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CONTINUOUS-WAVE LASER OSCILLATION OF Yb:FAP CRYSTALS AT A WAVELENGTH OF 1043nm*

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A continuous-wave laser oscillation was demonstrated with a Yb-doped fluorapatite (FAP) crystal pumped with a 905 nm Ti:sapphire laser. The output characteristics for different output couplers were investigated. A maximum power of 67mW at a 1043nm wavelength was obtained with 10% output coupler, pumped by a Ti:sapphire laser with 910mW power. This corresponds to a slope efficiency of 26.5%.

Keywords: continuous-wave laser, Yb:FAP crystal
PACC: 4260D, 4262, 4255R

I. INTRODUCTION

The Yb^{3+} ion has been recognized to serve as a laser ion when incorporated as a dopant ion into $Y_3Al_5O_{12}$ crystals and other garnets. Over the past few years, Yb^{3+}-based lasers have received substantial attention because of their larger emission cross section and longer upper level lifetime compared with Nd^{3+} doped into the same media.[1-2] Efficient laser action has been demonstrated in Yb-doped crystals such as YAG,[3-5] $Ca_5(PO_4)_3F$ (FAP). As a new host material for Yb^{+3} ions, FAP crystals have been developed recently.[6-9] Yb-based materials, which lase around 1μm, are aided by the simple electronic structure of Yb^{3+} ions which only have two accessible electronic states. In addition, the small quantum defect of ~10–15% leads to relatively large intrinsic laser slope efficiencies and favourable thermal performance. High-performance strained-layer diode lasers at a wavelength range of 0.9 and 1.1μm are available. This has stimulated interest in diode-pumped Yb^{3+} lasers. The ytterbium ions can be pumped by diodes since they have very simple energy levels. Because of their high gain, low threshold and high efficiency, it is possible to achieve a pumping efficiency of 90% with diode lasers. This can greatly simplify the laser design, since there are no side effects caused by flash-lamp pump. The absorption bandwidth of FAP crystals is only about 2nm, so the broadband flash-lamp pump is an inadequate means of pumping for the laser material. On the other hand, the diode laser wavelength can be tuned to match a particular output. The limited absorption features of Yb ions actually provide an advantage, since the lack of higher-lying excited states ensures the absence of detrimental processes such as up-conversion and excited-state absorption. Because of the low threshold and high efficiency of these crystals, they have been chosen as pre-amplifier crystals in the laser system for inertial confinement fusion (ICF) research in many laboratories.

In this paper we report on a continuous-wave, compact Yb:FAP laser at a wavelength of 1043nm. The pump is an all-state-solid Ti:sapphire laser which was tuned to 904.5nm to match the absorption band of the Yb:FAP crystal. With a 10% output coupler, a slope efficiency of 26.5% was obtained.

II. EXPERIMENTAL RESULTS AND ANALYSIS

From Fig.1, on the absorption and emission spectra of Yb:FAP with E//c, c is the axial direction of the FAP crystal, the pump band is at 905nm, while the energy extraction occurs at 1043nm. Since the FAP crystal is a uniaxial crystal, two orientations of electric field polarization are needed to characterize the dipole-allowed transitions of Yb ions. Both the pump and laser cross sections (at 905 and 1043nm) are con-

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siderably enhanced in the π polarization, so we should specify the preferred orientation of the laser element in any optical arrangement. Our experimental scheme is shown in Fig.1. An all-state-state 532nm laser (Millennia X, S-P Inc) is used to pump a Ti:sapphire laser, which is tunable from 880 to 980 nm. The Ti:sapphire laser used is a typical four-mirror configuration. Both concave mirrors have a 10cm radius of curvature. The transmission of the output coupler is 6% and the total length is 1.1m. In order to match the absorption band of the FAP crystal, we set the wavelength of the output laser at 904.5nm by rotating the prism. This laser beam then is focused onto the Yb:FAP crystal using a lens with an 80mm focal length. The crystal size is 5×5 × 10mm^3 with a Yb^{3+} concentration of 0.5 at.%. The crystal was coated with a high reflectance at 1043nm and an anti-reflectance at 904.5nm at the entrance end, and a high-reflectance at 904nm at the other end. This configuration can make the FAP crystal efficiently absorb pumping power and make the set-up compact. M6 is a concave mirror with a radius of curvature of 1000mm. M7 is a flat output coupler; we used two different transmissions of 3% and 10% respectively at 1040nm. To efficiently remove the heat generated with pump power from the crystal, the crystal was wrapped with indium foils and held in a copper block, which was cooled by recycling water.

