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Phosphate Glass Fiber Laser Materials and Architectures

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ABSTRACT

Kigre, Inc. is developing new rare-earth-doped fiber laser materials specifically for use in large mode area and super mode fiber laser architectures. In this work we describe new end-pumped clad fiber laser designs fabricated from high performance phosphate laser glass compositions. These fibers include erbium/ytterbium and ytterbium-only doped double clad designs with large mode areas and a third neodymium-doped "super mode" design with multiple cores, pumped at 940/975 and 808 nanometers respectively. Additional data on new heavily doped, low NA, side-pumped fiber laser architectures is also presented.

Key Words: Fiber Laser, Double Clad, Cladding Pump, Rare Earth Doped Fiber

1. NEW LASER GLASS MATERIALS & FIBER LASER DESIGNS

Conventional fiber lasers have generated output powers of 110 watts in single fiber lengths of 20 meters in a cladding-pumped configuration [1,2]. These fiber lasers used silica as a lasing material, similar to the silicate glasses used in the original glass lasers. In the thirty-some years since, the improvements in the gain of laser glasses have been dramatic. Beginning in mid-1960s with the American Optical NS and the French MG-915 silicate glasses, the development of the new glasses, culminating in Kigre's QX phosphate glasses, has demonstrated more than 20 times the power generation capability of their silicate counterpart [3]. It is reasonable to assume that these same attributes that have been shown to be of such value in glass lasers should also prove of value in fiber lasers. The unique attributes of phosphate glass can offer significant advantages to those who wish to produce optimized high power fiber lasers with new innovative architectures [4,5].

Phosphate glasses have a number of attractive properties, among which are the following:

?? Readily pulled into fibers of complex design
?? Good durability
?? Ion-exchangeable
?? Exhibit high cross sections for stimulated emission
?? Have very high solubility for rare-earth ions
?? Exhibit low concentration-quenching and no "clustering" effects
?? Exhibit low up-conversion losses
?? Wide bandwidth capability

In comparison with the standard silica fiber-laser, these properties translate into opportunities for new smaller, high power designs. For example, if we take a segment of QX/Er glass doped with erbium and ytterbium at levels approximately two order of magnitude higher than possible with silica, we find that we can generate greater than five watts at 1.54 microns in only 4 millimeters of material. *(See figure 1.)* In this case, the short-length construct had an effective core of 500 microns and although not of optimum doping concentration, managed efficiencies of approximately 20 percent. Improved versions these Large Mode Area (LMA) fiber constructs are being fabricated and tested in both end-pumped and side-pumped configurations.

