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Cryogenic Laser Operation of a “Mixed” Yb:YLuAG Garnet Crystal

Sami Slimi[1, *], Venkatesan Jambunathan[2], Mingyan Pan[3], Yicheng Wang[4], Weidong Chen[5], Pavel Loiko[6], Rosa Maria Solé[1], Magdalena Aguiló[1], Francesc Díaz[1], Martin Smrz[2], Tomas Mocek[2], and Xavier Mateos[1,#]
1.FiCMA-FiCNA-EMaS, Universitat Rovira i Virgili (URV), Campus Sescelades, E-43007 Tarragona, Spain
2.HiLASE Centre, Institute of Physics of the Czech Academy of Sciences, Za Radnicí 828, 252 41 Dolní Břežany, Czech Republic
3. Key Laboratory of Materials for High Power Laser, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China
4 Photonics and Ultrafast Laser Science, Ruhr Universität Bochum, Universitätsstrasse 150, 44801 Bochum, Germany
5 Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences, Fuzhou, 350002 Fujian, China
6. Centre de Recherche sur les Ions, les Matériaux et la Photonique (CIMAP), UMR 6252 CEA-CNRS-ENSICAEN, Université de Caen Normandie, 6 Boulevard Maréchal Juin, 14050 Caen Cedex 4, France
**e-mail :* sami.slimi@urv.cat, *#Serra Húnter Fellow*

In recent years, solid state lasers and based on Ytterbium (Yb^{3+}) ions emitting at ~1 µm have attracted significant attention due to their vast technological and scientific applications. At room temperature, Yb^{3+} ions represent a quasi-three-level laser scheme because of the finite population of Stark sub-levels of the ground state ($^2F_{7/2}$), leading to reabsorption at the laser wavelength that increases the laser threshold and hinders the optical efficiency. To overcome this limitation, the active medium could be cooled down to cryogenic temperatures, approaching the quasi-four-level laser scheme leading to much lower laser thresholds [1]. In addition, this helps to improve the thermal and thermo-optical properties of the gain material. Yttrium aluminium garnet $Y_3Al_5O_{12}$ (YAG) is the state-of-the-art laser host crystal for Yb^{3+} doping. In the present work, we report on the cryogenic laser operation of a compositionally “mixed” $(Y,Lu)_3Al_5O_{12}$ (YLuAG) garnet doped with Yb^{3+} ions.

A single crystal of Yb:YLuAG was grown by the Czochralski method using an [111] oriented seed in an Ar atmosphere. According to the ICP-AES analysis, its composition was $(Y_{0.554}Lu_{0.280}Yb_{0.166})_3Al_5O_{12}$. The crystal possessed a cubic garnet structure. The selected “mixed” composition is motived by: (i) lower melting point as compared to $Lu_3Al_5O_{12}$, (ii) lower consumption of the Lu_2O_3 reagent, (iii) additional inhomogeneous broadening of Yb^{3+} spectral bands [2].

The cryogenic laser experiments were carried out using an L-shaped asymmetric cavity. The uncoated laser element had an aperture of 4×4 mm^2 and a thickness of 2 mm. It was mounted in a copper holder at normal incidence and fixed to the cold finger of the optical cryostat providing a heat load of 13 W at 100 K. To maintain the sample temperature, a 50 Ω heater was connected to the cold finger and the sample temperature was monitored using a silicon sensor. As a pump source, a Volume Bragg grating (VBG) stabilized fiber-coupled diode laser emitting at 969 nm with a spectral bandwidth of 0.40 nm (N.A. = 0.22, fiber core diameter: 105 µm) was used. The unpolarized pump radiation was reimaged using achromatic lenses with a ratio of 1:2.5. For passive Q-switching, Cr^{4+}:YAG saturable absorbers (SAs) with 85% and 95% initial transmissions were used.

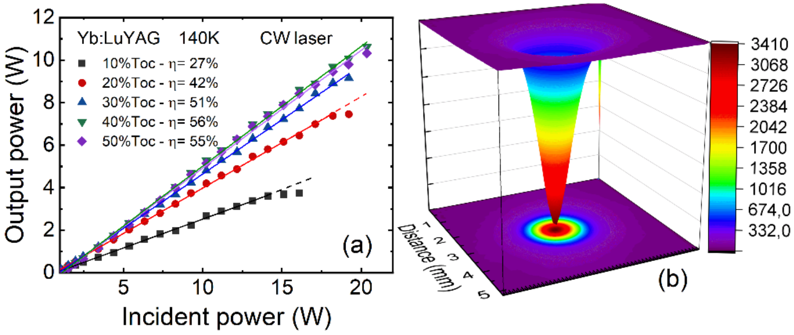

Fig. 1. CW cryogenic diode-pumped Yb:YLuAG laser: (a) input-output power characteristics for different transmissions of the output coupler (T_{OC}), η – slope efficiency, T = 140 K; (b) a typical far-field beam profile at the maximum output power.

Continuous-wave (CW) laser operation was realized initially at different temperatures in the range of 80 - 280 K with a step of 20 K using the same output coupler transmission (T_{OC} = 20%). As a result, we determined an optimum crystal temperature of 140 K for efficient laser operation, see Fig. 1(a) for the input-output dependences. The cryogenic diode-pumped Yb:YLuAG laser generated a maximum CW output power of 10.65 W at 1029 nm with a slope efficiency of 56% (with respect to the incident pump power) for T_{OC} = 40%. Figure 1(b) shows the far-field beam profile measured at the maximum output power corresponding to the fundamental transverse mode., In the passively Q-switched regime, using the SA with the initial transmission of 85%, the pulse energy / duration were 0.15 mJ / 201 ns at a repetition rate of 19.22 kHz.

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