

**Eye-Safe Erbium Glass Laser Transmitter Study
Q-Switched with Cobalt Spinel**

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ABSTRACT

This paper examines several characteristics and phenomenon associated with the optimization of diode pumped erbium ytterbium glass microlasers. Test results indicate that within an erbium ytterbium glass gain element, the excited erbium (laser) ion effective pump depth is larger than the excited ytterbium (sensitizer) ion effective pump depth. Designed specifically for diode pumping, JD phosphate laser glass host material exhibits high rare earth and sensitizer ion solubility. This enhanced doping capability allows the JD glass to be used in a variety of diode pump architectures that are not possible with most conventional crystal & glass laser materials. Our study has shown that new small gain element composite laser glass architectures & designs may be made used to more efficiently capture, contain and uniformly distribute the diode laser pump light. We expect this work to will lead to the next generation of high peak & average power "eye-safe" diode pumped microlasers for use in rangefinding, imaging, illumination tracking and targeting applications.

1. INTRODUCTION

Improvements in near-infrared detector technology has resulted in increased sensitivity and reduced laser power requirements for laser rangefinder transmitters. Present technology allows for reliable laser rangefinding measurements to be made on targets at great distances (limits of visibility) with only a few milli-Joules of Q-switched energy. Diode pumped solid-state laser technology provides for smaller, lighter and more efficient transmitters. They have become the preferred choice in new and upgraded laser systems. In this paper we report on progress in the development of new Q-switched diode pumped erbium glass transmitters operating at 1.54um. This "eye-safe" Class I laser is designed to produce output energies in the 2mj range which is suitable for the many rangefinder applications.

Our work includes the manufacture and testing of a new high gain rare-earth doped phosphate glass material designated JD glass. JD laser glass is readily optimized for diode pumped architectures due to its high solubility for a wide range of various rare-earth co-dopants and sensitizers. This enhanced doping capability allows the JD glass to be used in a variety of diode pump architectures that are not possible with most conventional crystal & glass laser materials. Using the JD glass we have optimized diode

pumped capture and containment in a number of novel DC (Double Clad) LMA (large Mode Area) fibers, micro-rods and micro-chip devices. For laser rangefinding we have developed new diode pumped JD microchip laser devices with improved Q-switched energy storage and extraction from a small (sub-millimeter) beam waist and short gain lengths.

2. BASIC CONSIDERATIONS

Current technology for the diode pumping of solid-state laser materials employs numerous architectures and designs as is evidenced in the literature [1,2,3]. These various pumping schemes may be grouped into two basic categories, longitudinal or transverse pump coupling. In longitudinal pumping (or end pumping) the diode pump is launched and propagated along the laser element gain length axis. In transverse pumping (or side pumping) the pump is launched and propagated at right angles to the laser element gain length axis. The objective is to effectively capture and contain the pump light inside of the laser gain medium and produce a uniform distribution of excited laser ions. Using conventional optics, it is often easier to use transverse pumping to create a uniform pump distribution throughout the gain element. Transverse pumping of relatively short gain length elements appears easier in theory as the resonator and pump cavity optics are placed in separate beam paths. However, side-pumping presents its own unique difficulties in the absorption and uniform distribution of pump energy. It is difficult to absorb significant pump energy when the absorption length is of the order of one millimeter, which is the diameter of the typical gain element.

In this work we employ a laser gain medium of co-doped erbium and ytterbium phosphate glass. The doping levels of erbium and ytterbium are designed separately to best conform to our desired pump absorption depth and gain length energy storage conditions. In these co-doped glasses the ytterbium concentration is optimized for effective absorption of pump light. The absorbed pump energy is then transferred to the erbium ions with a transfer rate of $\sim 500\mu\text{s}$ and efficiency of up to 95% [4]. For end pumping the effective pump depth is dictated by the ytterbium concentration. For example: for a glass containing 16.5% (wt) ytterbium oxide concentration, the absorption coefficient (α) is about 5/cm at 940nm.

We performed a series of experiments designed to measure the effective absorption depth by observing the fluorescence distribution along the pumping axis of the laser glass element. The fluorescence emission intensity is a good indicator of the laser & sensitizers ion upper level population. The fluorescence emission depth is a good representation of the pumping intensity distribution. In one set of fluorescence experiments, we measured the effective absorption on various samples with different erbium and ytterbium concentrations. The fluorescence emission was created by pumping the Er:Yb:glass samples with $\sim 50\text{mJ}$, at 940nm with a diode pump pulse width of 6ms duration. IR camera f-number values are used for emission intensity calibration.

