An efficient CW Nd:FAP laser

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An efficient CW Nd:FAP laser pumped by a dye (LD 700) laser, operated at the strong line at 1.0629 μm and the weak line at 1.1259 μm is presented. The comparison in threshold and efficiency of Nd:FAP with Nd:YAG laser at different spectrum lines is also demonstrated.

The emission spectrum of calcium fluorophosphate doped with neodymium ions (Nd:FAP) is a little different from Nd:YAG. For example, the strongest laser line in Nd:FAP is the transition from sublevel R_1 in the upper $^4F_{3/2}$ level to sublevel Y_1 in the lower $^4F_{11/2}$ level, which is 1.0629 μm rather than 1.064 μm in Nd:YAG. Nd:FAP is a bi-refringent crystal. The intensity of the strongest line of 1.0629 μm with π-polarization is 2.6 times that of the σ-polarization measured at room temperature. The intensity of 1.126 μm with σ-polarization is 6.3 times that of the π-polarization at 77 °K.[1] A 1.0629-μm flashlamp-pumped Nd:FAP laser has been reported.[2,3] In this letter, a dye-laser (LD 700) pumped, low-threshold and high-efficiency CW Nd:FAP laser operated at both 1.0629 μm and 1.1259 μm is presented, and a comparison in threshold and efficiency of Nd:FAP with the Nd:YAG laser are reported.

The experimental setup of the Nd:FAP laser is shown in Fig. 1. Because of the vertical polarization of the dye laser pumped by a Kr^+ laser, a Fresnel $\lambda/2$ prism was applied to rotate the polarization to be parallel. An astigmatic lens L_p with 7.5 cm local length focused the dye laser on the Nd:FAP disk. The dimension of the disk is 6.3 mm$\times$3 mm and its C axis lies in its surface. The radius of curvature of HR mirror M_1 is 10 cm, its transmission is 80% at the pumping wavelength. For the sake of obtaining both the strong and weak lines, two flat mirrors with different reflectivities are used to act as the coupler M_2, one with transmission of 98% at 1.06 μm, the other with reflectivity of $<40\%$ at 1.06 μm and reflectivity of $>99.8\%$ at 1.12 μm. A piece of glass without coating was inserted into the resonator as a FP etalon to narrow the linewidth and to tune the wavelength. A Coherent CR-210 power meter is used to measure the output power.

To get the strongest line, namely 1.0629 μm with π-polarization, the disk was arranged at the Brewster angle, and the C axis is parallel to the incident polarization. The length of the resonator is 3.5 cm. Tuning the dye laser to an absorption peak of the Nd:FAP in the vicinity of 0.75 μm, the wide spectrum output of 1.0629 μm with π-polarization as a function of the input is shown as curve I in Fig. 2. From curve I, the pumping threshold of 1.0629 μm with π-polarization is about 12 mW. There was about 152 mW of 1.0629 μm light with π-polarization to be measured under 340 mW pumping. The efficiency is 44.7% and its linewidth is about 1.0 cm^{-1}. After inserting the etalon the output was decreased to 104 mW with the linewidth being less than 0.5 cm^{-1}. Rotating the C axis to be perpendicular to the pumping polarization, the

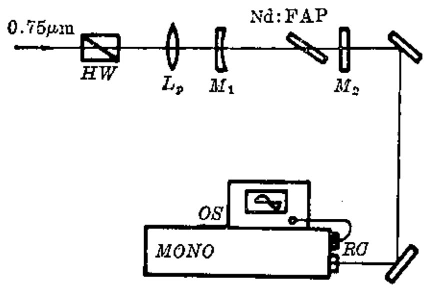

FIG. 1. The experimental setup of CW Nd:FAP laser. MONO is a half-meter monochromator, with a CCD imaging sensor at its exit.

relation of 1.0629 μm light with σ-polarization output to the input is shown as curve II in Fig. 2. Its threshold is about 23 mW which is a little bit higher than that for π-polarization, and the efficiency is 39%. About 70 mW of the narrow-line output was obtained by putting the etalon inside the cavity. If the incidence is normal to the disk, the laser beam is always polarized and the polarization is consistent with the *C*-axis, no matter what the direction of the *C* axis, crossed or parallel, to the polarization of the pump. This demonstrates that only the π-component can oscillate in this case because the π-component fluorescence is much stronger than the σ-component.

