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High Repetition Rate Q-switched Erbium Glass Lasers

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ABSTRACT

Many applications exist for eye safe lasers operating at high repetition rates. This paper will discuss the operation of Q-switched Er:glass lasers at high repetition rates with peak powers in the megawatt range.

1. INTRODUCTION

Laser emission from the $4_{I13/2}$-$4_{I15/2}$ transition of Er^{3+} doped glass was noted as early as 1965[1], however, until recently there were few commercially available Er:glass lasers and virtually no Q-switched Er:glass lasers. During the last several years, a number of manufacturers have offered eye-safe hand-held rangefinders that utilize Er:glass Q-switched lasers.[2,3]

As the major producer of Er doped laser glass, Kigre has devoted a large portion of its internally funded research and development effort towards the study of Er:glass, Er:glass lasers, and Er:glass Q-switching technology. This paper will highlight some of the technology that evolved during the study of high repetition rate electro-optically Q-switched Er:glass lasers at Kigre.

2. YB, ER AND CR, YB, ER DOPED PHOSPHATE GLASSES

Figures 1 and 2 illustrate the absorption spectra of QE-7 Yb,Er:phosphate laser glass and QE-7S Cr,Yb,Er:phosphate laser glass. In both plots, QE-7S has the higher absorption. From Figure 1, it is evident that QE-7 absorbs very little throughout the visible portion of the spectrum (400 - 900 nm). The only strong absorption in QE-7 is between 900 nm and 1 µm, due mainly to the 2F7/2 - 2F5/2 transition of Yb^{3+} (Figure 3). Unfortunately, the absorption of Yb^{3+} does not match the emission of either Krypton or Xenon gas discharges very well, making flashlamp pumping quite inefficient[4]. From experimental measurements, it is estimated that only about 2 percent of the capacitor bank energy will result in useful pump-energy for QE-7 when using a 1200 torr Xe flashlamp with a 3 mm bore and 45 mm arc length when pumped with a 15 Joule pulse for 1.5 ms.

Yb, Er:phosphate glass lasers are three level lasers when lasing at 1.535 µm**,** therefore, it is necessary that the population of the $4I_{13/2}$ metastable energy level exceed the population of the $4I_{15/2}$ ground state energy level. In order to calculate the zero loss condition (at the lasing wavelength) for a particular Er^{3+}

doping level, several assumptions may be made. Since the decay rates for the upper levels of Er^{3+} (4I 11/2 and higher) are several orders of magnitude shorter than the decay rate of the $4I_{13/2}$ metastable energy level[5], it is a reasonable assumption that all of the Er^{3+} ions are in either the $4I_{13/2}$ metastable or the $4I_{15/2}$ ground energy levels. The zero loss condition will be achieved when the metastable and ground state energy populations are equal, assuming there are no other losses in the glass. In QE-7 and QE-7S glasses this will occur when the population density of the metastable energy level is equal to half of the total Er^{3+} ion concentration (6.0×10^{18} ions/cm^3). In a -common size Er:glass rod of 3 mm diameter by 50 mm length, the energy required to reach the zero loss condition is about 275 mJ.

In order to increase the flashlamp pumping efficiency, Kigre developed QE-7S Cr,Yb,Er:phosphate laser glass[6]. QE-7S is similar to QE-7, except that QE-7S contains Cr^{3+} as a sensitizer. Cr^{3+} absorbs flashlamp radiation in two broad bands centered at 450 and 640 nm, emitting in a broad band centered at 760 nm. This allows energy to be transferred from Cr^{3+} to the $4I_{9/2}$ and $4I_{1/2}$ states of Er^{3+} and the $2F_{5/2}$ state of Yb^{3+}. This energy transfer makes QE-7S substantially more efficient for flashlamp pumping.

In addition to Nobel gas discharge pumping of Er:glass, several methods of laser excitation have been studied. Many authors have reported using Nd^{3+} doped lasers as optical pumps for Er:glass [5,7-8]. Anthon recently reported using a laser diode pumped ND:YAG laser to pump a CW Er:glass laser[9]. Hutchinson also recently reported direct diode laser pumping of Er:glass [10]. Hutchinson used-a GaAs/AlGaAs graded index, separate confinement heterostructure device to pump his Er:glass laser.

