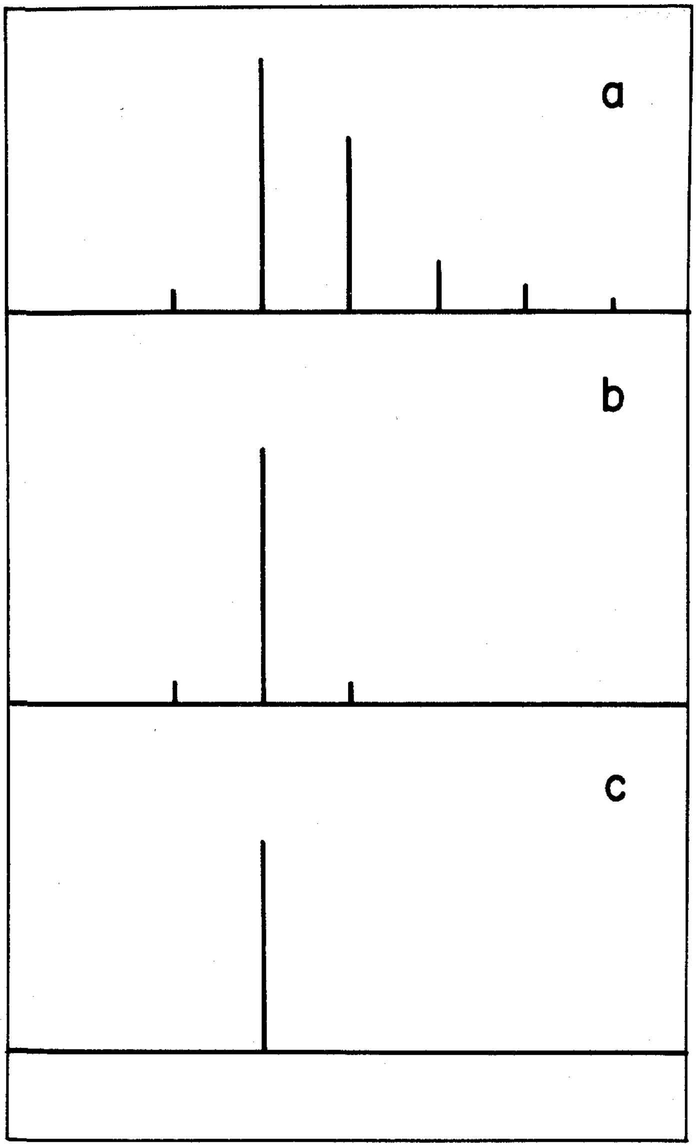

Fig. 1.

bining the oscillator-saturable absorber system with an amplifier operated under saturated conditions. This improved performance has been demonstrated on an oscillator-amplifier utilizing a single 1-m-long gain module. To date ~20 J pulses with no detectable (400:1) prepulses have been observed. More sensitive (>10^7:1) measurements of the main pulse to prepulse contrast are planned and further experiments on postpulse suppression will be reported.

15.8 Multiwavelength Cascade Solid Lasers. L. Esterowitz, R. C. Eckardt, and R. E. Allen, *Naval Research Laboratory, Washington, DC 20375*

(15 min)

In this paper we describe a new pumping technique for rare earth solid lasers which employs self-pumping from internal laser transitions to achieve inversion in other transitions. Cascade laser oscillation was achieved at room temperature in Ho:$LiYF_4$(YLF) at 1.67 μm ($^5I_5 \rightarrow {}^5I_7$) by populating the $^5I_5$ manifold via the $^5S_2 \rightarrow {}^5I_5$ laser transition at 1.40 μm.

In general, this process can proceed in a cascade manner down through the activator ion energy levels to produce simultaneous multiwavelength stimulated emission. There is a large degree of flexibility in choosing the desired laser wavelengths since in principle, one can selectively choose cavity mirrors that bypass unwanted transitions. Efficiency can be improved because losses associated with the many modes of decay to levels other than the initial laser level are eliminated. Crystal thermal loading is also minimized since the energy transfer is radiative. One of the more interesting features is the possibility of generating stimulated emission at wavelengths longer than 3 μm. Previous studies [1] have concluded that laser emission extending beyond 3.3 μm is unlikely since fluorescence at these long wavelengths is overwhelmed by nonradiative relaxation due to multiphonon emission.

The cascade laser process proposed here can avoid the severe limitations imposed by standard pump excitation techniques. Once inversion is achieved in a high-lying energy state, subsequent inversion can be obtained in lower-lying energy levels by self-pumping via laser transitions. Previous requirements that the upper laser level have a long fluorescent lifetime with small nonradiative decay rates are no longer necessary. In addition, a much wider choice of host crystals is now available since it is no longer necessary that the optical phonon energies of the crystal and/or the orbital coupling of the ion to the lattice be small. This opens up the possibility of achieving midinfrared laser operation in a large number of rare earth systems due to the presence of many suitable energy level separations.

