

# Diode Pumped Miniature Eye-Safe Laser Q-Switched by $U^{2+}$ : $CaF_2$ and $Co^{2+}$ : $MgAl_2O_4$

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Ruikun Wu, J.D. Myers, M.J. Myers, Christopher R. Hardy  
Kigre, Inc. 100 Marshland Road, Hilton Head Island, SC 29926  
E-mail: [kigreinc@cs.com](mailto:kigreinc@cs.com) Web Site: <http://www.kigre.com>

## ABSTRACT

We established a new diode array pumped Er:Yb:Glass test setup for evaluation of the laser performance and q-switch characteristics of various saturable absorber materials at 1.54 $\mu$ m. Pumping distribution and maximum gain was analyzed. Passive q-switched laser operation was demonstrated with both  $U^{2+}$ :  $CaF_2$  and  $Co^{2+}$ :  $MgAl_2O_4$ . TEM<sub>00</sub> Q-switch pulses with energy of 0.5mJ and pulse width of 10ns was obtained.

## INTRODUCTION

Eye safe output at 1.54 micron is very important laser source for various applications such as robot vision, rangefinder and laser radar in civil and military usage. For most such applications, laser performance of several tens of micro-joules to a few mille-joules pulse energy with nanosecond or even sub-nanosecond pulsewidth values are required. A new "butterfly" test-bed was established for these studies.

## BASIC CONSIDERATIONS

The semiconductor industry has developed many new and improved laser diodes for use in pumping solid-state laser materials. The 1-cm lone diode bar "array" has become an industry standard and basic element for pumping laser elements. A side pump dual diode bar test-bed has been established at Kigre for evaluation of the laser performance and q-switch characteristics of various saturable absorber materials at 1.54 $\mu$ m.

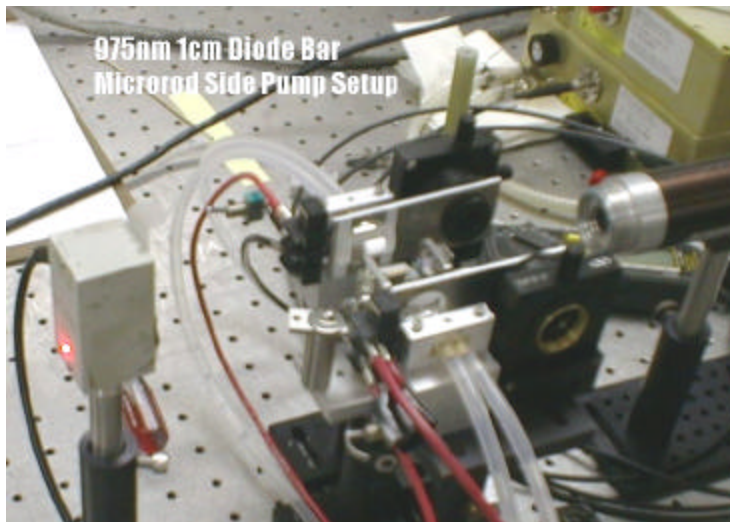


Fig. 1.

A picture of Kigre's miniature diode pumped  $\text{Er}^{3+}:\text{Yb}^{3+}$ :Glass (erbium glass) laser test-bed is shown in figure 1. This set up consist of two 15 watt, 975 nm, 1 cm long diode array bars used to “butterfly” side pump a ~500um to 3mm diameter x 12mm long laser micro-rod  $\text{Er}:\text{Yb}:\text{Glass}$  elements. The pump array's focused output beam is readily adjusted from a few hundred microns to a few millimeters in width. This focus adjustment allows us to effectively overlap the laser element's active area.

