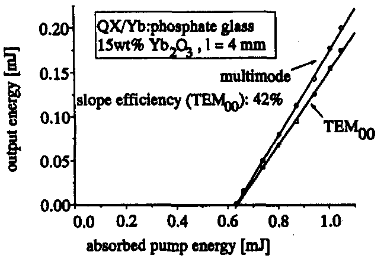
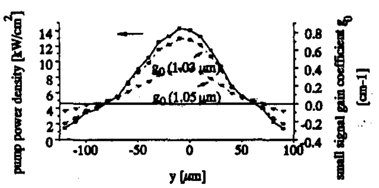


CThI1 Fig. 2 Output versus input characteristics of the transversely diode-pumped Yb:phosphate glass laser.



CThI1 Fig. 3 Measured pump power density $I(y)$ and calculated gain distribution $g_0(y)$ for two wavelengths in the plane perpendicular to the pump and laser beam propagation.

tion peak of the Yb:phosphate glass, $\sigma_e = 0.85 \times 10^{-20}$ cm²). To achieve the essential pump power density we formed a line focus of 0.1 mm × 4 mm within the glass sample using an imaging optic. Laser action occurred with a threshold pump energy of 0.63 mJ and a slope efficiency of 42% with respect to absorbed pump power. Because of operating with a single-pass absorption of the pump beam the maximum output energy is limited to 0.20 mJ (Fig. 2). Although the glass sample was not heat-sunk, no thermal problems were encountered. By measuring the beam profile, we determined the beam to be ~1.1 × diffraction limited.

Laser emission was demonstrated in the range from 1025 nm − 1060 nm with spectral widths of 1.0 to 3.0 nm (FWHM). The observed dependence on the resonator length delivered a clue for an effect influencing the spectral characteristics. We have measured the pump light distribution perpendicular to the resonator in a configuration with a $1/e^2$ spot radius of about 80 µm and the corresponding gain distribution along the resonator axis was calculated including reabsorption, for two specific wavelengths—1030 nm and 1050 nm. The calculation predicts reabsorption in dependence on the wavelength in regions where the pump-power density is lower than required for laser threshold. In this way, the reabsorption formed a spectrally selective aperture in the gain medium. This behavior is illustrated in Fig. 3 at the location of the waist by the wavelength-dependent waist diameter $2w_0$ of the laser mode. As a result, the lasing wavelength can be tuned by changing the mode volume of the laser.

We envisage a more efficient laser system by using an optimized pump configuration (cw and multi-pass) and an adapted thermal management, which is under investigation.

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CThI2 **10:45 am**

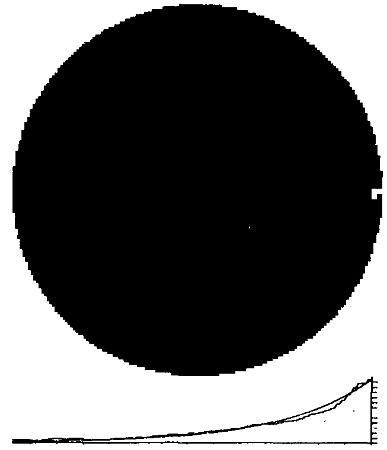
Infrared image studies of diode-pumped Yb^{3+}, Er^{3+}:glass

Ruikun Wu, Scott J. Hamlin, John D. Myers, J. Andrew Hutchinson,* Lawrence T. Marshall,* *Kigre Inc., 100 Marshland Road, Hilton Head Island, South Carolina 29926*

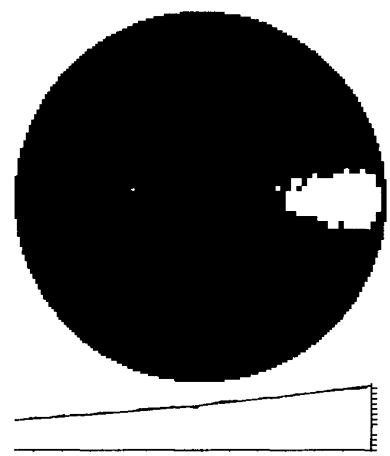
Laser emission at 1535 nm from Er^{3+}:glass laser is very useful due to its eye-safe wavelength and high transmission through fiber optics and the atmosphere. Some applications such as target designation, laser radar, law enforcement, and wind-shear detection require higher repetition rates and higher peak-power output than can normally be obtained from a conventional flashlamp-pumped Er^{3+}:glass laser. Diode pumping allows for considerably greater quantum efficiency, dramatically decreasing the thermal design constraints.

