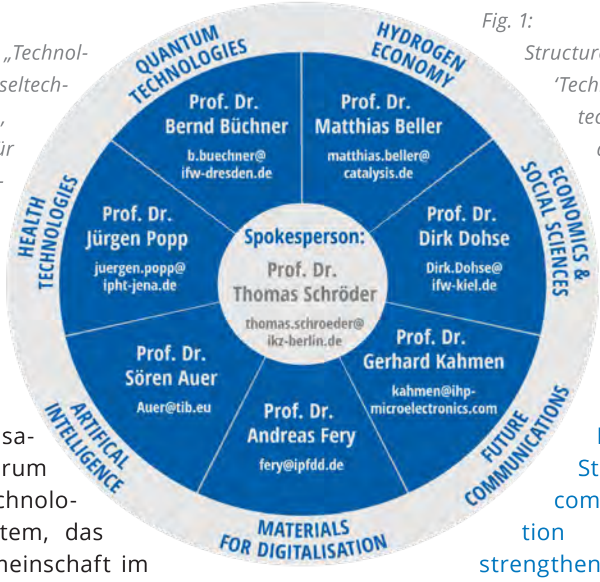


Fig. 1:
Structure of the Leibniz Strategy Forum ‘Technological Sovereignty’: Six key technologies – health technologies, artificial intelligence, materials for digitalisation, quantum technologies, hydrogen economy and communication & microelectronics – are considered holistically, including the newly established cluster of social and economic sciences.

Zusammenfassend lässt sich sagen: Das Leibniz-Strategieforum „TS“ bietet ein komplettes Technologie- und Innovationsökosystem, das die Beiträge der Leibniz-Gemeinschaft im Transformationsprozess der TS bündelt, stärkt und sichtbar in Wirtschaft, Gesellschaft und Politik nach außen positioniert (Abb. 2). Diese ganzheitliche Vorgehensweise wird zunächst am Beispiel von ausgewählten Leuchtturmprojekten demonstriert, die gesellschaftliche Fragestellungen innerhalb der ausgewählten Schlüsseltechnologien betreffen. So identifizieren jeweils 2-3 Leibniz-Institute in einer Schlüsseltechnologie ein innovatives Leuchtturmprojekt mit international anerkanntem Potenzial für künftige wirtschaftliche Verwertungen. Die Bearbeitung erfolgt basierend auf der bestehenden komplementären Expertise der beteiligten Institute entlang der Wertschöpfung. Weitere benötigte Kompetenzen können ggf. in freier Wahl mit Partnern außerhalb der Leibniz-Gemeinschaft aus der Wissenschaft sowie der Wirtschaft eingebunden werden. Auf diese Weise wird eine kritische Masse erreicht, um substanzielle und synergetische Beiträge zur Erreichung und Sicherung der technologischen Souveränität Deutschlands und Europas mit einer angemessenen Durchschlagskraft und über den Handlungsspielraum eines einzelnen Leibniz-Instituts hinaus zu leisten.

Ein Beispiel aus den Ingenieurwissenschaften an der Schnittstelle zwischen Elektronik und Photonik sei genannt: Die Entwicklung von elektronisch-photonischen integrierten Schaltkreisen für leistungsstarke Hochfrequenzanwendungen aus einer Kombination von III-V- und Silizium-Halbleiterschaltungen ist sicher ein klassisches, lang verfolgtes Forschungsfeld.
Produktanwendungen im Bereich 5G & 6G erzwingen nun mehr und mehr die schrittweise Markteinführung dieser komplexen Technologien. Im Bereich der Volumenkristalle unterstützen wir die Indiumphosphid, Kristall- & Waferentwicklung gemeinsam mit dem führenden III-V-Kristallunternehmen Freiberger Compound Materials (FCM). Neben dem Einsatz als Wafer gewinnen auch InP-Bonding-Verfahren auf Silizium dank Fortschritten in der Aufbau- und Verbindungstechnik an Bedeutung für elektronisch-photonische integrierte Schaltungen.

In conclusion, the Leibniz Strategy Forum ‘TS’ offers a complete technology and innovation ecosystem that bundles, strengthens and visibly positions the Leibniz Association’s contributions to the transformation process of TS in the economy, society and politics (Fig. 2). This holistic approach is initially demonstrated using the example of selected pilot projects that address social issues within the selected key technologies. In each case, 2-3 Leibniz Institutes identify an innovative pilot project in a key technology with internationally recognised potential for future commercial exploitation. The work is based on the existing complementary expertise of the participating institutes along the value chain. Other required competences can be integrated in free choice with partners outside the Leibniz Association from science and industry. In this way, a critical mass is reached in order to contribute substantially and synergistically to achieve and secure the technological sovereignty of Germany and Europe with an appropriate impact and beyond the scope of an individual Leibniz Institute.

An example from the engineering sciences at the interface between electronics and photonics should be mentioned: The development of electronic-photonic integrated circuits for high-performance high-frequency applications from a combination of III-V and silicon semiconductor circuits is certainly a classic, long-pursued field of research. Product applications in the area of 5G & 6G are now increasingly forcing the gradual market introduction of these complex technologies. In the field of volume crystals, we support indium phosphide, crystal and wafer development together with the leading III-V crystal company Freiberger Compound Materials (FCM). In addition to their use as wafers, InP bonding processes on silicon are also playing an increasingly important role in electronic-photonic integrated circuits thanks to advances in assembly and bonding technology. The IKZ is developing the InP microstructures, and the corresponding R&D is being pursued by other Leibniz institutes with technology platforms as part of the pilot project.

The Institute

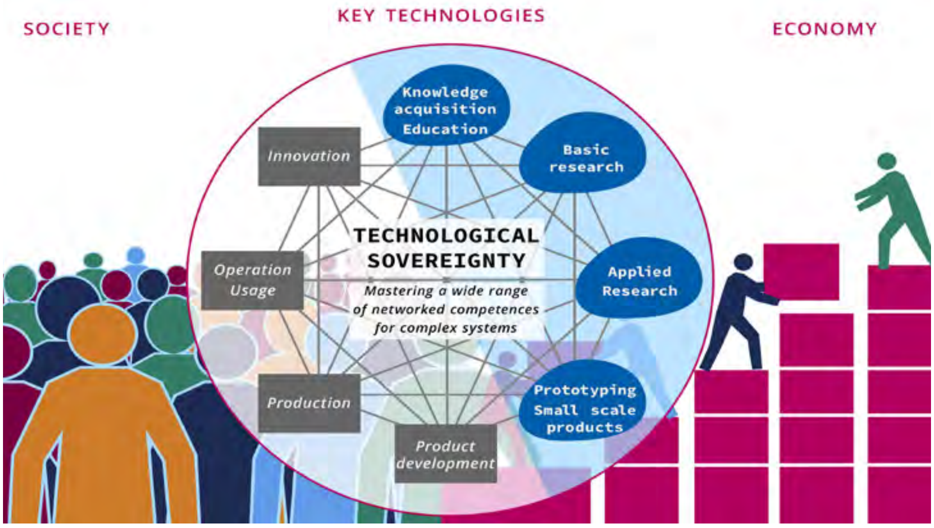


Abb. 2:
Die Stärke der Leibniz-Gemeinschaft, die sie von anderen großen Wissenschaftsorganisationen hervorhebt, liegt in der Fähigkeit, die Wertschöpfungskette von der Grundlagenforschung bis zur Entwicklung von Prototypen abzudecken (blau hinterlegter Teil im Kreis). Von besonderer Bedeutung ist auch der von Anfang an mitgedachte Einbezug der Gesellschaft in die Entwicklung neuer Technologien sowie die Anschlussfähigkeit der Entwicklungen insbesondere an Partnerschaften mit höheren TRL-Kapazitäten.

Fig. 2:
The strength of the Leibniz Association, which differentiates it from other large scientific organisations, is its ability to cover the value chain from basic research to the development of prototypes (blue part of the circle). Of particular importance is also the inclusion of society in the development of new technologies from the outset and the ability to connect developments to partnerships with higher TRL capacities in particular.

Das IKZ erarbeitet die InP-Mikrostrukturen, die entsprechende F&E wird im Rahmen des Leuchtturmprojektes von weiteren Leibniz-Instituten mit Technologie-Plattformen verfolgt. Die Sozial- und Wirtschaftswissenschaften vervollständigen derartige Entwicklungsprozesse durch Betrachtung von Fragen wie z. B. die Verfügbarkeit von Fachkräften, Rahmenbedingungen für das Wachstum junger, technologieorientierter Unternehmen, die Rolle der Digitalisierung und die digitalen Kompetenzen in der Bevölkerung sowie die Offenheit und Akzeptanz gegenüber neuen Technologien im Zentrum.

Aktivitäten des Forums im Jahr 2023

Förderung
Aktive Teilnahme am Format „Leibniz-Labs“;
Einreichung des Antrags
„Leibniz-Innovations-Inkubator“ (seit März 2023)

Events
Aktive Teilnahme an den Veranstaltungen (Auswahl)
VDI Fachgespräch „Materialien für Quanten-technologien“ (02.03.23)
- INAM Kick Off Event 2023 (23.02.23)
- InnoNation Festival (03.05.23)
- Konferenz „Handlungssicherheit in Forschungskooperationen mit China“ (22.05.23)
- SPECTARIS-Zukunftsfestival (11.09.23)

Interviews
- Gastbeitrag in Studie zur strategischen Autonomie (Benoît d’Humières, 14.08.23)
- Gastbeitrag in der SPECTARIS-Studie zur Autonomie der Photonik (Mike Bähren, Dezember 2023)

The social and economic sciences complement such development processes by considering issues such as the availability of skilled workers, framework conditions for the growth of young, technology-oriented companies, the role of digitalisation and digital skills in the population as well as openness and acceptance of new technologies at the centre.

Activities of the forum in 2023

Funding
Active participation in the ‘Leibniz Labs’ format;
submission of the ‘Leibniz Innovation Incubator’ (since March 2023)

Events
Active participation in the following events (selection)
- VDI expert discussion ‘Materials for quantum technologies’ (02.03.23)
- INAM Kick Off Event 2023 (23.02.2023)
- InnoNation Festival (03.05.23)
- Conference ‘Security of action in research cooperation with China’ (22.05.23)
- SPECTARIS Future Festival (11.09.23)

Interviews
- Guest article in study on strategic autonomy (Benoît d’Humières, 14.08.23)
- Guest article in the SPECTARIS study on the autonomy of photonics (Mike Bähren, December 2023)

2023 im Überblick
2023 at a glance

Materialien für die Quantentechnologie

Am IKZ wurde eine neue Molekularstrahlepitaxie-Anlage für das Wachstum von kernspinfreiem Silizium und Germanium in Betrieb genommen, um Materialeigenschaften für **Quantentechnologien** zu erweitern.

Das IKZ, weltweit führend in der Züchtung solcher Kristalle, verwendet diese Materialien nun in der MBE-Anlage. Hier werden Si und Ge unter Ultrahochvakuum verdampft, um dünne Schichten auf Si-Wafern zu züchten, die als Basis für die Entwicklung neuartiger Quantenmaterialien dienen.

Materials for Quantum Technologies

At IKZ, a new molecular beam epitaxy (MBE) system for the growth of nuclear spin-free silicon and germanium was inaugurated to advance material properties for **quantum technologies**.

IKZ has been researching the processing, purification, and growth of these crystals for decades, establishing itself as a leading competence center. These unique materials are now used as source material in the MBE system, where enriched Si and Ge are evaporated under ultra-high vacuum to grow thin layers on Si wafers, serving as the basis for further technology development.

Applikationslabor für die In-Situ Elektronenmikroskopie

Das IKZ erhält 2.5 Mio € EFRE Mittel zum Aufbau eines modernen **Applikationslabors zur ‚state-of-the-art' In-Situ Elektronenmikroskopie**. Das gesamte Projektvolumen umfasst ca. 6 Mio. €, das IKZ wird aus seinem Institutshaushalt in den Jahren 2024 bis 2026 weitere 3,5 Mio. € zum Ausbau beisteuern. Das Labor wird im Sinne einer offenen Infrastruktur nicht nur Nutzer aus dem akademischen, sondern auch aus dem industriellen Umfeld unterstützen.

Application lab for in-situ electron microscopy

The IKZ receives 2.5 Mio € ERDF funds to build up a modern **application laboratory on state-of-the-art in-situ electron microscopy**. The total project volume is on the scale of 6 Mio € and IKZ will thus contribute 3.5 Mio € from its institute budget in the years 2024 to 2026. As an open infrastructure, the laboratory will not only support users from academia, but also from industry.

Alexander-von Humboldt-Forschungspreis für Prof. Kookrin Char

Professor Kookrin Char von der Seoul National University (Südkorea) hat einen der renommierten Humboldt-Forschungspreise 2023 für seine herausragenden Arbeiten auf dem Gebiet der oxidischen Heteroepitaxie und Heterostrukturen erhalten. Professor Char wurde vom Leibniz-Institut für Kristallzüchtung nominiert und wird mehrere Forschungsaufenthalte am Institut im Jahr 2023 und darüber hinaus verbringen.

Alexander-von-Humboldt Research Award for Prof. Kookrin Char

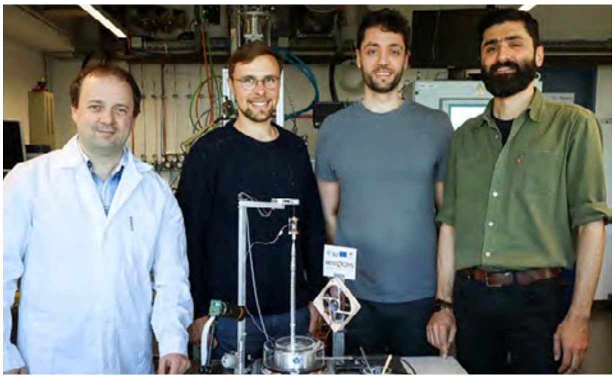
Professor Kookrin Char from the Seoul National University (South Korea) has been awarded one of the prestigious Humboldt Research Awards 2023 for his exceptional work in the field of oxide heteroepitaxy and heterostructures. Professor Char had been nominated by the Leibniz-Institut für Kristallzüchtung and is looking forward to his research stay at the institute in 2023 and beyond.

Girls' Day @ IKZ

Unter dem Motto »Arbeiten als Wissenschaftlerin, Tech-Gründerin, Mikrotechnologin: Ein Tag im Wissenschafts- und Technologiepark Adlershof« fand der **Girls' Day** dieses Jahr erstmal als gemeinsame Veranstaltung von WISTA Management GmbH, der Initiativgemeinschaft Außeruniversitärer Forschungseinrichtungen in Adlershof e. V. (IGAFA), Helmholtz-Zentrum Berlin für Materialien und Energie (HZB) und der Bundesanstalt für Materialforschung und Prüfung (BAM) statt.

Girls' Day @ IKZ

"Working as a scientist, tech founder, microtechnologist: A day at the Adlershof Science and Technology Park" was the headline of this year's **Girls' Day**, which was for the first time a joint event of WISTA Management GmbH, Initiativgemeinschaft Außeruniversitärer Forschungseinrichtungen in Adlershof e. V. (IGAFA) Helmholtz-Zentrum Berlin für Materialien und Energie (HZB) and Bundesanstalt für Materialforschung und Prüfung (BAM).



ERC Förderung für Lehrmittel

Für sein Projekt „Hands-on Materials Science for Education" (HANDSOME) wurde Dr. Kaspars Dadzis mit dem renommierten **Proof of Concept Grant des Europäischen Forschungsrats (ERC)** ausgezeichnet. Das Projekt wird mit 150.000 € für die für die Entwicklung leicht zugänglicher Lehrmittel für die Materialwissenschaft ausgestattet. Es baut auf dem ERC Starting Grant auf, mit dem Dadzis und sein Team seit 2020 einen neuen Ansatz zur Modellierung von Kristallzüchtungsprozessen entwickeln.

ERC Grant for education ressources

Dr. Kaspars Dadzis has been awarded the distinguished **Proof of Concept Grant from the European Research Council (ERC).** The project "Hands-on Materials Science for Education" (HANDSOME) will receive 150,000 Euro to develop accessible materials science education resources. The new project will build on the ERC Starting Grant, where Dadzis and his team have been working on a new approach to modelling crystal growth processes since 2020.

The Institute

IKZ @ Laser World of Photonics

Vom 27. bis 30. Juni nahm das IKZ zum ersten Mal als Aussteller an der **Laser World of Photonics** in München teil. Die renommierte Messe ist eine der führenden Veranstaltung für die Photonikindustrie und präsentiert die neuesten Innovationen in der Lasertechnologie, in Optik und Photonik-Anwendungen.

IKZ @ Laser World of Photonics

From June 27-30, IKZ participated as an exhibitor for the first time at the **Laser World of Photonics** in Munich. This prestigious trade fair is a leading event for the photonics industry, showcasing latest innovations in laser technology, optics, and photonics applications.

Stefan Püschel erhält den Optica Student Travel Grant

Stefan Püschel erhielt auf der CLEO/Europe-EQEC Konferenz 2023 den mit 500 € dotierten „Optica Student Travel Grant“. Dieser Preis wird an Erstautoren der bestbewerteten studentischen Beiträge verliehen, und wurde in diesem Jahr aus insgesamt 1759 Beiträgen ausgewählt. Stefan Püschel ist im dritten Jahr seiner Promotion in Dr. Hiroki Tanakas Gruppe am Leibniz-Institut für Kristallzüchtung (IKZ). In seinem Beitrag „Laser Cooling of an Yb:KY_3F_{10} crystal by 42 K“ berichtete er über die Laserkühlung von Festkörpern, wobei es gelang, einen Kristall durch Anti-Stokes-Fluoreszenz auf bis zu -26 °C zu kühlen.

Optica Student Travel Grant for Stefan Püschel

Stefan Püschel received the “Optica Student Travel Grant” of €500 at the CLEO/Europe-EQEC 2023 conference. This award is given to the first authors of the best-rated student contributions, and was selected this year from a total of 1759 submissions. Stefan Püschel is in the third year of his PhD in Dr. Hiroki Tanaka’s group at the Leibniz-Institut für Kristallzüchtung (IKZ). In his presentation “Laser Cooling of an Yb:KY_3F_{10} crystal by 42 K,” he reported on the laser cooling of solids, achieving a temperature reduction down to -26 °C in a crystal using anti-Stokes fluorescence.

The Institute

IKZ @ EQTC 2023

Mit seiner Forschung zu Materialien für Quantentechnologien präsentierte sich das Institut in diesem Jahr erstmals auf der **European Quantum Technology Conference EQTC 2023**. Die Konferenz zählt zu den größten Veranstaltungen der europäischen Quanten-Community und steht unter der Schirmherrschaft des europäischen Innovationsprogramms Quantum Flagship. Dr. Kevin-Peter Gradwohl, Leiter der Nachwuchsgruppe „SiGe-basierte Quantenmaterialien und Heterostrukturen" präsentierte das Institut und die Arbeiten seiner Gruppe zudem auf der Showcase Stage der Konferenz.

IKZ @ EQTC 2023

This year the institute presented its research on materials for quantum technologies for the first time at the **European Quantum Technology Conference EQTC 2023**, one of the largest events in the European quantum community and held under the auspices of the European Quantum Flagship innovation program. Dr. Kevin-Peter Gradwohl, head of the junior research group "SiGe-based Quantum Materials and Heterostructures", also presented the institute and the work of his group on the conference's showcase stage.

WODIL 2023 @ IKZ

Rund 40 Forscher aus Deutschland, Frankreich, der Tschechischen Republik, der Schweiz, Italien und Lettland kamen auf dem **12. deutsch-französischen Workshop zu Oxid-, Dielektrika- und Laser-Kristallen (WODIL 2023)** zusammen, um über die Forschung an Oxid-, Chalkogenid- und Halogenid-Einkristallen zu diskutieren. Diese werden als optische, piezoelektrische oder Laser-Materialien sowie als Substrate für piezoelektrische und oxidische elektronische Anwendungen eingesetzt. Der IKZ Doktorand Christian Rhode wurde von Crystal Research and Technology mit dem Preis für die beste Präsentation ausgezeichnet.

WODIL 2023 @ IKZ

Around 40 researchers from Germany, France, the Czech Republic, Switzerland, Italy and Latvia gathered at the **12th German-French Workshop on Oxide, Dielectric and Laser single crystals (WODIL 2023)** to discuss research involving oxide, chalcogenide and halide single crystals. These are used as optical, piezoelectric or laser materials, and as substrates for piezoelectric and oxide electronic applications. Christian Rhode, doctoral student at IKZ, received the Best Presentation award from Crystal Research and Technology.

Fraunhofer und IKZ bündeln Expertise zu Laserkristallen

Im November 2023 trafen sich das IKZ und der Fraunhofer-Verbund Light & Surfaces zu einem Austausch über das gesellschaftlich relevante Thema „**Laserkristalle: Kernkomponenten für die europäische Wirtschaft – Technologische Souveränität wiedererlangen!**“ Ziel des Treffens war es, ihre Kompetenzen entlang der Wertschöpfungskette zu bündeln und Synergien zu nutzen, um die technologische Souveränität Europas zu stärken.

Fraunhofer and IKZ combine expertise in laser crystals

In November 2023, the IKZ and the Fraunhofer Group for Light & Surfaces met to discuss the societal relevant topic of “**Laser crystals: key components for the European economy - regaining technological sovereignty!**” The aim of the meeting was to join forces along the value chain and exploit synergies in order to strengthen Europe’s technological sovereignty.

Erfolgreicher Technologietransfer von Materialien für Laseranwendungen

Das Leibniz-Institut für Kristallzüchtung und die Oxide Corporation, ein japanisches Unternehmen, das sich auf die Erforschung und Herstellung von Einkristallen und Lasergeräten spezialisiert hat, haben einen gemeinsamen Forschungs- und Entwicklungsvertrag über **den Technologietransfer von modernen einkristallinen Materialien für Laseranwendungen** geschlossen. Diese Zusammenarbeit bildet die Grundlage für weitere gemeinsame Forschungs- und Entwicklungsinitiativen mit Schwerpunkt auf kristallinen Materialien. Unser gemeinsames Ziel ist es, diese Fortschritte nahtlos in praktische Anwendungen zu integrieren, den Fortschritt in den Bereichen Laser und Optik zu fördern und auf diese Weise einen bedeutenden Beitrag zur gesellschaftlichen Weiterentwicklung zu leisten.

Successful laser materials technology transfer

Leibniz-Institut für Kristallzüchtung and Oxide Corporation, a Japanese company specializing in the research and manufacturing of single crystals and laser devices, have entered a joint research and development concerning the **technology transfer of advanced single crystalline materials for laser applications.** This collaboration sets the stage for further collaborative research and development initiatives focused on crystalline materials. Our collective aim is to seamlessly integrate these advancements into practical applications, fostering progress in the realms of lasers and optics, and in this way contributing meaningfully to societal development.

Treffen des DGKK-Arbeitskreises

Am 6. und 7. November fand am IKZ im Max-Born-Saal das Treffen des DGKK-Arbeitskreises **„Ultradünne Schichtsysteme, Wachstumskinetik und Layertransfer“** statt. Der ehemalige Arbeitskreis „Kinetik und Nanostrukturen“ hatte sich im Frühjahr neu aufgestellt, um auch eine Plattform auch für die Entwicklungen im Bereich von 2D-Schichten und Layer-Transfer zu bieten.

Meeting of the DGKK working group

On November 6th and 7th, the meeting of the DGKK working group “Ultrathin Layer Systems, Growth Kinetics, and Layer Transfer” took place at the IKZ in the Max Born Hall. The former working group “Kinetics and Nanostructures” had been reorganized in the spring to also provide a platform for developments in the field of 2D layers and layer transfer.

IKZ Sommerschule Polare Piezoelektrische Oxide

Von 6. – 8. September 2023 fand im Max-Born-Saal in Berlin-Adlershof die IKZ-Sommerschule 2023 mit dem Thema „Polare Piezoelektrische Oxide“ statt.

Sie wurde von der DFG-Forschungsgruppe 5044 „Periodische niedrigdimensionale Defektstrukturen in polaren Oxiden“ organisiert, der neben dem IKZ noch Gruppen der TU Clausthal, der Uni Gießen, der Uni Osnabrück und der TU Dresden angehören.
Den Gegenstand der Forschungsgruppe bilden polare oxidische Lithiumniobat-Lithiumtantalat-Mischkristalle als Modellsystem zur Untersuchung grundlegender materialwissenschaftlich-physikalischer Phänomene. Dazu gehören beispielsweise der Zusammenhang zwischen Defektstrukturen und dem Transport von Ladungsträgern. Etwa 40 Promovierende und 20 Forscherinnen und Forscher hörten Vorträge zu allgemein gehaltenen Themen wie die Grundlagen der Piezoelektrizität, Domänenwände, Kristallzüchtung und Epitaxie dünner Oxidschichten, die Untersuchung von Defekten, sowie elektroakustische Eigenschaften in piezoelektrischen Materialien. „Hands-on“ Trainings zur DFT-Modellierung oder zum Spektrometer-Selbstbau rundeten die Sommerschule ab, zusammen mit den Laborführungen am IKZ.