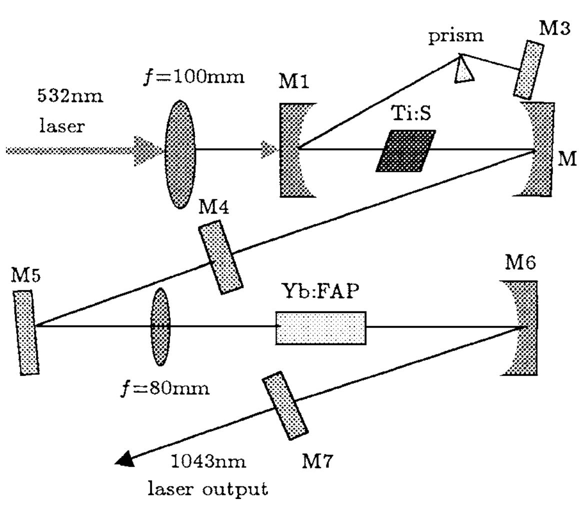

Fig.1. Schematic diagram of the experiment set-up. M1 and M2 are concave mirrors with a 10cm radius of curvature; M3 is a high reflective mirror at 850–950nm; M4 is a 6% output coupler mirror at 850–950nm; M5 is a high reflective mirror at 904nm with 45° incidence angle; M6 is a high reflective concave mirror at 1043nm with 10cm radius of curvature; and M7 is the output mirror at 1043nm.

Because the absorption bandwidth of Yb:FAP is only 2nm, it is necessary to finely tune the wavelength of the Ti:sapphire laser for efficient pumping. For this purpose, we used a spectrometer to monitor the wavelength and fixed it at 904.5nm by adjusting the prism. The maximum output power that we can gain from the Ti:S crystal is 1.2W at 904nm. Based on the pumping laser, the CW Yb:FAP laser running is realized for both output couplers. Figure 2 shows the results of the output power as a function of the incident pump power; the pump thresholds are 630mW and 660mW for 3% and 10% output couplers respectively. The highest output power of 67mW was obtained under the pump of 910mW with the 10% output coupler, which corresponds to a 26.5% slope efficiency and about 7% optical conversion efficiency. For the 3% output coupler, the slope efficiency is 6.8%.

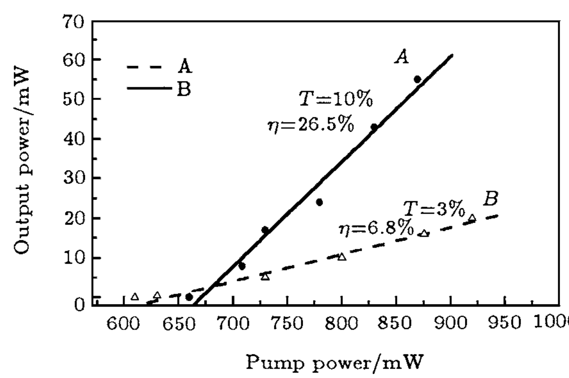

Fig.2. Output power versus the pump power for different output couplers; A is T=3% and B is T=10%.

From the data plotted in Fig.2, it could be found that the slope efficiency and the threshold power increase with the transmissivity of the output coupler. In fact, we can easily understand this from the following formula

$$\eta = \eta_0 \left(\frac{T}{T + L_d} \right). \qquad (1)$$

Here $\eta_0 = \lambda_p/\lambda_l$ is the quantum slope efficiency, for this experiment, η_0=86.8%. L_d is the loss inside the cavity, and T is the transmission of the output coupler. It is clear that the slope efficiency will increase with the increase of transmission. Theoretically, the slope efficiency of the Yb:FAP laser can reach about 86%. Our result shows that it is still much lower than that calculated. This may arise from the following facts. Firstly, the transmission of the output coupler is much smaller than the optimal one, which should be about 20% according to our calculation. Secondly, we found that the atmosphere flow leads the laser output power and wavelength to a poor stability, which decreases the pumping efficiency of the Yb:FAP laser. We may expect to improve it by using a cover. Thirdly, the crystal quality may need to be improved.

Ⅲ. CONCLUSION

We have demonstrated a continuous-wave Yb:FAP laser operation pumped with a Ti:sapphire laser at 904.5nm. The maximum output power of 67mW at a wavelength of 1043nm was obtained with a 10% output coupler. The slope efficiency was about 26.5%. In the experiment, we found that an unstable pump wavelength will lead to an unstable output power. With further optimization for the laser set-up and using an output coupler with higher transmission, it is possible to produce higher output power.

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