Co-doping effects on anti-Stokes fluorescence cooling in Yb:YLF

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Laser cooling by anti-Stokes fluorescence is an emerging technology allowing for cooling of solids from room temperature to cryogenic temperatures. It can be achieved when optically active ions, e.g., Yb^{3+}, emit more energy than they absorbed in a phonon-assisted process, and hence the solid cools down[1]. Highest purity crystals are required to mitigate parasitic loss mechanisms. The lowest recorded temperature of 87 K was achieved in Yb(5%),Tm(16ppm):YLF ($LiYF_4$), enabled possibly by a beneficial interaction between Tm and Er impurities[2].

We grew four crystals by the Czochralski method to measure the effect of rare earth impurities on laser cooling in Yb(5%):YLF crystals. Apart from the Yb^{3+} content, the crystals were undoped, co-doped with 40 ppm Er^{3+}, with 40 ppm Tm^{3+}, or both Er and Tm. The setup shown in Fig. 1a was used to measure cooling rates for varying intensities. The results are shown in Fig. 1b. The reference crystal had the highest cooling rates, almost independent of intensity, and cooled from 22°C to –50°C when absorbing 2 W. Yb,Tm:YLF shows constant but lower cooling rates. In contrast, the Er,Yb:YLF and Er,Tm,Yb:YLF cooling rates depend strongly on the excitation intensity due to inversion-dependent interaction between the dopants, even inducing a change from cooling to heating.

We conclude that in contrast to previous reports Er^{3+} and Tm^{3+} impurities reduce the cooling efficiency by two independent mechanisms and detrimental interaction at high excitation intensities. Hence, highest-purity crystals seem to be the best way to achieve lowest temperatures by anti-Stokes fluorescence cooling.

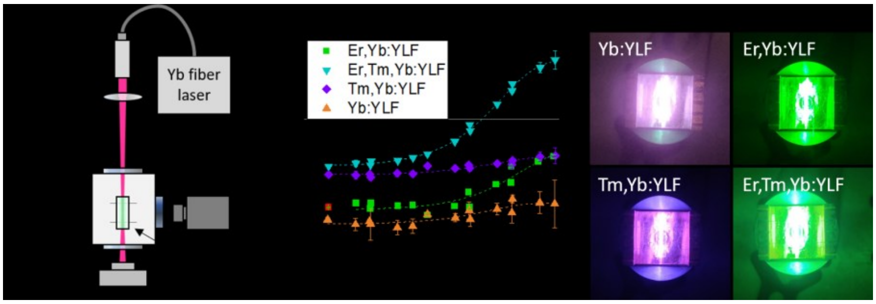

Fig. 1. (a) Setup of the intensity dependent cooling test. (b) Cooling rates vs. intensity plot of the differently co-doped samples in semi-logarithmic scale. (c) Visible parasitic upconversion luminescence of the different crystals excited in the setup by 10 W at 1020 nm.

References

[1] D. V. Seletskiy, R. Epstein, and M. Sheik-Bahae, "Laser cooling in solids: Advances and prospects," Reports Prog. Phys. **79**, 096401, 2016.
[2] M. P. Hehlen, J. Meng, A. R. Albrecht et al., "First demonstration of an all-solid-state optical cryocooler," Light Sci. Appl. **7**, 1–10, 2018.