IKZ Summer School 2023 Polar Piezoelectric Oxides

From 6–8 September 2023, the IKZ Summer School 2023 with the topic “Polar Piezoelectric Oxides” took place in the Max Born Hall in Berlin-Adlershof.

It was organized by the DFG Research Unit 5044 “Periodic low-dimensional defect structures in polar oxides”, which, in addition to the IKZ, also includes groups from the TU Clausthal, the University of Gießen, the University of Osnabrück and the TU Dresden.
The research group focuses on polar oxide lithium niobate-lithium tantalate solid solutions as model system for investigating fundamental phenomena in materials science and physics. These include, for example, the relationship between defect structures and the transport of charge carriers. About 40 doctoral students and 20 researchers attended lectures on general topics such as the fundamentals of piezoelectricity, domain walls, crystal growth and epitaxy of thin oxide layers, the investigation of defects and electroacoustic properties in piezoelectric materials. “Hands-on” training on DFT modeling or spectrometer self-construction complemented the summer school, together with lab tours at the IKZ.

IKZ International Guest Fellowship Award 2023 „Freestanding Functional Oxide Films" an Prof. Nini Pryds verliehen

Der IKZ International Guest Fellowship Award 2023 wurde an Prof. Nini Pryds von der Technischen Universität Dänemark (DTU) für seine maßgeblichen Beiträge auf dem Gebiet der Manipulation von freistehenden Perowskitschichten verliehen.

Oxide bieten – abhängig von Zusammensetzung und Struktur – viele verschiedene funktionale Eigenschaften, die sich gezielt durch Gitterverspannungen, Bildung von Heterointerfaces oder Stöchiometrieabweichungen beeinflussen lassen. Die Herstellung und Stapelung von freistehenden Oxidmembranen ermöglicht die Entwicklung einer innovativen Plattform für unterschiedliche Materialien und Materialkombinationen mit neuartigen Eigenschaften, jenseits der Möglichkeiten der klassischen Heteroepitaxie. Das IKZ beschäftigt sich seit 3 Jahren mit der Herstellung und Stapelung solcher freistehenden kristalliner Schichten.

Mit dem IKZ International Guest Fellowship Award 2023 soll ein international renommierter Wissenschaftlicher aus dem neu aufkommenden Forschungsgebiet der freistehenden dünnen Oxidschichten geehrt, und eine internationale Zusammenarbeit mit dem IKZ auf diesem Gebiet etabliert werden. Der diesjährige Preisträger ist Prof. Nini Pryds von der DTU, ein international anerkannter Wissenschaftler auf dem Gebiet der dünnen Perowskitschichten. Er hat herausragende Beiträge zu neuen Disziplinen wie „Nanoionik" und „Iontronik" geleistet, die sich mit dem Entwurf und der Kontrolle von grenzflächenbezogenen Phänomenen in schnellen ionischen und elektronischen Leitern befassen. Seit geraumer Zeit beschäftigt sich Prof. Nini Pryds auch mit Synthese, Transfer und Charakterisierung von freistehenden kristallinen Oxidschichten.

Die Auszeichnung wurde im Rahmen des Workshops „Freestanding Functional Thin Films" am IKZ überreicht. Das Programm bot neben der Preisverleihung an Prof. Nini Pryds auch mehrere Vorträge zu dem Thema und die Möglichkeit zur Diskussion über gemeinsame zukünftige Kooperationen und Forschungsanträge.

IKZ International Guest Fellowship Award 2023 "Freestanding Functional Oxide Films" granted to Prof. Nini Pryds

The IKZ International Guest Fellowship Award 2023 has been awarded to Prof. Nini Pryds from the Technical University of Denmark (DTU) for his significant contributions in the field of manipulation of free-standing perovskite layers.

Depending on their composition and structure, oxides offer many different functional properties that can be specifically influenced by lattice strains, the formation of heterointerfaces or deviations from the stoichiometry. The production and stacking of free-standing oxide membranes enables the development of an innovative platform for different materials and material combinations with novel properties, beyond the possibilities of classical heteroepitaxy. IKZ has been dealing with the production and stacking of such free-standing crystalline layers for 3 years.

The IKZ International Guest Fellowship Award 2023 is intended to honour an internationally renowned scientist from the newly emerging research field of free-standing thin oxide layers, and to establish international cooperation with the IKZ in this field. This year's winner is Prof. Nini Pryds from the DTU, an internationally well-known scientist in the field of thin perovskite layers. He has made outstanding contributions to new disciplines such as "nanoionics" and "iontronics", which deal with the design and control of interface-related phenomena in fast ionic and electronic conductors. In recent years, Prof. Nini Pryds has also been working on the synthesis, transfer and characterization of free-standing crystalline oxide layers.

The award was presented during the "Freestanding Functional Thin Films" workshop at the IKZ. In addition to the award ceremony for Prof. Nini Pryds, the program offered several lectures on the subject and the opportunity to discuss future joint collaborations and research proposals.

Prof. Thierry Duffar (Vorsitzender der Preiskommission, Mitte) und Prof. Koichi Kakimoto (Präsident der IOCG, rechts) überreichen Prof. Peter Rudolph (links) den Laudise-Preis

Prof. Thierry Duffar (chairman of the prize committee, center) and Prof. Koichi Kakimoto (president of IOCG, right) present Prof. Peter Rudolph (left) with the Laudise Prize

Laudise-Preis für Prof. Peter Rudolph

Unser langjähriger Kollege Prof. Peter Rudolph wurde während der 20. Internationalen Konferenz für Kristallzüchtung (ICCG-20) in Neapel mit dem Laudise-Preis der International Organization for Crystal Growth (IOCG) ausgezeichnet.

Der renommierte Laudise-Preis wird von der Internationalen Gesellschaft für Kristallzüchtung (IOCG) alle drei Jahre für außergewöhnliche Leistungen an Wissenschaftler auf dem Gebiet der Kristallzüchtung verliehen, die einen besonderen Beitrag insbesondere auch in Sicht auf technologische Lösungen lieferten.

Prof. Peter Rudolph ist mit dem Preis für seine außergewöhnlichen Leistungen, mit einem tiefen Verständnis für die Grundlagen des Kristallwachstums in Verbindung mit technologischen Anwendungen auf dem Gebiet verschiedener Halbleiter (II-VI, III-V und Silizium) geehrt worden. Seine Arbeiten umfassten dabei wichtige Erkenntnisse ausgehend von Strukturen der Schmelze, Punktdefektdynamik, in situ Stöchiometriekontrolle, Versetzungsnetzwerken bis hin zum Einsatz äußerer Felder. Er hat in seinem Berufsleben ca. 250 wissenschaftliche Publikationen, darunter 2 Monographien, 8 Editionen, 29 Buchbeiträge sowie 35 Patente veröffentlicht. Von 1995 bis 2011 war er als wissenschaftlicher Mitarbeiter und später auch als Leiter der Abteilung „Technologieentwicklung“ am IKZ beschäftigt.

Sein Name ist ebenfalls eng mit der Anwendung von Magnetfeldern in der Kristallzüchtung verknüpft: Als Projektleiter am IKZ entwickelten er und sein Team die KRISTMAG®-Technologie, die durch den Einsatz dynamischer Magnetfelder auf halbleitende Schmelzen eine Verbesserung der Materialeigenschaften der gezüchteten Kristalle ermöglicht. Diese Innovation führte vom Konzept bis zur industriellen Anwendung und wurde 2008 mit dem Technologiepreis Berlin-Brandenburg ausgezeichnet.

Laudise Prize for Prof. Peter Rudolph

Our long-time colleague Prof. Peter Rudolph was awarded the Laudise Prize of the International Organization for Crystal Growth (IOCG) during the 20th International Conference on Crystal Growth (ICCG-20) in Naples.

The renowned Laudise Prize is awarded every three years by the International Organization for Crystal Growth (IOCG) for exceptional achievements in the field of crystal growth to scientists who have made a special contribution, particularly with regard to technological solutions.

Prof. Peter Rudolph was honored with the award for his exceptional achievements in a deep understanding of the fundamentals of crystal growth in connection with technological applications in the field of various semiconductors (II-VI, III-V and silicon). His work includes important insights into melt structures, point defect dynamics, in situ stoichiometry control, dislocation networks and the use of external fields. In his professional carrier he has published around 250 scientific publications, including 2 monographs, 8 editions, 29 book contributions and 35 patents. From 1995 to 2011 he worked at the IKZ as a researcher and later on also as the head of the Technology Development department.

His name is also closely associated with the application of magnetic fields in crystal growth: As project leader at the IKZ, he and his team developed the KRISTMAG® technology, which improves the material properties of grown crystals by applying dynamic magnetic fields on semiconducting melts. This innovation was developed from concept to industrial application and was awarded the Berlin-Brandenburg Innovation Award in 2008.

From Order to Disorder – Berlin Science Week 2023

Die 8. Berlin Science Week vom 1. – 10. November 2023 stand ganz im Zeichen von Mobilitäts- und Energiewende, Herausforderungen und Zukunft der Arbeit in der Wissenschaft, Fortschritte in Quantum Technologien und Kernfusion sowie Synergie von Kunst und Wissenschaft. Mit rund 200 Veranstaltungen, etwa 500 Speakern und mehr als 35.000 Besucherinnen und Besuchern bot sie über die ganze Stadt verteilt ein umfassendes Programm, bei dem für jeden etwas dabei war.

Das IKZ präsentierte sich hierbei mit der Fragestellung „From Hot & Cold Crystals – Why order matters“ und zeigte auf beeindruckende Weise verschiedenste Phasenübergänge in Experimenten. In den Demonstrationen wurde den Besuchenden das Funktionsprinzip von Handwärmern nähergebracht oder gezeigt, wie man eine eigene Nebelmaschine baut. Besonderes Interesse brachte auch die Frage hervor, was man bei -50°C am Südpol nicht tun sollte, wenn man am Leben bleiben will.

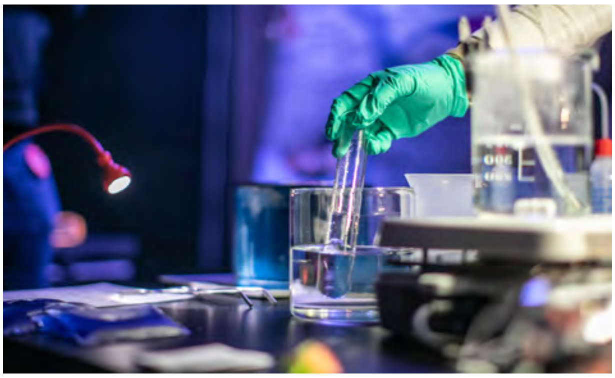
Den Rahmen für die Demonstrationen bot der vom Paul-Drude-Institut für Festkörperelektronik organisierte Abend im FORUM Holzmarktstraße, welcher ganz im Motto „Phasenübergänge in Materie, Geist und Gesellschaft“ stand und von scharfsinnigen Debatten über Kunst, Naturwissenschaften und politische Systeme begleitet war.

From Order to Disorder – Berlin Science Week 2023

The 8th Berlin Science Week from November 1 – 10, 2023 was all about the mobility and energy transition, the challenges and future of work in science, advances in quantum technologies and nuclear fusion, and the synergy of art and science. With around 200 events, around 500 speakers and more than 35,000 visitors, it offered a comprehensive program throughout the city with something for everyone.

The IKZ presented itself with the topic “From Hot & Cold Crystals - Why order matters” and impressively demonstrated various phase transitions in experiments. In the demonstrations, visitors were introduced to the functional principle of hand warmers or shown how to build their own fog machine. The question of what you shouldn’t do at -50°C at the South Pole if you want to stay alive also aroused particular interest.

The framework for the demonstrations was provided by the evening organized by the Paul Drude Institute for Solid State Electronics at the FORUM Holzmarktstraße, which was themed “Phase Transitions in Matter, Mind and Society” and was accompanied by sharp-witted debates about art, science and political systems.



Photos: Florian Ritter/Paul-Drude-Insitut Berlin

The Institute

Höchste Reinheit: Wegweisend bei der Entwicklung von Fluorid-kristallen

Interview mit Hiroki Tanaka, Nachwuchsgruppenleiter am IKZ

Fluorid-Einkristalle sind Schlüsselkomponenten für eine Vielzahl von Photonik-Anwendungen wie Lasermaterialien, optische Hochleistungsisolatoren sowie nichtlineare Frequenzwandler und optische Fenster mit hervorragenden Eigenschaften im tiefen UV-Bereich. Dr. Hiroki Tanaka wurde in 2023 von der Leibniz-Gemeinschaft für die Förderlinie der Leibniz-Junior Research Groups ausgewählt und leitet die Nachwuchsgruppe „Fluoridkristalle für photonische Anwendungen" am IKZ. In diesem Interview möchten wir mit ihm über seine Forschung und Ziele sprechen, welche Möglichkeiten ihm das IKZ bietet und was ihn antreibt.

Wie sieht Ihre Arbeit am IKZ aus?

Ich leite ein interdisziplinäres Forschungsteam am IKZ, das sich mit Fluorid-Einkristallen für die Photonik beschäftigt. Unser Ziel ist es, die Grenzen der derzeitigen Photonentechnologien zu erforschen und zu erweitern, indem wir Materialengpässe beseitigen. Dies umfasst sowohl die Materialwissenschaft als auch die Optik und zielt darauf ab, ultrareine Fluoridkristalle herzustellen, die für die Weiterentwicklung der Photonik entscheidend sind.

Und woran genau arbeiten Sie?

Derzeit arbeite ich an zwei Hauptthemen: Laserkühlung von Festkörpern durch Anti-Stokes-Fluoreszenz und nichtlineare Optik im Vakuum-UV-Spektralbereich. Die Laserkühlung von Festkörpern ist eine innovative Technologie, bei der feste Materialien einfach durch Laseranregung gekühlt werden, wodurch der Weg für kompakte, vibrationsfreie kryogene Kühlsysteme geebnet wird. Dieser Kühlprozess, bei dem die Anti-Stokes-Fluoreszenz zum Einsatz kommt, reagiert sehr empfindlich auf die Qualität der Kristalle, insbesondere auf deren Verunreinigungen. Daher müssen sich die Wissenschaftlerinnen und Wissenschaftler im Bereich der Kristallzüchtung mit diesem Problem befassen, um weitere Fortschritte auf diesem Gebiet zu erzielen.
Darüber hinaus weisen Fluoridkristalle eine perfekte Durchlässigkeit im Vakuum-UV-Bereich (<200 nm) auf, während Oxidkristalle nicht transparent sind. Die nichtlineare Lichtumwandlung in einem solch kurzwelligen Spektralbereich ist für verschiedene Anwendungen äußerst wünschenswert. Unser Ziel ist es, eine neue, auf Fluoridkristallen basierende Technologie für kohärente Dauerlichtquellen in diesem Zielbereich zu entwickeln.
Neben der Grundlagenforschung werden von meinem Team auch Dienstleistungen auf dem Gebiet der Kristallzüchtung erbracht, einschließlich des Technologietransfers an Industriepartner.

Unprecedented high purity: pioneering in developing fluoride crystals

Interview with Hiroki Tanaka, Junior research group leader at IKZ

Fluoride single crystals are key components for a variety of photonics applications such as laser materials, high power optical insulators, as well as nonlinear frequency converters and optical windows with superior properties in the deep-UV region. Dr. Hiroki Tanaka has been selected by the Leibniz Association for the Leibniz-Junior Research group funding line in 2023 and is leading the "Fluoride Crystals for Photonics Applications" group at IKZ. leading the junior research group "Fluoride Crystals for Photonics Applications" at IKZ since April 2019. In this interview, we would like to talk to him about his research and goals, what opportunities the IKZ offers him and what drives him.

What does your work involve at the IKZ?

I lead an interdisciplinary research team at IKZ focusing on fluoride single crystals for photonics. Our goal is to explore and push the limits of current photonics technologies by addressing material bottlenecks. This involves both materials science and optics, aiming to produce ultra-pure fluoride crystals critical for advancing photonics.

And what exactly are you working on?

Currently, I am working on two main topics: laser cooling of solids by anti-Stokes fluorescence and nonlinear optics in the vacuum UV spectral range. Laser cooling of solids is an innovative technology that refrigerates solid materials simply through laser excitation, paving the way for compact, vibration-free cryogenic cooling systems. This cooling process, utilizing anti-Stokes fluorescence, is highly sensitive to the quality of the crystals, particularly their impurities. Therefore, crystal growth scientists must address this issue to further advance the field.
Additionally, fluoride crystals exhibit perfect transparency in the vacuum UV range (<200 nm), where oxide crystals are not transparent. Nonlinear light conversion into such a short-wavelength spectral range is highly desirable for various applications. We aim to develop a new fluoride crystal-based technology for continuous-wave coherent light sources in this target range.

The Institute

Ich erhalte häufig Anfragen nach speziellen Fluoridkristallen, die entweder nicht kommerziell erhältlich sind oder kundenspezifische Spezifikationen erfordern. Viele dieser Anfragen kommen aus dem Optik- und Laserbereich, wo mein Hintergrund in der Optik es mir ermöglicht, die Anforderungen der Kunden schnell zu verstehen und zu erfüllen.

Welche Bedeutung hat diese Arbeit für die Gesellschaft?

Fortschritte in der Photonik-Technologie haben das Potenzial, verschiedene Bereiche zu revolutionieren, darunter auch die Quantentechnologie. Durch die Überwindung von Materialbeschränkungen kann unsere Forschung die Umsetzung von Spitzentechnologien erleichtern, die der Gesellschaft in vielerlei Hinsicht Vorteile bringen werden. Beispielsweise arbeiten wir derzeit an $BaMgF_4$-Kristallen mit hoher UV-Durchlässigkeit, um durch nichtlineare Frequenzumwandlung schmalbandige kohärente Lichtquellen unter 200 nm zu entwickeln. Diese Lichtquellen werden für die Thorium-Kernuhr dringend benötigt, um eine genauere Definition der Sekunde zu erreichen. Dies ist ein Beispiel dafür, wie ein bestimmter Kristall für den Fortschritt in der Spitzenwissenschaft unverzichtbar ist.

Welche Möglichkeiten bietet Ihnen das IKZ für Ihre Forschung? Was ist das Besondere an Ihrer Arbeit hier?

Das IKZ bietet ein einzigartiges Fachwissen im Bereich der Kristallzüchtung, das für meine Forschung von entscheidender Bedeutung ist. Die einzigartige Kombination aus fortschrittlichen materialwissenschaftlichen Fähigkeiten und einem Schwerpunkt auf Grundlagen- und angewandter Forschung passt perfekt zu den Zielen meines Projekts. Dieses Umfeld unterstützt innovative Ansätze zur Überwindung von Materialbeschränkungen in der Photonik.

Können Sie in Worte fassen, was Sie motiviert?

Mich treibt der Wunsch an, einen Beitrag zur wissenschaftlichen Gemeinschaft zu leisten und Technologien voranzutreiben, die die Gesellschaft maßgeblich beeinflussen können. Das Potenzial, kritische Herausforderungen in der Photonik durch innovative Materialwissenschaft zu lösen, ist ein starker Motivator.

Was könnte dies für Ihre Karriere bedeuten?

Die Leitung eines Forschungsteams und die erfolgreiche Bewältigung der Herausforderungen in diesem Projekt stellen wichtige Meilensteine in meiner akademischen Laufbahn dar. Diese Errungenschaften können mich als führend auf dem Gebiet der Materialwissenschaften und der Photonik etablieren und eröffnen mir Möglichkeiten für weitere Forschung, Zusammenarbeit und potenziell größere Verantwortung in der wissenschaftlichen Gemeinschaft.

Besides fundamental research, my team also manages crystal growth service activities, including technology transfer to an industrial partner. I frequently receive inquiries for special fluoride crystals, which are either commercially unavailable or require custom specifications. Many of these requests come from the optics and laser sectors, where my background in optics allows me to rapidly comprehend and address client requirements.

What is new about your research?

Our research is pioneering in developing fluoride crystals with unprecedentedly high purity. These ultra-pure crystals are essential for advancing various photonics applications, which currently face limitations due to the unavailability of suitable crystalline materials. We have the expertise to prepare high-purity fluoride compounds by removing oxide impurities through a chemical method. Additionally, we are developing a new system to reduce metal impurities during the crystal growth process.

Why is it important for society?

Advancements in photonics technology have the potential to revolutionize various sectors, including quantum technologies. By overcoming material limitations, our research can facilitate the implementation of cutting-edge technologies that promise to benefit society in numerous ways. For example, we are currently working on $BaMgF_4$ crystals with high UV transparency for developing narrow-line coherent light sources below 200 nm through nonlinear frequency conversion. These light sources are highly desired by the thorium nuclear clock community for achieving a more precise definition of a second. This exemplifies how a specific crystal is indispensable for advancing cutting-edge science.

What opportunities does the IKZ offer you for your research? What is special about your work here?

IKZ offers unparalleled expertise in crystal growth, which is crucial for my research. The institute's unique combination of advanced materials science capabilities and a focus on both basic and applied research aligns perfectly with the goals of my project. This environment supports innovative approaches to overcoming material limitations in photonics.

Can you put into words what motivates you?

I am driven by the desire to contribute to the scientific community and to advance technologies that can significantly impact society. The potential to solve critical challenges in photonics through innovative materials science is a powerful motivator.

What could this mean for your career?

Leading a research team and successfully overcoming the challenges in this project represent significant milestones in my academic career. These achievements can establish me as a leader in the field of materials science and photonics, opening up opportunities for further research, collaboration, and potentially greater responsibilities in the scientific community.

Bericht der Promovierenden

Das Jahr 2023 war für die PhD-Studierenden ein ereignisreiches Jahr, mit vielen Veranstaltungen und der Aussicht auf zukünftige Veränderungen.

Im Laufe des Jahres hatten wir mehrere PhD-Veranstaltungen, darunter unsere monatlichen Seminare und Grillfeste im Sommer. Diese Veranstaltungen boten Möglichkeiten zum Wissensaustausch und zur Entspannung für die PhD-Studierenden und trugen zu einem Gemeinschaftsgefühl bei. Um das Jahr festlich ausklingen zu lassen, planten wir ein PhD-Weihnachtstreffen. Diese Veranstaltung beinhaltete Quizspiele und Pizza, was eine unterhaltsame und ansprechende Möglichkeit war, die Erfolge der Doktoranden zu feiern und sich nach einem Jahr harter Arbeit zu entspannen.

Eine neue Initiative in diesem Jahr war die Gründung einer Python-Arbeitsgruppe. Diese Gruppe hat vielen Studenten dabei geholfen, sich mit Python vertraut zu machen und die Sprache zur Lösung ihrer Probleme einzusetzen. Die kollaborative Umgebung der Arbeitsgruppe hat die Programmierfähigkeiten der Doktoranden verbessert und uns darin geschult, Datenanalysen und andere forschungsbezogene Aufgaben besser zu bewältigen. Dr. Carsten Richter und Dr. Sebastian Brückner unterstützten diese Aktivitäten umfassend. Obwohl die Arbeitsgruppe derzeit pausiert, ist geplant, sie in Zukunft wieder aufzunehmen.

Im Mai 2024 unternahmen wir eine PhD-Exkursion nach Freiberg. Wir besuchten das Institut für Angewandte Physik (IAP) der TU Bergakademie Freiberg unter der fachkundigen Leitung von Dr. Franziska Beyer vom Fraunhofer-Institut und Prof. Dr. Daniel Hiller von der TU Bergakademie Freiberg. Dieser Besuch bot einen umfassenden Einblick in die Vorbereitung der Bauelemente im Reinraum, gefolgt von ihren elektrischen und spektroskopischen Tests und ihren Anwendungen in photovoltaischen Geräten.

Report of the doctoral students

The year 2023 has been a filled one for PhD students, with many events and the perspective of changes in the future.

Throughout the year, we had several PhD events, including our monthly seminars and barbecues during summer. These events provided opportunities for knowledge exchange and relaxation for the PhD students, adding to a sense of community. To close the year on a festive note, we planned a PhD Christmas gathering. This event included quizzes and pizza, which was a fun and engaging way for students to celebrate their achievements and unwind after a year of hard work.

A significant new initiative this year was the formation of a Python workgroup. The collaborative environment of the workgroup has enhanced the skills of the students, making us more adept in handling data analysis and other research-related tasks. Dr. Carsten Richter and Dr. Sebastian Brückner provided thorough support for these activities. Although currently paused, the workgroup is planned to resume in the future.