Pictures of the IR emission data are shown in figure 1. A summary of the data is shown in Figures 2 and 3.

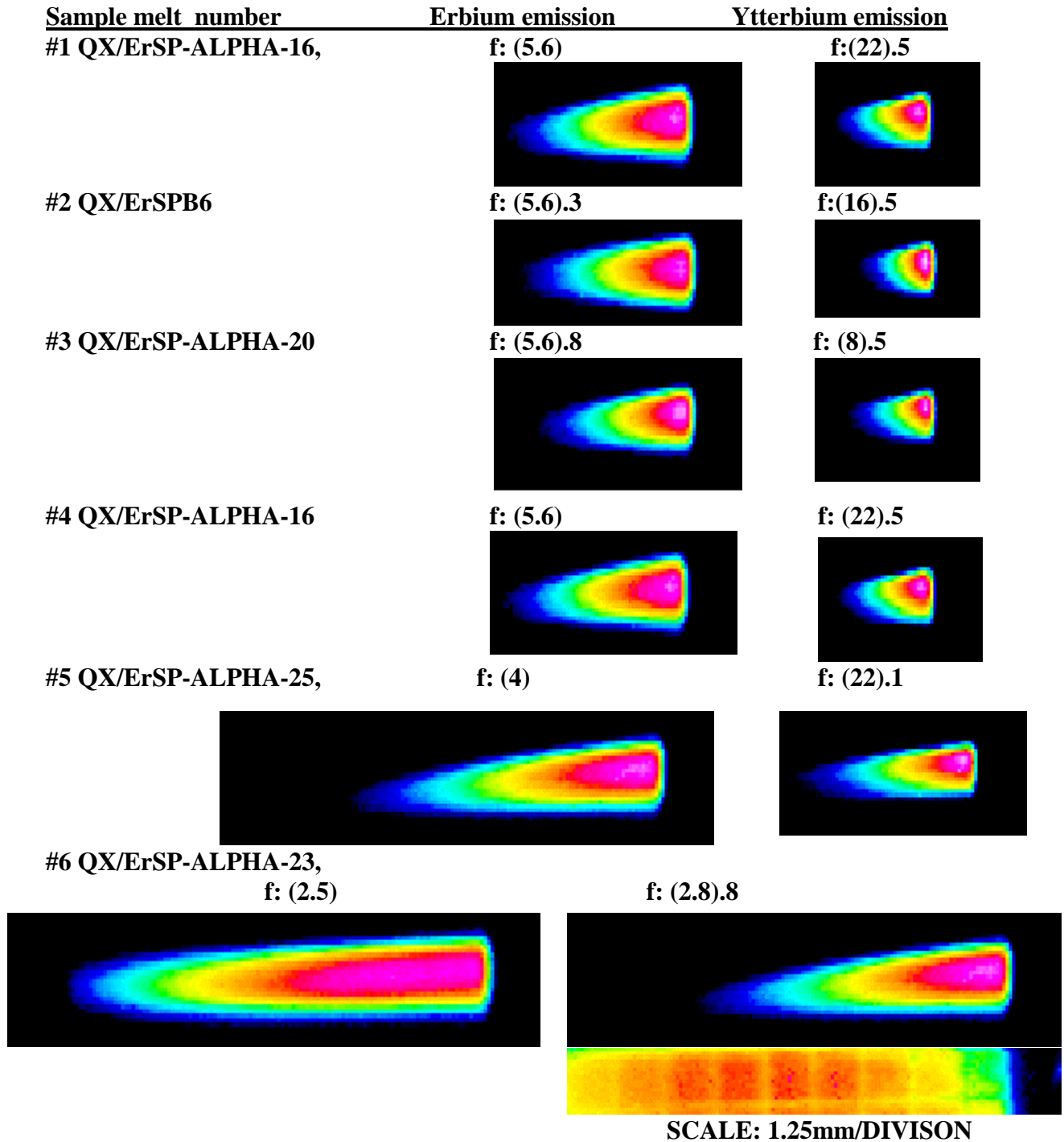


Fig. 1 Er:Yb:glass absorption depth fluorescence measurement data

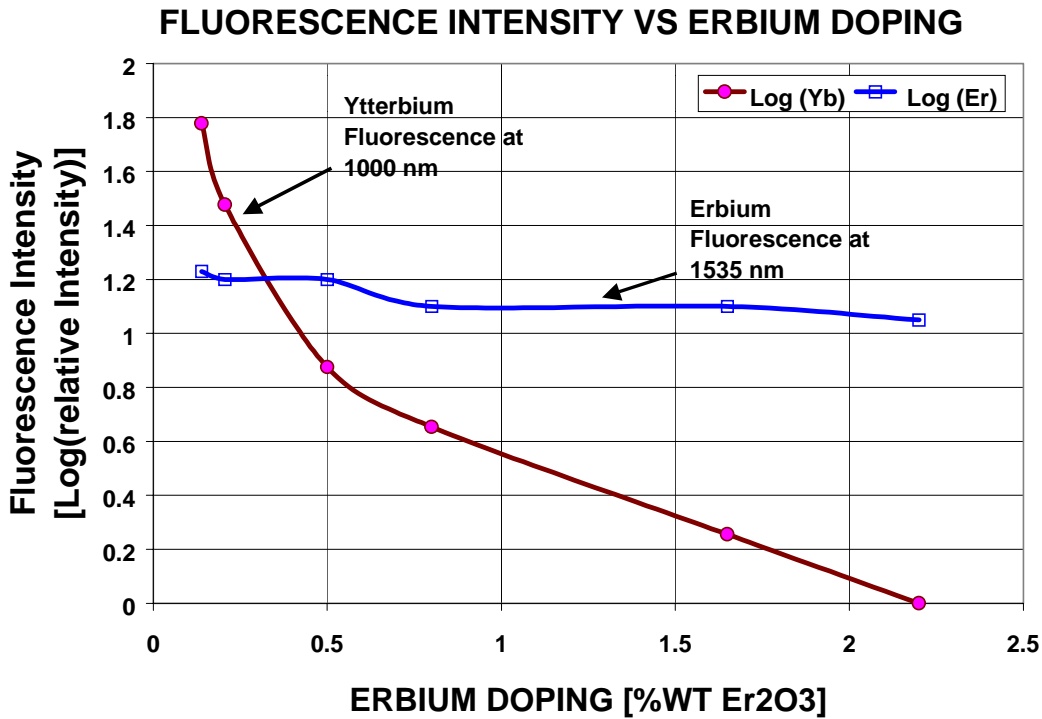


Fig. 2 Fluorescence Intensity vs Erbium Doping Concentration

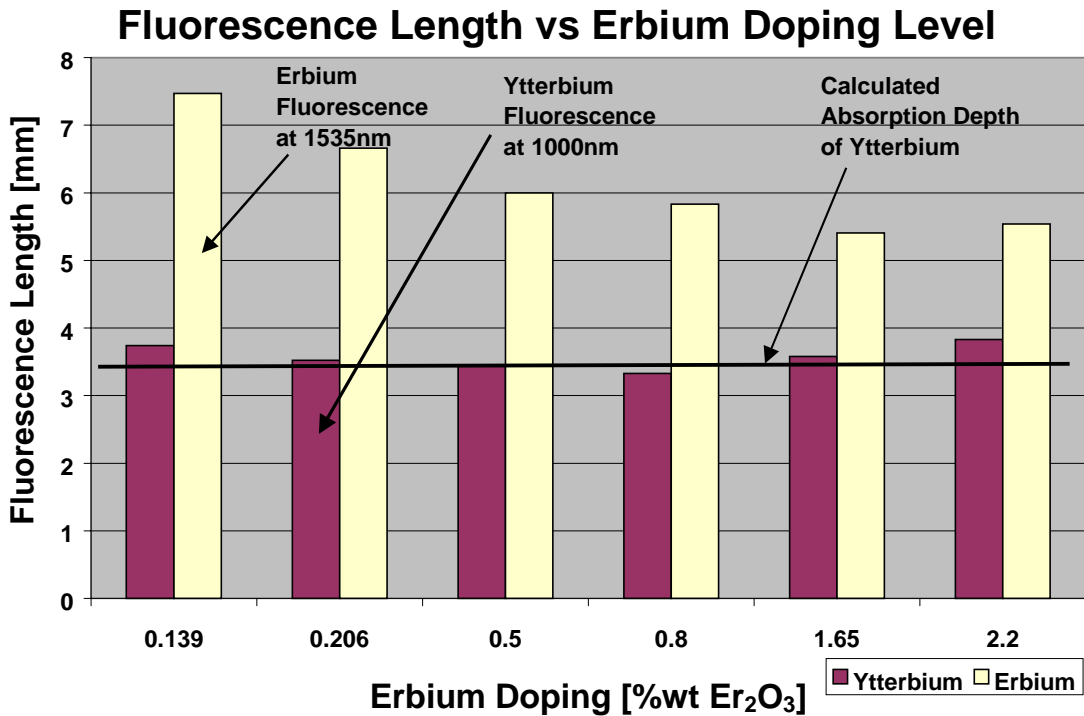


Fig. 3 Fluorescence Depth vs. Erbium Doping Concentration

The 940nm pump beam is provided from a Jenoptik 50W, 600um dia. fiber coupled diode array. The pump is collimated and then introduced into the glass sample. The fluorescence distribution is imaged into an Electro-Physics infrared camera and recorded with a Sensor-Physics frame grabber software. A filter is used to segregate the erbium and ytterbium fluorescence emission. For each sample we select a proper aperture to insure the maximum intensity level just under saturation. The f-numbers are recorded with each picture taken. The f-number provides us with the relative intensity of the fluorescence. Figure 2 & 3 summarize the