cence 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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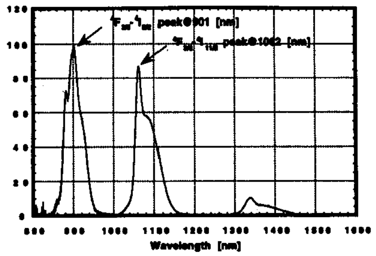
The high thermally resistant material for high average power laser has been required with scalability because the present laser materials do not have enough thermal properties. The quartz glass is a very special material, which has not only a low thermal expansion coefficient indicating high thermal 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]

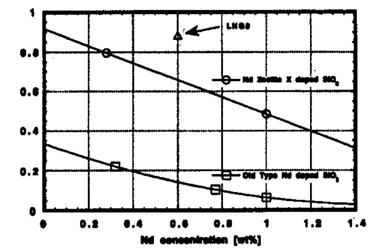
Three methods, conventional melting,[2] plasma torch CVD,[3] and Sol-Gel,[4] have been tried to make neodymium laser medium using SiO_2 glass. But the great success to making the Nd-doped SiO_2 has not been achieved because the high concentration also causes the Nd clustering (Nd_2O_3) in SiO_2 matrix,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



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]

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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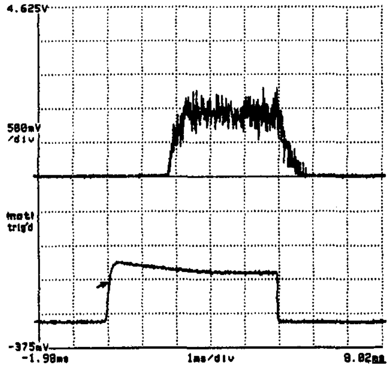
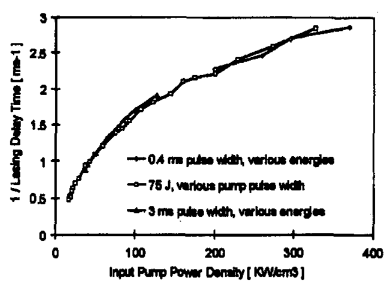
Erbium laser glasses have generated considerable interest because of their capability to emit eye-safe 1.54-μm laser radiation directly.[1,2] The relatively high threshold associated with the three-level laser system of Er^{3+} ion ${}^4I_{13/2}$-${}^4I_{15/2}$ transition and the low thermal-loading 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.

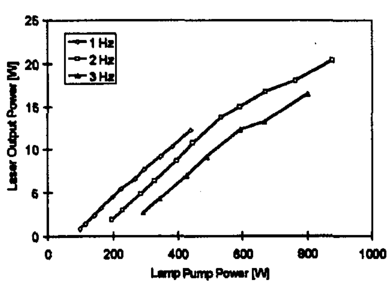
A power supply delivering a variable square pulse was employed to investigate the pump dynamics process. The pulse duration was adjustable from 0.1 to 10 ms. Figure 1 illustrates a typical lamp pump pulse and laser pulse. The reciprocal delay time between pump pulse and laser pulse for a given resonator 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



CThI4 Fig. 1 Lamp pump pulse and laser pulse.



CThI4 Fig. 2 The effect of peak pump power density on the reciprocal of the lasing delay time for a 3 mm × 80 mm rod.



CThI4 Fig. 3 Laser output power vs lamp pump power.

should be maintained below 20 KW/cm^3 in order to use the pump energy efficiently.