In May 2024, we embarked on an enriching PhD excursion to Freiberg. We visited the Institute of Applied Physics (IAP) of the TU Bergakademie Freiberg under the expert guidance of Dr. Franziska Beyer from the Fraunhofer Institute and Prof. Dr. Daniel Hiller from TU Bergakademie Freiberg. This visit provided a comprehensive insight into the preparation of devices in the cleanroom, followed by their electrical and spectroscopy testing, and their applications in photovoltaic devices. After an informative morning, we enjoyed a lunch break before heading to the Museum Terra Mineralia for a private tour. The tour offered us a chance to learn about the extensive mineral collection and the natural occurrence of various crystals. This excursion was a great experience, combining scientific learning with cultural enrichment.

The Institute

Nach einem informativen Vormittag genossen wir eine Mittagspause, bevor wir zum Museum Terra Mineralia für eine private Führung aufbrachen. Die Führung gab Einblick über die umfangreiche Mineraliensammlung und das natürliche Vorkommen verschiedener Kristalle. Diese Exkursion war eine großartige Erfahrung, die wissenschaftliches Lernen mit kultureller Bereicherung verband.

In diesem Jahr haben wir auch eine Umfrage durchgeführt, um die Zufriedenheit unserer PhD-Kolleg*innen zu überprüfen. Wir freuten uns, dass die meisten Studierenden im Allgemeinen zufrieden sind. Die Umfrage offenbarte jedoch Bedenken bezüglich langer Arbeitszeiten und fehlender Unterstützung im Bereich der psychischen Gesundheit innerhalb des Instituts. Diese Probleme wurden auf der Lenkungsausschusssitzung vorgestellt, was zu einem Folgetreffen mit Thomas Schröder und Matthias Bickermann führte. Darüber hinaus hatten wir eine Präsentation von Carsten Richter (Ombudsperson) und Janet Zapke (Verwaltungsleiterin) im PhD-Seminar, um einige der in der Umfrage und im Treffen hervorgehobenen Themen anzugehen. Sie gaben Ratschläge, wie wir vorgehen sollten, wenn wir auf Probleme wie Diskriminierung, Rassismus, Misshandlung und Missbrauch am Arbeitsplatz stoßen. Leider bleibt das Problem der Unterstützung im Bereich der psychischen Gesundheit ungelöst, und uns ist klar, dass dies ein komplexes Thema in der akademischen Welt ist.

Zudem lasen wir mit Besorgnis im Newsletter vom Juni über die einseitige Entscheidung, dass PhD-Studierende in naher Zukunft keine festen Arbeitsplätze mehr haben werden, sondern in Gemeinschaftsbüros arbeiten sollen. Diese Entscheidung wurde mit dem Direktor und anderen Institutsmitgliedern besprochen, aber viele Fragen und Bedenken bleiben offen.

Rückblickend auf das vergangene Jahr können wir erhebliche Fortschritte und Stabilität im Vergleich zu den Herausforderungen von 2022 feststellen. Die verbesserten Lieferketten, erfolgreiche Veranstaltungen und neue Initiativen wie die Python-Arbeitsgruppe haben zu einem produktiven und ansprechenden Jahr für alle PhD-Studierenden am IKZ beigetragen. Es gibt jedoch noch wichtige Probleme zu lösen, insbesondere in Bezug auf die Unterstützung im Bereich der psychischen Gesundheit und die Büroplatzregelungen. Darüber hinaus haben 4 Studierende erfolgreich ihre Dissertationen verteidigt. Wir freuen uns auf weitere Verteidigungen, neue PhD-Studierende, Grillfeste und Exkursionen im nächsten Jahr!

This year, we also prepared a survey to check the satisfaction of our PhD peers. We were pleased to find that most students are generally satisfied. However, the survey revealed concerns about long working hours and the lack of mental health support within the institute. These issues were presented at the steering committee meeting, prompting a follow-up meeting with Thomas Schröder and Matthias Bickermann to address these concerns. Furthermore, to tackle some of the issues highlighted in the survey and meeting, we had a presentation from Carsten Richter (Ombudsperson) and Janet Zapke (Verwaltungsleiterin) in the PhD seminar. They provided guidance on how to proceed if we encounter problems such as discrimination, racism, mistreatment and abuse in our workplace. Unfortunately, the issue of mental health support remains unresolved, and it is clear to us that it is a complicated matter in academia.

Additionally, in June's newsletter, we were concerned to read about the decision that PhD students will, in the near future, no longer have specific working places but rather shared offices. This decision was addressed with the director and other institute members, but many questions and concerns remain open.

Reflecting on the past year, we can see significant progress and stability compared to the challenges of 2022. The improved supply chain, successful events, and new initiatives like the Python workgroup have contributed to a productive and engaging year for all PhD students at IKZ. However, there are still important issues to be resolved, particularly regarding mental health support and office space arrangements. Additionally, in 2023, 4 students successfully defended their theses. We are looking forward to more defenses, new PhD students, barbecues and excursions in the next year!

Marketing – Transfer – Service @ IKZ

Die Verfügbarkeit kristalliner Materialien mit definierten und zuverlässigen Eigenschaften ist ein Schlüsselelement für die Entwicklung moderner Technologien, insbesondere in den Bereichen Photonik und Elektronik. Diese Technologien tragen zur Bewältigung der Herausforderungen bei, denen sich unsere Gesellschaft unter anderem in den Bereichen Energie, digitale Vernetzung, Gesundheit und Umwelt gegenübersieht.
Das IKZ entwickelt daher besonders vielversprechende kristalline Materialien bis hin zu Kleinserien, um die Forschung und Entwicklung moderner Technologien insbesondere im europäischen Raum zu ermöglichen. Zu den aktuellen Angeboten zählen Aluminiumnitrid-Substrate und Galliumoxid-Schichten. Unsere Galliumoxid-Substrate können über unseren Partner CrysTec GmbH bezogen werden.

Aluminiumnitrid

Einkristallines Aluminiumnitrid (AlN) ist ein vielversprechender Werkstoff für zahlreiche moderne Anwendungen in der Mikro- und Optoelektronik. Zu seinen herausragenden Eigenschaften gehören eine große Bandlücke, hohe Wärmeleitfähigkeit und chemische Stabilität. Dadurch eignet es sich unter anderem für Anwendungen in der Optoelektronik z. B. als UV-C Leucht- und Laserdioden zur Desinfektion, in der Metrologie, oder in der Leistungselektronik z. B. für High Electron Mobility Transistoren (HEMT) zur Elektromobilität.

Wir haben Verfahren und Technologien für die Herstellung von AlN-Substraten mit hoher kristalliner Qualität, hoher UV-Transparenz und hoher Oberflächengüte entwickelt. Einkristalline Wafer mit epi-ready Oberflächen sind gemäß den Spezifikationsblättern in verschiedenen Qualitätsstufen vom IKZ beziehbar zu Forschungszwecken bzw. für die Technologieentwicklung. Aktuell sind Wafer mit dem Durchmesser 10 mm auf Anfrage verfügbar, im Laufe des Jahres 2024 werden auch 1 Zoll Wafer angeboten. Außerdem ist die Demonstration von 2-Zoll-Substraten bis Ende 2024 geplant.
www.ikz-berlin.de/angebot/aluminiumnitrid

Galliumoxid – Substrate und Epitaxie

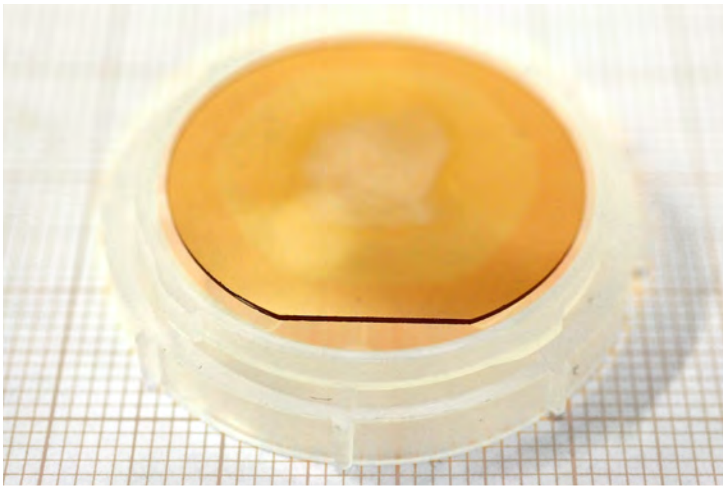
Seit mehr als 15 Jahren wird am IKZ das Halbleitermaterial Ga_2O_3 gezüchtet und untersucht. Es stellt die derzeitigen „Stars" der Halbleitertechnologie – Float-Zone-Silizium (Si), Siliziumcarbid (SiC) und Galliumnitrid (GaN) – bezüglich der Effizienz bei Anwendungen in der Leistungselektronik weit in den Schatten. Das IKZ ist derzeit das einzige Institut in der EU, an dem Galliumoxid-Einkristalle hergestellt werden können. „Unser Kompetenzschwerpunkt waren bisher v. a. der Anlagenbau, die Kristallzüchtung und die Kristallanalyse.

Marketing – Transfer – Service @ IKZ

The availability of crystalline materials with defined and reliable properties is a key element for the development of modern technologies, particularly in the fields of photonics and electronics. These technologies contribute to addressing the challenges our society faces in areas such as energy, digital networking, health, and the environment.
IKZ therefore develops particularly promising crystalline materials up to small series to enable research and development of modern technologies, especially in Europe. The current offerings include aluminum nitride substrates and gallium oxide layers. Our gallium oxide substrates can be obtained through our partner CrysTec GmbH.

Aluminum Nitride

Single-crystal aluminum nitride (AlN) is a promising material for numerous modern applications in micro- and optoelectronics. Its outstanding properties include a wide bandgap, high thermal conductivity, and chemical stability. This makes it suitable for applications in optoelectronics, such as UV-C light-emitting and laser diodes for disinfection, in metrology, or in power electronics, such as high electron mobility transistors (HEMT) for electric mobility.



Aluminiumnitrid-Substrat/Aluminium nitride substrate

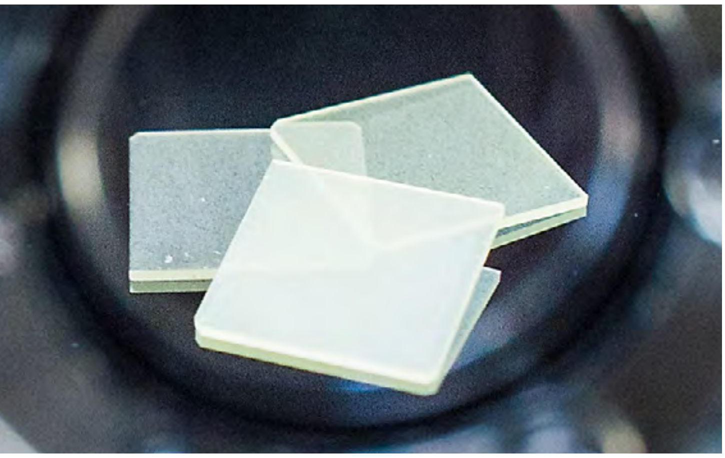
We have developed processes and technologies for the production of AlN substrates with high crystalline quality, high UV transparency, and high surface quality. Single-crystal wafers with epi-ready surfaces are available from IKZ for research purposes or technology development according to the specification sheets in various quality grades. Currently, wafers with a diameter of 10 mm are available on request. By the end of 2024, 1-inch wafers will also be offered, and the demonstration of 2-inch substrates is planned by the end of 2024.
www.ikz-berlin.de/angebot/aluminiumnitrid

The Institute

Die Technologien zur effizienten Präparation großflächiger Substrate mit definierten Eigenschaften, die benötigt werden, um das Material für die Leistungselektronik umfassend zu erforschen und zu optimieren entwickeln wir gerade", betont Dr. Thomas Straubinger der als Leiter der IKZ-Sektion Kristalle für Elektronik verantwortlich für die Fertigung von Galliumoxid-Prototypsubstraten ist.

An dieser Stelle kommt das mittelständische Berliner Unternehmen CrysTec ins Spiel. Es ist mit dem IKZ bereits seit vielen Jahren über Forschungsprojekte und Substratpräparationen aus deren Spezialkristallen für den weltweiten Forschungsmarkt der Oxidelektronik verbunden. Die am IKZ gezüchteten Kristalle haben einen Durchmesser von bis zu 2 Inch und können semiisolierend (für laterale Leistungselektronik) oder leitfähig (für vertikale Leistungselektronik) sein. Während leitfähiges Material aktuell exklusiv für Forschungsthemen am IKZ genutzt wird, können semiisolierende Substrate mit (100) Orientierung und verschiedenen Off-Cuts von unserem Industriepartner CrysTec GmbH bezogen werden; die Ga_2O_3 Kristalle selbst werden hierzu am IKZ gezüchtet.

Parallel zu der Züchtung der Volumenkristalle haben wir zudem eine Technologie für die Abscheidung von β-Ga_2O_3 Schichten mit geringer Defektdichte, hoher Elektronenmobilität und hoher Oberflächenqualität mittels MOVPE (Metallorganische Gasphasenepitaxie) entwickelt.



Galliumoxid-Wafer
Gallium oxide wafers

Gallium Oxide – Substrates and Epitaxy

For over 15 years, the semiconductor material Ga_2O_3 has been grown and studied at IKZ. It far surpasses the current "stars" of semiconductor technology – float-zone silicon (Si), silicon carbide (SiC), and gallium nitride (GaN) – in terms of efficiency for power electronics applications. IKZ is currently the only institute in the EU capable of producing single-crystal gallium oxide. "Our main focus so far has been on equipment construction, crystal growth, and analysis of the grown crystals. Currently, we are developing technologies for the efficient preparation of large-area substrates with defined properties, which are needed for the in-depth study and optimization of the material for power electronics," emphasizes Dr. Thomas Straubinger, head of the IKZ section Crystals for Electronics, responsible for the production of gallium oxide prototype substrates.

IKZ and CrysTec GmbH are partners in the provision of gallium oxide substrates.
Das IKZ und die CrysTec GmbH kooperieren in der Bereitstellung von Galliumoxid-Substraten.

At this point, the medium-sized Berlin company CrysTec comes into play. For many years, it has been in close cooperation with IKZ for many years through research projects and substrate preparations of IKZ's specialty crystals for the global oxide electronics research market. The crystals grown at IKZ have a diameter of up to 2 inches and can be semi-insulating (for lateral power electronics) or conductive (for vertical power electronics). While conductive material is currently used exclusively for research topics at IKZ, semi-insulating substrates with (100) orientation and various off-cuts can be obtained from our industrial partner CrysTec GmbH; the Ga_2O_3 crystals themselves are grown at IKZ.

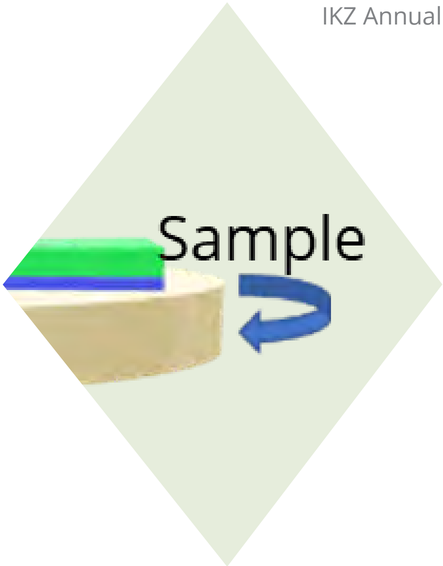
The Institute

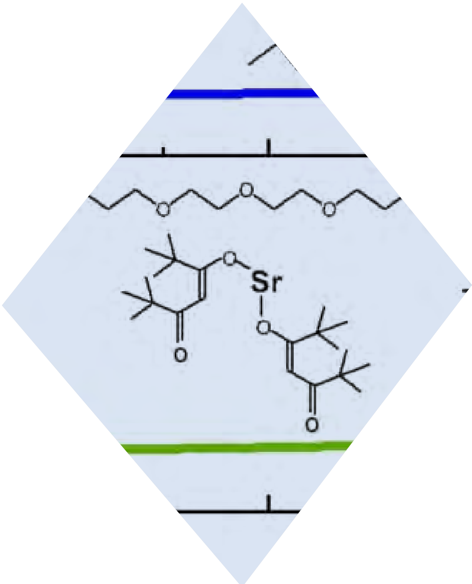
Wir bieten diese Epitaxie-Schichten höchster Qualität in einem breiten Schichtdickenbereich und mit spezifischen Dotierungskonzentrationen an. Unser Epitaxieverfahren ist kompatibel mit den kristallinen Orientierungen (100) 4°off und (010) und hat das Potential für die Heteroepitaxie auf Fremdsubstraten wie Si, SiC, GaN…. etc. Homo- und heteroepitaktische Schichten können individuell angepasst werden, Standard-Spezifikationen finden sich unter:
https://www.ikz-berlin.de/angebot/galliumoxid

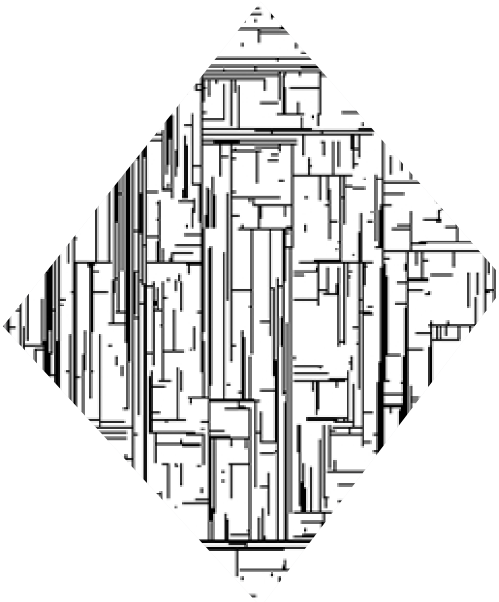
Einen Überblick über unsere Serviceleistungen findet sich hier:
https://www.ikz-berlin.de/transfer-service/service-marketing
Hier finden Sie auch unsere Broschüren.

Along with bulk crystal growth, we have also developed a technology for the deposition of β-Ga_2O_3 layers with low defect density, high electron mobility, and high surface quality using MOVPE (Metal-Organic Vapor Phase Epitaxy). We offer these high-quality epitaxial layers in a wide range of thicknesses and with specific doping concentrations. Our epitaxy process is compatible with the crystalline orientations (100) 4° off and (010) and has the potential for heteroepitaxy on foreign substrates such as Si, SiC, GaN, etc. Homo- and heteroepitaxial layers can be customized, and standard specifications can be found at:
https://www.ikz-berlin.de/angebot/galliumoxid

An overview of our services can be found here:
https://www.ikz-berlin.de/transfer-service/service-marketing
You can also find our brochures on this site.







Nanostructures & Layers

Potential of La-Doped $SrTiO_3$ Thin Films Grown by Metal−Organic Vapor Phase Epitaxy for Thermoelectric Applications

Aykut Baki[1], Mohamed Abdeldayem[1], Carlos Morales[1], Jan Ingo Flege[2], Detlef Klimm[1], Oliver Bierwagen[3], and Jutta Schwarzkopf[1]

[1] Leibniz-Institut für Kristallzüchtung, Berlin, Germany
[2] Paul-Drude-institut für Festkörperelektronik, Berlin, Germany
[3] Brandenburgische Technische Universität Cottbus-Senftenberg, Cottbus, Germany

In our environment, many heat sources can be found whose parasitic waste heat can be exploited for energy harvesting concepts representing one possible component of the future energy transition. Furthermore, it enables devices to be operated independently of the power grid or batteries, as is necessary for sensor or monitor applications in health applications, for example. It makes use of the thermoelectric effect, in which a temperature difference is converted into electrical energy. On the atomic scale, the applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side, thereby generating electrical energy. However, most thermoelectric materials used are based on materials that are environmentally unfriendly such as Pd and Te. Consequently, for sustainability reasons, there is a demand for more environmentally friendly materials that are in addition more stable at high temperatures and in harsh atmospheres with at least comparable and appropriate thermoelectric properties.

The key characteristic of thermoelectric materials is given by the Seebeck coefficient (or thermopower) S which is inversely proportional to charge carrier density n ($S \sim n^{-2/3}$), the electrical (σ), and thermal (κ) conductivity, which together define the dimensionless figure of merit ($ZT= \frac{S^2\sigma}{\kappa} T$) of the material. Highly efficient materials are specified by a high-power factor ($S^2\sigma$) and low thermal conductivity κ.

$SrTiO_3$ is a promising material for thermoelectric applications because it exhibits a large Seebeck coefficient even at high temperatures [1] and it is chemically inert and stable up to 1000°C. Electrical conductivity of actually insulating $SrTiO_3$ is achieved by the substitution of Sr or Ti by elements with different oxidation state. In particular, La^{3+} is suitable to replace Sr^{2+} due to the similarity of the ionic radii and it provides an extra free electron which causes electrical conductivity [2].

In order to achieve sufficiently high electrical conductivity, films must be grown with high crystalline perfection and precisely controlled doping concentration.

This requires a growth method that allows the epitaxial growth of thin films with high structural quality and low defect density. Metal−organic vapor phase epitaxy (MOVPE) enables the epitaxial growth of stoichiometric well-ordered $SrTiO_3$ thin films [3] at oxygen partial pressures that are orders of magnitude higher than in physical methods like pulsed laser deposition (PLD) or molecular beam epitaxy (MBE). The independent control of the partial pressure of all constituents (including the doping element) permits the precise adjustment of the chemical composition of the films. Further advantage of MOVPE is the easy upscaling possibility, which makes it suitable for industrial applications. However, up to now, very few reports have addressed the epitaxial growth of $SrTiO_3$ with MOVPE [4], due to the limited availability, complex handling, and challenging delivery into the gas phase of the metal−organic (MO) precursors.

In MOVPE all constituent elements are used as MO source material which have to be introduced as gas into the reaction chamber. However, since the precursors for La-doped $SrTiO_3$ - $Sr(tmhd)_2$-tetraglyme, $Ti(OiPr)_2(tmhd)_2$, and $La(tmhd)_3$ - are solid, they have to be dissolved in a suitable solvent (here: toluene), delivered by peristaltic pumps to a flash evaporation system to convert the liquid to the gas phase and transported with Ar as carrier gas into the reaction chamber. The MO precursors have to be decomposed at the heated substrates and form – together with oxygen as a reacting gas – the desired perovskite phase if the supplied ratio of the elements is appropriate in the gas phase. One of the key parameters in this method is the temperatures of the flash evaporators, which critically determine the effectivity of the vaporization of the precursor-toluene mixtures and depend on the chemical element and the precursors' ligands. For that purpose, we studied the thermal decomposition behavior of the MO precursors by thermogravimetric analysis method which records the loss of material mass as a function of temperature, and gives information about the material decomposition behavior (see Fig. 1).

Nanostructures & Layers

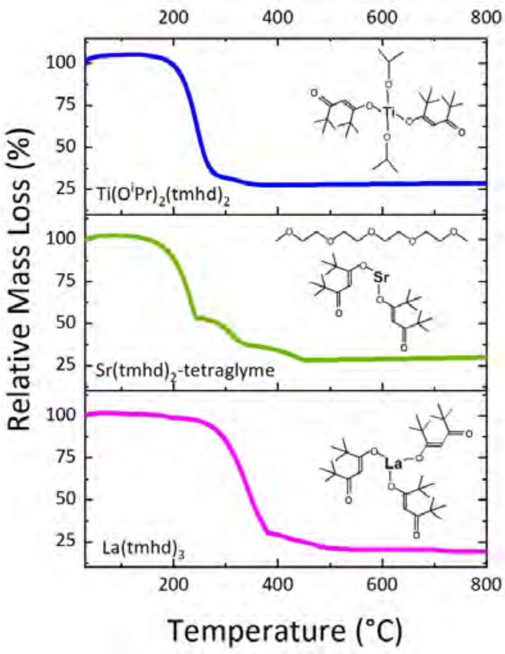


Fig. 1
Thermogravimetric analysis of the MO precursors
(a) $Ti(OiPr)_2(tmhd)_2$, (b) $Sr(tmhd)_2$-tetraglyme, (c) $La(tmhd)_3$.
Chemical structure of each organic compound is illustrated in the relevant graphs [5].