Er^{3+}:glass operates on a three-level lasing scheme when lasing at 1535 nm. In order to achieve reasonable thresholds, it is necessary to minimize the Er^{3+} doping concentration. In addition, because the Er^{3+} absorption cross section is relatively weak, Er^{3+}:glass is normally sensitized with a high concentration of Yb^{3+} ions to better match the wide spectrum of flashlamp pumping.

Recent technological advances in the manufacture of InGaAs laser diode arrays have brought commercial laser diodes, in the wavelength range of 900–1000 nm, to market from several manufacturers. This wavelength range matches the strong Yb^{3+} $^2F_{7/2}$-$^2F_{5/2}$ transition, making it an ideal pumping source for Yb^{3+}, Er^{3+}:glass. In this paper we report the initial results of experimental studies using an infrared image camera to map the Yb^{3+} and Er^{3+} fluorescence in a side-pumped, Er^{3+}:glass laser configuration.



CThI2 Fig. 1 Fluorescence profile at 1000 nm (Yb^{3+}) (Fit: $\alpha = 23$ cm^{-1}).



CThI2 Fig. 2 Fluorescence profile at 1535 nm (Er^{3+}) (Fit: $\alpha = 5$ cm^{-1}).

Two laser diode arrays of 1-cm length have been used in our experiments. The peak wavelength is 947 and 976 nm with a linewidth of about 6 nm at room temperature. Both diode arrays produce about 60 W peak power when driven with a 100 Amp current pulse. The laser material, QE-7N, has an absorption coefficient of about 5 and 20 cm^{-1}, respectively, at the two wavelengths.

The 1-cm diode bar pumps the polished barrel QE-7N $\phi 2 \times 10$ mm rod from side. A Micronviewer model 7290 video camera with a vidicon tube having a photoconductive target plate with spectral response range from 400 to 2200 nm was used to monitor the fluorescence and lasing profiles of the laser rod. Filters were employed to separate the Er^{3+} and Yb^{3+} fluorescence.

Figures 1 and 2 illustrate the fluorescence at about 1000 nm from Yb^{3+} and at 1535 nm from Er^{3+} across the rod, when pumped at 976 nm. The exponential intensity of the Yb^{3+} fluorescence was expected; however, the Er^{3+} fluorescence profile has a considerably different distribution indicating the transfer of energy from Yb^{3+} to Er^{3+} is not a linear process.

The energy transfer process in Yb^{3+}, Er^{3+}:glass is indeed quite complicated. The experimental results suggest there may be a strong spatial cross relaxation allowing the pumping energy to be transferred between many Yb^{3+} ions before being transferring to an Er^{3+} ion. Such a migration process could be exploited to homogenize the gain media. A considerable amount of theoretical and experimental results is presented.

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CThI3 **11:00 am**

Uniform dispersion of rare-earth ions in quartz glass using Zeolite X and its applications for high-power laser

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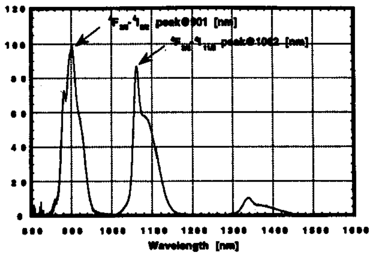
The high thermally resistant material for high average power laser has been required with scalability because the present laser materials do not have enough thermal properties. The quartz glass is a very special material, which has not only a low thermal expansion coefficient indicating high thermal tolerance, but also high transmittance at the ultraviolet region and a low nonlinear refractive index. Naito *et al.* reported the SiO_2 was suitable for ICF laser driver medium.[1]

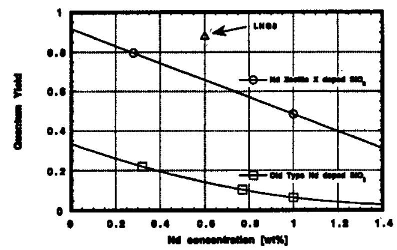
Three methods, conventional melting,[2] plasma torch CVD,[3] and Sol-Gel,[4] have been tried to make neodymium laser medium using SiO_2 glass. But the great success to making the Nd-doped SiO_2 has not been achieved because the high concentration also causes the Nd clustering (Nd_2O_3) in SiO_2 matrix, thus degrading the laser properties.