fluorescence data. The samples contain approximately the same ytterbium concentration (>16% wt.) and different erbium concentrations (up to 2.2% wt.). According to figure 2, the intensity of the ytterbium fluorescence decreases with increased erbium concentration. This effect is attributed to the change in energy transfer time from the ytterbium to erbium as a function of erbium ion density. As a result of this change, the efficiency of the energy transfer process is improved. The erbium fluorescence intensity, however, appears to be constant, regardless of the erbium concentration.

In figure 3, the depth of the ytterbium fluorescence appears to be independent of the erbium concentration, and corresponds well with the calculated absorption depth. However, the depth of the erbium fluorescence extends well beyond the calculated absorption depth of the ytterbium, and decreases with increasing erbium concentration.

From these experiments, we conclude the following:

1. The pump penetration is a function of the ytterbium absorption coefficient.
2. The energy transfer from ytterbium to erbium significantly extends the effective pump penetration.
3. The energy transfer from the ytterbium to the erbium remains efficient over a significant range of erbium concentrations.

3. NEW LASER GLASS FOR DIODE PUMPING

Kigre recently developed a new family of laser glass material designated JD glass. JD glass was developed specifically for diode pumping applications. The glass's properties include a very high solubility for a wide range of various rare-earth co-dopants and sensitizers. This enhanced doping capability allows JD glass to be used in a variety of diode pump architectures that are not possible with conventional crystal & glass laser materials.

One design guideline use in these studies involves the calculated pump energy distribution in the laser material. We assume that the $\alpha_{yb} * L = 2$ (α_{yb} —absorption coefficient in cm⁻¹, L—length of laser material). This means that the laser rod absorbed 86.5% of pump energy in single pass. Absorbed pump energy data is plotted in figure 4.