3. Q-SWITCHING OF ER:GLASS

Although the cross section of Er:phosphate glasses are considerably higher than Er:silicate glasses, they are still quite low in comparison to Nd:glasses. QE-7 has a cross section of about 8×10^{-21} cm^2. Although Er:glass has a low cross section, a three level lasing system, and difficulties in optical pumping, many researchers have been able to Q-switch Er:glasslasers.

The first Q-switched Er:glass lasers utilized mechanical devices such as rotating mirrors or porro prisms to change the Q of the resonator cavity. Currently, rotating prisms are still the most popular method of Q-switching an Er:glass laser. The MELIOS transmitter, which is the largest production quantity Er:glass laser, also utilizes a rotating prism as a Q-switch [ll]. NEC recently introduced a hand-held, eyesafe laser range finder that utilizes a frustrated total internal reflection (FTIR) device to modulate the cavities Q[3].

Kigre has been experimenting with electro-optical Q-switching of Er:glass lasers. Two basic resonator designs are used depending Upon the repetition rate of the laser. If the repetition rate is low, a LiNbO3 Pockels cell with a transverse field is used. The LiNbO3 crystal is cut with Brewster faces, so that it also functions as a polarizer with an extinction ratio of approximately 10, which is sufficient due to the low gain of the Er:glass.

When operating glass lasers at repetition rates of more than one pulse per second, thermal induced birefringence becomes evident. In order to lase with a glass laser at higher repetition rates, a polarization insensitive Q-switch mlist be used. Researchers at Kigre have developed a proprietary electro-optic polarization insensitive Q-switch for high repetition rate lasers. This Qswitch will be presented at a future electro-optic conference.

4. KIGRE'S XE SERIES OF Q-SWITCHED ER:GLASS LASERS

Kigre has developed and markets several laser systems, operating at 1.535 µm, that utilize QE-7S Cr,Yb,Er:phosphate glass. The XE-100 laser utilizes the Brewster Q-switch described in Section 3. It is air cooled and capable of operating at ten pulses per minute, with about 15 mJ of output in a 40 ns pulse. The XE-100 laser rod is 3 mm diameter by 30 mm long.

The XE-200 and XE-300 laser systems utilize the polarization insensitive Q-switch, and operate up to two and four pulses per second respectively. Both systems actively cool the laser rod and flashlamp with liquid coolant. The pulse energy of both systems are about 15 mJ in less than a 50 ns pulse. Several XE-200 laser systems are currently being used in atmospheric studies and a XE-300 system is in use as an experimental Lidar transmitter.

5. CURRENT AND PLANNED WORK

Currently, Kigre is designing the next XE series laser system, which will be designated XE-400. In this unit, it is planned to use a simmered flashlamp and Kigre's newly developed variable pulse width flashlamp driver. This flashlamp driver delivers square wave pulses, continuously adjustable from 100 µs to 10 ms, allowing the flashlamps color temperature to be decreased for more efficient pumping. The XE-400 system's goal is. five pulses per second with over a half megawatt of peak power.

The current limitation in peak power from Q-switched Er:glass lasers is the damage threshold of the $LiNbO_3$ Q-switch, the polarizer, and the antireflection coatings on the Q-switch and the polarizer. Researchers at Kigre plan to use the XE-400 as a test bed for testing more damage resistant optics, coatings, and resonator designs.

In addition to these resonators, Q-switches, and power supply developments, researchers at Kigre have been experimenting with the Er:glass itself. The first run of clad QE-7S laser rods was recently completed and is currently receiving promising results from tests in a XE-100 laser system. The cladding and core dimensions are chosen such that a tangential ray incident upon the outer diameter of the cladding will be refracted into a tangential ray incident upon the diameter of the core. This cladding makes the core appear larger in diameter, thus increasing the pump chamber's coupling efficiency.

New Er:glass composition experiments are also being conducted at Kigre in which both the base composition and the dopants are being varied. One of the main motives in these experiments is the development of Er:glasses optimized for laser and diode laser pumping.