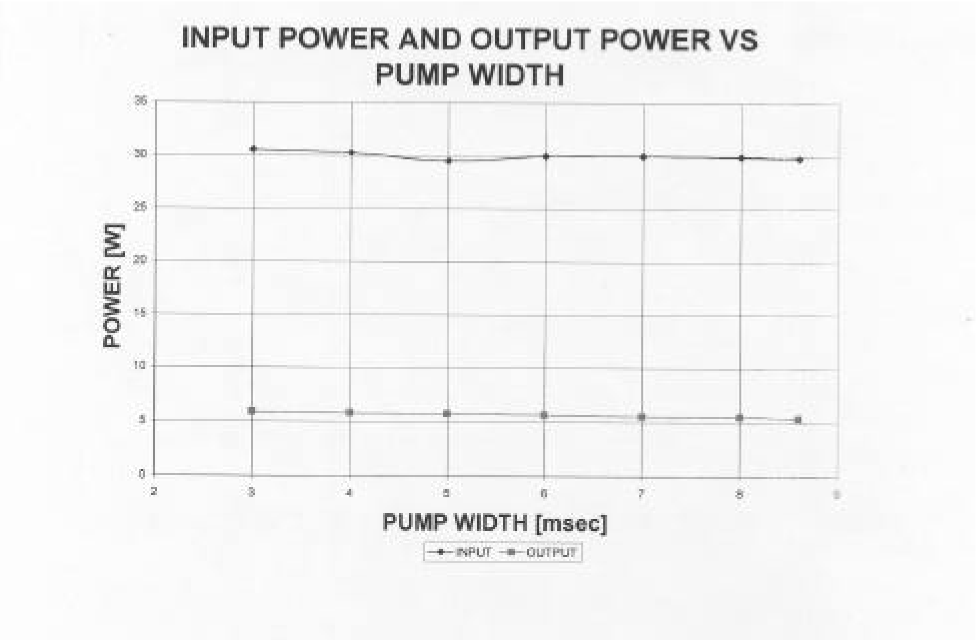


Figure 1. Performance data for 4 mm long micro-fiber laser with differing pump widths, using a 30-watt 943nm diode pump.

2. Double-Clad Large Mode Area Erbium/Ytterbium Fiber

We have recently begun the evaluation of a double-clad erbium/ytterbium fiber with the following characteristics:

- ?? Core is 25 micron diameter, erbium/ytterbium with an index of refraction of 1.535
- ?? Inner cladding is a square 400 micron cladding with an index of refraction of 1.531
- ?? Outer cladding is a polymer coating with an index of refraction of 1.398
- ?? Numerical Aperture of core is 0.11
- ?? Numerical aperture of inner cladding is 0.62

A cross-sectional view of this fiber is shown in figure 2.

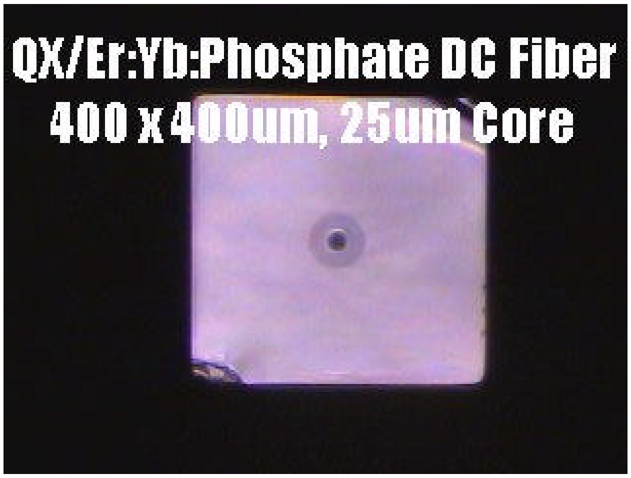


Figure 2 Cross-section view of QX/Er DC LMA fiber

A 30 cm-long sample if this QX/Er fiber was mounted on an aluminum V-channel and end-pumped with a 30 watt, 943 nm CW diode laser coupled to a 600 micron diameter delivery fiber. The resonator consisted of the following coated optics:

?? Pump inlet end; HR at 1.54 um, AR at 940 nm
?? Outlet end; HR at 940 nm, AR at 1.54 um
?? Resonator output coupler; Fresnel reflection of polished end.

The performance data is shown in figure 3. Figure 4 shows the laboratory set-up. Note the green up-conversion from the Er^{+3} $2H_{9/2} – 411_{3/2}$ transition. The slope and optical efficiency for the test data is approximately 30%.

