Tuning Characteristics And New Laser Lines In An Nd:YAP CW Laser

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***Abstract*—We have investigated the CW laser properties of Nd-doped yttrium-aluminum-perovskite (YAP) in a Kr arc-lamp, pumped cavity. Seven laser transitions within the $^4F_{3/2}$–$^4I_{11/2}$ multiplet have been observed. A simple Lyot filter is used to select the particular transitions. The tuning characteristics of the transitions at 1.0795 and 1.0845 μm were also obtained with the addition of a thin, uncoated etalon within the cavity. Tuning widths of 32 and 23 Å, respectively, were obtained.**

Introduction

THERE were early reports on the possible use of neodymium ions in the crystalline host, yttrium-aluminum-perovskite, $YAlO_3$ (YAP), as a replacement for YAG. This early enthusiasm was based on reports of high average power in pulsed systems and high CW power output with thresholds and efficiencies comparable to YAG [1]–[3]. Interest in this system was further motivated by the fact that the Perovskite structure results in an orthorhombic symmetry and consequently yields polarized laser output [4]. The YAP laser is then free from the depolarizing thermal birefrigence which affects YAG performance when polarizing optics are inserted in the YAG cavity.

Difficulties with purity in crystal growth of the YAP led eventually to a loss of interest in the material. Recently, however, W. C. Heraeus GmbH, West Germany, has been able to grow high optical quality YAP laser crystals in commercial quantities, and there is renewed interest in the material for applications in which a polarized output is desirable [5].

The availability of high-quality crystals of YAP from Heraeus, and the published, detailed fluorescence spectrum which suggested that efficient CW (or pulsed) tunable laser emission in the 1.05–1.1 μm spectral region might be possible led us to further investigate this material. Our interest was primarily motivated by the possibility of obtaining tunable laser emission at 1.0834 μm, corresponding to the resonance transition in helium-three on the 2^3S–2^3P line.

Experimental Results

A. Laser Performance

We report here the CW laser and tuning characteristics of Nd:YAP. Massey and Yarborough [4] reported earlier the efficient CW generation of power in Nd:YAP. They observed CW emission from two of the $^4F_{3/2}$–$^4I_{11/2}$ transitions (1.0645 and 1.0795 μm) and two of the $^4F_{3/2}$–$^4I_{13/2}$ transitions (1.3391 and 1.3411 μm). They also observed three additional $^4F_{3/2}$–$^4I_{11/2}$ transitions (1.0729, 1.0909, and 1.0989 μm) when the system was flash-pumped with 20 J from a Kr flashlamp. We report here CW laser emission from seven lines within the $^4F_{3/2}$–$^4I_{11/2}$ multiplet: 1.0645, 1.0729, 1.0795, 1.0845, 1.0909, 1.0921, and 1.0989 μm. Since Nd:YAP exhibits a fluorescence spectrum which is broader than Nd:YAP, we have also obtained tuning curves for the 1.0795 and 1.0845 μm transitions.

The $YAlO_3$–Nd crystal, obtained from Heraeus, was 90 mm in length × 5 mm in diameter. The standard Nd doping is 0.7 percent and the orthorhombic crystal is cut with its crystalline "*a*" axis along the rod length. The laser rod was mounted in a Micro-Controle laser, model YAG-904, which is pumped by two CW krypton arc lamps.

The $YAlO_3$, because of its structure, is optically biaxial with the laser emission polarized either along the *b* or *c* crystalline axes (depending upon wavelength). Fig. 1 shows the biaxial properties of the material. The emission from the $^4F_{3/2}$–$^4I_{11/2}$ transitions directed along the *a* axis is shown for the fluorescence polarized parallel to the *c* axis (upper curve) or polarized parallel to the *b* axis (lower curve). The relative intensities of the two curves for the two polarizations suggest how any tuning elements such as Lyot filters or Brewster prisms should be oriented within the cavity for a particular wavelength. Thus, with no polarizing elements within the cavity, the output of the laser will be centered on the 1.0795 μm transition and will be polarized along the crystalline *c* axis. Detailed information about the spectroscopic properties of the biaxial

