Straintronics of two-dimensional materials

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How can one stretch an atomically thick membrane, and what happens to it in the process? In this talk, we use controllably strained 2D materials (2DMs, such as graphene or transition metal dichalcogenides) as a new platform to study the static and dynamic response of electrons, excitons, and phonons. In the process, we find that the mechanical properties of 2DMs qualitatively differ from that of their three-dimensional counterparts.

First, we find that the inevitable out-of-plane crumpling modifies every mechanical property of 2DMs, making their mechanical response more akin to biological membranes than solid objects. Specifically, the out-of-plane crumpling renders the thermal expansion coefficient negative and substrate-dependent, decreases Young's modulus, increases the bending rigidity by several orders of magnitude, and changes the sign of the Poison's ratio. Second, we examine the effect of the mechanical strain on phonons in 2DMs. We use strain engineering to control the bandstructure of 2DM phononic crystals and to realize new nanomechanical spectrometers. Finally, we use mechanical strain to control excitons, Coulomb-bound electron-hole pairs in 2D semiconductors. We identify exciton types, bring different excitons into resonance, and control exciton flows in controllably strained devices.