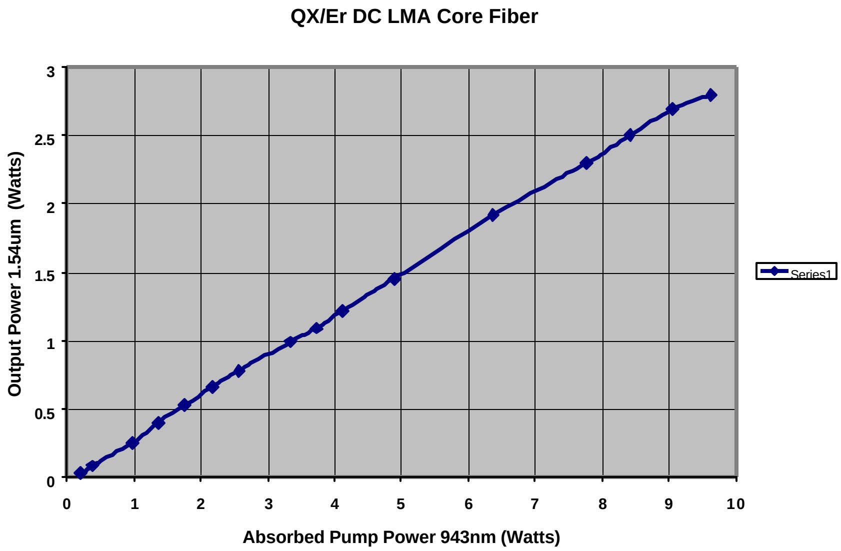


Figure 3 QX/Er DC LMA fiber laser performance data

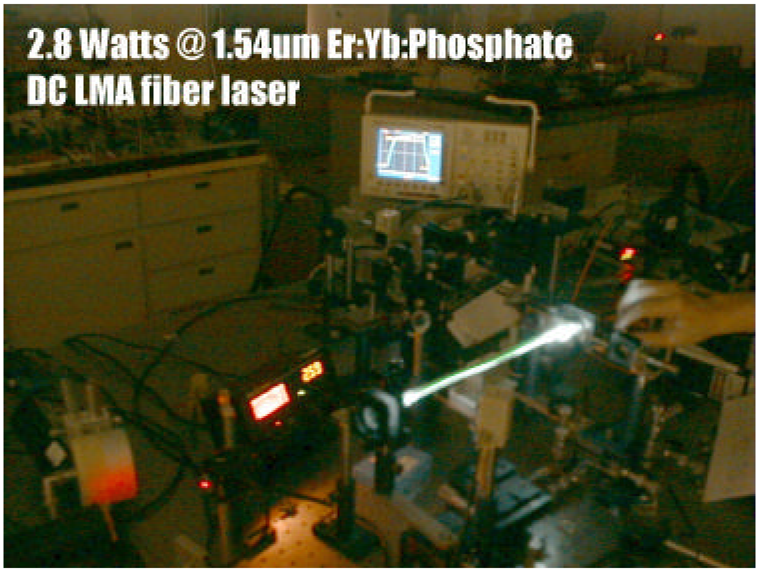


Figure 4 QX/Er Fiber laser laboratory setup exhibiting "green" upconversion emission from the Er^{+3} $^2H_{9/2}$–$^4I_{13/2}$ transition

3. DOUBLE-CLAD LARGE MODE AREA YTTERBIUM FIBER

We have also begun the evaluation of a double clad large mode area fiber with these characteristics:

?? Core is 25 micron diameter ytterbium doped QX with an index of refraction of 1.529
?? Inner cladding is a square 400 micron cladding with an index of refraction of 1.522
?? Outer cladding is a polymer coating with an index of refraction of 1.398
?? Numerical Aperture of the core is 0.14
?? Numerical Aperture of the inner cladding is 0.60

A cross-sectional view of the fiber is shown in figure 5

Figure 5 Cross-section view of QX/Yb DC LMA fiber

The yield from this draw of QX/Yb fiber was poor due to problems with the outer cladding polymer jacket application equipment. Much of the fiber produced was found to be smaller than the targeted 400 micron square cladding design. Figures 6 and 7 show the set-up and initial lasing of the ytterbium-doped phosphate fiber laser. Note in figure 7, the blue emission that appears to be up-conversion due to the presence of Yb^{+2} ions. (This up-conversion might also be due to the presence of impurities such as other rare-earth contaminants.)