The butterfly side pumping setup has many advantages. There is enough pump power density and subsequent gain to support passive Q-Switching operations. The configuration is scalable in pump power from a single or double bar device to a stacked multiple-bar device with output powers reaching up to 500W for each 1cm length. The pumping wavelength is readily changeable through the selection of different standard diode bars available on the market (for example, 915nm, 940nm, 975nm, and 980nm)

One advantage for pumping Kigre's  $\text{Er}:\text{Yb}:\text{Glass}$  is that the glass doping concentration may be made very high without adverse affects of fluorescence lifetime quenching. The measured fluorescence lifetime of erbium remains above 8msec, even with up to 7% (wt.%)  $\text{Er}_2\text{O}_3$  concentration. Pumping with the butterfly configuration produces enough gain to reach the high upper state inversion requirements required for passive Q-Switching high erbium doped laser glass.

Figure 2 and 3 show the gain vs. doping for different gain lengths and doping levels. In these calculations it is assumed we are working with a three level operation and 100% inversion. For a passive Q-Switched laser the maximum gain requirement is about 3-dB gain in single pass. Figure 2 indicates that 1-cm erbium glass length will produce a maximum of 3-dB gain with 1%wt  $\text{Er}_2\text{O}_3$ .

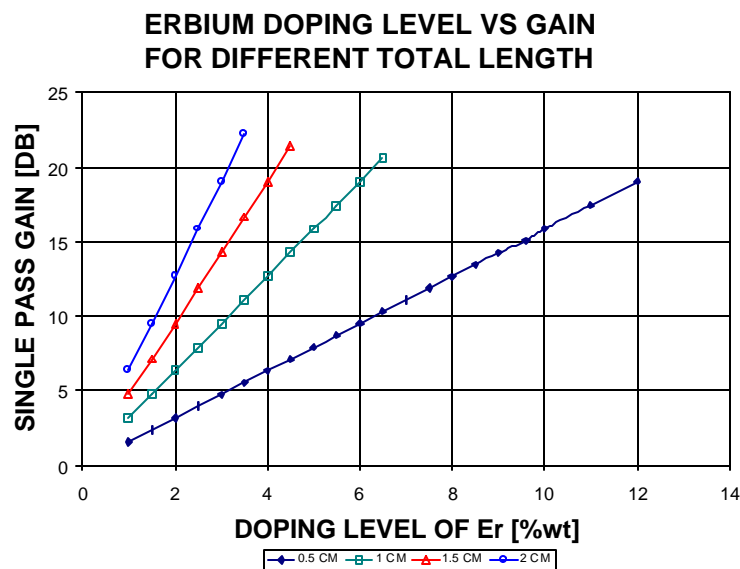


Fig. 2.

Figure 2 also shows that we may use 1cm gain length to reach 20 dB gain for communication applications. An Ultra-short EDFA or EDWA is possible in phosphate glasses with high erbium concentrations.

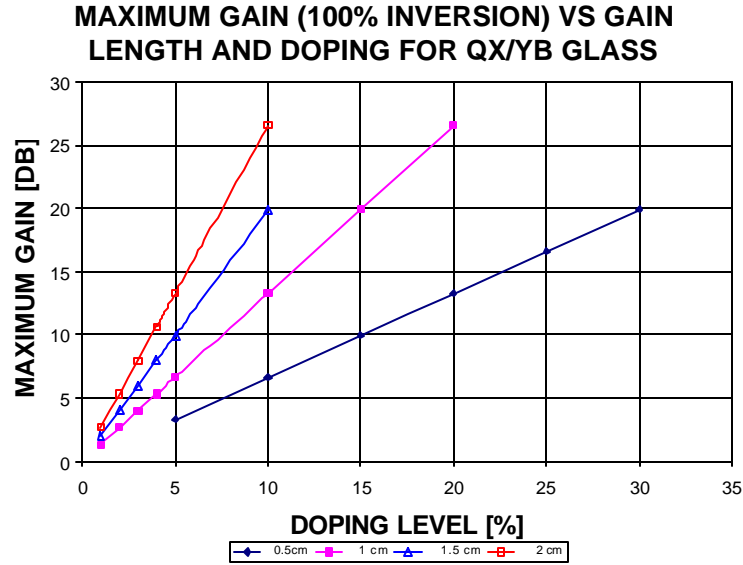


Fig. 3.