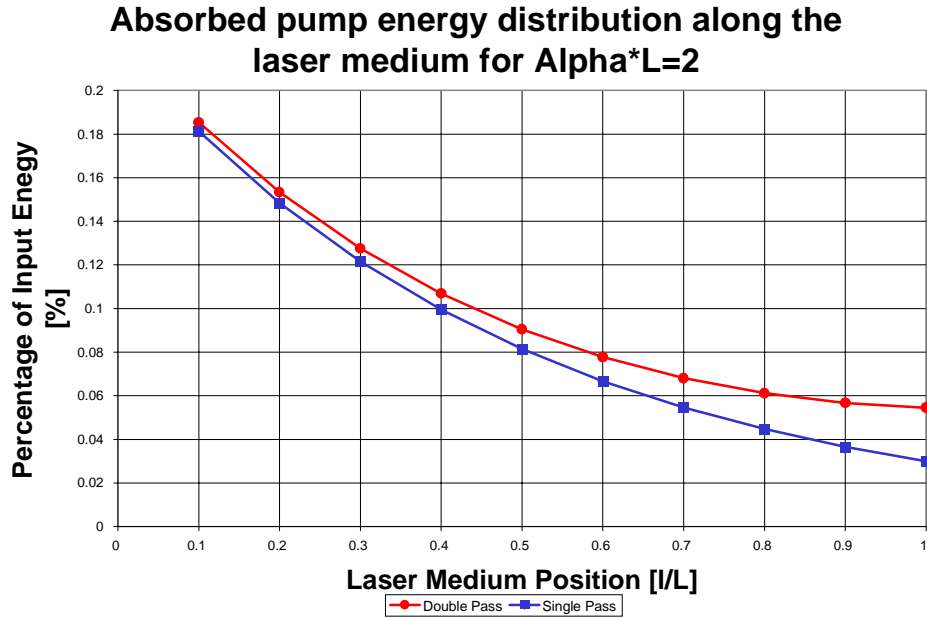


Fig. 4 Single pass absorbed energy in gain element

4. LASER DEVICE

This particular test bed uses a Thales 20 watt CW 940nm diode pump delivered through a 400 μm diameter fiber. The pump laser output is modulated with a 3ms pulse width at various pump pulse repetition rates. We evaluated a number of different diode pump array optical coupling methods including single and multiple staged lens imaging systems, tapered fibers, fiber bundles and lens ducts. Parameters such as the pump fiber numerical aperture, pump beam diameter and pump power density were modified and evaluated in terms of the resulting resonator beam waist, energy distribution profile, peak power and mode quality. Laser glass samples were also evaluated for their performance under high thermal loading conditions.

As shown in figure 5, fast and relatively easy initial end pumped power absorption test is performed on candidate QX/Er & JD laser glass materials. Two standard resonator mirrors with conventional coatings are typically employed. One mirror used for the pump input window and exhibits $\sim 97\%$ transmission in the 900nm to 1000nm range and also used as a resonator high reflector with $R \sim 99.95\%$ for the 1550nm to 1650nm range. The second mirror is used at output side of laser medium with $\sim 97\%$ transmission in the 1500nm to 1650nm range and with $\sim 99.5\%$ reflectivity at the pump wavelength. This second mirror reflects the un-absorbed pump energy back into the rod or disk for a second pass. The QX or JD glass micro-disk or micro-rod test sample is sandwiched between those two mirrors. The output coupler is placed in front of the

sandwiched optics. In figure 6 we show the influence of various laser resonator output couplers on a QX/Er micro-disk sample.

