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CW Laser Oscillations and Tuning Characteristics of Neodymium-Doped Lithium Niobate Crystals

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Abstract—**We have obtained over 250 mW of CW laser emission at 1084 nm from a neodymium-doped single crystal of lithium niobate when the rod was end pumped by 1 W from a Kr$^+$ laser at 752 nm. Thresholds of less than 30 mW are obtained with a weak output coupler, rising to 220 mW with a 35 percent transmitting output mirror. The laser could be tuned over 3 nm around the peak at 1084.4 nm with a thin, uncoated etalon in the cavity.**

INTRODUCTION

EARLY reports of laser emission in neodymium-doped single crystals of lithium niobate were confined to pulsed operation [1], [2]. While the results were promising, the optical quality of the crystals was poor and the device exhibited large photorefractive effects [3]. The large electrooptical and nonlinear coefficients made this material attractive for devices which combine good laser characteristics with the possibility of optical harmonic generation, optical parametric oscillation, and optical modulation.

Recently, lithium niobate crystals of good optical quality have become available. Further, it has been determined that the addition of 5 mole percent of magnesium oxide to the lithium niobate reduces photorefractive effects [4], [5]. Thus, Fan *et al.* were elegantly successful in demonstrating the rather remarkable laser properties of Nd-doped lithium niobate when the material was pumped by an Ar$^+$ pumped dye laser at 598 nm [6]. This group also has demonstrated internal Q switching and self-frequency doubling and has recently extended their observations to diode pumping [7].

In this paper, we describe our work on the CW properties of this material when pumped by 1 W of Kr$^+$ laser light at 752 nm. The device is characterized by good efficiency, high gain, and low thresholds, and is easily tunble in a region of the spectrum which contains the helium metastable resonance transitions. Optical pumping of the helium metastable atom at 1083 nm has led to a large number of interesting applications [8], [9], and the availability of laser emission from a well-behaved, easily available material which can be tuned to this wavelength will extend the range of applications [10]. Optical pumping of He^3 and He^4 allows us to obtain significant polarizations of the electronic and nuclear spins in these atoms. Many of the applications require the optical processing of large numbers of spins and would benefit from the availability of a laser source.

EXPERIMENTAL RESULTS

The cavity used in these experiments is shown schematically in Fig. 1. The element $M1$ is a meniscus which acts as both a focusing lens for the Kr$^+$ pump radiation and as a curved mirror forming one end of the laser cavity. The focal length of the equivalent lens and the radius of curvature of the mirror are both about 4.2 cm. The meniscus was transparent to the pump radiation, but totally reflecting at 1084 nm. The pump radiation is focused onto one end of the lithium niobate crystal with a beam waist of approximately 20 μm in diameter. The laser beam radius in the cavity varied from approximately 20 μm at the front of the crystal to 100 μm at the exit face. The lithium niobate crystal was cut in the form of a rectangular parallelepiped 4 × 4 × 10 mm and contained 0.5–1.0 at percent Nd. The long dimension coincides with the crystalline "y" axis. The laser output was polarized along one of the short edges coinciding with the crystalline "c" axis. The surfaces of the crystal were anti-reflection coated at 1084 nm. An AR-coated lens of focal length 2.75 cm was mounted on a traveling stage so that the fluorescence from the crystal could be focused at points between the output mirror $M2$ and infinity. The total cavity length was approximately 25 cm. The gain and threshold measurements were made with this cavity. For the tuning characteristics, a thin, uncoated etalon and/or a Lyot filter could be added to the cavity.

A. Laser Performance

The laser performance of the crystal was obtained for output couplers having transmissions ranging from 1 to 35 percent with input pump powers up to 1.2 W at 752 nm. Fig. 2 shows the power output obtained at the fluorescence peak as a function of input power for output mirrors of 35, 16, 4, and 1 percent. The positions of the elements within the cavity were adjusted initially for minimum threshold and then remained unchanged. Slope efficiencies calculated from the equation

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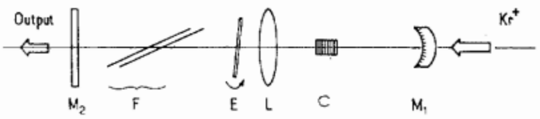

Fig. 1. Schematic of the laser cavity. $M1$ is a dichroic meniscus which focuses the Kr^+ pump power near the front surface of the crystal and also acts as a curved total reflector for one end of the cavity. L is a lens and $M2$ is a plane output coupler of transmission T. A single-plate Lyot filter F and a thin, uncoated etalon E is added to the cavity for wavelength tuning.