The distribution of absorbed pumping power in different positions within the gain medium was also analyzed. The results were shown in figure 4. The cross section of gain medium is divided into 40 vertical plane sections or layers. These layers run parallel to the side pumping input faces and extend from the pump faces into the center of the square shaped Er:Yb:Glass element. Each data point shows the percent of pump power absorbed in a given cross sectional layer. The absorbed pump power is not uniform in the square shaped gain medium because of the exponential nature of absorption. More uniformly absorbed pump power may be realized, however, the price we pay is lower absorption. The curve of total absorbed 92% in figure 4 corresponds to 975nm pumping and an absorption coefficient of 15/cm. While the curve shown in figure 5 is for 940nm pumping and  $\alpha = 6/cm$ .

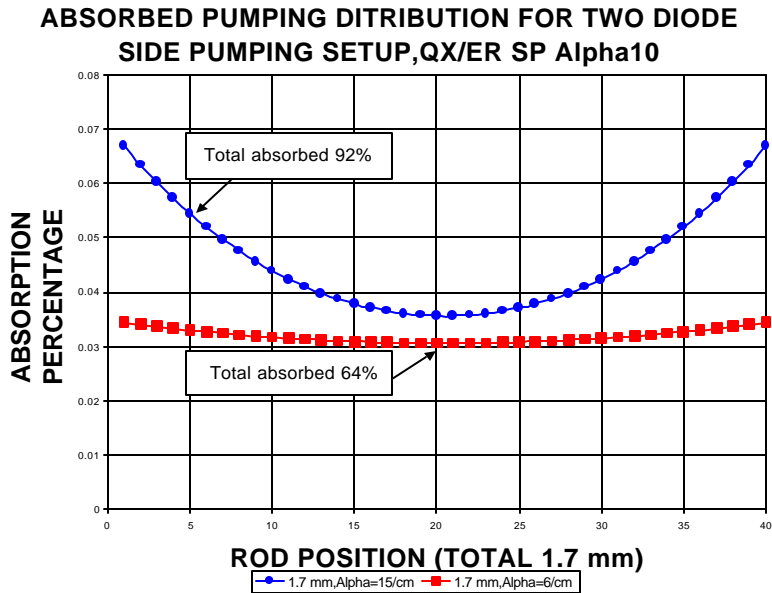


Fig. 4.

A great advantage for miniature laser structures is that the pump volume may be controlled within a small area and readily matched to the mode volume of laser beam. The design of the butterfly erbium glass laser test bed allows for improved coupling efficiencies by reducing the erbium glass pump volume, increasing the pump power density, and providing a better optimized mode match overlap. The laser micro-rod may be a normal bulk erbium glass rod, ribbon, block, or clad glass rod/fiber architecture. For the glass fiber the core diameters may range from ~100 micron to 1 mm with undoped glass cladding diameters of 1-3mm. Large diameter fiber micro-rods are manufactured as a bi-product of Kigre's fiber optic preform processing.

A typical micro-square rod (sqrod) or ribbon fiber preform size rod is 1mm X 1.5mm X 10mm. Long. Although the sqrod size is small, the total stored Erbium ion energy level is ~ 0.12 joules only for 1% (wt%)  $\text{Er}_2\text{O}_3$  concentration. This exemplifies the potential for the diode pumped Er:Yb:Glass sqrod laser to produce high output energies.

In one experiment, two 1cm bars each with 15 w cw output at 975 nm were used to side pump the Erbium glass rod. The maximum pump energy is about 105mj with an 8 msec pump pulse width for each diode. With higher doping concentration erbium glass, such as 1%  $\text{Er}_2\text{O}_3$  or 2% (wt%)  $\text{Er}_2\text{O}_3$ , we are required to focus the pump beam to a 0.3mm X 10mm region in order to reach the threshold.