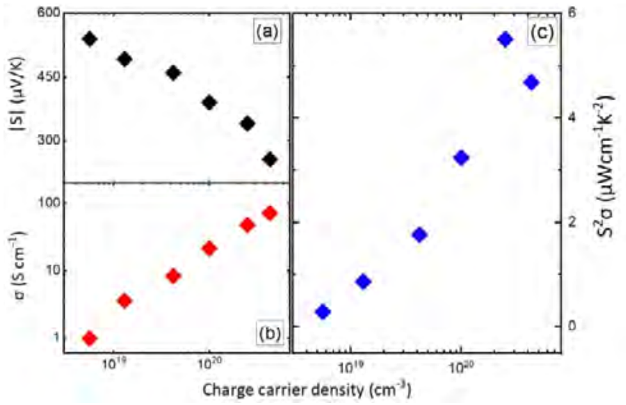


Fig. 2
(a) Absolute value of the Seebeck coefficient |S|,
(b) conductivity σ, and (c) power factor $S^2\sigma$ as a function of the charge carrier density n [5].

From these measurements we concluded that 210˚C is a suitable flash evaporation temperature where partial decomposition of all precursors takes place, and which is well below the total decomposition temperature that provides thin film growth by MOVPE.

Starting from undoped, stoichiometric $SrTiO_3$ films, by additionally introducing the $La(tmhd)_3$ precursor into the gas phase 30 – 50 nm thick La-doped $SrTiO_3$ films were epitaxially grown on $SrTiO_3$ substrates without a significant formation of a foreign phase and n-type conductivity. By precisely controlling the concentration of the La precursor in the precursor solution, the charge carrier density n in the La-$SrTiO_3$ thin films was varied between 5.7×10^{18} and 4.3×10^{20} cm^{-3} showing a linear relationship to the La concentration. From the electrical conductivity and the Seebeck coefficient ISI the power factor $S^2\sigma$ was calculated as a function of the charge carrier concentration n which reveals a maximum value of 5.7 μWcm^{-1} K^{-2} at $n = 2.3 \times 10^{20}$ cm^{-3} as shown in Fig. 2. These values are only slightly lower compared to those obtained for MBE films, which is tentatively explained by the formation of a small number of Ruddlesden-Popper-like defects and associated antiphase boundaries. Our results verify the good quality of our MOVPE-grown films and their high potential for thermoelectric application. More details can be found in the published paper [5].

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Real-time Monitoring of Homo- and Heteroepitaxial Ga_2O_3 MOVPE processes

Ta-Shun Chou, Saud Bin Anooz, Jana Rehm, Thi Thuy Vi Tran, Arub Akhtar, Zbigniew Galazka, and Andreas Popp

Leibniz-Institut für Kristallzüchtung , Berlin, Germany

The novel semiconductor material gallium oxide (Ga_2O_3) has the potential for low-loss and cost-effective power electronics and could, therefore, significantly contribute to a lower energy loss during the energy transition[1]. Such applications require high-quality β-Ga_2O_3 layers (both homo and heteroepitaxial) preferred grown by metal-organic vapor phase epitaxy (MOVPE) with precise thickness and doping concentration control. To ensure precise control over the quality and consistency of growth processes for homo- and heteroepitaxy, in-situ monitoring throughout the growth process is pivotal for comprehending interfacial reactions and the growth mechanisms of oxide semiconductors. However, such a technique is generally developed and tailored for nitrides and other compound semiconductors, but not yet for β-Ga_2O_3. To explore the potential of in-situ monitoring in β-Ga_2O_3 technology, this work summarizes the IKZ development of in-situ monitoring for homo- or hetero-epitaxially grown *β-Ga*$_2O_3$ films by MOVPE.

Homoepitaxy

Among all potential techniques, reflectance spectroscopy is considered to be one of the most promising methodologies to in-situ monitor the MOVPE process, which has been widely used in the MOVPE-grown homoepitaxial GaAs, InP, and their related compounds. However, challenges arose regarding monitoring the MOVPE-grown homoepitaxial β-Ga_2O_3 films since commonly used reflectance anisotropy/difference spectroscopy (RAS/RDS) is only suitable for crystals with a cubic crystal structure, which is not the case for β-Ga_2O_3 (monoclinic structure). To tackle this challenge, a multiwavelength reflectometer that operates at different wavelengths (405 nm, 633 nm, and 950 nm) is used to measure how light reflects off the growing film and the substrate below (see Figure 1). The reflectance signal gives us information about the phase difference, related to the difference in refractive index between the film and the substrate. The signal from different wavelengths tells us different aspects of the growing film. The shorter wavelength is generally more sensitive to the surface roughness changes and the growth rate fluctuation due to its relatively shorter periodicity. On the other hand, the longer wavelength might interact with the free carriers within the film and tell us more about the carrier-induced refractive index shift owing to doping. The researchers and the engineers need to combine all collected information from different wavelengths to judge the film quality.

The commonly collected reflectance transient is shown in Figure 2a, which does not show any obvious Fabry-Pérot oscillation for the growth rate determination. However, some useful information might be hidden due to a low signal-to-noise ratio since the growing film naturally has a different refractive index than the substrate due to different incorporated impurities. We innovatively apply the autocorrelation function[2] (a common technique to reveal the periodic signal from the received noise) to Figure 2a, which revealed the hidden periodicity as a typical Fabry-Pérot oscillation in the autocorrelated domain, as shown in Figure 2b. Thus, it is possible to determine the film thickness (with the growth rate as well) with the Fabry-Pérot formula and the periodicity (the time difference of peak-to-peak or valley-to-valley) instead of the destructive characterizations like scanning electron microscope (SEM) and secondary ion mass spectrometry (SIMS). Moreover, the information such assurface roughness evolution, growth mode transitions, and impurity incorporation,can be revealed by comparing real and autocorrelated regime. Specifically, in-situ doping measurements can be conducted effectively by fitting the reflectance spectrum using the Drude model.

Heteroepitaxy

In-situ monitoring heteroepitaxy by the multiwavelength reflectometer is normally easier due to the intrinsic refractive index difference between the growing film and the substrate. Growing β-Ga_2O_3 on c-plane Al_2O_3 has recently been widely reported as a potential layer structure for the β-Ga_2O_3-based deep-ultraviolet (DUV) photodetector. The reflectance transient from the β-Ga_2O_3-on-Al_2O_3 process shows significant Fabry-Pérot oscillation without any additional treatments that the IKZ research group used to determine the film thickness and the high-temperature refractive index without other ex-situ measurements (i.e., ellipsometry and X-ray diffraction (XRD)).

Nanostructures & Layers

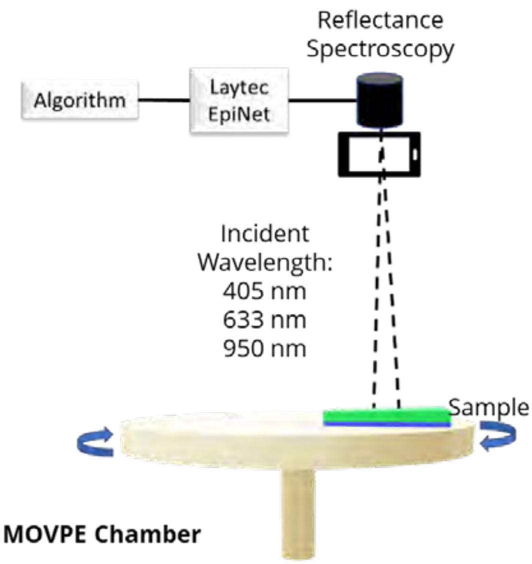

Fig. 1
Schematic representation of the measurement arrangement of EpiNet in-situ monitoring system under the condition of the MOVPE system[2].

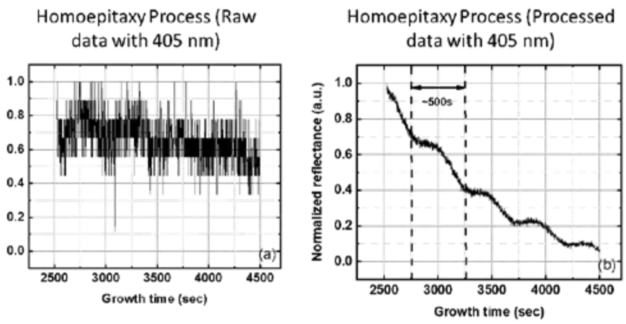

Fig. 2
Reflectance spectrum in (a) real-time domain and (b) autocorrelation domain recorded simultaneously during the homoepitaxy growth of Si-doped β-Ga_2O_3 on the semi-insulating β-Ga_2O_3 substrate at an incident wavelength of 405 nm[2].

Simply knowing the film thickness is important, but we are interested in more. Recently, by implementing optical simulations like effective medium approximation (EMA) and transfer matrix method (TMM)[3], we are able to fastly and precisely control the film thickness and quality by in-situ fitting the collected reflectance spectrum and extracting the optical constants, which helps to evaluate the quality film in terms of checking surface roughness fluctuation and refractive index deviation at high temperature and ensure a high-quality layer of lateral-built devices. Moreover, with the rising attention to the Al-alloy of β-Ga_2O_3, heterostructures like β-$(Al_xGa_{1-x})_2O_3$-on-β-Ga_2O_3 with its extraordinary physical properties will be the next candidate to benefit from the method described above.

In conclusion, the in-house development of in-situ monitoring workflow is a vital and cost-effective measure for non-destructively controlling the physical properties and quality of films. This is important to the growth process and the future industrialization of Ga_2O_3. As demonstrated in the GaN industry, such technology enhances efficiency and facilitates real-time adjustments, leading to significant advancements in material quality, production yields, and overall process optimization, offering a pathway to industrial mass production of β-Ga_2O_3/ β-$(Al_xGa_{1-x})_2O_3$ in the near future. Further details can be found in [2] and [3].

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Strain relaxation in SiGe heterostructures for quantum technologies by a geometric Monte Carlo approach

Kevin-P. Gradwohl, Chen-Hsun Lu, Yujia Liu, Carsten Richter, Torsten Boeck, Jens Martin, and Martin Albrecht

Leibniz-Institut für Kristallzüchtung , Berlin, Germany

Within the demonstrated realizations of qubits, solid-state-based approaches – such as electron spin-qubits in gate-defined quantum dots in Si/SiGe heterostructures – are highly auspicious. Such Si-based qubits promise a compact implementation, due to their small footprint of few hundred nanometers, as well as great potential for scalability attributed to their compatibility with the existing Si-based electronic technology. Furthermore, the prospect to utilize isotopically enriched Si and Ge to implement nuclear spin-free qubits can push the quantum coherence times in the regime of seconds, which might be the key to open the door to universal quantum computing [1].
The material requirements for such Si-based heterostructures are enormous and difficult to meet. In particular, the qubits are hosted in an epitaxially grown biaxiallystrained Si layer, which together with the quantum confinement in such structures lifts the conduction band degeneracy. However, even small strain fluctuations, such as caused by crystal defects like dislocations, make reliable large-scale integration of qubits impossible. Hence, we investigated the formation of misfit dislocation (MD) networks in tensile strained Si, and the related plastic relaxation by comparing real dislocation networks imaged by electron microscopic methods with results of dislocation networks from purely geometric Monte Carlo simulations [2].

The strained Si layers were grown by molecular beam epitaxy (MBE) above the critical thickness of MD formation on fully strainrelaxed $Si_{1-x}Ge_x$ (0 0 1) virtual substrates with a Ge concentration of x = 0.3. The dislocations were investigated by electron channeling contrast imaging (ECCI) measurements, as can be seen in Fig. 1a and 1b. The dislocation contrast is difficult to maintain on a large scale; hence the MD and threading dislocation (TD) segments were marked in Fig. 1b by utilizing several ECCI images of the same area with slightly different tilt angles of the sample.

The MD segments form from existing TDs within the SiGe virtual substrate originating due to the lattice misfit with respect to the Si bulk substrate, and run along the <1 1 0> direction at the (0 0 1) Si/SiGe interface until they meet another MD, which hinders further elongation due to the associated strain fields. This yields this very characteristic dislocation patterns of MDs being blocked by orthogonal MDs, as can be seen in Fig. 1b.

Since the experimental statistics of such networks is rather small, and difficult to obtain, their characteristics was studied by a purely geometric Monte Carlo simulation. Hereby, the TDs were randomly distributed in a two-dimensional plane and the MDs form in orthogonal directions until they hit another MD. The term 'geometric' refers to the fact that in the simulations no other physical interaction has been considered. However, this model needs to introduce certain assumptions how the MD segments form as function of time, since this determines where the MDs are blocked by other MDs. In this study, two simple cases were investigated, namely either all MDs form simultaneously, or MDs form one after each other in a random fashion (which is referred to as non-simultaneous here). Simulated MD networks arising from 10000 TDs are shown in Fig. 2a and 2b for simultaneous and non-simultaneous MD formation, respectively.

From the simulation results it was possible to conclude that the ratio of the TD spacing to MD spacing is a constant characteristic for the respective dislocation networks. This ratio converged for large simulations toward 2.0 for simultaneous, and 2.9 for non-simultaneous MD formation, respectively. The convergence of this ratio with respect to the TD number is quite slow, and can only be demonstrated with simulations, since available experimental statistics is insufficient. The importance of this ratio stems from the fact that MD formation is directly proportional to the relaxation of Si quantum well layers [2, 3] and consequently effecting spin coherence.

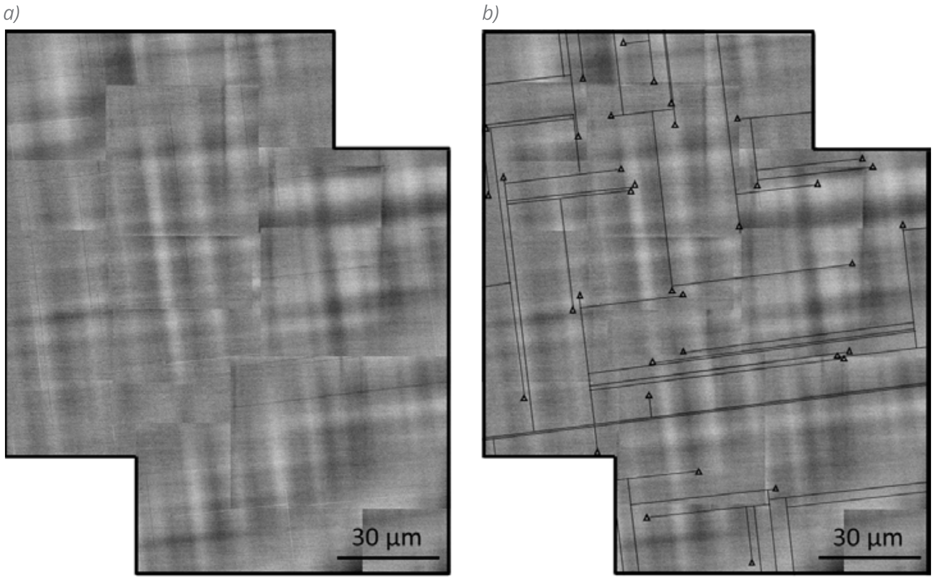

Fig. 1
(a) Stitched ECCI images of a dislocation network in a strained Si layer on SiGe grown by MBE,
(b) the same ECCI images as in (a) with the misfit and threading dislocation segments marked by black lines and black triangles, respectively (modified Figure from Ref. [2]).

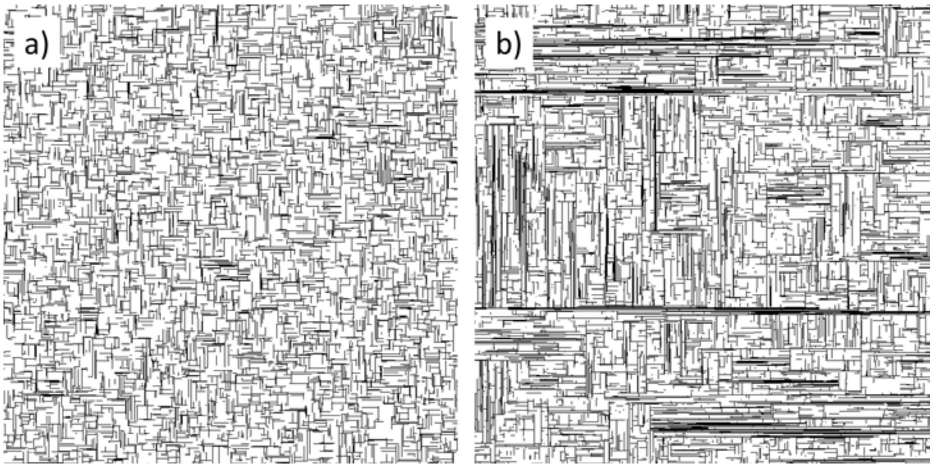

Fig. 2
(a) and (b) resulting misfit dislocation network from a geometric Monte Carlo simulation for simultaneous and non-simultaneous misfit dislocation formation, respectively (modified Figure from Ref. [2]).

It was also possible to distinguish the MD networks arising from different simulation conditions by comparing their fractal box dimension, which turned out to be 1.24 for the experimentally observed network. This is in good agreement with the simulations for non-simultaneous MD formation, which can be explained by the strain fluctuations due to compositional fluctuations in the SiGe virtual substrates (cross-hatch pattern).

Our investigations highlight the characteristics of MD networks in Si/SiGe heterostructures relevant for qubits. It was possible to clarify the MD formation mechanism for the experimentally observed MD networks. An important constant in this context, we established the ratio of TD spacing to MD spacing being directly proportional the plastic relaxation of the Si layer.

Acknowledgement

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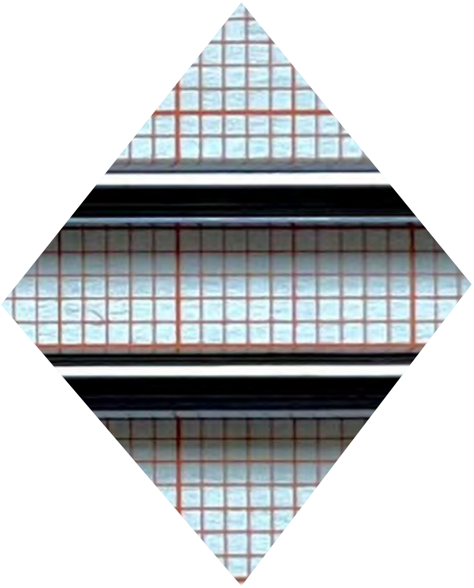

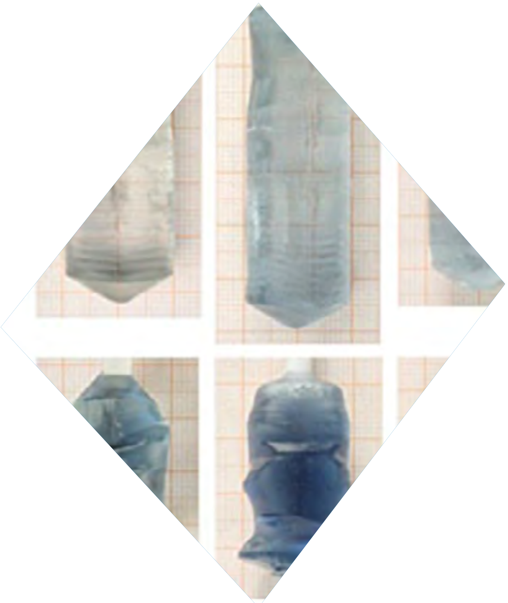

Volume Crystals

Monocrystalline silicon fibers for mirror suspension in gravitational-wave detectors

Iryna Buchovska, Lucas Vieira, Max Scheffler, Frank Kiessling, Judith Klewinghaus, Nikolay Abrosimov, Kathleen Schindler, Iason Tsiapkinis, Arved Wintzer, Kaspars Dadzis, Robert Menzel

Leibniz-Institut für Kristallzüchtung (IKZ), Berlin, Germany

Third generation Gravitational-Wave Detectors (3G-GWD) aim to achieve unprecedented sensitivity and resolution for detecting and studying gravitational-waves and hold immense promise for expanding our understanding of the universe. To reduce thermal noise, future 3G-GWD, such as the Einstein Telescope (ET), will operate at cryogenic temperatures, which is a key to increase the detection sensitivity at intermediate frequencies [1]. The interferometer mirror and the mirror suspension systems in previous GWD generations were made of fused silica, operating at room temperature. Crystalline silicon can instead be used for the ET interferometer test mass mirrors and mirror suspension system due to its excellent material properties at cryogenic temperatures [2]. The four mirror suspensions must carry the 200 kg weight of each mirror and must be made of thin fibers to isolate the mirrors from environmental noise [1]. For the ET suspension system, a fiber diameter of 3 mm is considered in this work. A mirror suspension system made of crystalline Si fibers is attractive because of the high mechanical quality factor Q, the very low thermal expansion coefficient, the high strength-to-weight factor and compatibility with the Si mirrors [3].

The Si fibers suitable for the mirror suspension system should be of high purity and free from defects to ensure high mechanical strength and Q factor, low thermal noise and avoid shifting or introducing new resonant frequencies. Since the mirror suspension is one of the most critical design components for the performance of the future ET, research is needed for the development of a growth method that allows a production of thin fibers with a well-defined diameter within very tight tolerances, diameter uniformity along the fiber axis, fiber roundness, smooth surface properties and homogeneity of bulk material properties.

In a frame of the joint research project, "Third generation gravitational-wave telescope 3G-GWD (BMBF/No. 05A20BC1)", we developed the growth setup that enables stable growth of thin monocrystalline Si fibers which will be tested for application in the ET suspension system [4]. The setup for this research was designed at IKZ on the basis of a float zone furnace, which is capable of performing the classical FZ process as well as pedestal growth. Both growing techniques were tested and upgraded for the growth of thin Si fibers and are based on the same approach of inductively heated vertical zone melting.

In the standard FZ method, feed material is supplied from above the inductor and the crystal is pulled in downward direction. Conversely, in the pedestal method, feed material is supplied from below the inductor and the crystal is pulled upwards. The dimensions of Si fibers required for elaboration of the next generation GWDs are set at 3 mm in diameter and at least 0.5 m in length. In order to provide the required parameters, machine grinded polycrystalline Si slim rods with 8 mm diameter were found to be an optimal feed material for the growth with minimal diameter variations. Fig.1 shows both FZ and Pedestal setups, which were developed in this research, holding polycrystalline feed rods and grown fibers [4].

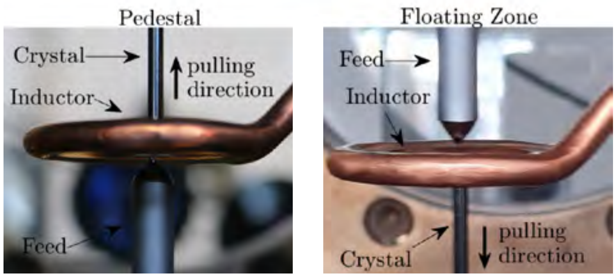

Fig. 1
Single crystalline Si-fiber growth using the pedestal (left) and FZ (right) configurations

Volume Crystals

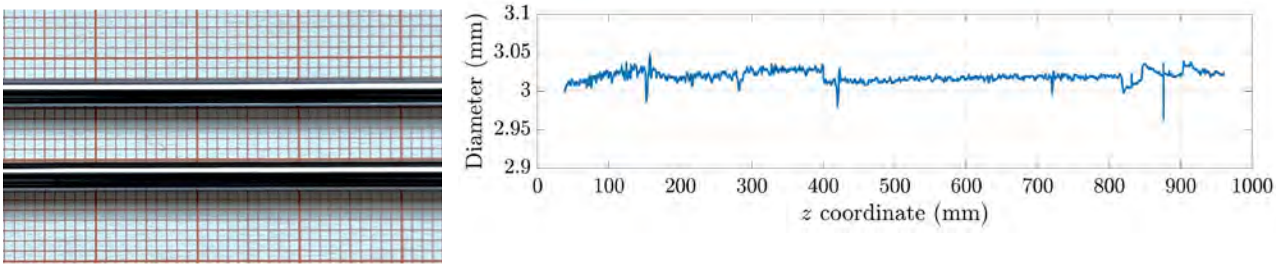

Fig. 2
a) Si fibers grown by FZ (top) and pedestal (bottom) methods.
b) Crystal diameter along the fiber length, grown by FZ method.

Both growth setups utilized the water-cooled copper HF inductor that provided induction heating power generated by a 2.5 MHz supply unit. The growth process was observed by using a hybrid device that combines a ratio pyrometer with an infrared camera in the same spectral range, and the temperature distribution of Si fibers during the process was thus carefully analyzed. During our research, the FZ and Pedestal growth recipes were further optimized by consequent experimental adjustment of process parameters such as pulling and pushing rate, crystal/feed rotation, power input etc. to achieve stable process conditions.

Based on the empirical data obtained, we developed a multiphysics numerical model that simulates the coupling between electromagnetism, heat transfer, fluid flow and phase boundaries for these techniques within the same mathematical framework, which facilitates direct comparisons of both growth techniques. Model validation was addressed using experimental measurements and satisfactory agreement was obtained [4]. The understanding of the growth process enabled by the model facilitates further optimization of crystal quality and diameter stability.