To demonstrate the feasibility of the cascade laser process, we used the doubled output of a Nd:Glass (ED-2) laser to pump the trivalent holmium sample. The source was tuned to 535 nm for pumping directly into the $^5F_4$ manifold which is in thermal equilibrium with the $^5S_2$ manifold. The green pump beam was focused with a cylindrical lens to a line 0.4-mm wide at the 1/e intensity points. Transverse pumping was used with the 1%-Ho:YLF crystal which had α = 12 cm^{-1} at 535 nm.

In our configuration, threshold for laser oscillation occurs when 1 mJ is absorbed in the active cavity volume. This is about 10 percent of the total pump beam energy. The laser oscillation was restricted to the TEM_{00} transverse mode by the width of the pump beam and the edge of the crystal. Pumping with 15 mJ (i.e., 1.5 mJ effectively absorbed) yielded 175 μJ in the 1.40-μm laser line ($^5S_2 \rightarrow {}^5I_5$) and 90 μJ in the 1.67-μm laser line ($^5I_5 \rightarrow {}^5I_7$). Thus even with pump energies only 50 percent above threshold, a conversion efficiency of 17 percent was achieved for simultaneous laser operation at 1.40 and 1.67 μm. Even more impressive is the greater than 50 percent conversion in going from the 1.40- to the 1.67-μm laser transition.

This is the first reported demonstration of a cascade laser process in solid crystalline materials with oscillation at two separate transitions. This is also the first room temperature demonstration of laser action in holmium at 1.67 μm. In addition, the cascade laser technique offers a promising new approach in obtaining solid lasers at wavelengths longer than 3 μm.

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15.9 Active-Passive Mode-Locked Flashlamp-Pumped Dye Laser. M. D. J. Burgess, R. Fedosejevs, P. Jaanimagi, M. C. Richardson, *National Research Council, Ottawa, K1A OR6, Canada*

(15 min)

This paper presents the first results obtained on the combined active and passive mode-locking of a flashlamp-pumped, dye laser. Such a system provides a simple, low-jitter means of synchronizing a relatively high-energy picosecond pulse to an external event and should prove particularly suitable to the study of laser-generated plasmas, photochemistry, and relaxation phenomena.

Dual modulation techniques have been used previously on flashlamp-pumped neodymium [1–4] and ruby [5] lasers. However, the broader bandwidth and greater gain of the dye laser leads to shorter pulses and simpler synchronism than has been achieved with the above configurations. Similar techniques have been applied to CW dye lasers to give subpicosecond pulses [6], but of low power output ($\leqslant$ 1 nJ).

The oscillator comprised a 76-mm long, 4-mm diameter flowing dye cuvette, a 100-percent plane mirror forming part of the 1-mm thick flowing dye saturable absorber cell, a prism tuning element, a 3-mm thick, 40-mm long $LiNbO_3$ electrooptic modulator, and a partially transmitting concave output mirror. The amplifying medium was a 1×10^{-4} mole/l concentration of Rh6G perchlorate in ethanol, and various concentrations of DODCI in ethanol were used as the saturable absorber. Active mode-locking at 75 MHz was achieved by applying up to 250 V to the modulator crystal. A single pulse was switched out electrooptically from the pulse train.

The system was characterized by simultaneous measurements of the laser pulse duration (ps streak camera), spectrum, switch-out time, and synchronism of the pulse to the applied RF voltage. The pulse duration was studied as a function of DODCI concentration and amplitude of the RF voltage. Pulses of 10 ps duration and 2.5 μJ energy were produced with a 1.3 percent depth of modulation and a DODCI concentration of 5×10^{-5} mole/l.

The jitter in the synchronism was found to decrease as the applied RF voltage increased. The rms jitter under the above optimum conditions was less than the measurement accuracy of 125 ps.

It was also found that the relative delay between the peak of the switched-out pulse and the applied RF voltage was dependent upon the depth of modulation. Such a dependence has not been reported previously, but it is to be expected according to a recent theoretical treatment of active passive mode-locking [7].

Experiments are now in progress on a larger system to examine the agreement with theory in more detail and to provide sufficient output energy for optical diagnostics of high-power CO_2 laser-produced plasmas.

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15.10 FM Mode-Locked $Nd_{0.5}La_{0.5}P_5O_{14}$ Laser.

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(15 min)

Using the high-Nd-concentration material $Nd_{0.5}La_{0.5}P_5O_{14}$ [(Nd, La)PP], we have constructed an FM mode-locked laser with output pulses ~ 14-ps wide at a repetition rate of 480 MHz. The primary advantages of this material are its wide fluorescence bandwidth, ~ 25 cm^{-1}, and its large emission cross section, which simultaneously allow short laser pulses and low threshold CW operation.