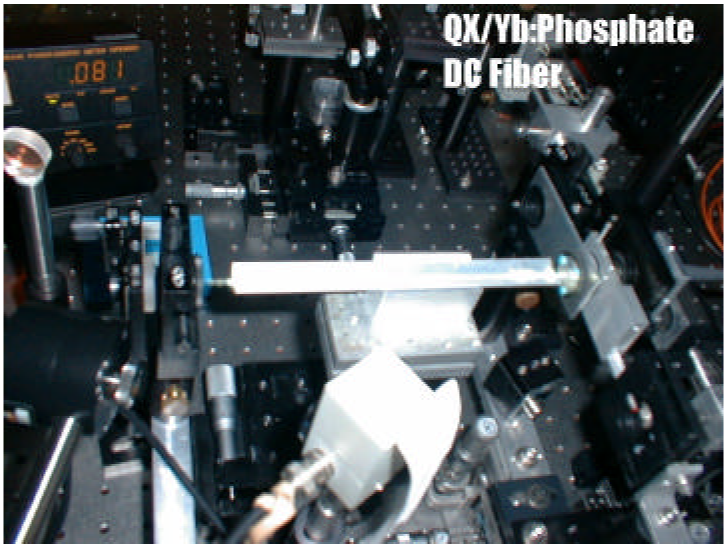


Figure 6 QX/Yb fiber laser laboratory setup

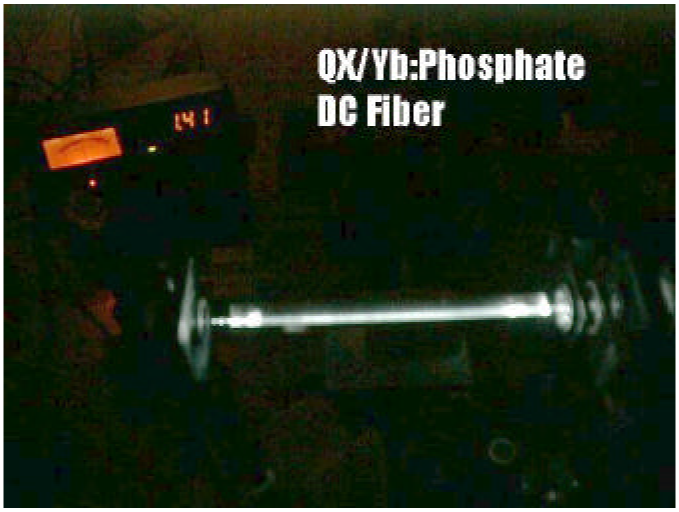


Figure 7 QX/Yb fiber laser "blue" emission possibly due to the presence of Yb^{2+} ions

Figure 8 shows an oscilloscope trace of the output of an 18 cm long sample of the QX/Yb fiber output with a 3 millisecond, 36 millijoule (absorbed) pump pulse at 943 nm. The laser output energy is approximately 2 millijoules. We suspect that the 1060 nm output wavelength is shifted due to the very high ytterbium concentration versus the limited pump intensity. This shift is due to the re-absorption of the ytterbium emission by the ytterbium absorption band. It is estimated that a least 5% of the ytterbium must be inverted to permit lasing at the edge of the absorption spectra. Similar spectral shifts were obtained in QX/Yb, doped at 15 weight percent, by Griebner, et.al. [7].