The developed setups and adjusted process parameters obtained during this research successfully ensured the growth of 0.5 m to 1.0 m long Si fibers by both pedestal and FZ techniques. The stable growth conditions during the growth process ensured the constant height and shape of the melt as observed by the operator and the infrared camera. The resulting fibers grown by the FZ and pedestal techniques are compared side-by-side in Fig.2 a) [4]. The diameter of the fibers remains constant along the entire length of the crystal and is measured to be 3.0 mm, with maximum deviation of less than 0.1 mm. The results of diameter measurements, performed along nearly 1 m long fiber grown by FZ technique, are shown in Fig.2 b) [4].

Fibers grown using the pedestal technique exhibit a closely similar diameter profile. Consequently, the stability of the growth process resulted in uniformity of the resulting fiber diameter. These very encouraging results show that both setups and respective growth recipes developed in this study enable stable growth of monocrystalline Si fibers with uniform diameter suitable for application in the ET suspension system. In the follow-up project (BMBF/No. 05A23BC1) fiber shapes for fiber to mirror attachment techniques are currently investigated at IKZ.

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Heavily-doped bulk p-type germanium crystals for advanced optoelectronic applications

Aravind Subramanian, Alexander Gybin, Pradeep C Palleti, Christo Guguschev, Uta Juda, Nikolay V. Abrosimov and R. Radhakrishnan Sumathi

Leibniz-Institut für Kristallzüchtung (IKZ), Berlin, Germany

Modern applications such as artificial intelligence, 6G wireless communication or virtual reality are increasing the need for advanced micro- and opto- electronic technologies. The interesting properties of germanium (Ge), such as its highest hole mobility among the commonly known semiconductors (>2000 $cm^2\ V^{-1}\ s^{-1}$), smaller bandgap (0.66 eV), and its compatibility with Si-based CMOS technology, have rejuvenated interest in this material [1].

Ge already serves as an integral component in III-V based solar cells, infrared optics, gamma-ray detectors, quantum technologies [2] and some of the state-of-the-art Si-based technologies [3]. Presently, low-resistivity Ge substrates are achieved via ion implantation techniques which introduce dopants in Ge mostly under non-equilibrium conditions [1]. Although high dopant concentration in Ge (> solubility at equilibrium conditions) is achievable, dopant implanted Ge substrates suffer from loses mainly arising due to the damage of the crystallinity during implantation [4]. Like Si, large diameter Ge bulk crystals can be grown dislocation free via the melt using the Czochralski (Cz) method. However, introducing large dopant concentration in the melt to grow doped Ge bulk crystals can be challenging due to multiple factors such as 1) constitutional supercooling leading to small angle grain boundaries and loss of crystallinity, 2) equilibrium segregation (k_0) of dopants and solubility limits in the Ge solid (crystal) and liquid (melt) phases causing inhomogeneous distribution of dopant concentration in the crystal [5,6], and 3) larger effect (as compared to intrinsic Ge) of thermal stresses at the crystal-melt interface proving detrimental to the microstructure of the crystal. Nevertheless, with extensive experimentation and process optimization, high crystalline quality p-type Ge bulk crystals (<10^5 dislocations/cm^2) can be grown using the Cz method [5]. The conventionally used p-type dopants in Ge are gallium (Ga) and boron (B). Interestingly, the segregation behaviour of the two dopants differs significantly. Ga shows low segregation (K_{0Ga} 0.087), leading to higher concentrations at the crystal's end, whereas B exhibits high segregation (K_{0B} > 4), resulting in higher concentrations at the crystal's start near the seed.

Fig. 1
One of the heavily Ga doped Ge crystals grown at nearly optimised conditions (left), poly-crystalline end cone of the crystal where the Ga solubility limit is reached (right)

In efforts to grow heavily doped p-type Cz-Ge crystals, several crystals with the <100> orientation were grown. One of the crystals is shown in Figure *1*. Ga (dopant) was introduced along with the Ge feedstock in a graphite crucible. The growth experiments were performed under an argon atmosphere. The 60 mm diameter crystals were grown with a constant pulling speed of 30 mm/h, and the process was mainly controlled by maintaining a uniform temperature gradient. Due to segregation-driven effects, the crystallisation temperature slightly decreases towards the end-conus. Hence maintaining a constant diameter of such crystals is challenging. The Ga concentrations in the grown crystals were quantified using the µ-XRF technique is shown in Figure *2a*. The chemically determined concentrations were then compared to the electrical properties determined using the 4-point probe method. The results show that up to 8 x $10^{19}\ cm^{-3}$ Ga atoms were incorporated into the crystal [5]. The experimental segregation coefficients (k_{eff}) of Ga in Ge, were observed to be varying between 0.014 to 0.08 (e.g. in the crystal shown in Figure 1), slightly lower than the k_{0Ga}

Volume Crystals

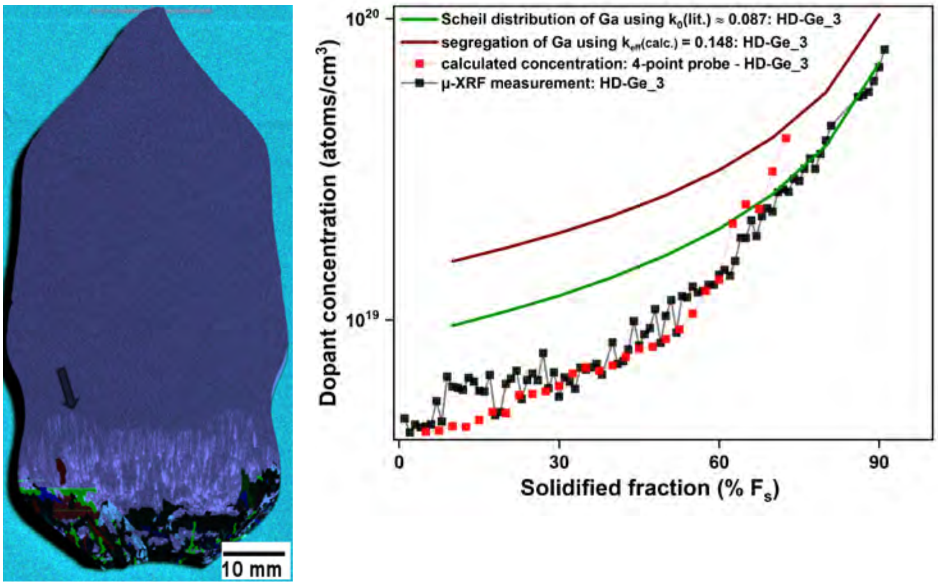

Fig. 2
(a) Concentration profile of Ga in the Ge crystal presented in figure 1. The chemically determined concentration from μ-XRF is compared to the electrically active charge carrier concentration, and to the theoretical segregation curve (Scheil profile) of Ga in Ge. Reproduced from Ref. [11], under a Creative Commons attribution 4.0 international.
(b) EDLM map of the wafer cut from the vertical direction along the growth direction [100]. Reproduced from Ref. [11], under a Creative Commons attribution 4.0 international.

The dislocations (terminating on the surface of the wafer) in the crystal were decorated using the IEEE standard defect etchant for Ge and the etch pits were counted. The dislocation density was measured in the top (F_s; 10%) middle (F_s; 40-50%) and bottom (F_s; 70-80%) regions in the crystal. The dislocation density at the bottom region was less than 10^5 cm^{-2}. These dislocations are predominantly observed to originate within the crystal from its edges as a result of thermal stress. A qualitative analysis along the entire crystal length has been carried out using the energy dispersive Laue mapping (EDLM) is shown in Figure 2b. The EDLM map revealed the formation of small angle grain boundaries preceding the evolution of poly-crystalline structure, nearly at the end part of the crystal. The formation of large number of small angle grain boundaries, mainly due to constitutional supercooling, seems to occur at the Ga concentrations of around 2 x 10^{20} cm^{-3}. Along with constitutional supercooling, another main reason for the formation of the poly-crystalline region is the solubility limit of Ga in Ge (5 x 10^{20} cm ^{3}). The obtained result is in good agreement with the previously reported solubility limit of Ga. This study [5] demonstrated the feasibility of growing highly-doped Ge bulk crystals with a high crystalline quality (< 10^5 dislocations/cm^2) and large number of active charge carrier concentration enabling the production of efficient low resistively substrates from the grown crystals.

Acknowledgement

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Volume Crystals

Bulk single crystals and physical properties of β-$(Al_xGa_{1-x})_2O_3$ (x = 0 – 0.35) grown by the Czochralski method

Zbigiew Galazka, Andreas Fiedler, Andreas Popp, Steffen Ganschow, Albert Kwasniewski, Palvan Seyidov, Mike Pietsch, Andrea Dittmar, Saud Bin Anooz, Klaus Irmscher, Manuela Suendermann, Detlef Klimm, Ta-Shun chou, Jana Rehm, Thomas Schröder, Matthias Bickermann

Leibniz-Institut für Kristallzüchtung, Berlin, Germany

In the last decade, β-Ga_2O_3 has experienced enormous development in bulk crystal growth technology, epitaxial film growth, device fabrication and in research into the underlying physics of that compound. This is the result of a large bandgap of 4.85 eV, proper application-relevant electrical properties including a wide doping range and a high theoretical breakdown field of 8 MV/cm, as well as availability of large single crystals and different epitaxial techniques, which allow to fabricate devices for a diversity of applications, such as high-power electronics, UV optoelectronics, radiation detectors, and high temperature gas sensing. To enhance the capability of switching high voltages, β-Ga_2O_3 can be doped with aluminium (Al) that increases the bandgap, and thus the breakdown field.
Due to the lack of lattice-matched substrates, β-$(Al_xGa_{1-x})_2O_3$ films were hitherto grown heteroepitaxially on β-Ga_2O_3 substrates and exhibited rather poor structural quality. The present work, which we have already published [1, 2], was aimed to demonstrate the growth of bulk β-$(Al_xGa_{1-x})_2O_3$ single crystals with very high Al concentration [Al] (up to 35 %), suitable for homoepitaxy, and evaluate basic structural, electrical, and optical properties as a function of this concentration.
20 mm and 55 mm diameter β-$(Al_xGa_{1-x})_2O_3$ single crystals were grown by the Czochralski method utilizing Ir crucibles and inductive heating, as we described in details e.g. in Ref. [3]. The crystals were either undoped, or intentionally doped with Si or Mg. The growth rate was around 1.5 mm/h, the growth atmosphere contained an inert gas as well as oxygen (2 – 14 vol.%).
The melting point increases with increasing [Al], and the measured melting points follow the liquidus of the published phase diagram of the Ga_2O_3 – Al_2O_3 system. Segregation forces the crystal to grow at higher [Al] than that what is present in the melt, and as a consequence, subsequent crystallization proceeds with a decreasing [Al].

The effective segregation coefficient increases with [Al] from k_{eff}(Al) = 1.1 at low [Al] < 10 mol.% to k_{eff}(Al) = 1.2 at higher [Al]. So, for instance, at [Al] = 30 % in the melt, the first crystallized fraction (CR = 4 %) contains 36 mol.% Al, while the lower part of the crystal (CR = 17 %) contains 33 mol.% Al (measured by ICP-OES) [2].

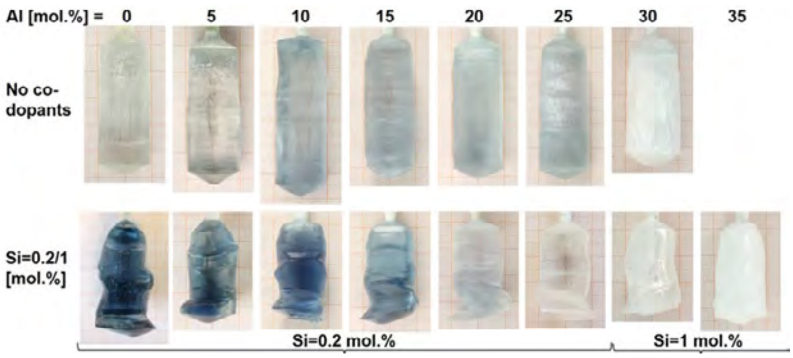

Fig. 1
β-$(Al_xGa_{1-x})_2O_3$ single crystals grown by the Czochralski method with no other intentional doping (first row) and co-doped with Si = 0.2 or 1 mol.% in the melt (second row).
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Fig. 1 shows Czochralski-grown β-$(Al_xGa_{1-x})_2O_3$ single crystals with [Al] = 0 – 30 mol.% in the melt with no intentional co-doping (first row) and with [Al] = 0 – 0.35 mol.% and co-doped with Si (second row). All the crystals with [Al] = 0 – 25 mol.% were single crystals with no polygrains. All of them crystallized in the monoclinic system according to XRD powder diffraction. β-$(Al_xGa_{1-x})_2O_3$ single crystals with no intentional co-doping are all straight cylinders with bluish coloration indicating semiconducting behavior due to the presence of free charge carriers.

Volume Crystals

The crystals co-doped with Si are shorter with a cylindrical length of 20 – 25 mm, beyond which a foot or spiral forms. This is due to free carrier absorption that absorbs heat in the near-infrared spectrum. As heat accumulates in the growing crystal, it leads to interface inversion after reaching a certain length. This phenomenon we have discussed in detail in previous reports (e.g., [4]). Remarkably, weakening of the color intensity occurs with increasing [Al], and the color vanishes at high [Al] ³ 25 mol.% in contrast to crystals doped with Al only. This clearly indicates a decrease of the free electron concentration. More details on the electrical properties and its potential impact on device properties are provided in [2].

β-$(Al_xGa_{1-x})_2O_3$ single crystals with [Al] = 0 – 25 mol.% in the melt revealed good structural quality characterized by narrow rocking curves with FWHM = 30 – 50 arcsec for [Al] = 0 – 25 mol.% for both 20 mm and 55 mm diameter crystals. All lattice constants in Fig. 2 linearly decrease with [Al] in β-$(Al_xGa_{1-x})_2O_3$ crystals, with a-axis having the largest drop, followed by c-axis, and b-axis. Anisotropic shrinkage of the lattice constants causes an increase (also linear) of the angle β between the [100] and [001] crystallographic directions (not shown here).

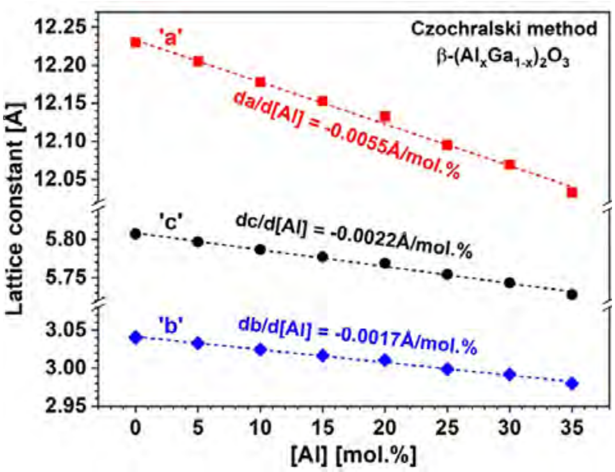

Fig. 2
(a) Lattice constants a, b, and c of the monoclinic β-$(Al_xGa_{1-x})_2O_3$ system vs. [Al] (x = 0 - 0.35).
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The near-edge absorption of β-$(Al_xGa_{1-x})_2O_3$ single crystals was gathered by optical absorbance measurements. The absorption edge with E||b-axis shifts with [Al] from about 270 nm at [Al] = 0 mol.% to about 230 nm at [Al] = 30 mol.%. A similar shift of the absorption edge towards shorter wavelengths is also observed for E||c-axis. So, the band-gap absorption of β-$(Al_xGa_{1-x})_2O_3$ can be tailored for deep UV optoelectronic applications, such as photodetectors or optical filters.

Bandgap values, Eg, were evaluated from the near-edge absorption coefficients for direct transitions (a μ $(E - Eg)^{1/2}$), and shown in Fig. 3 for E||b and E||c. The Eg values increase substantially linearly and equally for both polarizations, by 0.75 eV at [Al] = 30 mol.% with respect to pure β-Ga_2O_3.

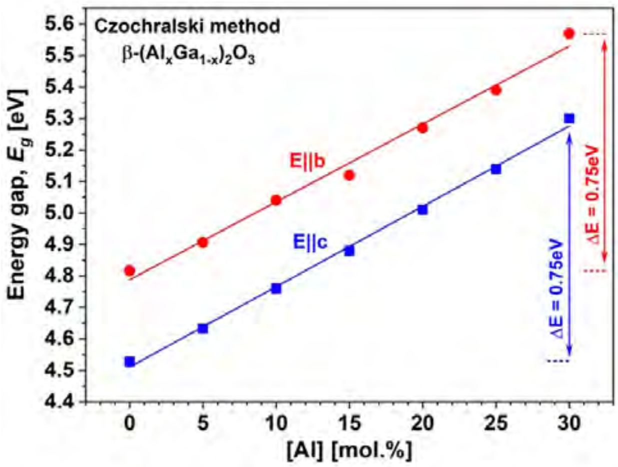

Fig. 3
Direct bandgap for polarization parallel to b- and c-axes of β-$(Al_xGa_{1-x})_2O_3$ single crystals grown by the Czochralski method.
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Thermal analysis in the $LiNbO_3$—$LiTaO_3$ system

Umar Bashir, Detlef Klimm, Klaus Böttcher, Steffen Ganschow, Matthias Bickermann

Leibniz-Institut für Kristallzüchtung, Berlin, Germany

Lithium niobate ($LiNbO_3$) and its isostructural counterpart lithium tantalate ($LiTaO_3$) are technologically important synthetic oxides with unique properties. Both materials are characterized by a large spontaneous polarization and are vastly employed for applications in linear and nonlinear integrated optics as well as surface acoustic wave generation. Despite obvious chemical and structural similarities both compounds show some strikingly different properties. $LiNbO_3$ has a high Curie temperature (1195 °C) nearly reaching the melting point (1253 °C) while $LiTaO_3$ (melting temperature 1650 °C) undergoes the ferro-to-paraelectric phase transition already at 608 °C. Both materials are birefringent, but while $LiNbO_3$ is optically negative, $LiTaO_3$ is positive. These properties, among others, have motivated the investigation of the behavior of $LiTa_xNb_{1-x}O_3$ (LNT) solid solutions of such similar and yet different materials. The research is funded by the DFG in the frame of the research group FOR5044. The objective of the subproject led by IKZ is the comprehensive investigation of crystallization of LNT and the provision of suitable, well-characterized samples.

In our first contribution [1] we focussed on the temperature of the ferroelectric phase transition, in particular on the composition dependence. We measured specimen prepared from previously grown solid solution single crystals containing various Ta atomic fractions x_{Ta}. The crystals were grown using the Czochralski technique with inductive heating of a cylindrical crucible made of precious metal, depending on the growth temperature either Pt or Ir. In case of an Ir crucible the process was conducted in protective Ar atmosphere with addition of small amounts (< 1 Vol%) of O_2, otherwise in air. Starting materials were mixtures of the congruently melting compositions of LN, respectively LT, namely 48.4 mol% Li_2O. With respect to the expected substantial component segregation—the distribution coefficient of LT exceeds a value of 3 for Nb-rich melts—a rather pulling rate of 0.5 mm/h was set in order to suppress constitutional supercooling and related phenomena.

From the grown crystals, homogeneous areas were prepared for thermal measurements after X-ray elemental fluorescence (XRF) analysis. Three measurements were performed under identical conditions (i) with empty reference and sample crucibles (base line), (ii) with Al_2O_3 powder as standard with known $c_p(T)$ function, and (iii) with the powdered sample. The results of the first heating deviated significantly from those of subsequent heating cycles – probably due to the outgassing of adsorbed surface contaminations, or from yet unreproducible thermal contact between crucible bottom and reference. The results of the latter three measurements, however, proved to be almost identical. Hence, the average of $c_p(T)$ functions from these heating segments was used for further evaluation.

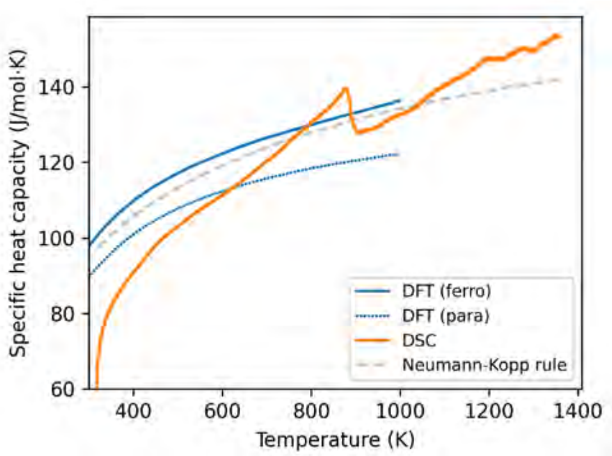

Fig. 1
Temperature dependence of the specific heat capacity of LT obtained from our measurement (orange curve) in comparison with values from DFT calculations and an estimation based on the application of the Neumann-Kopp rule.

Fig. 1 shows exemplarily the experimental results for pure LT along with the results of the DFT calculations performed by Felix Bernhardt and Simone Sanna at the University of Gießen. Moreover, an estimation of $c_p(T)$ by the Neumann-Kopp additive rule is shown, based on FactSage [2] data for the simple metal oxides. Taking into account the simplification of the Neumann-Kopp rule, the agreement with our results can be considered satisfactory. The computational results show a similar trend. In particular, the difference between the paraelectric and the ferroelectric phases are consistent with the experimental observation.

Volume Crystals

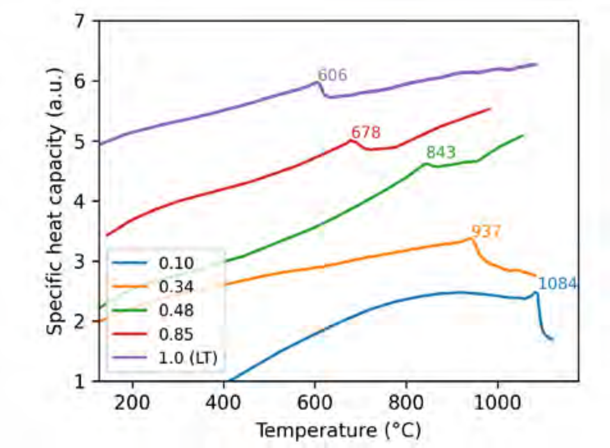

Fig. 2
Temperature dependence of the specific heat capacity for several LNT solid solution crystals. The numbers in the legend give the LT mole fraction (in the crystal).

The temperature profile of the specific heat capacity for a series of solid solution crystals with the measured (XRF) Ta atomic fractions listed in the legend are shown in Fig. 2. The maximum of the ferroelectric transition peak corresponds to the Curie temperature T_c, and is plotted as a function of the Ta atomic fraction x_{Ta} in the crystal in Fig. 3. The linear dependence $T_C = f(x_{Ta})$ is obvious. For pure LN and very Nb-rich ($x_{Ta} < 0.1$) crystals, T_c is beyond the measuring range. Our results are in excellent agreement with data reported by other groups.

Our investigations have shown that the phase transition temperature of LNT solid solution crystals can be determined by measuring the specific heat capacity of specimen. The temperature itself is a linear function of composition by means of [Ta]:[Nb] ratio. Therefore, thermal analysis can, in turn, be utilized to estimate the composition of a solid solution crystal. Further details can be found in [1].

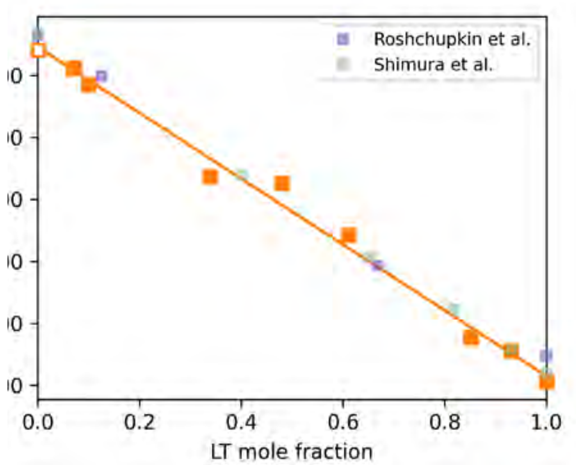

Fig. 3
Dependence of the ferroelectric Curie temperature on composition of LNT. Comparative data were taken from [3] and [4], the value of pure LN from [5].

