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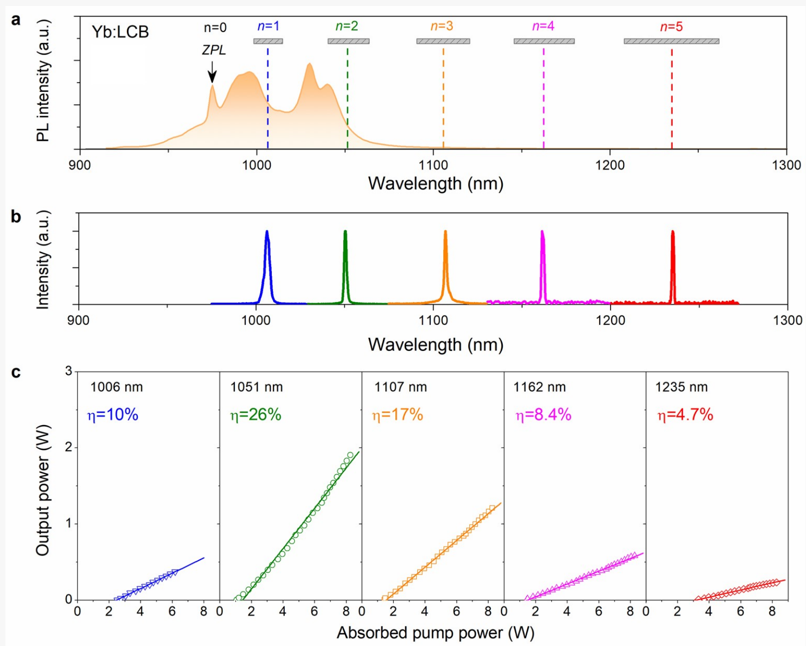
Phonon engineering in Yb:La2CaB10O19 crystal for extended lasing beyond the fluorescence spectrum

CHINA, October 19, 2023 /EINPresswire.com/ -- The direct lasing outside the fluorescence [spectrum] is deemed impossible owing to the ‘zero-gain’ cross-section. However, when electron-phonon coupling meets laser oscillation, an energy modulation by the quantized phonon would happen, thus directly creating some unprecedented lasers with extended wavelengths by phonon engineering. Here, we demonstrate the multiphonon-assisted lasing in a Yb:La2CaB10O19 crystal, far beyond its spontaneous fluorescence spectrum. This work gives new opportunities to search for on-demand lasers in the darkness.



a, Fluorescence spectrum of Y-cut Yb:LCB at room temperature. b, Laser spectrum with different phonon number n = 1 ~ 5. c, Laser output power versus the absorbed pump power for various phonon numbers.

Electron and phonon are two fundamental particles (quasi-particles) of condensed matter and their interplay in single crystals can create many interesting physical phenomena, such as polariton, charge density wave, up-conversion fluorescence, etc. In laser crystal, the electronic transitions of active ion can be manipulated by its surrounding lattice vibrations, thereby the emitting photon energy gradually decreases or increases by the creation or annihilation of quantized phonon. Therefore, some broadband laser wavelengths can be designed by the selective amplification of phonon-assisted emission, including Ti:Sapphire, alexandrite, Cr:LiSAF, and so on. However, all these laser wavelengths still locate inside the spontaneous fluorescence spectrum, or slightly outside with a few nanometers.

In multiphonon-assisted emission, the creation of high-order phonons can reduce photon energy step by step, thus pushing laser wavelengths far beyond the spontaneous fluorescence spectrum. Recently, Liang et. al. demonstrated such a multiphonon-assisted lasing in Yb:YCa4O(BO3)3 (Yb:YCOB) crystal with phonon number n = 3~8, which attributed to constructive interactions of vibrational modes from “free-oxygen” sites. However, borates containing “free-oxygen” are very rare, less than one percent of the total rare-earth borates, thereby giving a limitation for searching more strong-coupling laser materials. Therefore, searching new structural motif in rare-earth borates is very essential to elaborate the physics mechanism of multiphonon coupling lasing, and also find their distinctive applications in our life.

Yb-doped La2CaB10O19 (Yb:LCB) crystal is a multi-functional laser crystal invented by Prof. Yicheng Wu in 1998. Here, the authors present a broadband laser emission in Yb:LCB crystal beyond its fluorescence spectrum. The electron-phonon coupling intensity is calculated by Huang-Rhys S factor and the phonon-assisted fluorescence lineshape is predicted numerically. A broadband lasing emission spectrum (1000-1280 nm) is obtained by amplifying the weak multiphonon-assisted transitions step-by-step with increasing phonon numbers n=1 ~ 6. Theoretical calculations show that such a substantial lasing spectrum is devoted to multiphonon coupling at a dangling “quasi-free-oxygen” site, as demonstrated by the in-situ Raman experiment.

The potential of Cheng and colleagues' work does not end there. “Yb:LCB is a non-centrosymmetric crystal, it is possible to make a multidisciplinary coupling between multiphonon-coupled lasing and frequency-doubling, thus making a self-frequency doubling laser with the extended wavelengths in the visible range or self-OPO laser in mid-infrared range.” they added.

“This multiphonon coupling laser represents a significant step forward for broadband tunable sources and provides a versatile route for many applications, e.g. ultrafast laser, frequency-comb, laser display and dermatology. This would be a milestone work in solid-state laser engineering, as the invention of ruby and Ti:sapphire.” the scientists forecast.

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