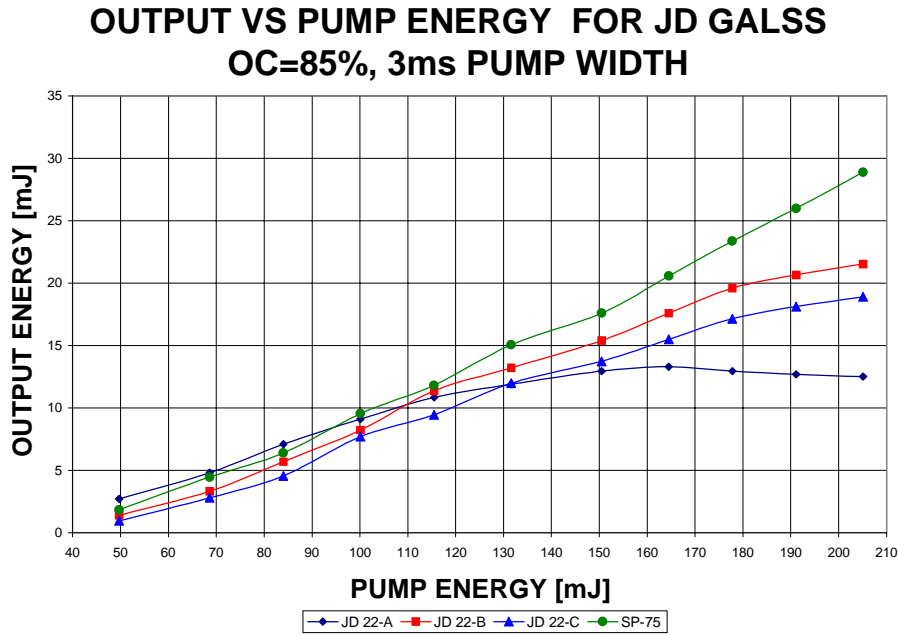


Fig. 5 JD glass micro-disk laser performance comparison

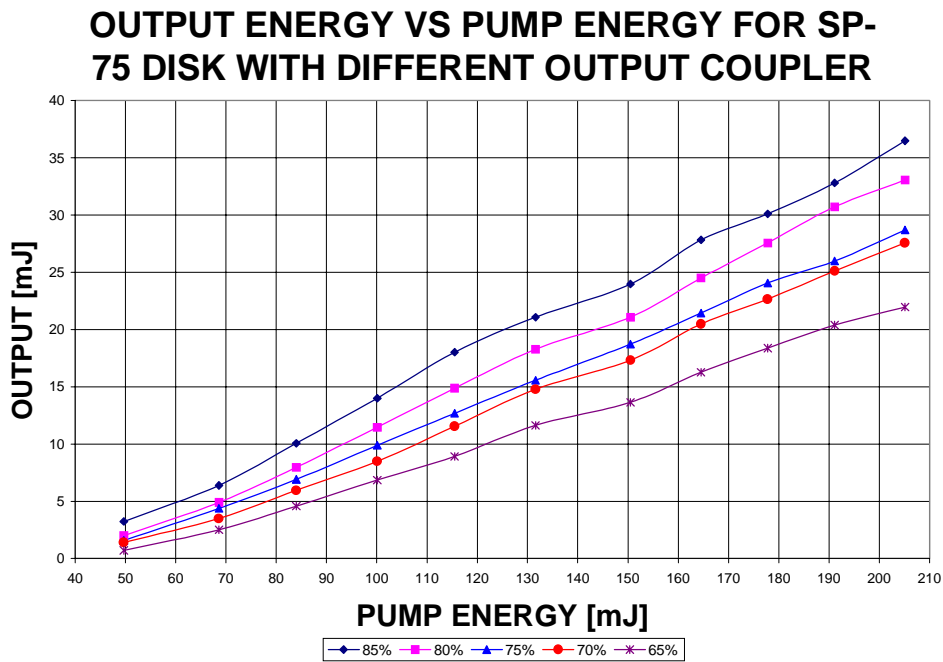


Fig. 6 Influence of output couplers on a QX/Er micro-disk sample

Laser glass samples were tested at various pump power levels by increasing the pulse repetition rates and evaluating the thermal lensing and laser output beam mode characteristics. Figure 7 shows this data.

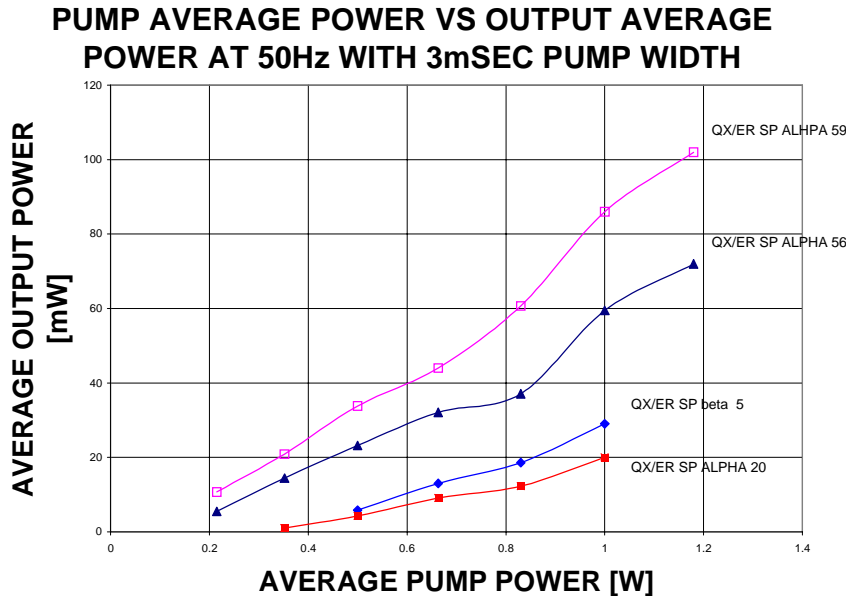


Fig. 7 Influence of average pump power on laser glass samples

Cobalt Spinel ($\text{Co}^{2+}:\text{MgAl}_2\text{O}_4$) appears to be the favorite passive Q-switch material for use with erbium glass lasers operating at 1.54 μm [6,7]. Commercial Cobalt Spinel samples purchased from Northrop Grumman and Saint-Gobain. These samples were tested for Q-switching performance in a Kigre laboratory resonator. The effective internal transmission of the Q-switch samples could be modified by using different combinations of pump numerical aperture, pump beam diameter and pump power density. In our testing, internal transmissions of 80% to 90% T readily produced Q-switched laser output energies of ~1.5 mJ TEM₀₀ mode.

5. CONCLUSION

The test data indicates that further improvements are readily possible with additional optimization work. Smaller gain element designs may be manufactured with new composite glass architectures to more efficiently capture, contain and uniformly distribute the diode laser pump light. Further optimization of the erbium and ytterbium doping concentration and additional improvements in the pump beam coupling are expected to result in higher power and higher efficiency diode pump 1.54 μm laser transmitters.

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