Acknowledgement

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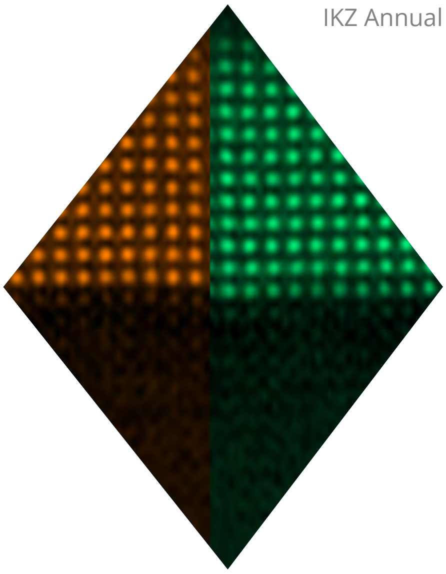

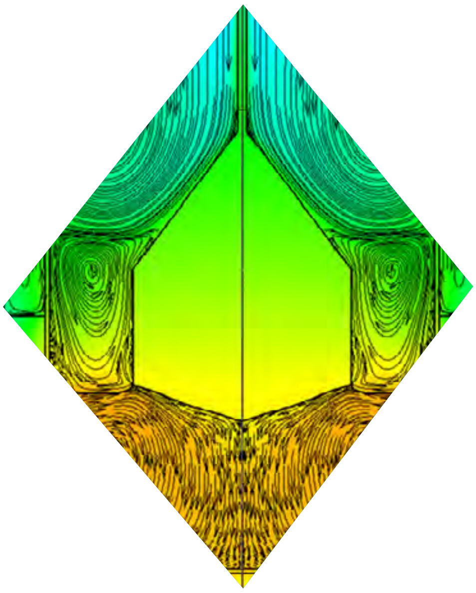

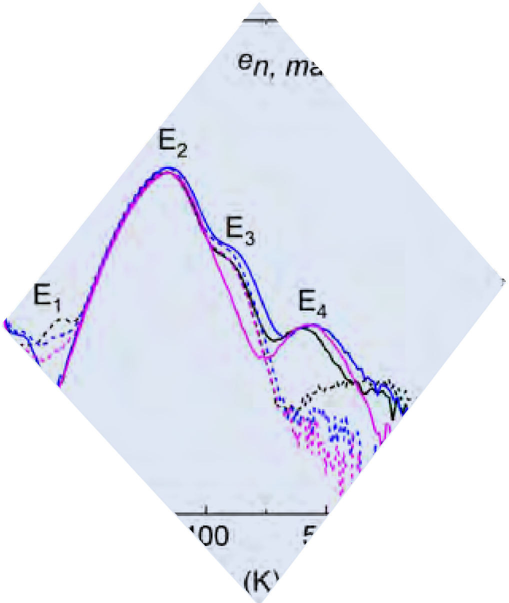

Materials Science

Thermal stability of Schottky contacts and rearrangement of defects in β-Ga_2O_3 crystals

Palvan Seyidov,[1] Joel B. Varley,[2] Ymir Kalmann Frodason,[3] Detlef Klimm,[1] Lasse Vines,[3] Zbigniew Galazka,[1] Ta-Shun Chou,[1] Andreas Popp,[1] Klaus Irmscher,[1] and Andreas Fiedler[1]

[1]Leibniz-Institut für Kristallzüchtung, Berlin, Germany
[2]Lawrence Livermore National Laboratory, Livermore, USA
[3]Department of Physics/Centre for Materials Science and Nanotechnology, University of Oslo, Norway

Beta-gallium oxide (β-Ga_2O_3) as an ultra-wide bandgap oxide semiconductor has attracted great interest recently. Due to a wide possible n-type doping range of 10^{15} – 10^{21} cm^{-3} with an electron mobility of nearly 200 cm2/Vs, a bandgap of about 4.85 eV, and a breakdown field of ~8 MV/cm, β-Ga_2O_3 is a promising material for next-generation power electronics. Besides great physical properties, the possibility of growing large bulk β-Ga_2O_3 single crystals from the melt, for example at IKZ by the Czochralski method (Cz), allows the fabrication of large surface area substrates with high crystalline quality, enabling device fabrication at an industrial level. Ultimately, this could result in cheaper and more reliable devices compared to other wide bandgap semiconductors such as GaN or SiC. Static measurements on power electronic devices such as Schottky diodes, MESFETs, and MOSFETs confirm the high potential of β-Ga_2O_3. However, reliability measurements such as multiple-switching stress tests have received less attention so far. Additionally, components in power electronics are always operated at their thermal limit in order to achieve maximum switching efficiency. Since gallium oxide is thermally stable up to 1100-1200 °C, the thermal limit is set by the device periphery. Because the metal-to-semiconductor interface is the most critical component in Schottky diodes and MESFETs, the thermal stability of this interface is of high significance. Even though the total collapse of the Schottky barrier may not be expected at moderate device operating temperatures like 650 K, already minor changes at the Schottky interface can occur, like intermixing of atoms leading to a change of barrier height or diffusion of atoms from the contact metal into the charge depletion zone inducing new defect levels in the channel. It has already been observed that some defect levels within the band gap of β-Ga_2O_3 alter under annealing and reverse bias.

Therefore, a comprehensive study on the thermal stability of the most prominent Schottky contact metals (Au, Ni and Pt) on β-Ga_2O_3 under thermal load of up to 650 K has been performed by IKZ in collaboration with Joel Varley's group from Lawrence Livermore National Laboratory (LLNL) and Lasse Vines' group from University of Oslo (UiO).

At IKZ, Schottky barrier height, ideality factor, and net doping density have been evaluated by current-voltage (I-V) and capacitance-voltage (C-V) measurements before and after a thermal load of 650 K (results summarized in Table 1). Thermodynamic calculations were performed using "FactSage" to determine the stability of the interface between the metal and semiconductor, which helps explaining the experimental results. The results indicate oxidation of Ni contacts, strong alloying of Au-Ga at the Au/β-Ga_2O_3 interface, and only slight intermixing of Pt-Ga at the Pt/β-Ga_2O_3 interface, making Pt the most stable contact.

Schottky contact	Ideality factor η		Schottky barrier height SBH (eV)		Net doping density N_d–N_a (cm^{-3})	
	Pristine	*After thermal load*	*Pristine*	*After thermal load*	*Pristine*	*After thermal load*
Au	1.04	1.2	1.11	0.75	1.1×10^{17}	1.1×10^{17}
Pt	1.05	1.08	1.23	1.11	1.7×10^{17}	1.7×10^{17}
Ni	1.06	1.04	0.93	1.03	1.4×10^{17}	1.4×10^{17}

Table 1.
Summary of the parameters derived from the RT I-V and C-V measurements for Au, Pt, and Ni Schottky diodes. Reprint from [1] under the Creative Commons Attribution (CC BY) license.

Since intermixing of the atoms from the metal contact and β-Ga_2O_3 is predicted by the thermodynamic calculations, we investigated the defect levels of the (100) β-Ga_2O_3 crystals grown by the Cz method at IKZ using deep-level transient spectroscopy (DLTS) in a 100 K-650 K (ramp-up) and 650 K-100 K (ramp-down) temperature cycle (see Fig. 1 (a)). Several defect levels below the conduction band minimum (E_C) at E_{01} = 0.41 eV, E_1 = 0.60 eV, E_2 = 0.77 eV, E_3 = 0.96 eV, and E_4 = 1.17 eV were detected (see Fig. 1 (b)). In the temperature ramp-down DLTS measurement, the defect level E_4 disappeared, and the defect level at E_1 appeared for all Schottky contacts.

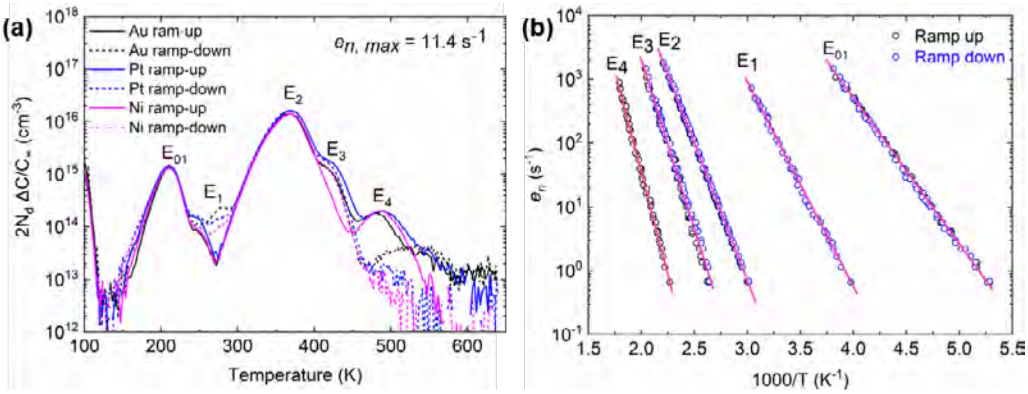

Fig. 1
(a) DLTS spectra of Au, Pt, and Ni Schottky contacts. The related DLTS parameters are the rate window setting for the peak maximum $e_{n,max}$ = 11.4 s^{-1}, the reverse voltage V_r = -4 V, the pulse voltage V_p = 0 V, and the pulse width t_p = 100 µs.
(b) Representative Arrhenius plot of emission rates in the peak maximum of the Au contact for each trap level.
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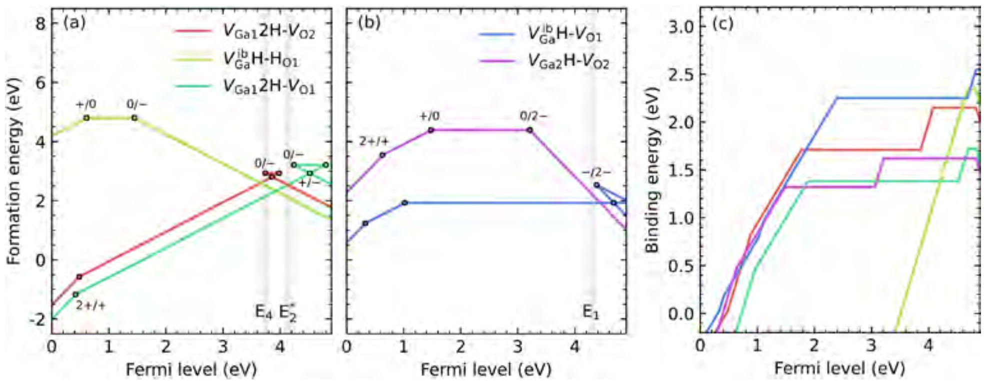

Fig. 2
Calculated formation energies under intermediate (average between Ga-rich and O-rich) conditions of the most favorable configurations of (a) doubly and (b) singly hydrogenated Ga-O divacancies in β-Ga_2O_3.
The $V_{Ga1}2H$-V_{O2} and $V_{Ga}^{ib}H$-V_{O1} complexes display thermodynamic charge-state transition levels that are close in Fermi-level position to the measured ionization energy for E_4, E_2^* and E_1, respectively.
(c) Calculated binding energies for the hydrogenated divacancies (same color code as in (a) & (b)).
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Hybrid-functional calculations have been carried out by our collaborators from LLNL and UiO to understand the defect transformation (see Fig. 2).

A consistent model was derived when considering the Fermi-level position during growth and the quasi-Fermi-level position under bias and temperature in the Schottky diode. The defect at E_C – 1.17 eV is tentatively assigned to a doubly-hydrogenated divacancy complex consisting of a gallium vacancy (V_{Ga}) and an oxygen vacancy (V_O) in the arrangement $V_{Ga1}2H$-V_{O2} (assigned to E_4). The transformation of the defect can be explained by a rearrangement of the divacancy complex accompanied by the dissociation of one hydrogen atom during the temperature sweep under bias.

The more stable resulting defect is a singly-hydrogenated divacancy complex of different arrangement $V_{Ga}^{ib}H$-V_{O1} well-fitting to the defect level at E_C – 0.60 eV. These studies provide insight into the behavior induced by these common Schottky contacts and possible evolution associated with the thermal load. More details can be found in [1].

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Materials Science

Numerical modelling of Cz- β-Ga_2O_3 crystal growth in reactive atmosphere

Gagan Kumar Chappa[1], Vladimir Artemyev[2], Andrey Smirnov[2], Detlef Klimm[1], Natasha Dropka[1, *]

[1] Leibniz-Institut für Kristallzüchtung , Berlin, Germany
[2] Semiconductor Technology Research d.o.o. Belgrade (STR), Serbia

β-Ga_2O_3 crystals, with their unique properties such as wide band gap and high-temperature stability, are attracting attention for use in power electronics and optoelectronic devices. Growing large-diameter β-Ga_2O_3 crystals using the Czochralski (Cz) method presents challenges. One major obstacle is non-stoichiometric evaporation, particularly of O_2, leading to poor crystal quality [1]. While introducing O_2 helps to minimize evaporation, it reacts with the expensive Ir crucible, forming IrO_2 and shortening its lifespan. Previous research proposed using a dynamic atmosphere of Ar and CO_2 to address the oxidation issue [2]. CO_2 decomposes at high temperatures, releasing O_2 to stabilize the Ga_2O_3 melt and suppress evaporation. However, CO_2 can have negative effects on crystal properties, and IrO_2 formation remains a concern.

This study explores SO_2 [3] as a potential alternative to CO_2 in the Cz-growth process for β-Ga_2O_3. SO_2 offers a unique advantage by increasing O_2 concentration at high temperatures which is crucial for Ga_2O_3 melt stability, while reducing O_2 concentration at lower temperatures helps in minimizing Ir oxidation. We investigated the optimal SO_2 concentration for suppressing melt evaporation and maintaining ideal stoichiometry using a combined approach of thermodynamic calculations and CFD coupled chemical modeling.

Thermodynamic equilibrium calculations were performed using Factsage software to determine the effect of SO_2 and CO_2 concentrations on the Ga_2O_3-Ir system in a temperature regime from room to melting point temperature. These calculations included gas-phase and solid-state equilibria and species interactions. Additionally, CFD modeling was utilized using CGsim software to simulate the influence of various SO_2 and CO_2 concentrations on melt stoichiometry and O_2 distribution within the furnace for different hot zone designs. The CFD model incorporated heat transfer, fluid flow, and species transport. By simulating the growth environment, the model allowed to predict temperature distribution, flow field, and O_2 distribution across the melt surface.

This study also includes the impact of the melt's free surface area on the required SO_2 and CO_2 concentrations for different crucible sizes used for growing 2-inch and 4-inch diameter crystals. A parameter called Stoich is introduced to measure the melt's deviation from ideal stoichiometry, determining the amount of SO_2 gas needed to achieve the desired Ga_2O_3 melt composition.

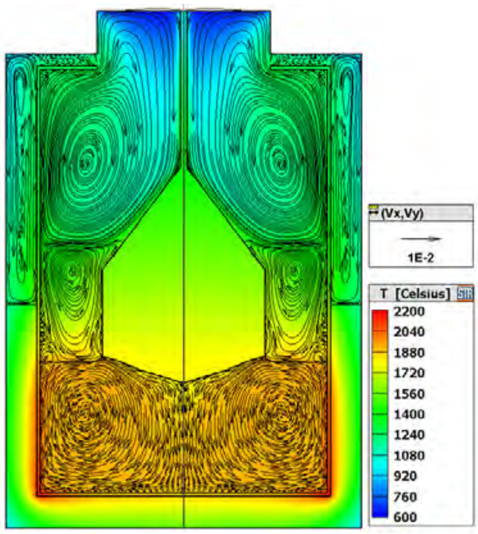

Fig. 1
The temperature distribution in the crystallization zone of the furnace. Reprint from [3] under the Creative Commons Attribution (CC BY) license.

We performed axisymmetric, steady-state simulations to analyze the temperature and flow field in the hot zone Fig. 1. Three different crucible-crystal diameter combinations were considered. The model treats the melt and gas as incompressible fluid, we used the one equation turbulence model for computing the flow of both gas and melt. The Boussinesq approximation is used to account for buoyancy effects. The furnace is heated by an inductive heater with a frequency of 30 kHz and the rotation rate of the crystal and the pulling rate was 5rpm and 1.5 mm/h, respectively. The pressure of the carrier gas Argon was 2 atm. The Rosseland model was used to tackle the semitransparency of the Ga_2O_3 crystal.

Materials Science

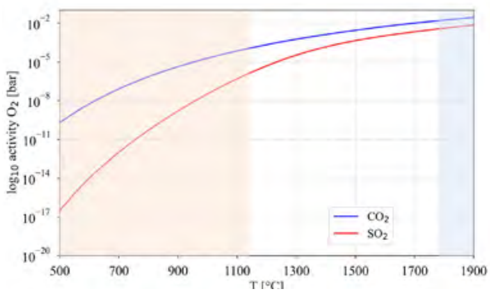

Fig. 2
O_2 activity resulting from the decomposition of SO_2 and CO_2 as a function of temperature. Reprint from [3] under the Creative Commons Attribution (CC BY) license.

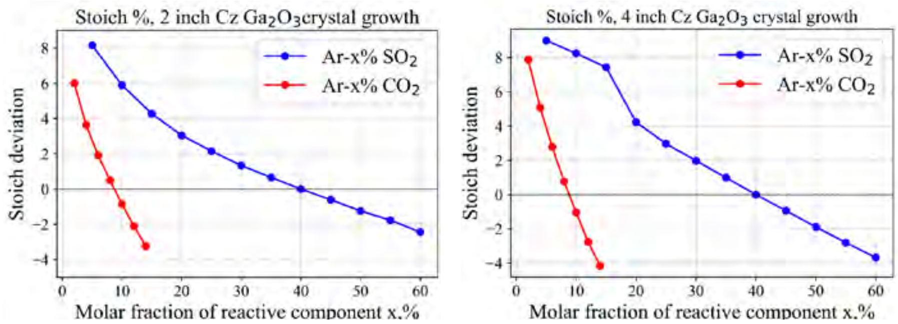

Fig. 3
The impact of SO_2 and CO_2 concentrations on the averaged Stoich parameter for both 2-inch and 4-inch crystals.
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The chemical model treats the Ga_2O_3 melt as a solution of gallium Ga^{3+} and oxygen O^{2-} ions. Species like atomic O and Ga_2O form at the melt surface and then are carried away by convection and diffusion. Boundary conditions are implemented at both the gas/melt and crystal/melt interfaces. At the gas/melt interface, the diffusion fluxes of atomic O and Ga_2O are equal to their respective non-stoichiometric evaporation rates. On the melt side, the mass fractions of Ga^{3+} and O^{2-} ions are adjusted to reflect the deviation of gaseous O_2 and Ga_2O from stoichiometry. At the crystal/melt interface, Ga^{3+} and O^{2-} ions incorporate into the crystal at the same ratio as their mass fractions in the melt, maintaining zero net movement of ions.

Figure 2. depicts the O_2 activity from SO_2 and CO_2 decomposition at various temperatures. SO_2 decomposition yields a significantly lower $p(O_2)$ compared to CO_2 in the critical temperature regime for Ir oxidation. However, SO_2 can still act as an O_2 source at the Ga_2O_3 melting point 1820°C.

The study [3] revealed that introducing SO_2 into the growth atmosphere effectively suppressed the evaporation of the Ga_2O_3 melt and significantly reduced Ir crucible oxidation compared to CO_2. Figure 3. shows that the optimal SO_2 concentration for achieving a stoichiometry condition is around 40%, while CO_2 achieves stoichiometry at a lower concentration of 9%. The study finds that cases with large diameter crucibles therefore having larger free melt surfaces reduce the requirement lower SO_2 and CO_2 concentrations to attain stoichiometry compared to crucibles with smaller free melt surfaces. This is attributed to the larger melt free surface facilitating improved O_2 exchange throughout the melt, thereby preventing localized O_2 accumulation near the crucible and promoting a more uniform distribution of O_2. These findings suggest that crucible design and growth parameters can be optimized to achieve the desired process conditions.

The average O_2 concentration in the furnace atmosphere indicates Ir crucible corrosion. Calculations show that an SO_2 atmosphere reduces the average O_2 concentration by 30% compared to a CO_2 atmosphere, helping to protect the crucible. Additionally, using a large diameter crucible with either SO_2 or CO_2 further reduces the O_2 concentration around the crucible by up to 20%. These findings provide a base for large-scale high-quality β-Ga_2O_3 crystal growth using the Cz method, but further research is needed to address other challenges like e.g. the formation of elemental Ga on the melt that might lead to an eutectic with the Ir crucible [4].
More details of this work can be found in [3].

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Impact of Polar Discontinuity on Surface Segregation and Interface Termination: Insights from $LaInO_3/BaSnO_3$

Martina Zupancic,[1] Wahib Aggoune,[2] Alexandre Gloter,[3] Georg Hoffmann,[4] Franz-Philipp Schmidt,[5] Zbigniew Galazka,[1] Daniel Pfützenreuter,[1] Aysha A. Riaz,[6] Christoph Schlueter,[7] Houari Amari,[1] Anna Regoutz,[6] Jutta Schwarzkopf,[1] Thomas Lunkenbein,[5] Oliver Bierwagen,[4] Claudia Draxl,[2] and Martin Albrecht[1]

[1]Leibniz-Institut für Kristallzüchtung, Berlin, Germany
[2]Institut für Physik and IRIS Adlershof, Humboldt-Universität zu Berlin, Germany
[3]Université Paris-Saclay, CNRS Laboratoire de Physique des Solides, Orsay, France
[4]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany
[5]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany
[6]Department of Chemistry, University College London, London, United Kingdom
[7]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Polar discontinuities at oxide interfaces provide unique opportunities to manipulate charge states and generate two-dimensional electron gases (2DEGs). In ABO_3-type perovskites, the (001) surface is typically the most energetically stable, often terminating with either AO or BO_2 layers. These surface terminations can exhibit different polarities depending on the crystallographic orientation. For example, in perovskites with orthorhombic symmetry (Pbnm space group), a polar nature may be observed along the [001] direction, while cubic perovskites often remain nonpolar due to their symmetry. A well-known example is the $LaAlO_3/SrTiO_3$ interface, where a 2DEG forms due to charge transfer between polar and nonpolar layers. At this interface, the polar LaO^+ layer donates electrons to the TiO_2^0 layer in $SrTiO_2^0$. If $SrTiO_3$ is terminated with SrO^0, the AlO_2^- layers in $LaAlO_3$ can create a two-dimensional hole gas. Precise atomic-level control over surface properties is crucial in these systems, as the polarity of the surface terminations directly affects the electronic behavior of the heterostructure.

In a study that has been performed with several partners within the Science Campus GraFOx we explored the relationship between polar discontinuity compensation and surface segregation. Our focus has been on the heterostructures formed by the wide-bandgap cubic semiconductor $BaSnO_3$ and orthorhombic $LaInO_3$. Given the increasing interest in two-dimensional electron gases for applications in novel electronic devices, $BaSnO_3$ is distinguished from other perovskites by its exceptional electron mobility at room temperature of 300 $cm^2V^{-1}s^{-1}$.

To investigate the interfaces between $BaSnO_3$ and $LaInO_3$, we employed a range of techniques, including scanning transmission electron microscopy (STEM), electron energy loss spectroscopy (EELS), X-ray photoelectron spectroscopy (XPS), and density functional theory (DFT) calculations. Our research covered both bulk $BaSnO_3$ samples grown at IKZ and heterostructures of $LaInO_3/BaSnO_3$ deposited on $DyScO_3$ and $SrTiO_3$ substrates, using molecular beam epitaxy (by our partners at PDI) and pulsed laser deposition methods (at IKZ).

Our transmission electron microscopy (TEM) experiments on pristine $BaSnO_3$ bulk crystal surfaces (Fig. 1), are consistent with density functional theory (DFT) calculations, showing that BaO is the predominant surface termination for $BaSnO_3$ across a broad range of chemical potentials.

At the interface between $BaSnO_3$ and $LaInO_3$, however, we observed an SnO_2 termination using atomic resolution electron energy loss spectroscopy (EELS) and energy-dispersive X-ray spectroscopy (EDX) (Fig. 2). These microscopic findings are consistent with electrical measurements indicating the presence of a two-dimensional electron gas (2DEG) at the interface. Furthermore, X-ray photoelectron spectroscopy (XPS) revealed that when nonpolar BaO-terminated surfaces are overgrown with polar $LaInO_3$, an SnO_2 termination forms at the interface, while BaO accumulates on the surface of $LaInO_3$. This change in interfacial termination can be attributed to the segregation of barium toward the growth surface.