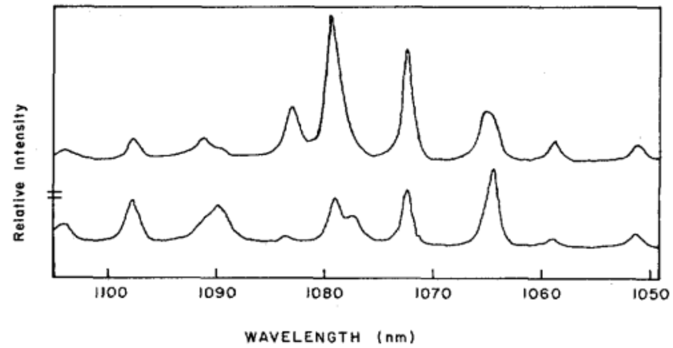

Fig. 1. Fluorescence of YAP crystal excited by CW, Kr lamps for two different polarizations of light. Upper curve = polarizer parallel to the *c* axis. Lower curve = polarizer parallel to the *b* axis.

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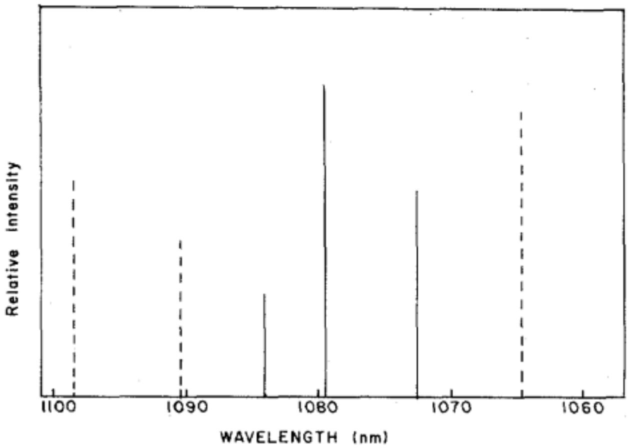

Fig. 2. Position and relative intensity of different lines emitted by the YAP laser in a cavity including a $T = 0.5$ percent coupler and a single-plate Lyot filter at Brewster angle. Full lines = Lyot filter oriented for no loss for the polarization parallel to the c axis. Dotted lines = Lyot filter oriented for minimum loss with the polarization parallel to the b axis.

$YAlO_3$–Nd laser crystals may be found in the paper by Kaminski *et al.* [6].

The output power at 1.0795 μm, as a function of the pumping intensity, depends strongly on the transmission of the output mirror. For instance, 60 W output power was observed with a $T = 10$ percent coupler, using a 40 cm long cavity with two plane mirrors, each of the two Kr lamps emitting 4 kW. In general, output powers are comparable to that obtained with YAG crystals of the same size under similar conditions, although thresholds for YAP are slightly higher. YAP also has a somewhat greater thermal lensing effect than YAG; consequently, at high pumping power, the cavity should either be rather short if made of two plane mirrors or include at least one divergent mirror to compensate for the thermal lensing.

In order to obtain laser emission at the several transitions represented in the fluorescence spectra shown in Fig. 1, we used a Lyot filter in the cavity. This filter is a 7 mm thick quartz plate inserted at the Brewster angle for a laser polarization parallel to the c crystallographic angle. It allowed tuning the laser to three different lines at 1.0729, 1.0795, and 1.0845 μm (full lines in Fig. 2). The same Lyot filter could also be inserted at the Brewster angle for a polarization parallel to the b axis (perpendicular to the previous one). The laser could then be tuned to the three other lines at 1.0645, 1.0909, and 1.0989 μm (dotted lines in Fig. 2). Fig. 2 shows the relative intensity of emission of these lines for a resonator consisting of two plane mirrors, the output mirror having a transmission of 0.5 percent. The required orientation of the Lyot filter for optimum emission on these two sets of lines agrees with the polarization observed for maximum fluorescence (see Fig. 1) in each case.

We were also able to use a thin, uncoated glass etalon (0.2 mm thick) in place of the Lyot filter to selectively force the laser to oscillate on transitions other than $\lambda = 1.0795$ μm. In this case, a second glass plate, inserted at the Brewster angle for polarization parallel to the b axis, enhances emission from the 1.0645 and 1.0989 μm lines.