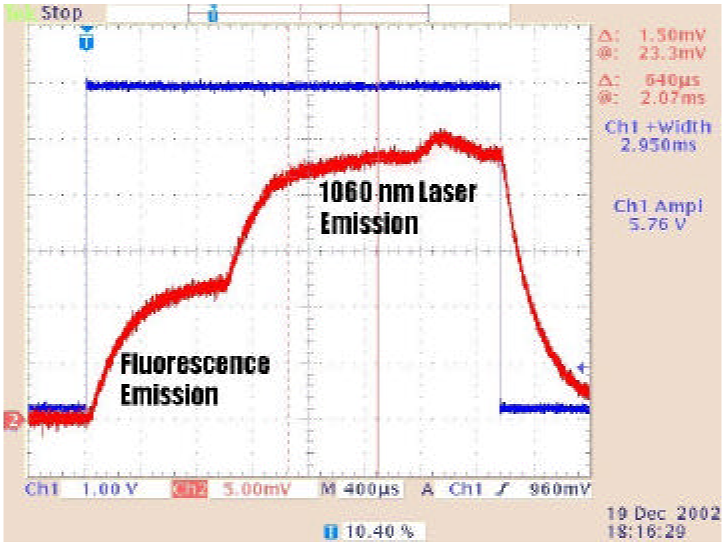
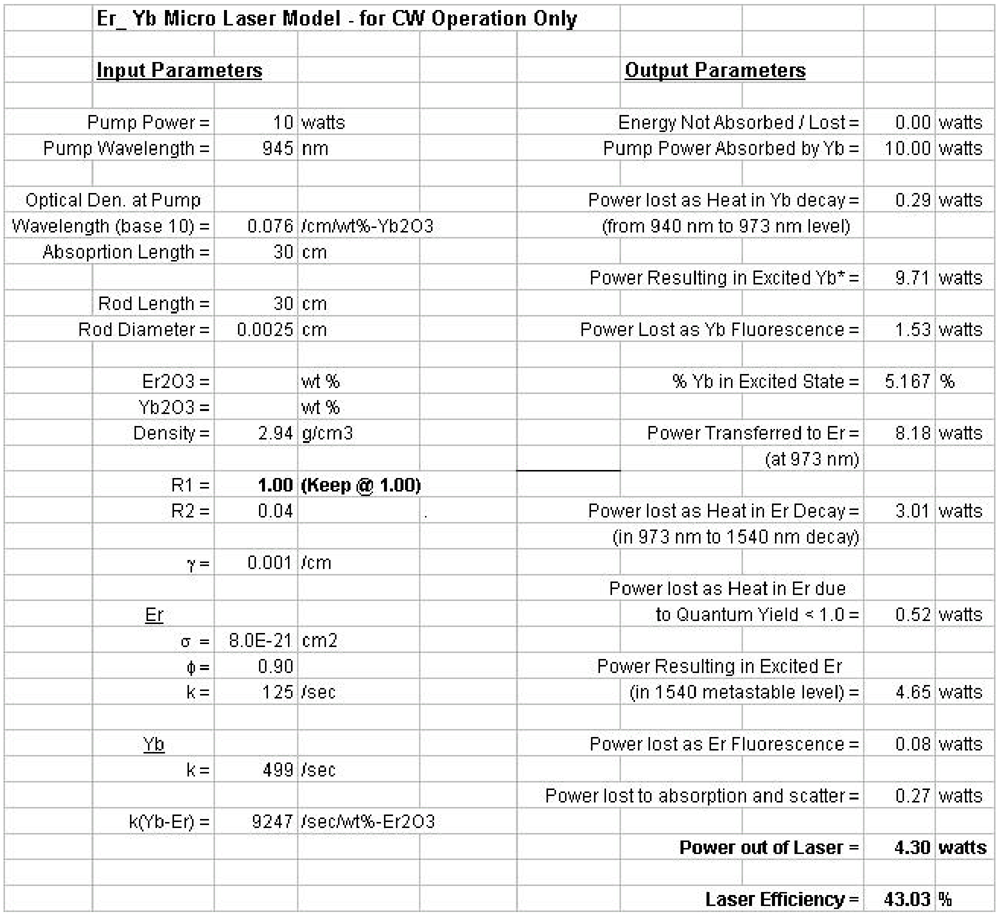


Figure 8 Emission trace for an 18cm long sample of the QX/Yb fiber output with a 3ms, 36mj (absorbed) 943nm pump pulse.

4. SUMMARY

We believe that this initial fiber laser performance data is promising. Further improvements in large mode area fiber architectures, pump insertion, and pump containment schemes along with optimization of dopant levels should result in the generation of very high power levels at efficiencies approaching 50 percent, as predicted in the computer model shown in Figure 9. Further, the 943 nm pump is very attractive for military applications due to its insensitivity to pump wavelength changes caused by temperature variations as shown in figure 10.