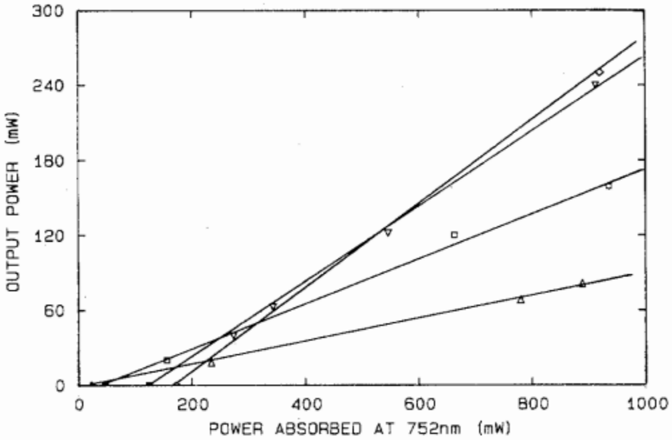

Fig. 2. Output power of the Nd:$LiNbO_3$ laser as a function of the absorbed input power pump at 752 nm for different output couplers. See text for crystal orientation.

$$S = P_{out}/(P_{abs} - P_{th})$$

are 37, 33, 20, and 10 percent, respectively. P_{abs} is the absorbed pump power and P_{th} is the absorbed pump power at threshold. At 752 nm, approximately 78 percent of the incident pump light was absorbed; the laser output was independent of the polarization of the 752 nm pump beam. Threshold absorbed pump power levels as a function of the transmittance of the output coupler is shown in Table I. The laser emission is linearly polarized. No photorefractive effects were observed. A single-pass loss of 5 percent in the crystal including the AR coatings was determined by measuring absorption losses at the laser wavelength with a Cary spectrophotometer. Better performance can be expected as the crystal quality is improved. The results shown here, however, are entirely satisfactory for many applications.

The crystal shows a strong absorption at both 752 and 810 nm. The strong absorption at this wavelength suggests that results similar to those reported here should be available with diode pumping of the lithium niobate crystal.

B. Tuning Characteristics

The width of the fluorescence is significantly greater than the corresponding width in an Nd-doped YAG crystal. Fan *et al.* attributed the increased width to the two distinct sites occupied by the Nd^{3+} ion [6], [11]. The increased width suggested the possibility of tuning the laser output. A 0.2 mm thick, uncoated etalon was inserted in the cavity without noticeable reduction in the laser output power. With a 16 percent output coupler, the emission could be tuned over 3 nm. The output power as a function of wavelength is shown in Fig. 3. The pump power was 1.1 W. As the output wavelength approached the tuning range limit, the laser oscillated simultaneously at two wavelengths separated by 2 nm, corresponding to the free spectral range of the etalon. For example, we obtained 60 mW at 1083.2 nm while simultaneously obtaining 120 mW at 1085.5 nm. The laser bandwidth was about 0.3 nm as measured by a 0.75 m grating monochromator. When a single-plate Lyot filter (6 mm thick) was added to the cavity, the second emission line could be suppressed. In this case, 60 mW was obtained at 1083.1 nm with no other emission present. The failure of the device to yield an increase in the power at 1083.1 nm when the Lyot filter was added to suppress the emission at 1085.5 nm suggests that there is a large inhomogeneous broadening present in the Nd:$LiNbO_3$. With the etalon adjusted to the fluorescence peak, insertion of the Lyot filter in the cavity resulted in no additional loss.

TABLE I
Absorbed Pump Power at Threshold Versus Output Mirror Transmission

Mirror Transmission (Percent)	Threshold (mW)
35	172
16	62
4	39
1	23

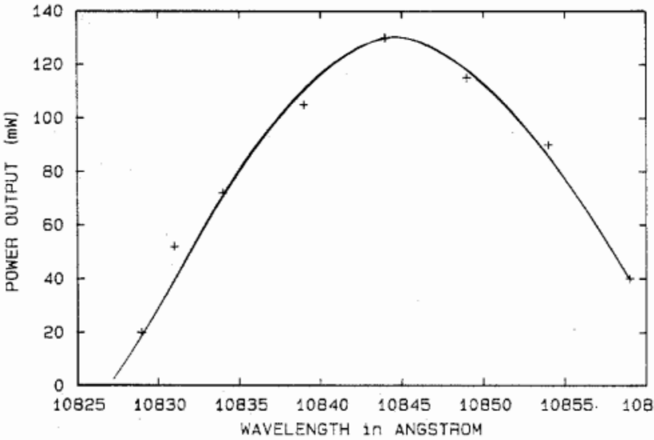

Fig. 3. Tuning curve for the Nd:$LiNbO_3$ crystal obtained with a single-plate Lyot filter 0.2 mm thick, uncoated etalon in the cavity. The crystal is pumped with about 1.0 W of Kr^+ laser light at 752 nm. The output mirror is 16 percent transmitting.

CONCLUSIONS

Neodymium-doped lithium niobate appears to have thresholds, gain, and efficiencies comparable to Nd:YAG. It is a promising contender as a solid-state laser device, especially when one considers its electrooptic properties. The significantly broader fluorescence also permits easy tuning of the laser emission in an interesting region of the spectrum. For the immediate future, we hope to significantly extend the tuning range of the device and investigate the use of etalons with different reflectivities in an effort to restrict the laser oscillation to only a few longitudinal modes.

The use of diode arrays at 810 nm as a pump source is presently in progress with the hope that a compact, efficient, tunable source can be obtained for optical pumping applications.

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J. Zachorowski, photograph and biography not available at the time of publication.