Thermal lensing is one of the major factors limiting the high-average-power output for flashlamp-pumped Er^{3+}-doped laser glass rods. A variety of configurations of glass rods were fabricated to test laser threshold, slope efficiency, thermal lensing, and maximum thermal-loading capability. By combining these test results and theoretical calculations, a rod size of 5-mm diameter and 152-mm long was selected as the primary test configuration for high-average-power output. A lamp pump pulse width of 5 ms was selected in order to maintain pump peak power density in the efficient range according to the results of our pumping dynamics investigation. Laser tests were performed in a FEM33M56K chamber pumped with a K982 flashlamp. The thermal lensing influence was suppressed by reducing the resonator length. Figure 3 demonstrates laser output power as a function of pump power at various repetition rates. Twenty Watts of average power at 1.54 μm has been achieved, which is several times greater than current commerically available Er^{3+} glass lasers. The pump power is far below the maximum thermal-loading capability of this new glass material, suggesting higher output powers are obtainable by further optimization of the laser design.

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CThI5 **11:30 am**

Improved lasing lifetime of de-oxygenated xerogels doped with pyrromethene dye

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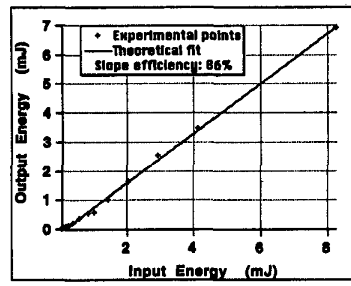
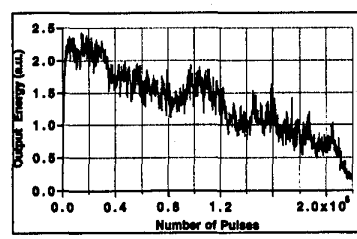
In the search of all-solid-state tunable lasers in the visible, solid-state dye lasers are promising tools. Both polymer and xerogel can be host matrices for organic dyes. A lot of research has been done in order to improve the photostability and thermostability of the organic molecules encaged in the matrix by using new molecules such as pyrromethenes or perylenes. Also, new matrices with less dopants mobility and better thermal conductivity have been recently developed to reduce the degradation of the dyes.

In this communication, we report on new dye-doped xerogel matrices that fulfil the requirements needed for efficient and long lifetime amplifying media. Our samples were prepared using a sol-gel process, from methyltriethoxysilane or vinyltriethoxysilane precursors. The general synthesis of silica-based sols and gels has been previously reported,[1-3] and is based on, and the hydrolysis of silicon alkoxide performed under, acidic conditions with acetone as common solvent.

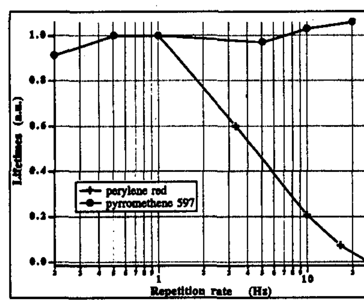
We used these materials as gain media of solid-state dye lasers, and demonstrated efficient laser operation with a stable plano-concave cavity pumped by a nanosecond frequency-doubled Nd:YAG



CThI5 Fig. 1 Conversion efficiency of the laser cavity emitting at 568 nm using a pyrromethene 580 doped sample (MTEOS matrix, concentration = 2×10^{-4} mol/l, thickness = 1 cm).



CThI5 Fig. 2 Output energy function of the number of pulses using an oxygen-free pyrromethene 597 doped sample (MTEOS matrix, concentration = 5.5×10^{-4} mol/l, thickness = 1 cm).



CThI5 Fig. 3 Relative lifetimes versus repetition rate of perylene and pyrromethene xerogel doped samples used as gain media in solid-state lasers (normalized at one for 1 Hz repetition rate).

laser. Best results were obtained with pyrromethene dyes.

Slope efficiencies above 70% and up to 86% were obtained in the ten millijoule output energy range with pyrromethene doped samples (Fig. 1). Perylene-doped samples were only about half as efficient. Tunability was obtained by introducing a prism in the cavity. Several tens of nanometers in several bands, ranging from 550 nm to 650 nm, were obtained with the different dyes. The tuning range values are similar to those obtained in equivalent doped solutions.

Furthermore, in our search for new dye matrix environment favoring the or-