6. CONCLUSION

Recently, there has been a high demand for Er:glass and Er:glass laser systems operating at the eyesafe wavelength of 1.535 µm for the purposes of lidar, traffic enforcement, helicopter wire avoidance, wind shear measurements, communications, and other areas where human contact with the laser radiation is possible. Sales of QE-7N and QE-7S Er:glasses are now at an all time high, and it is believed that as the technology of Er:glass lasers become more mature, the demand will increase further.

7. ACKNOWLEDGMENTS

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FIGURE 1

ABSORPTION SPECTRA OF QE-7 AND QE-7S

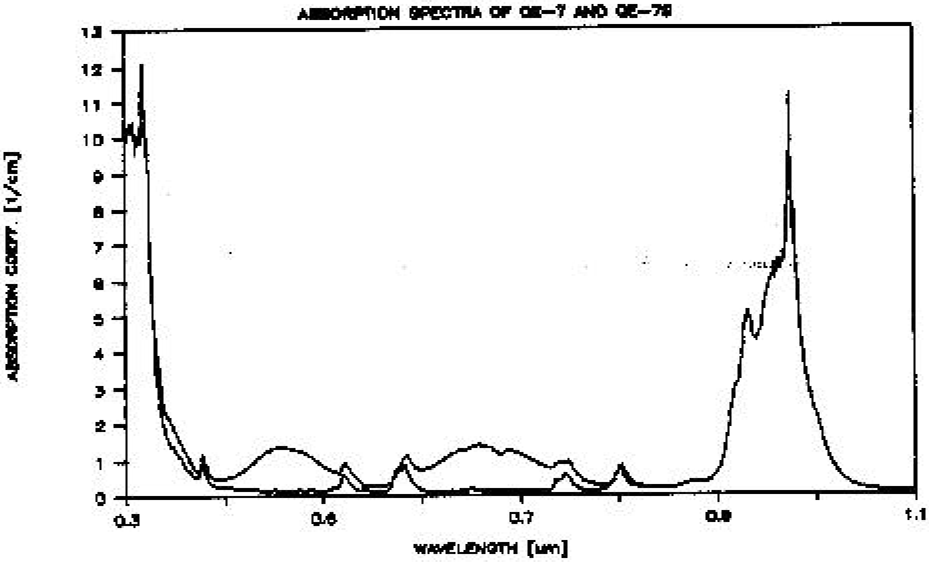

FIGURE 2

ABSORPTION SPECTRA OF QE-7 AND QE-7S

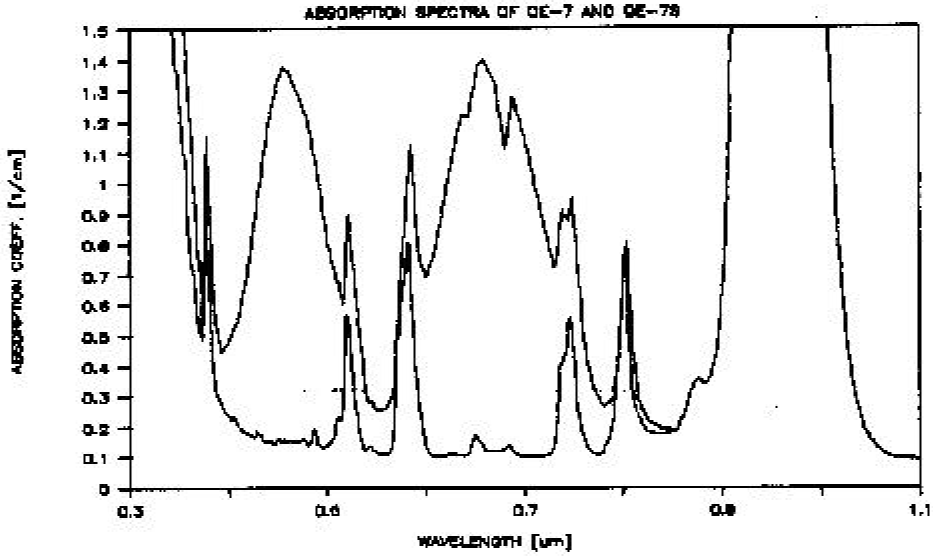

FIGURE 3

Yb^{3+},Er^{3+}:Phosphate Glass System