Crystal growth and high-efficient laser performances of lighted doped fluorite mid-infrared laser crystals

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Mid-infrared (mid-IR) lasers are significantly important for the development of remote sensing, laser surgery, high-precision material processing, etc. However, the efforts of power scaling of mid-IR solid-state lasers are often obstructed by the laser performance of the gain medium, i.e., rare earth doped crystals, which has become a bottleneck for the progress of mid-IR laser related applications [1]. As the main challenge for mid-IR laser crystals is the self-terminating of the mid-IR laser transitions, the strategy of high concentration doping of rare earth (RE) ions, e.g., Tm^{3+} and Er^{3+} for lasing at ~1.9 μm and ~2.8 μm respectively, is frequently applied to improve the energy transfer efficiency between RE ions and achieve continuous-wave (CW) laser operation [2]. Such a high concentration doping, on the other hand, will dramatically enhance the thermal effect and limit the laser output power.

In the lattice of fluorite crystals such as CaF_2 and SrF_2, RE ions tend to gather as "clusters" rather than distribute uniformly. Therefore, the energy transfers between RE ions are enhanced even in lightly doped crystals, which can be regarded as a solution for the restriction of high concentration doping of mid-IR laser crystals [3]. In our research, Tm^{3+} and Er^{3+} doped fluorite crystals are synthesized using Bridgman method. Combing first-principles calculations, spectroscopy measurements and structural characterizations, the evolution of RE "clusters" as well as the relationship between RE "clusters" and spectroscopic parameters is analyzed. By enhancing the cross relaxation of Tm^{3+} ions, ~1.9 μm CW laser with a slop efficiency of over 80% and a quantum efficiency close to 200% is achieved using a 2 at.% Tm:SrF_2 crystal [4]. By tailoring the energy transfers between neighboring Er^{3+} ions, watts level ~2.8 μm CW laser with a slope efficiency close to Stokes limit (~35%) is generated in both 1 at.% Er:CaF_2 and 3 at.% Er:SrF_2 crystals [5,6]. Additionally, ~2.8 μm CW laser of slope efficiency exceeding 20% is achieved using a Er:CaF_2 crystal doped by only 0.5 at.% Er^{3+}, indicating the restriction of high concentration for Er^{3+} doped mid-IR crystals can be completely solved taking advantage of "clustering" behavior of RE ions [6]. The outstanding laser performance indicate that these lightly Tm^{3+} and Er^{3+} doped crystals are promising candidate for high-power mid-IR solid-state lasers.

References

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