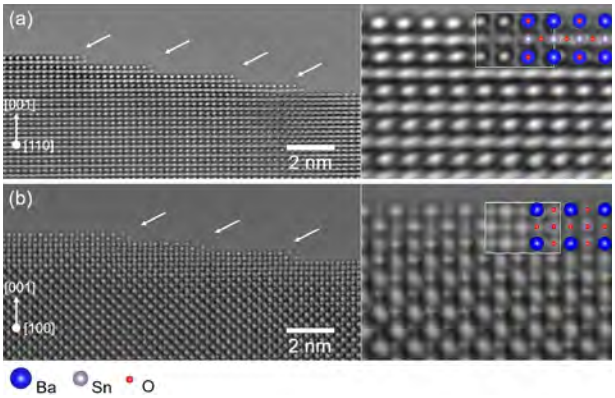

Fig. 1
HRTEM image of the $BaSnO_3$ (001) surface along [110] projection (a) and [100] projection (b). The right panels in (a) and (b) represent magnified sections of (001) surfaces along with white frame insets of HRTEM simulations and overlaid atomic models.
White arrows indicate the one-unit-cell-high atomic steps on the surface of $BaSnO_3$.

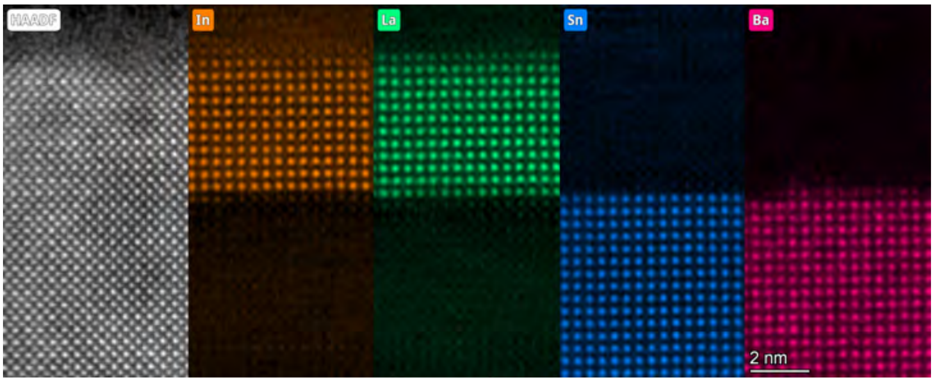

Fig. 2
Atomic resolution EDX map of the $LaInO_3$/$BaSnO_3$ interface. The interface is Sn terminated. In the HAADF image the interface between $LaInO_3$/$BaSnO_3$ is not visible due to the low atomic number contrast.

DFT calculations confirm that this configuration is most energetically favorable. The calculations further suggest that the compensating of the polar discontinuity between the polar $LaInO_3$ and nonpolar $BaSnO_3$ plays a crucial role in driving the segregation of barium. This compensation mechanism is facilitated by the gradual reduction of the octahedral tilts, transitioning from the orthorhombic structure of $LaInO_3$ to the cubic structure of $BaSnO_3$, accompanied by polar and non-polar distortions at the interface. Notably, our results highlight the effectiveness of the n-type SnO_2 interface in mitigating this discontinuity.

While in classical semiconductors surface energy, solubility, and strain are the prominent factors well-known to influence segregation, in perovskites also polar-nonpolar discontinuities play an important role. This factor can ultimately determine the interface termination. Understanding the complex interplay of these forces at perovskite interfaces is crucial for designing advanced electronic devices that exploit two-dimensional electron gases (2DEGs). Mastery of these interface properties is key to unlocking the full potential of perovskite-based heterostructures for innovative technological applications.

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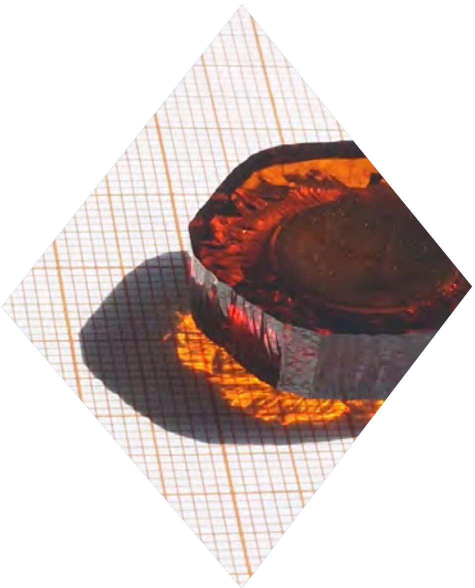

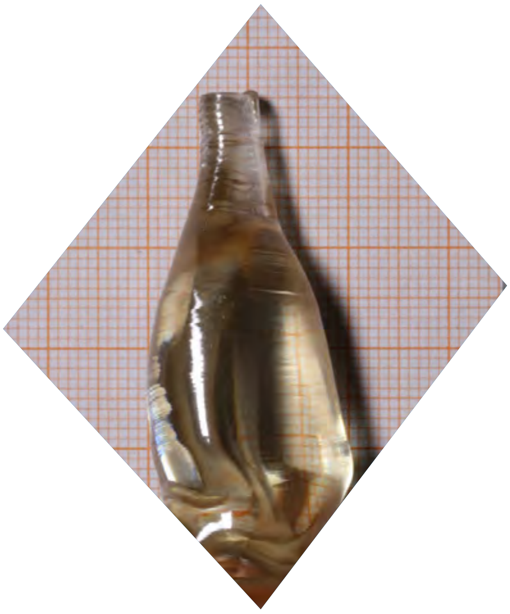

Application Science

Application Science

Efficient diameter enlargement of bulk AlN single crystals with high structural quality

Carsten Hartmann, Carsten Richter, Andrew Klump, Matthias Bickermann, Thomas Schröder, Thomas Straubinger

Leibniz-Institut für Kristallzüchtung , Berlin, Germany

The ultra-wide band gap semiconductor AlN, as well as the ternary AlGaN alloy, have a number of attributes that make this material system promising for electronic and optoelectronic devices [1,2]. Leveraging their extremely wide bandgap, Al(Ga)N enables the production of LEDs emitting deep into the far ultraviolet C (UVC) spectrum. The primary applications for such devices, covering the wavelength range from 220 nm to 280 nm, include disinfecting of water and surface sterilization. In addition to their potential in deep-UV photonics, devices based on AlN present compelling prospects for the advancement of next generation high-frequency power conversion. Notably, AlN-based high-power transistors have the potential to outperform those made from the two most common wide bandgap semiconductors, SiC and GaN.

To fully exploit the potential of the Al(Ga)N system, high-quality native AlN substrates with industrially relevant diameters are required. Offering a promising way forward is the growth of bulk AlN crystals by Physical Vapor Transport (PVT). In recent years, this approach to the growth of AlN with a high degree of crystallinity has advanced significantly, laying the foundation for substantial improvements in device performance. But typically, diameter expansion during PVT growth is very limited, necessitating many crystal generations to achieve efficiently usable diameters ≥ 2 inches.
Recently, our team has introduced an approach that overcomes this restriction [3]. We have developed a seed holder design that places the seed on a TaC pedestal (Fig. 1). With this arrangement, crystals grow freely without contact to parasitic grains. This design allows high radial thermal gradients – the driving force for diameter expansion.

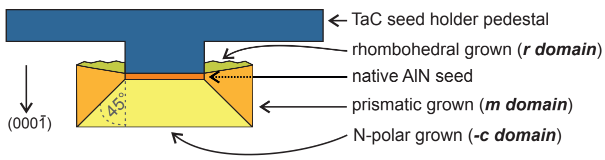

Fig. 1
Simplified sketch of the seed holder design: TaC pedestal and fully faceted grown crystal with an expansion angle of 45°

This novel configuration has led to significantly increased lateral growth rates. At a seed temperature of 2230 °C, growth rates reach approximately 200 μm/h in both the N-polar and prismatic m directions, resulting in huge expansion angles of around 45° along the entire crystal length. The full diameter spans the entire crystal length, ensuring uniform (final crystal) diameter for all cut c-plane wafers.

Starting point are nearly perfect 8 mm c plane seeds (threading dislocation density TDD < 5 x 10^2 cm^{-2}) cut from spontaneous nucleated AlN crystals. With just three subsequent seeded growth runs, we magnified dimensions, producing AlN crystals with diameters of more than 30 mm, which are very suitable for preparing 1-inch substrates (Fig. 2).

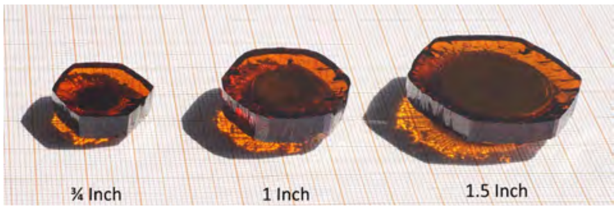

Fig. 2
Three AlN crystals of subsequent crystal generations (3/4 inch, 1 inch, and 1.5 inch in diameter)

The rise in diameter and accessibility must be accompanied by the preservation of high material quality. To identify the lateral dislocation distribution on wafers with very low dislocation densities, one can turn to X-ray topography or defect-selective etching.

We have investigated an m-plane sample cut from a seeded crystal with 20 mm in diameter using white-beam X-ray topography (Fig. 3). The $11\bar{2}\bar{2}$ reflection, which is sensitive to all possible types of dislocations (a, c, and a+c type) reveal that the entire -c grown domain of this sample is dislocation free. The only dislocations that exist are in the m domain near the -c/m boundary and in the r domain. We find that dislocations start at the seed rim and stay in the m area without crossing the -c/m domain boundary. We have also observed additional contrast features at several domain boundaries and within the m domain, caused by strain that stems from different impurity concentrations.

Application Science

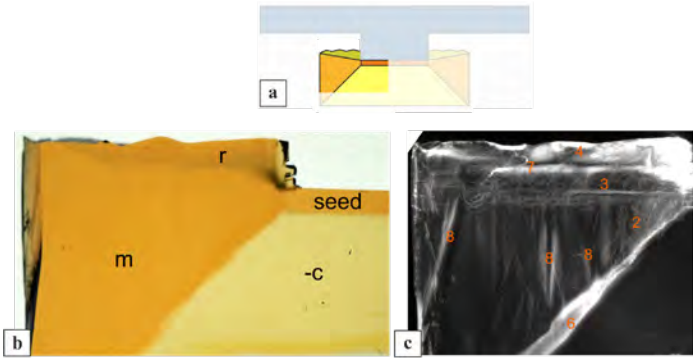

Fig. 3
(a) A sketch with a highlighted area of an m-plane sample prepared from a seeded crystal with diameter of 20 mm;
(b) Transmission photograph of a 1 mm-thick cross-section m plane sample. The several growth domains (-c, m, and r) are distinguishable by the different colors.
(c) White-Beam X-Ray Topography (WB-XRT) stitched images ($11\bar{2}\bar{2}$ reflection) of the cross-section sample. No dislocations are visible in the -c grown domain (1). Dislocations (TDD < $5 \times 10^3 cm^{-2}$) exist only in the m domain near the -c/m boundary (2), in the upper part of the m domain (3) and in the r domain (4). The lower half of the sample is dislocation free. Strain contrasts are visible at the domain boundaries (5,6,7) and within the m-domain (8).
The WB-XRT image was recorded by Merve Pinar Kabukcuoglu, Elias Hamann, and Daniel Hänschke from the Institute for Photon Science and Synchrotron Radiation, Karlsruhe Institute of Technology. We thank the Institute for Beam Physics and Technology for the operation of the storage ring, the Karlsruhe Research Accelerator.

To uncover the lateral defect distribution over the entire diameter, we characterized a wafer with 34 mm in diameter by defect-selective etching (Fig. 4). The medium etch-pit density is 5 x 10^3 cm^{-2} inside the 25 mm target diameter. Outside the 25 mm diameter a linear arrangement of dislocations is observed at the domain boundary between the -c and m grown domains. The origin of the associated etch pits can be traced back to dislocations formed at the seed rim, which continued along the -c/m boundary in the m domain.

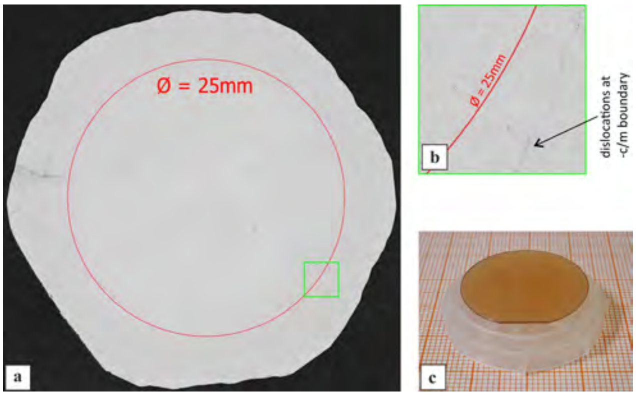

Fig. 4
a)+b)
Defect selective etched AlN wafer with a diameter of 34 mm an average etch-pitch density of 5 x 10^3 cm^{-2} inside the 25 mm target diameter. The -c/m domain boundary with an increased etch-pit density is outside of the 25 mm target diameter (green square);
c) 25 mm epi-ready AlN substrate.

The process discussed above is well suited for achieving 25 mm substrates with EPD = TDD < 10^4 cm^{-2} within only two or three subsequent crystal growth runs starting from high quality spontaneously nucleated seed crystals. This technology could provide a shortcut to the development of commercial substrates with diameters of 2 inch and 100 mm with TDD < 10^4 cm^{-2} by selecting seed wafer close to the top of the crystal without −c/m boundary.

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Application Science

Ultrafast mid-infrared lasers based on Tm^{3+}:$YScO_3$

Anna Suzuki[1,2,3], Sascha Kalusniak[1], Hiroki Tanaka[1], Mario Brützam[1], Steffen Ganschow[1], Masaki Tokurakawa[2], and Christian Kränkel[1]

[1]Leibniz-Institut für Kristallzüchtung (IKZ), Berlin, Germany
[2]Institute for Laser Science, University of Electro-Communications, Tokyo, Japan
[3]Current affiliation: Photonics and Ultrafast Laser Science, Ruhr-University Bochum, Germany

Mixed sesquioxides are attractive host materials for lasers. They combine good thermal conductivity with a disordered lattice, which features broad spectra [1] demanded for ultrafast lasers with high average power. We recently demonstrated the Czochralski growth of the mixed sesquioxide crystal $YScO_3$. The parent compounds yttria and scandia have melting points in excess of 2450 °C, which is above the melting point of iridium crucibles. In contrast, $YScO_3$ melts at ~2150 °C enabling the Czochralski growth from iridium crucibles, the approach commonly applied for other laser materials such as YAG [2].

Tm^{3+}-doped crystals are attractive gain materials for efficient lasers in the 2 µm spectral rage. Tm^{3+} ions exhibit strong absorption at wavelengths around 790 nm suitable for high-power diode pumping. At high doping concentrations, a cross-relaxation process efficiently populates the upper laser level $^3F_4$. In this way, one pump photon creates two Tm^{3+} ions in the upper laser level. This so-called "two-for-one" pumping scheme enables high slope efficiencies of up to 80% [3].

In this work, Tm^{3+}-doped $YScO_3$ crystals were grown by the Czochralski method from an iridium crucible. Fig. 1 shows photos of two as-grown boules with different Tm^{3+}-doping levels.

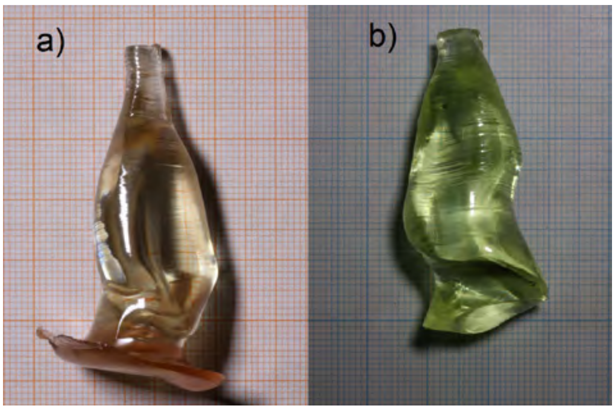

Fig. 1.
Photos of (a) Tm^{3+}(2.2 at.%):$YScO_3$ and (b) Tm^{3+}: (3.1 at.%): $YScO_3$.

The boule shown in Fig. 1 (a) has a length of 55 mm and a diameter of >15 mm, while the boule in Fig. 1 (b) has a length of 48 mm and a diameter of ~18 mm. The first crystal was grown in a static argon atmosphere and exhibits a brownish coloration, which could be removed by annealing in a mixture of 5% H_2 and 95% N_2 at 1500 °C. The second crystal was thus grown under a flow of argon to flush residual oxygen responsible for the coloration. This crystal is clear, the greenish color is caused by the Tm^{3+}-doping ions.

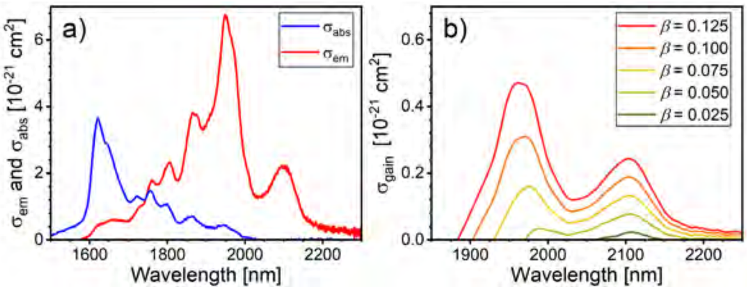

Fig. 2
(a) Absorption and emission cross sections of Tm^{3+}:$YScO_3$.
(b) Gain cross sections at different inversion levels.

Fig. 2 (a) shows the absorption and emission cross sections of Tm^{3+}:$YScO_3$. The main emission peaks are found at 1949 nm and 2099 nm with FWHM bandwidths of ~100 nm. Fig. 2 (b) shows the calculated gain cross sections for different inversion levels. The spectra are broad and flat, and support laser operation in the water vapor absorption free range beyond 2000 nm up to more than 2100 nm, and is among the longest peak wavelengths found for Tm^{3+}-doped gain materials.

Application Science

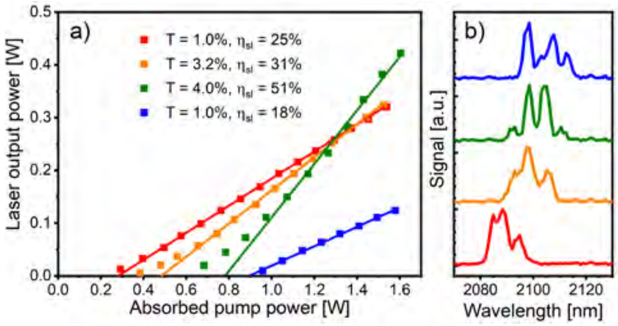

Fig. 3
Laser characteristics (a) and laser spectra (b) for different output coupler transmissions using the Tm^{3+}(3.1 at.%):$YScO_3$ crystal. The legend is valid for both figures.

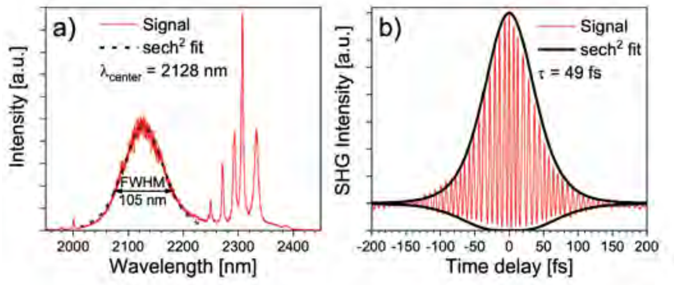

Fig. 4.
(a) Optical spectrum and (b) autocorrelation trace of the shortest pulses obtained with Tm^{3+}(3.1 at.%):$YScO_3$. The peak structures around 2300 nm and 2000 nm are caused by Kelly sidebands owing to the high intracavity peak intensity.

Fig. 3 shows the laser characteristics and spectra obtained using a 4-mm thick Tm^{3+}(3.1 at.%):$YScO_3$ sample which yielded the best laser results under 790-nm-pumping. The highest slope efficiency of 51% and the maximum output power of 422 mW were obtained using an output coupling mirror with 4.0% transmission for the laser wavelength around 2100 nm. These efficiencies are higher than those of Tm^{3+}-doped mixed sesquioxide ceramic lasers [1].

In collaboration with the research group of Masaki Tokurakawa at the University of Electro-Communications in Tokyo, Japan, we performed further experiments utilizing the large emission bandwidth of $Tm^{3+}YScO_3$ for the generation of ultrashort pulses by Kerr lens mode-locking. We utilized the same gain crystal, but here the crystal was directly pumped into the upper laser level at a wavelength of 1.6 µm enabling similar slope efficiencies compared to 796-nm-pumping in continuous wave laser operation.

For the Kerr lens mode-locking experiments, the crystal was placed at Brewster's angle in the focus between two concave cavity mirrors to achieve the intensities required to start mode-locking by the ultrafast lensing introduced by the Kerr effect.
The optical spectrum and the autocorrelation trace of the shortest pulses are shown in Fig. 4. The pulses were as short as 49 fs corresponding to only 7 optical cycles of 2 µm radiation. At a pulse repetition rate of 96.7 MHz the average output power amounted to 126 mW at a center wavelength of 2128 nm.

These pulses are the shortest of any mode-locked Tm^{3+}-doped mixed sesquioxide laser at ~2.1 µm. This was enabled by the broad and flat gain profile of Tm^{3+}:YScO3. Based on these laser results, further power scalability of ultrafast Tm^{3+}:$YScO_3$ lasers can be expected.
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C. Kränkel, A. Suzuki, S. Kalusniak, S. Ganschow, M. Tokurakawa: *Kerr-lens mode-locked Tm^{3+}-doped mixed sesquioxide single crystal laser at 2.1 µm; Advanced Solid-State Lasers Conference 2023;* Tacoma, USA, October 8-12, 2023

C. Kränkel: *Rare-earth doped fluoride crystals for solid-state laser cooling; International summer School on Rare-earth-doped Optical Materials;* Krakow, Poland; August 27-September 1, 2023

C. Kränkel: F*luoride crystals as host materials for visible lasers; International summer School on Rare-earth-doped Optical Materials;* Krakow, Poland; August 27-September 1, 2023

C. Kränkel: A*pplications for crystals: Rare-earth-doped solid-state lasers II: visible lasers; DAAD exchange program, University of Chemistry and Technology;* Prague, Czechia, October 16-17, 2023

C. Kränkel: *Applications for crystals: Rare-earth-doped solid-state lasers I: infrared lasers; DAAD exchange program, University of Chemistry and Technology;* Prague, Czechia, October 16-17, 2023

C. Kränkel: *Applications for crystals: Host materials for solid-state-lasers; DAAD exchange program, University of Chemistry and Technology;* Prague, Czechia, October 16-17, 2023

W. Miller, A. Sabanskis, A. Gybin, K.-P. Gradwohl, A. Wintzer, K. Dadzis, J. Virbulis, R. R. Sumathi: *A Coupled Computing of the Dislocation Development During the Czochralski Growth of Germanium; DKT2023;* Augsburg, Germany, March 15 -17, 2023

W. Miller, T. Schulz, L. Lymperakis, A. Klump, M. Albrecht: *Kinetic Monte Carlo Simulations for the epitaxy of AlN and AlGaN on AlN(0001); 3rd International Symposium on Modeling of Crystal Growth Processes and Devices;* Channai, India, (Online), March, 6-8, 2023

W. Miller: *A Kinetic Monte Carlo Tool for Computation of Epitaxial Processes Programmed in Julia; MMS days;* Potsdam, Germany, April 17-19, 2023

W. Miller, T. Schulz, L. Lymperakis, A. Klump, M. Albrecht: *Growth kinetics of AlN and AlGaN deposition on AlN(0001): A kinetic Monte Carlo study; The 6th International Workshop on Ultraviolet Materials and Devices;* Metz, France, June 6 -8, 2023

W. Miller: *Numerical Simulations in Bulk Crystal and Layer Growth; Warsaw4PhD School;* Warszawa, July 3, 2023

P.Gaal, M. Khosla, D. Hensel, M. Brede, D. Schmidt, J. Schwarzkopf: *Spatiotemporal Dynamics of a Martensitic Phase Transition in $(K,Na)NbO_3$; PLU2023;* Czestochowa, Poland, September 15, 2023

Talks and Presentations

P.C. Palleti, Pradeep Chandra Palleti, Alexander Gybin, Andrea Dittmar and R. Radhakrishnan Sumathi: *Investigation of factors influencing in the zone refining process of very high-purity germanium; ICCGE-20;* Naples, Italy, July 30-August 4, 2023

A. Popp, S. Bin Anooz, T.-S. Chou, J. Rehm, V. Tran, R. Grüneberg, A. Fiedler, Palvan Seyidov, Z. Galazka, R. Schewski, M. Pietsch, A. Kwasniewski, M. Schmidbauer, W. Miller, K. Irmscher, M. Albrecht, J. Schwarzkopf: *Epitaxial Growth of (100) β-Ga_2O_3 by MOVPE; DKT 2023;* Augsburg, Germany, March 15-17, 2023

