TECHNOLOGY Trends

A New Tunable Solid-State Laser

BY V. PETRICEVIC, S. K. GAYEN AND R. R. ALFANO

The eighties have been a decade of rapid development for tunable solid-state lasers[1] with progress reaching the point where tunable solid-state lasers are making headway in the marketplace and attracting the financial community's interest. In the area of laser applications, interest in tunable solid-state lasers stems from their many advantages over dye lasers. These include wide wavelength tunability, compactness, long operational lifetime, rigidity and ease of handling — all of which make them highly reliable and extremely suitable for spaceborne remote sensing, ranging, lidar and optical communication applications.

> *A new tunable solid-state laser of chromium-activated forsterite offers wide tunability and a variety of applications.*

Tunable solid-state lasers also have a high potential for medical applications in eye surgery, cutting tissues, treating birthmarks and removing kidney stones. Industrial applications include on-line pollutant-emission monitoring and fiber optic communications along with basic scientific research.

In this article, we will introduce a new tunable solid-state laser system: Chromium-activated forsterite (Cr^{3+}: Mg$_2$SiO$_4$), which has the potential for tunability from 850-1400nm — one of the most widely tunable laser systems in this spectral region. Chromium-based crystals that are known to lase, cover a spectral range of 700-1100nm. The first laser, ruby, operates only at a well defined wavelength of 694.3nm. Four different hosts are necessary to cover the 700-1100nm range. The Cr^{3+}: Mg$_2$SiO$_4$ system extends the range further into the infrared and shows promise of covering most of the range and beyond.

We have observed pulsed laser action in Cr^{3+} at room temperature.[2] The emission is centered at 1235nm, and has a bandwidth (FWHM) of 22nm. In the following sections, we will introduce the characteristics of the host crystal, present the basic spectroscopic properties of the system, describe the laser experiments and measurements, and point out the possibilities of the system.

Forsterite, like alexandrite, is a member of the olivine family of crystals and is a naturally occurring gem. The crystal appears different when looked at from different directions. Along the [100] axis it appears to have a bluish hue, along [010] it appears violet, while along the [001] axis it looks greenish.

Single crystals of Cr^{3+}:Mg$_2$SiO$_4$ may be grown by the Czochralski method. The crystal is easy to grow, and large crystals (several centimeters long and about a centimeter in diameter) are readily grown. The single crystal of Cr^{3+}:Mg$_2$SiO$_4$ used for spectroscopic and laser action measurements presented in this article was grown by the Czochralski method at the Electronic Materials Research Laboratory of the Mitsui Mining and Smelting Co. Ltd., in Japan. The crystal is a 9mm × 9mm × 4.5mm rectangular parallelepiped with the three mutually orthogonal axes oriented along the b, c and a crystallographic axes of the crystal. The crystal contains 0.04 atomic percentage of Cr^{3+} ions, which is equivalent to a chromium-ion concentration of 6.9×10^{18} ions/cm^3.

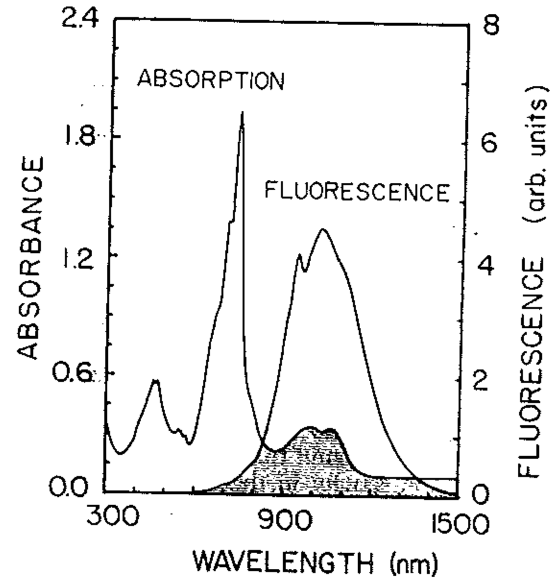

Figure 1.
Absorption and fluorescence spectra of Cr^{3+}:Mg$_2$SiO$_4$ at room temperature.