As is well known, the concentration quenching is caused by the cross relaxation process.[5] Nd-doped SiO_2 causes stronger quenching at lower concentrations than the usual modified glass phase materials, such as silicate or phosphate glass, because of Nd clustering. The clustering in the Nd-doped SiO_2 is certified as Nd_2O_3 hexagonal type crystal whose Nd-Nd distance is 3.7 Å by x-ray powder diffraction method. The critical length of cross relaxation process for the phosphate laser glass was reported as 4.07 Å.[5] So, it is clear that the Nd_2O_3 in SiO_2 is the main reason for fluorescence quenching.

To keep Nd-Nd distance separately, we use the Zeolite X as the doping material, which is powder about 1 μm in size and is composed by Si, Al, Na. Nd^{3+} ions are located in only the D6R site and the Na ions are completely eliminated due to its ion exchange replacement with



CThI3 Fig. 1 The fluorescence spectrum Nd Zeolite X-doped SiO_2 (Nd_2O_3:1.0wt%).



CThI3 Fig. 2 The quantum yield of Nd Zeolite X-doped SiO_2 and other glasses are shown. Nd Zeolite X-doped SiO_2 is more improved than the old type Nd-doped SiO_2.[6]

special treatment. Each center of D6R is separated by 8.8 Å, so that Nd^{3+} ions have been separated enough in the Zeolite X cage.

We fabricated the Nd Zeolite X-doped SiO_2 by the Sol-Gel method with the colloidal silica. The Nd Zeolite X and colloidal silica powder mixture was gelled and dried and then sintered to be optically transparent.

The fluorescence property of Nd Zeolite X-doped SiO_2 (Nd_2O_3:1.0wt%) is shown in Fig. 1. The peak fluorescence wavelength of $^4F_{3/2}$ to $^4I_{11/2}$ transition of Nd^{3+} is at 1062 nm, which is able to work as an amplifier of YAG laser (@1064 nm). Fluorescence lifetime is 403 μs and stimulated emission cross section is calculated as 1.15×10^{-20} cm^2. These values are suitable for high-power laser application. Figure 2 shows the quantum yield of the Nd Zeolite X-doped SiO_2 and other laser glasses that was measured by integrating sphere method. The measured quantum yield of Nd Zeolite-doped SiO_2 at 1.0wt% (Nd_2O_3) reaches up to 50%. Nd Zeolite X-doped SiO_2 is more improved than the old type Nd-doped SiO_2.[6]

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CThI4 **11:15 am**

High-average-power 1.54-μm Er^{3+}:Yb^{3+}-doped phosphate glass laser

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Erbium laser glasses have generated considerable interest because of their capability to emit eye-safe 1.54-μm laser radiation directly.[1,2] The relatively high threshold associated with the three-level laser system of Er^{3+} ion $^4I_{13/2}$-$^4I_{15/2}$ transition and the low thermal-loading capability associated with typical laser glass materials have restricted the average output power of Er^{3+} glass lasers to a few watts. A new chemically strengthened phosphate laser glass, designated QX/Er, has been developed, which exhibits a high thermal-loading capability in combination with superior laser performance. The spectral properties of this new glass and the Q-switched, high-repetition-rate operation were reported.[3,4] This paper describes our achievement of a laser with an average output power of 20 W at 1.54 μm and a slope efficiency of 4% based on our detailed investigation on pump dynamics, thermal behavior, and long-pulse laser performance of this new glass material. To our best knowledge, this is the most powerful and efficient lamp-pumped Er:glass laser to date.

A power supply delivering a variable square pulse was employed to investigate the pump dynamics process. The pulse duration was adjustable from 0.1 to 10 ms. Figure 1 illustrates a typical lamp pump pulse and laser pulse. The reciprocal delay time between pump pulse and laser pulse for a given resonator reflects the energy transfer rate from Yb^{3+} to Er^{3+} ion due to the fact that the heavily doped Yb^{3+} ions in QX/Er glass are capable of hosting more than 300 J energy per cubic centimeter glass. It is noted that the laser pulse may be delayed more than 200 μs after the pump is stopped. The effect of peak pump power on the reciprocal of the lasing delay time for a 3-mm diameter and 80-mm long rod is shown in Fig. 2, which indicates the energy transfer rate increases with peak pump power with a decreasing slope. Experimental results and theoretical analysis show that the energy transfer process from Yb^{3+} to Er^{3+} is slow, although very efficient, and dominates the pumping process. The peak pump power density