A Popp: *Metalorganic Vapor Phase Epitaxy (MOVPE); Summer School BTU-CB-SB;* Cottbus, Germany; September 9, 2023

A.Popp, S. Bin Anooz, T.-S. Chou, J. Rehm, A. Fiedler, Palvan Seyidov, Z. Galazka, R. Schewski, M. Pietsch, A. Kwasniewski, M. Schmidbauer, W. Miller, K. Irmscher, M. Albrecht: *Epitaxial Growth development of (100) β-Ga_2O_3 by MOVPE; DGKK DEMBE 2023;* Stuttgart, Germany, November 27-29, 2023

A. Popp, T.-S. Chou, S. B. Anooz, R. Grüneberg, V. T. T. Thuy, J. Rehm, A. Akhtar, Z. Galazka, P. Seyidov, K. Irmscher, M. Albrecht, A. Fiedler: M*OVPE of (100) β-Ga_2O_3 for vertical power devices – challenges to epitaxial growth process; GOX-2023;* Buffalo (NY), USA, August 13-16, 2023

S. Püschel, C. Kränkel, H. Tanaka: L*aser cooling of an Yb^{3+}-doped KY_3F_{10} crystal by 42 K; Conference on Lasers and Electro-Optics (CLEO/Europe-EQEC) 2023;* Munich, Germany; June 26-30, 2023

S. Püschel, H. Tanaka, C. Kränkel: *Ytterbium-doped KY_3F_{10} as a promising material for optical cryocoolers; SPIE Photonics West 2023;* San Francisco, USA; January 28 – February 2, 2023

J. Rehm, T.-S. Chou, A. Akhtar, R. Grüneberg, S. Bin-Anooz, A. Fiedler, M. Schmidbauer, A. Popp: *The challenge to grow β-$(Al_xGa_{1-x})_2O_3$ on (100) off-oriented β-Ga_2O_3 by MOVPE; DPG Spring Meeting 2023;* Dresden, Germany, March 28, 2023

C. Rhode: *The interconnection of resistive and structural switching in non-stoichiometric $SrTiO_3$-thin films; 12th German-French Workshop on Oxide, Dielectric, and Laser Crystals;* Berlin, Germany, September 21-22, 2023

C. Richter: *Multiscale analysis of the real structure of crystals by X-ray diffraction imaging; ECS8*: European Crystallography School 2023; June 18-24, 2023

C. Richter: *X-ray diffraction microscopy applied to semiconductor materials and devices; RÅC International Summer School Focal theme: X-ray and neutron research on bio-inspired materials and sustainable energy technology;* September 01-08, 2023

A. Sabanskis, A. Wintzer, C. Guguschev, J. Virbulis, K. Dadzis: *Numerical study of thermal stresses and dislocation dynamics during growth of oxide and fluoride crystals from melt; International Conference on Crystal Growth and Epitaxy (ICCGE20);* Naples, Italy, July 30 – August 4, 2023

A. Sabanskis, K. Dadzis, A. Wintzer, J. Virbulis: *New open-source software for simulation of thermal stresses and dislocations in crystals during the growth process; 9th International Scientific Colloquium "Modelling for Materials Processing" (MMP2023);* Riga, Latvia, September 18–19, 2023

T. Schröder: *On the importance and opportunities of advanced crystals for electronic & photonic technologies in European Union; TU Posnan, Politechnika Poznańska;* Posnan, Poland; April 06, 2023

T. Schröder: *Kristallzüchtung für HighTec Produkte; Mineralogisches Museum, Philipps Universität Marburg, Fachbereich Geographie;* Marburg, Germany; June 01, 2023

T. Schröder: *Crystals for electronic & photonic technologies in European Union; University of Tours;* Tours, France; July 12, 2023

T. Schröder: *Crystals and Crystal Components for EU Technology Sovereignty: IKZ R & D strategy in electronics and photonics; Infineon Innovation Days, Infineon Technologies Dresden, GmbH & Co. KG;* Dresden, Germany; November 15, 2023

T. Schröder: C*rystalline materials for future electronics; Workshop on Recent Advances in thin Film Research, Technische Universität Darmstadt;* Darmstadt, Germany; November 24, 2023

T. Schröder: *Secure and sustainable materials supply chains; Panel member in panel discussion at Innovation Network Advanced Materials, INAM Berlin;* Berlin, Germany; February 23, 2023

T. Schröder: *Das Leibniz-Strategieforum Technologische Souveränität: Die letzten 2 Jahre und die nächsten Schritte; Leibniz-Präsidiumssitzung, Berlin*; Berlin, Germany; February 28, 2023

T. Schröder: *Forschung und Entwicklung unter der Perspektive technologischer Souveränität: Das Beispiel des Leibniz-Strategieforums Technologische Souveränität; Spectaris Branchentag Photonik,* Lübeck; Lübeck, Germany; March 01, 2023

Talks and Presentations

T. Schröder: *Fachgespräch zum Ausbau der Materialexpertise in Quantenmaterialien in Deutschland und Europa; VDI Fachexpertentreffen Quantenmaterialien;* Düsseldorf, Germany; March 02, 2023

J. Schwarzkopf, S. Bin Anooz, Y. Wang, M. Neis, H. Wöffen, D. Mayer, R. Wördenweber, M. Schmidbauer: *Manipulation of piezoelectric domain formation and surface acoustic wave propagation in (K,Na)NbO$_3$ thin films by strain and defect engineering; EMRS Fall Meeting, Symposium V. Piezoelectric polar oxides;* Warsaw, Poland; September 18-21, 2023

J. Schwarzkopf, A. Baki, M. Abdeldayem, J. Stöver, K. Irmscher, H. Amari, M. Albrecht, S. Liang, D. Fink, D. Mayer, R. Wördenweber: *MOVPE of strain and defect engineered perovskite thin films; 5th Functional Oxide Thin Films for Advanced Energy and Information Technology Conference;* Cancun, Mexiko; February 12-15, 2023

J. Schwarzkopf: E*pitaxy of polar oxide thin films; FOR5044 Summer School 2023 Periodic low-dimensional defect structures in polar oxides;* Berlin, Germany; September 6-8, 2023

J. Schwarzkopf: *Epitaxial growth of lead-free ferroelectric (K, Na)NbO$_3$ thin films and the impact of strain; Nanoscience Colloquium, Universität Hamburg;* Hamburg, Germany; June 27, 2023

P. Seyidov, J. B. Varley, Y. K. Frodason, D. Klimm, L Vines, Z. Galazka, T.-S. Chou, A. Popp, K. Irmscher, A. Fiedler: *Requirements for lateral β-Ga$_2$O$_3$ MESFETs: Thermal stability of Schottky contacts and rearrangement of defects; Ultra-wide bandgap oxide semiconductors (UWO2023);* Bristol, UK, June 5, 2023

P. Seyidov, J. B. Varley, J.-X. Shen, Z. Galazka, T.-S. Chou, A. Popp, M. Albrecht, K. Irmscher, A. Fiedler: *Charge State Transition Levels of Ni in β-Ga$_2$O$_3$ crystals Eminently Suitable Candidate for Compensation; The 6th U.S. Workshop on Gallium Oxide (GOX 2023);* Buffalo, USA, August 13- 16, 2023

I.-A. Shah, M. Abdeldayem, C. Liu, T. Schulz, J. Martin, H. Amari, C. Richter, K. Irmscher, J. Schwarzkopf, M. Albrecht, A. Fiedler: *Electrode dependent electrical properties of MOVPE grown Sr deficient SrTiO$_3$ thin film based memristive switches; 12th German-French Workshop on Oxides, Dielectrics, and Laser Crystals (WODIL 2023);* Berlin, Germany, September 21-22, 2023

K. Stolze, I. Peracchi, C. Richter, J. Martin, T. Schulz, R. Kernke, C. Frank-Rotsch, P. Steglich; I*nvestigation of µm-Thin InP Single Crystals for Heterogeneous Integration of III V on Si via Micro-Transfer-Printing; EMRS Fall Meeting 2023;* Warsaw, September 18-21, 2023

T. Straubinger, C. Hartmann, M. Albrecht, A. Klump, T. Schröder, M. Bickermann, C. Richter, M. Kabukcuoglu, S. Bode, E. Hamann, S. Haaga, M. Hurst, D. Hänschke: *Growth of 1-inch aluminium nitride crystals with efficient diameter increase technology and structural characterization; SPIE Photonics West;* San Francisco, January 30, 2023

T. Straubinger, C. Hartmann, M. Albrecht, A. Klump, T. Schröder, M. Bickermann, C. Richter, M. Kabukcuoglu, S. Bode, E. Hamann, S. Haaga, M. Hurst, D. Hänschke: *Growth of 1-inch aluminium nitride crystals; Hausseminar TUB;* Berlin, Germany, May 10, 2023

T. Straubinger, C. Hartmann, M. Albrecht, A. Klump, T. Schröder, M. Bickermann, C. Richter, M. Kabukcuoglu, S. Bode, E. Hamann, S. Haaga, M. Hurst, D. Hänschke: A*luminium nitride prototype substrates with low dislocation density for the fabrication of 230nm light-emitting-diodes (skin disinfection) and ultraviolet laser-diodes; ams-OSRAM coffe & office;* Regensburg, Germany; May 25, 2023

A. Subramanian, C. Richter, C. Guguschev, M. Schmidbauer and R. R. Sumathi: *Investigating the microstructural defects in heavily-doped Ge ingots using X-ray imaging techniques; DGKK Annual Meeting (DKT2023);* Augsburg, Germany, March 15-18, 2023

A. Subramanian, A. Gybin, C. Guguschev, C. Richter, A. Kwasniewski, N. Abrosimov, R. R. Sumathi, K. P. Gradwohl: *Growth and structural investigation of Ge$_{x}$-Si$_{1-x}$ crystals up to 15% Si content using the Czochralski method; DGKK-Arbeitskreis "Massiv Halbleiter Kristalle";* Erlangen, Germany, October 4-5, 2023

R. R. Sumathi: *High purity semiconductor materials for fundamental and technological applications; International Materials Conclave (IMC-2023);* Pune, India, March 8-10, 2023

R. R. Sumathi, P. C. Palleti, A. Gybin, U. Juda, P. Amoroso, J. Slotte, F. Tuomisto: *Point defects and dislocations studies in high-purity Ge crystals; DGKK Annual Meeting (DKT2023);* Augsburg, Germany, March 15-18, 2023

R.R. Sumathi, P. C. Palleti, P. Seyidov, M. Pietsch, A. Gybin, A. Fiedler: *Conductivity type transition in high-purity germanium bulk materials; ISTDM/ICSI-2023;* Como, Italy, May 21-25, 2023

R. R. Sumathi, R. Menzel, I. Buchovska, N. Abrosimov: *Semiconductor bulk crystals for quantum computing; Future of Computing, INAM;* Berlin, Germany, November 28, 2023

Talks and Presentations

R.R. Sumathi, N. Abrosimov, R. Menzel: *Crystalline materials: Embracing the redefinition of physical unit "kg-mass".; DAE – Solid State Physics Symposium (DAE-SSPS-23);* Vizag, India, December 21-24, 2023

A. Suzuki, S. Kalusniak, S. Ganschow, C. Kränkel, M. Tokurakawa: C*omparison of mode-locked* $Tm^{3+}:YScO_3$ *mixed sesquioxide laser and* $Tm^{3+}:Lu_2O_3$/$Tm^{3+}:Sc_2O_3$ *combined active gain media laser; The 12th Asia-Pacific Laser Symposium (APLS);* Hokkaido, Japan, September 4-7, 2023

A. Suzuki, S. Kalusniak, H. Tanaka, S. Ganschow, C. Kränkel, M. Tokurakawa: *Ultrashort pulse generation in 2-μm spectral range using combined gain and mixed gain materials; 43rd Annual Meeting of the Laser Society of Japan 2023;* Nagoya, Japan; January 18-20, 2023

A. Suzuki, S. Kalusniak, H. Tanaka, S. Ganschow, C. Kränkel, M. Tokurakawa: *Spectroscopic and laser properties of Tm-doped* $YScO_3$ *crystals; 70th JSAP Spring Meeting 2023;* Tokyo, Japan; March 15-18, 2023

M. Tokurakawa, R. Mitsui, A. Suzuki, C. Kränkel: *Development of a* $Tm^{3+}:Lu_2O_3/Yb^{3+}:Sc_2O_3$ *laser for observation of two-photon induced emission; 43rd Annual Meeting of the Laser Society of Japan 2023;* Nagoya, Japan; January 18-20, 2023

I. Tsiapkinis, K. Dadzis: *Calculation of the shape of melt free surface using the finite volume method and interface tracking for crystal growth applications; Leibniz MMS Days 2023;* Potsdam, Germany, April 17–19, 2023

I. Tsiapkinis, A. Wintzer, K. Dadzis: *Multiphysics simulation of heat transfer, phase boundaries and melt flow for crystal growth applications; 18th OpenFOAM Workshop (OFW18);* Genoa, Italy, July 11–14, 2023

I. Tsiapkinis, A. Wintzer, S. Foroushani, K. Dadzis: *Ultrasonic Doppler velocimetry for melt flow in model experiments for Czochralski crystal growth; 9th International Scientific Colloquium "Modelling for Materials Processing" (MMP2023);* Riga, Latvia, September 18–19, 2023

I. Tsiapkinis, A. Wintzer, S. Foroushani, K. Dadzis: *Validation of high-frequency electromagnetic models for crystal growth applications; 9th International Scientific Colloquium "Modelling for Materials Processing" (MMP2023);* Riga, Latvia, September 18–19, 2023

A. Uvarova, P. Eckhof, L. Hülshoff, P. Wegener, S. Kalusniak, C. Kränkel: *Growth and efficient laser operation of Yb-doped mixed sesquioxides; Conference on Lasers and Electro-Optics (CLEO/Europe-EQEC) 2023;* Munich, Germany; June 26-30, 2023

L. Vieira, I. Buchovska, I. Tsiapkinis, A. Wintzer, K. Dadzis, R. Menzel: *Simulation of the Growth of Crystalline Si fibers for 3rd Generation Gravitational Wave Detectors; 9th International Scientific Colloquium „Modelling for Materials Processing" 2023;* Riga, Latvia September 18-19, 2023

H. T. Wöffen, M. Neis, J. Schwarzkopf, D. Mayer, P. Gaal, R. Wördenweber: *(*K_x*,* Na_{1-x}*)*NbO_3*-Based Thin Film Surface Acoustic Wave Sensors as label-free Biosensors; 4th European BioSensor Symposium 2023;* August 27-30, 2023

Patents

Semiconductors

J. Boschker, Ch. Frank-Rotsch, M. Zorn, T. Schröder
Substrat für ein Halbleiterbauelement Halbleiter-vorrichtung und Verfahren zum Herstellen eines Substrats für ein Halbleiterbauelement
DE102020131850, US 18/039668

K. Stolze, P. Steglich, K, Berger, U. Juda, J. Martin
Verfahren und Vorrichtung zum Herstellen einer Halbleiterstruktur
Transfer Printable Single-Crystalline Coupons
DE 102022100661.1, EP23151074.4

M. Wünscher, H. Riemann
Vorrichtung für das tiegelfreie Zonenziehen von Kristallstäben
(Apparatus for continuous zone-melting a crystalline rod)
DE102012022965B4, EP 2920342B1 (DE, DK, LV)

N. Abrosimov, J. Fischer, H. Riemann, M. Renner
Verfahren und Vorrichtung zur Herstellung von Einkristallen aus Halbleitermaterial
Process and apparatus for producing semi-conductor single crystals
DE102010005520B4

K.-P. Gradwohl, S. Radhakrishnan, A. Gybin, J. Fischer, C. Guguschev
Vorrichtung zum Herstellen eines einkristallinen Halbleiters mittels Zonenreinigung
Apparatus for producing a single-crystal semiconductor by zone refining
DE 102023132842.5

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Oxides and laser materials

Z. Galazka, R. Uecker, D. Klimm, M. Bickermann
Method for growing beta phase of gallium oxide (ß-Ga_2O_3) single crystals from the melt contained within a metal crucible
EP3242965B1 (AT, BE, CH, DE, CZ, ES, FR, GB, IT, NL, PL), KR101979130B1, US20170362738A1

Z. Galazka, R. Uecker, R. Fornari
Method and apparatus for growing indium oxide (In_2O_3) single crystals and indium oxide (In_2O_3) single crystal
US10208399

C. Guguschev, M. Brützam, D. Schlom, H. Paik
Method and setup for growing bulk single crystals
DE102020114524A1, US20200378030A1, KR1020200138082A

C. Guguschev, E. Haurat, D. Klimm, C. Kränkel, A. Uvarova
Verfahren und Vorrichtung zum Züchten eines Seltenerd-Sesquioxid-Kristalls
Method and device for growing a rare earth sesquioxide crystal
DE102020120715, WO/EP21748512.7

Z. Galazka, S. Ganschow, M. Bickermann, T. Schröder, W. Häckl
Method and apparatus for producing electrically conducting bulk ß-Ga_20_3 single crystals and electrically conducting bulk ß-Ga_20_3 single crystal
EP22154305.1, PCT/EP/2023051212, TW 112102595

Z. Galazka, S. Ganschow, M. Bickermann, T. Schröder
Melt-grown bulk b-$(AlxGa_{1-x})_2O_3$ single crystals and method for producing bulk b-$(AlxGa_{1-x})_2O_3$ single crystals
PCT/EP2022/078252, TW 112138623

Aluminium nitride

A. Dittmar, C. Hartmann, J. Wollweber, M. Bickermann
(Sc, Y):AlN Einkristalle für Gitter-angepasste AlGaN Systeme
(Sc,Y):AlN single crystals for lattice-adapted AlGaN systems
KR1020180048926A

C. Hartmann, T. Straubinger
Kristallzüchtungsvorrichtung und Verfahren zum Züchten eines Halbleiters
Crystal growth design and method for growing a semiconductor
DE 102022119343.8, US18/363366

Semiconducting layers and nanostructures

O. Ernst, T. Boeck, F. Lange, H.-P. Schramm, T. Teubner, D. Uebel
Verfahren zur Mikrostrukturierung
(Method for Microstructuring)
DE102020126553

Patents

D. Uebel, R. Bansen, T. Boeck, O. Ernst, H.-P. Schramm, T. Teubner
Silizium-basierte Wafer und Verfahren zur Herstellung von Silizium-basierten Wafern (Silicon-based wafers and method of fabricating silicon-based wafers)
DE102020132900

O. Ernst, D. Uebel, T. Boeck
Verfahren zur Herstellung von isotopenangereicherten Germanium-Wasserstoffverbindungen (Process for the preparation of isotope-enriched germanium-hydrogen compounds)
DE 102022105177.3, PCT/EP2023/054384

S. Zahedi-Azad, T. Boeck, O. Ernst, H.-P. Schramm, D. Uebel
Verfahren und Züchtungsaufbau zum Herstellen lokalisierter Strukturen
(Method and growth setup for the fabrication of localized structures)
DE 102022116962.6

Oxide layers

M. Albrecht, A. Baki, K. Irmscher, T. Schulz, J. Schwarzkopf, J. Stöver
Verfahren zum Herstellen eines Kristalls mit Perowskitstruktur
Formingless Resistive Switching by Off-Stoichiometry Control of ABO3 Perovskites
DE1020132049, PCT/EP2021/082505

T. Chou, A. Popp, W. Häckl
Method for producing a gallium oxide layer on a substrate
EP 21187231.2, PCT/EP 2022/069433, TW 111126459

S. Bin-Anooz, T.-S. Chou, W. Häckl, A. Popp
Method for producing a gallium oxide layer on a substrate
EP 22194558.7

X-Ray optics

P. Gaal
Bereitstellen eines transienten Gitters (Providing a transient grid)
DE102019132393B4, PCT/EP2020/082942

Committees

Committees

M. Bickermann: IGAFA e.V. – the scientific network of the non-university research institutions located in Berlin-Adlershof e.V.; member of the board

M. Bickermann: Elected Member of the DFG Review Board for Materials Science 406-03 (Term 2020-2023)

Ch. Frank-Rotsch: DGKK-Schriftführerin

Ch. Frank-Rotsch: ENCG council member

Ch. Frank-Rotsch: IOCG member of executive committee

C. Guguschev: IUCr member of the commission on crystal growth and characterization of materials,

T. Schröder: Coordinator of the European Networks on Crystal Growth (ENCG), Member of council

T. Schröder: Member of DESY Photon Science Council, Hamburg

T. Schröder: Chairman of the Bord of Forschungsverbund Berlin e.V. (until September 2023)

T. Schröder: Deputy Chairman of the "Deutsche Gesellschaft für Kristallzüchtung" DGKK

T. Schröder: Deputy Member of the Leibniz-Association Presidium, Berlin (since September 2023)

T. Schröder: Member of DESY Photon Science Council, Hamburg

T. Schröder: Speaker Leibniz Association: Strategy Forum on Technological Sovereignty, Berlin

T. Schröder, Member of the "Leibniz-Mentoring-Program", Leibniz Association, Berlin, 2023

T. Schröder: Deputy Spokesperson of the Section D: Mathematics, Natural Sciences, Engineering of the Leibniz Association, Berlin, since Sep. 2023

Conference committees

M. Albrecht: 14th International Conference on Nitride Semiconductors 2023 (ICNS-14), Fukuoka, Japan; member of the program committee

M. Bickermann: 14th International Conference on Nitride Semiconductors 2023 (ICNS-14), Fukuoka, Japan; member of the program committee

M. Bickermann: 6. International Workshop on UV Materials and Devices 2023 (IWUMD 2023), Metz, France, June 5-8, 2023, Member of the Program Committee

M. Bickermann: 20. International Conference on Crystal Growth (ICCGE-20), Naples, Italy, Jul 30-Aug 4, 2022, Member of the Program Committee

K. Dadzis: 9th International Scientific Colloquium "Modelling for Materials Processing" (MMP2023), Riga, Latvia, September 18-19, 2023. Member of the Scientific Committee

C. Kränkel: 12th German-French Workshop on Oxide, Dielectric and Laser single crystals (WODIL 2023), Berlin, Gemany, Steering Committee

C. Kränkel: Advanced SOlid State Lasers Conference, Tacoma, USA, member of the materials program committee

C. Kränkel: European Optical Society Annual Meeting (EOSAM) 2023, Dijon, France, Comitee member

T. Schröder: 12th German-French Workshop Oxide, Dielectric and Laser single crystals (WODIL 2023), Berlin, Germany, chair

Journals/Editors

M. Bickermann: Editor, Journal of Crystal Growth (Elsevier B.V.)

M. Bickermann: Associate Editor, Progress in Crystal Growth and Characterization of Materials (Elsevier B.V.)

N. Dropka: Crystals; topical advisory panel

W. Miller: Editorial Board of Crystals

Teaching and Education

Matthias Bickermann
Kristallzüchtung I: Grundlagen und Methoden
Technische Universität Berlin, Institute of Chemistry

Kristallzüchtung II: Methoden und Anwendungen
Technische Universität Berlin, Institute of Chemistry

Peter Gaal, Christian Heyn (Universität Hamburg UHH), Guido Meier (UHH), Lars Tiemann (UHH)
Proseminar: Grundlagen nanostrukturierter Festkörper
Universität Hamburg

Frank Kießling
Versuche und Messungen zu Kristallzüchtung und Kristallstrukturen
Schüler-Kristallographielabor an der Lise-Meitner-Schule Berlin

Detlef Klimm
Phase Diagrams
Humboldt-Universität zu Berlin, Department of Chemistry

Christian Kränkel, Tim Schröder (HU Berlin)
Humboldt-Universität zu Berlin, Department of Physics

Martin Schmidbauer
X-Ray Scattering: Basics and Applications in Materials Science
Humboldt-Universität zu Berlin, Department of Physics

Thomas Schröder, Ted Masselink (HU Berlin), Roman Engel-Herbert (PDI)
New directions in electronics, optoelectronics and devices
Humboldt-Universität zu Berlin, Department of Physics

Thomas Schröder, Radhakrishnan Sumathi, Jens Martin
Grundlagen und Methoden der modernen Kristallzüchtung
Humboldt-Universität zu Berlin, Department of Physics

Leibniz-Institut für Kristallzüchtung (IKZ)
Director: Prof. Dr. Thomas Schröder
Max-Born-Straße 2
12489 Berlin
Germany

Phone +49 (0)30 6392 3001
Fax +49 (0)30 6392 3003
Email cryst@ikz-berlin.de
Online www.ikz-berlin.de

Annual Report 2023

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Leibniz-Gemeinschaft

Leibniz-Institut für Kristallzüchtung (IKZ)

Max-Born-Straße 2
12489 Berlin
Germany

Phone +49 (0)30 6392 3001
Fax +49 (0)30 6392 3003
Email cryst@ikz-berlin.de

www.ikz-berlin.de