The room-temperature fluorescence and absorption spectra of Cr^{3+}:Mg$_2$SiO$_4$ for $E \parallel b$ crystallographic axis are shown in Figure 1. The fluorescence spectrum was excited by the 488nm radiation from an argon-ion laser and recorded by a germanium photodiode detector-lock-in-amplifier combination at the end of a 0.25m monochromator equipped with a 1000nm blazed grating. The room-temperature spectrum is a broad band covering 700-1400nm. The room-temperature fluorescence lifetime is 15μsec. The absorption spectrum is characterized by two broad bands centered at 740nm and 460nm attributed at the $^4A_2 \rightarrow {}^4T_2$ and $^4A_2 \rightarrow {}^4T_1$ absorption transitions, respectively, of the Cr^{3+} ion. The broad weak absorption band between 850-1150nm is not observed in the excitation spectrum. This indicates that the origin of this absorption is not transitions in the Cr^{3+} ion, but in some other impurity ions, e.g., Fe^{3+} in the host crystal.[4] It is evident from Figure 1 that this background absorption overlaps a significant spectral region of Cr^{3+}:Mg$_2$SiO$_4$ emissions and inhibits laser action in that region. Both the emission and absorption spectra of such systems depend strongly on the polarization of the incident light

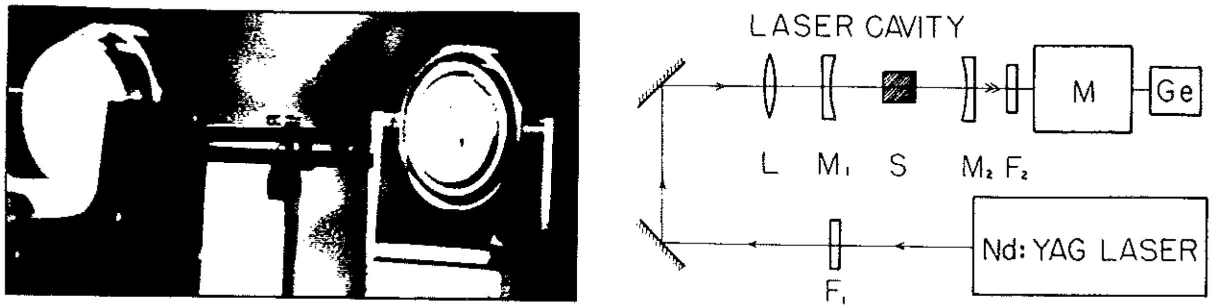

Figure 2.
A photograph of the laser cavity (left), and a schematic of the experimental arrangement for investigating laser action in Cr^{4+}*:* Mg_2SiO_4*. Key:* F_1 *= 1060nm blocking filter,* F_2 *= 532nm blocking infrared transmitting filter,* M_1 *= back mirror,* M_2 *= output mirror,* L *= lens,* S *= sample,* Ge *= germanium photodiode detector,* M *= monochromator.*

and the orientation of the crystallographic axes in the sample.

Laser action

The experimental arrangement for investigating the laser action in Cr^{4+}:Mg_2SiO_4 is shown in Figure 2(a), and drawn schematically in Figure 2(b). The sample is placed at the center of a stable resonator formed by two 30cm-radius mirrors placed 20cm apart. The mirrors were dielectric coated to transmit the 532nm pump beam, and to have high reflectivity in the 1150-1250nm spectral range. It should be noted that this spectral region does not correspond to the peak of fluorescence spectrum, but was chosen to minimize background absorption.

The sample was longitudinally pumped by frequency-doubled 532nm, 10ns (FWHM) pulses from a Q-switched Nd:YAG laser (Quanta Ray DCR-1) operating at a 1 repetition rate. The pump beam was linearly polarized along the b axis and propagated along the a axis of the sample. It was focused 3cm before the sample by a 25cm-focal-length lens. The radius of the pump beam at the center of the sample is ~600μm. The output from the laser cavity was analyzed by a 0.25m monochromator, monitored by a germanium photodiode detector and dis-