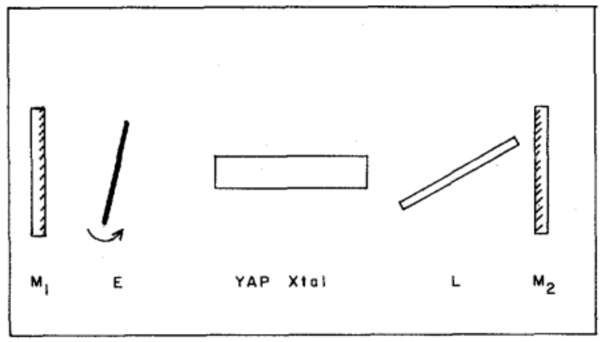

Fig. 3. Tuning the YAP laser emission with a Lyot filter L (7 mm thick quartz plate) and a solid etalon E (uncoated 0.2 mm glass plate).

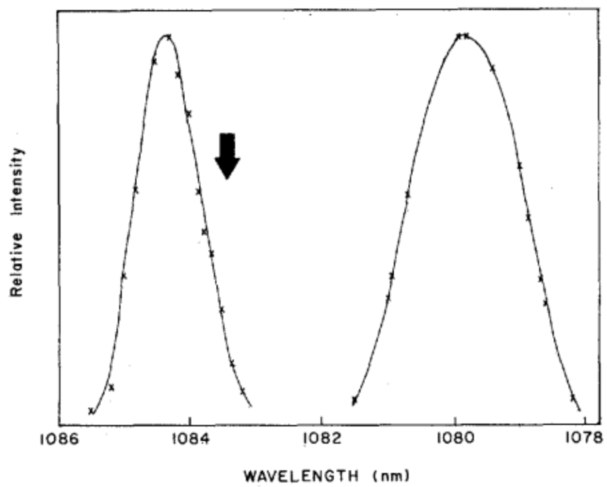

Fig. 4. Tuning curve of two lines emitted by the YAP laser obtained with the cavity shown in Fig. 3. End mirrors M_1 and M_2 are total reflectors. The actual amplitude of the two curves is not equal; the peak at 1.0845 μm is weaker than the peak at 1.0795 μm and has been magnified. The wavelength of the helium 2^3S–2^3P transition at 1.0834 μm is indicated by an arrow.

B. *Laser Tuning Characteristics*

We also investigated the tuning of the laser across several of the main transitions. Coarse tuning to a particular transition was achieved with the Lyot filter, while fine tuning within the transition was obtained with a thin glass etalon 0.2 mm thick, as shown in Fig. 3. Fig. 4 displays the results obtained for the main fluorescence peak at 1.0795 μm and for the weaker transition at 1.0845 μm. The cavity mirrors were both nominally total reflectors and the Kr lamp current was 16 A, corresponding to a 4 kW emission for each lamp. Fig. 4 shows a tuning range of about 32 Å for the line around 1.0795 μm and 23 Å for the other one around 1.0845 μm. A small fraction of the laser power could be extracted from the cavity, either through the weakly transmitting mirror (one of them is $T = 0.3$ percent and allows 5 W output at the peak of the 1.0795 μm line) or by making use of the reflected light from the faces of the intracavity Lyot filter. Increasing the transmission of one of the cavity mirrors increases the output power, but decreases the tuning range on each line. For instance, for the main peak, the tuning range reduces to 12 Å while the output power increases to 40 W when using a $T = 1$ percent coupler. Let us remark that these tuning ranges are significantly broader than the corresponding ones for YAG [7], as expected from the different widths of the fluorescence curves for YAP and YAG.

C. Applications

We were particularly interested in obtaining a laser source that could be tuned to the infrared resonance transitions in helium-three (1.0834 μm). This wavelength is used by a number of groups utilizing optical pumping techniques to obtain ensembles of spin-polarized helium-three nuclei [8], [9] for fundamental investigations of the quantum properties of a spin-polarized Fermi system [10] and in nuclear physics [11]. In order to test this application, the output of the laser was tuned to the helium resonance transition indicated in Fig. 4. Using the laser emission reflected from the face of the Lyot filter, we were able to obtain nuclear polarizations in helium-three exceeding 10 percent by optical pumping. Considerable improvement can be expected if the cavity is optimized for this particular wavelength. While we did not obtain the tuning characteristics of the other transitions shown in Fig. 2, we fully expect that tuning ranges similar to those shown in Fig. 4 would be achieved.

Conclusions

The Nd:YAP laser system has several attractive features, chief of which is the absence of thermally induced birefrigence, and in certain applications it may be a useful substitute for Nd:YAG. The slightly broader fluorescence spectrum of Nd in YAP compared to YAG may also render it useful in specialized applications in which a tunable source may be required—as in optical pumping applications [12], [13].

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