Er_ Yb Micro Laser Model - for CW Operation Only					
Input Parameters			**Output Parameters**		
Pump Power =	10	watts	Energy Not Absorbed / Lost =	0.00	watts
Pump Wavelength =	945	nm	Pump Power Absorbed by Yb =	10.00	watts
Optical Den. at Pump			Power lost as Heat in Yb decay =	0.29	watts
Wavelength (base 10) =	0.076	/cm/wt%-Yb2O3	(from 940 nm to 973 nm level)		
Absoprtion Length =	30	cm			
			Power Resulting in Excited Yb* =	9.71	watts
Rod Length =	30	cm			
Rod Diameter =	0.0025	cm	Power Lost as Yb Fluorescence =	1.53	watts
Er2O3 =		wt %	% Yb in Excited State =	5.167	%
Yb2O3 =		wt %			
Density =	2.94	g/cm3	Power Transferred to Er =	8.18	watts
			(at 973 nm)		
R1 =	**1.00**	**(Keep @ 1.00)**			
R2 =	0.04		Power lost as Heat in Er Decay =	3.01	watts
			(in 973 nm to 1540 nm decay)		
γ =	0.001	/cm			
			Power lost as Heat in Er due		
Er			to Quantum Yield < 1.0 =	0.52	watts
σ =	8.0E-21	cm2			
ϕ =	0.90		Power Resulting in Excited Er		
k =	125	/sec	(in 1540 metastable level) =	4.65	watts
Yb			Power lost as Er Fluorescence =	0.08	watts
k =	499	/sec			
			Power lost to absorption and scatter =	0.27	watts
k(Yb-Er) =	9247	/sec/wt%-Er2O3			
			Power out of Laser =	**4.30**	**watts**
			Laser Efficiency =	**43.03**	**%**

Figure 9 Computer modeling that suggest QX/Er erbium-ytterbium fiber laser optical efficiency may be increased from ~30% to ~ 43%

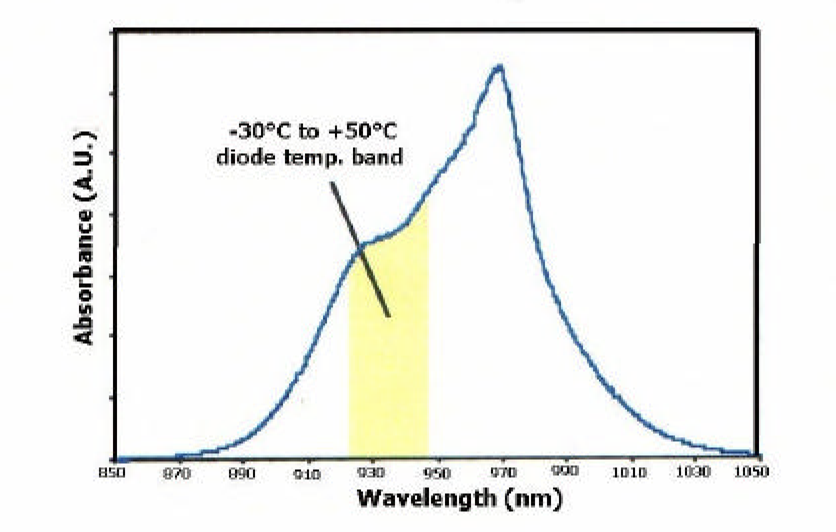


Figure 10 Broad Yb^{3+} absorption spectra shows insensitivity to 940nm diode pump wavelength changes caused by temperature variations

Overall efficiencies of the double clad, large mode area erbium/ytterbium glass fiber architectures are shown to increase with smaller cladding to core ratios, higher ytterbium concentrations, optimized erbium concentrations, and lower pump coupling losses. Higher ytterbium concentration values increase the ytterbium to erbium energy transfer efficiency. Higher ytterbium concentration also tends to shorten the pump absorption length that in turn, contributes to improving pump containment [8].

5. FUTURE WORK

A second QX/Yb double clad, large mode area fiber is presently being fabricated in light of the problems encountered during the pulling of the first fiber, resulting in the poor yield of quality fiber samples. A third neodymium-doped double clad fiber with multiple cores, designed for "supermode" laser emission at a1.053 microns is currently in the final stages of fabrication. Performance data for this fiber will be generated and presented at a later date. New side-pumped fiber and end-pumped double clad fiber architectures are under construction. The newer designs are optimized to take advantage of the phosphate glass attributes. Improvements in gain architecture and pump containment should result in substantial improvements in efficiencies.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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