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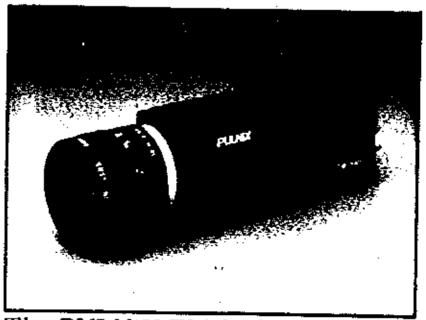

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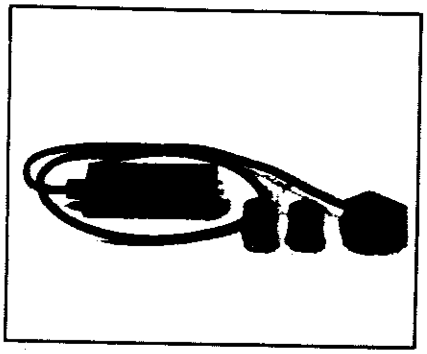

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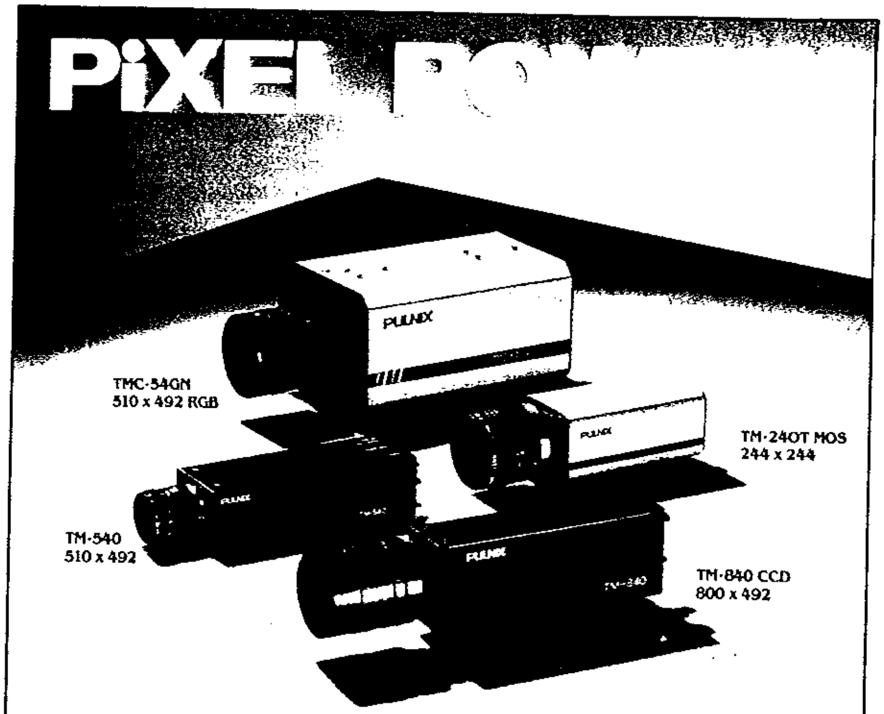

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played on a fast oscilloscope. No dispersive element was placed in the cavity and the laser operated in a free-running pulsed mode.

Pulsed laser operation was readily obtained for pumping at or above the lasing threshold energy of 2.2mJ. A single output laser pulse was obtained, implying a gain-switched operation, a consequence of pump-pulse duration being shorter than the lasing-level lifetime.

The spectrum peaks at 1235nm and has a bandwidth (FWHM) of 25nm. The measured slope efficiency is ~1.5 percent for the cavity configuration described above. With an optimized cavity, we expect the slope efficiency to increase substantially. We have observed laser action in this crystal for E ∥ a and c axes as well. This appears to be a unique property of this system, since most of the systems, including alexandrite, lase in only one preferred direction.

The chromium-activated forsterite system has a high potential to be a very useful and practical laser system in optical communications and ranging. The spectral range for laser emission is expected to extend from 850-1400nm if the parasitic impurity absorption can be minimized by improving the crystal growth technique. The output at the low-energy end of this laser is of particular importance for transmission through optical fibers and eye-safe ranging. The large fluorescence bandwidth promises ultrashort pulse generation through mode-locked operation. Since large crystals can be readily grown, the system may be used as an amplifier medium in the near infrared region as well. ☐

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