The laser design, illustrated to scale in Fig. 1, uses an astigmatically compensated three-mirror cavity of the type commonly used for dye lasers [1]. The small-mode waist at the laser crystal provides a low threshold, while the long cavity arm where the phase modulator is inserted has a wide, nearly collimated beam. The laser crystal is 3.5-mm long with faces polished at Brewster's angle and a laser polarization along the highest gain *b* direction. We have used (Nd, La)PP rather than NdP_5O_{14} in order to lower the fluorescence concentration quenching and decrease the $^4I_{11/2}$ resonant absorption loss. Crystals were grown by the technique described in [2]. Nearly all of the pump radiation at 585 nm is absorbed in the crystal except for a small amount used for alignment.

The phase modulator is a crystal of $LiNbO_3$, 4 mm^2 $\times$ 20 mm long, mounted in a tuned package with Q $\simeq$ 150 to lower the RF drive power.

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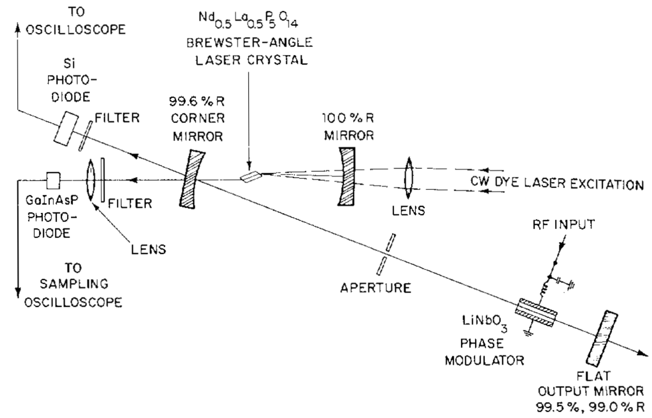

Fig. 1. Schematic diagram of FM mode-locked $Nd_{0.5}La_{0.5}P_5O_{14}$ laser.

We have measured the modulation depth at 633 nm with a HeNe laser, and using reported data on the electrooptic coefficients at 633 nm and 1060 nm [3], the phase retardation at the laser wavelength of 1050 nm was found to be $\delta \simeq 0.5\sqrt{\text{power}}$ rad$-$W$^{-1/2}$. The optical length of the laser cavity, which was adjusted to match the 480-MHz center frequency of the modulator circuit, was about 31 cm.

The laser output was measured by several methods. At the partially transmitting corner mirror, one beam was detected with a relatively slow Si photodiode in order to monitor the average output power, and the other beam was focused onto a small-area GaInAsP photodiode (provided by C. E. Hurwitz of Lincoln Laboratory) from which the output was put into a sampling oscilloscope. This output, with a detector-limited, minimum-measured width of 80 ps, was used for coarse alignment of the cavity and to monitor continuously the output pulse train. The beam from the flat output mirror was measured by three different methods: direct second-harmonic generation (SHG) enhancement with a $Ba_2NaNb_5O_{15}$ crystal, pulse intensity correlation with a scanning Michelson interferometer followed by the SHG crystal, and spectral measurement with a scanning Fabry-Perot interferometer.

Using two output mirrors with 0.5-percent and 1.0-percent transmission, thresholds of 23 mW and 28 mW were measured, with corresponding single-ended slope efficiencies of 5.6 percent and 9.7 percent, respectively. The round-trip nonresonant internal loss was calculated to be 1.4 percent. Typical single-ended average output powers were from 4 to 8 mW. The maximum-measured SHG enhancement factor of 36 implies a pulse duration of ~ 20 ps, assuming a Gaussian pulse shape. The direct intensity correlation scans seemed to be more sensitive to the cavity alignment, but the minimum measured correlation function width was 20 ps, implying a Gaussian pulse width of 14 ps. This is less than half the shortest value reported for CW Nd:YAG lasers [4]. With modulation power of 300 mW ($\delta \simeq 0.27$) and cavity loss of 0.03, the pulsewidth calculated from the theory of [3] is 13.6 ps, in excellent agreement with the measurement. The product of the measured spectral width and pulse duration was ~ 0.66, compared to the theoretical value of 0.624 [3] showing that no significant extraneous frequency chirp was present.

The high-gain density of (Nd, La)PP allows the use of very small laser crystals, with resulting advantages of lower dispersion and use of shorter laser cavities. With lower cavity loss, greater modulation, and higher modulation frequency, pulses less than 10-ps wide should be attainable. Development of suitable semiconductor lasers or LEDs to pump the 800-nm Nd^{3+} absorption band should enable development of a small and efficient (Nd, La)PP mode-locked laser.

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