For pumping erbium glass elements with higher doping concentrations or larger volumes, diode arrays capable of higher pump energies are required. Commercial diodes are now available with stacks of 10 1cm arrays that produce output powers of 500 Watts. For example, in reference [1] two stacked diode bars were used in a butterfly configuration with a total peak pump power of 1.2KW. Another method that may be used to supply high pump power densities for side pumping is the use of multiple fiber pigtailed diodes. The typical output is 1 watt from 100-micron fiber. The total pump power may reach 80 w if 80 X 100 $\mu$  fibers are arranged into a 1 cm line. The pigtailed diode pump source has the potential to produce better coupling and high pump power densities. It will be used in place of the conventional 1 cm diode arrays in future experiments.

## EXPERIMENTAL RESULTS

Experiments were performed on a 10mm long bulk erbium glass "sqrod" sample with a 1.5 x 1.5mm cross-section. The pump beam from each 1 cm diode array was collimated by a 300 micron fiber lens and then focused down by a cylindrical lens of 20mm focal length to a 300 micron wide stripe inside the erbium glass sqrod. The two 1 cm diode bars were used to pump the sqrod from opposing sides in a " butterfly" configuration.

Laser experiments are demonstrated with two different Erbium glass sq rods. Sqrod #1 is 1.7 X 1.7 X 10mm with a doping of 0.66%  $\text{Er}_2\text{O}_3$  and 16.89% (wt%)  $\text{Yb}_2\text{O}_3$ . Sqrod #2 is 1 X 1 X 10mm with 2.2%  $\text{Er}_2\text{O}_3$  and 22%  $\text{Yb}_2\text{O}_3$ . Both sqrods are not coated. The long pulse (free running) output performance of these sqrods is show in figure 5 and 6. For sqrod #1, with 200mj pumping, the maximum free running laser output energy was ~10mj @ 1.54 $\mu$ m in ~6ms pulse width. The near field of the output beam exhibits a rectangle shape about 0.3 x 1.5mm that corresponds directly to the pump area cross section.