The fluorescence intensity of 1.1259 μm light with σ-polarization is only 0.07 times that of 1.0629 μm with π-polarization. Therefore, to get such a weak line to oscillate, the stronger line of 1.0629 μm has to be limited. For this reason, the coupler has to be coated with high transmission (60%) for 1.0629 μm and high reflectivity (99.8%) for 1.1259 μm. Setting the Nd:FAP disk at the Brewster angle and the *C* axis perpendicular to the pump polarization, the input-output relation of 1.1259-μm radiation with σ-polarization is shown as curve III in Fig. 2. Its threshold was measured to be 45 mW. The 84 mW wide-spectrum output was received under 340 mW pumping, with efficiency of 24%, and the linewidth is about 5.1 cm^{-1}. After inserting the etalon, the narrow-line output was 45 mW. Since this wavelength has a wider fluorescent spectrum of about 14 cm^{-1},[1] the tuning range for this wavelength is correspondingly wider. It was about 12 cm^{-1}. Figure 3 shows the comparison of wide spectrum (a) and narrow line (b) oscilloscope traces of 1.1259 μm. Similarly, rotating the *C* axis to 90°, the 1.1259-μm light with π-polarization is shown as curve IV in Fig. 2.

The CW Nd:FAP and Nd:YAG laser operation efficiencies and thresholds were compared under the same experimental conditions. For the threshold, the Nd:FAP laser is less than half of

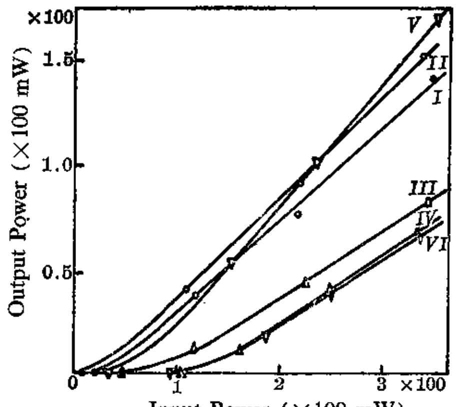

FIG. 2. Curves showing the input-output relations of Nd:FAP and Nd:YAG laser lines.
Nd:FAP:
I 1.0629 μm (π-)
II 1.0629 μm (σ-)
III 1.1259 μm (σ-)
IV 1.1259 μm (π-)
Nd:YAG:
V 1.0641 μm
VI 1.1225 μm

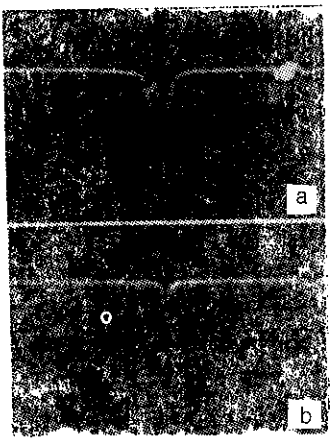

FIG. 3. Linewidths of 1.1259 μm.
(a) wide spectrum
(b) narrow line

the Nd:YAG. For the efficiency, although the strong line (1.06 μm) in Nd:FAP is not as high as Nd:YAG, the weak line (1.12 μm with σ-polarization) in Nd:FAP is better than that of Nd:YAG. These experiments show that the 1.1259-μm laser is easy to tune to 1.126 μm; its quadruple frequency 281.5 nm is the exciting wavelength for Hg^+ two-photon transition from $5D^{10}6S^2\,{}^2S_{1/2}$ to $5D^9 6S^2\,{}^2D_{5/2}$.

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