**OUTPUT ENERGY VS PUMP ENERGY FOR ROD 1**  
**1.7X1.7X10mm,0.64%wt Er, 17%wt Yb**

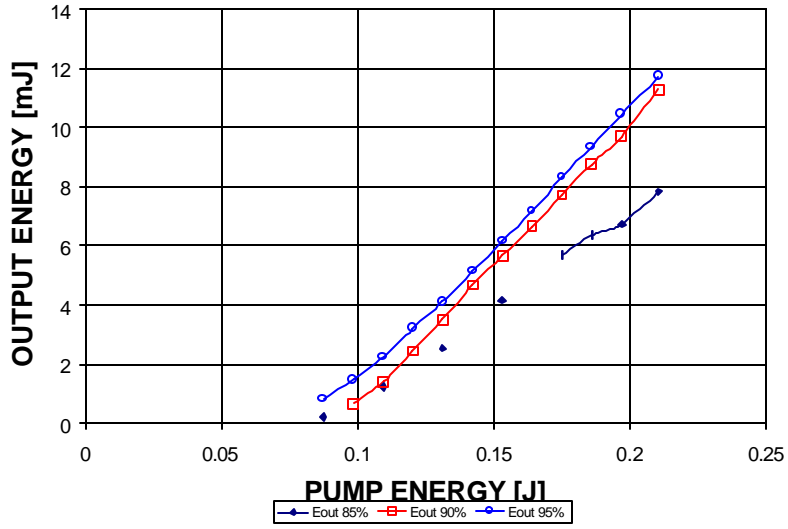


Fig. 5

**OUTPUT ENERGY VS PUMP ENERGY FOR ROD 2**  
**1X1X10mm, 2.2%wt Er, 22%wt Yb, 95% OC**

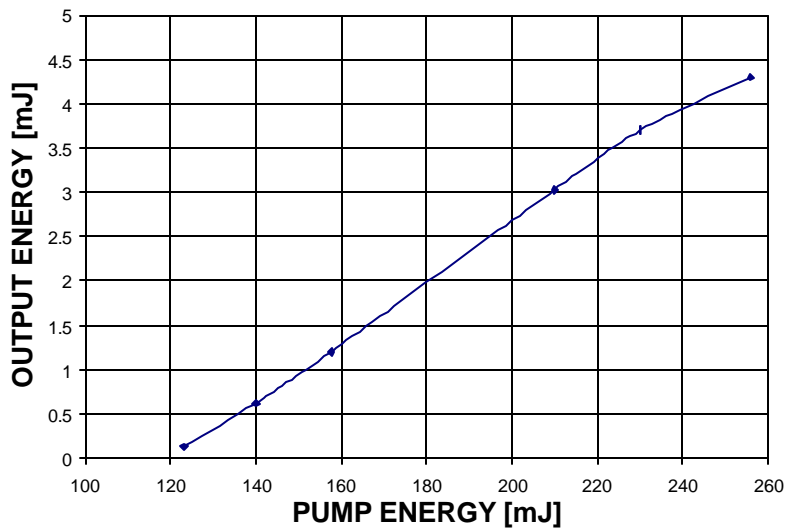


Fig. 6

The Q-Switch operation is demonstrated for srod #1. For sqrod #2 the lasing occurred only with the 95% reflectivity output coupler. It appears that laser threshold was not reached at lower output coupler reflectivity. This implies that there was not enough pump energy to supply greater than 50% inversion for 2.2% erbium oxide doping concentration.

Table 1. SUUMARIED RESULTS OF QS OPERATIONS

QS Material	Initial Transmittion	Sample Thickness	Laser O.C.	Pump Energy	QS Output(mJ)	QS Pulse Width	Mode
CaF2	90%	0.5mm	90%	246mJ	0.317	15.8 nsec	TEMoo
	85%	0.7	90%	288	No Lasing		
	95%	0.3	85%	131	0.019	700	TEMoo
	90%	0.5	85%	228	0.232	17	TEM10
Co2+	90%	0.7	85%	219	0.5	10	TEM10

Passive q-switched laser operation was demonstrated with both  $U^{2+}$ : CaF and  $Co^{2+}$ :  $MgAl_2O_4$  by using sqrod #1 as gain medium. The Q-Switch results are summarized in table 1. TEMoo Q-Switch pulses with energy of 0.5mJ and pulse width of 10ns was obtained. This data compares well with other  $U^{2+}$ : CaF and  $Co^{2+}$ :  $MgAl_2O_4$  by passive q-switch erbium glass laser studies. [2,3,4]

## REFERENCES

1. T.Yanagisawa, K. Asaka, K. Hamazu, and Y. Hirano, " 11-mJ, 15Hz single-frequency diode-pumped Q-switched Er, Yb: Phosphate glass laser", Optics Letter, Vol. 26, No 16, pp1262/Aug.15, 2001.
2. R. Stultz, M. Camargo, M. Lawler, D. Rockafellow, M. Birnbaum, "Diode-Pumped Er:Yb:Glass Mini-Transmitter", Presentation at the OSA Advanced Solid-State Laser Conference, (ASSL)1998.
3. R. Wu, J. Myers, M. Myers, B. Denker, B. Galagan, S. Sverchkov, J. Hutchinson, W. Trussel, " $Co^{2+}$ : $MgAl_2O_4$  Crystal Passive Qswitch Performance at 1.34, 1.44 and 1.54um", OSA Advanced Solid-State Laser Conference, ASSL, 2000.
4. S. Girard, A. Lagatski, M. Fromager, K. Ai tAmeur, R. Moncorgé, M. Bettinelli, B. Ferrand, M.J. Myers, "Experimental and Theoretical Characterization of Different Saturable Absorbers for Passive Q-switching Er Doped Glass Laser", CLEO/Europe 2001, Poster C-PSL 126, Conf. Digest pp96, Munchen, June 18-22, 2001.