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New high power rare-earth-doped fiber laser materials and architectures

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ABSTRACT

Kigre is developing new rare-earth-doped glass fiber laser materials specifically for use in multiple clad and multiple core LMA (Large Mode Area) and super mode (guided wave) fiber laser constructs. In this work we describe new end-pump double clad fiber laser designs fabricated from high performance phosphate laser glass compositions. One DC (Double Clad) LMA fiber is doped with erbium/ytterbium for 1.54um laser emission. Another DC LMA fiber is doped with ytterbium for 1.03um laser emission. A third DC multiple core "supermode" fiber is doped with neodymium for 1.053um laser emission. Initial fiber laser performance data is presented. The erbium/ytterbium & ytterbium only doped fibers are end-pumped at 940/975nm with 40-Watt fiber coupled laser diodes. The neodymium-doped fiber is end-pumped with an 808nm 40-Watt fiber coupled laser diodes. Design and performance data for new side-pumped, highly doped phosphate DC LMA fiber laser architectures are presented.

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

1. NEW LASER GLASS MATERIALS & FIBER LASER DESIGNS

Phosphate glasses are readily pulled into fibers; exhibit high cross section, gain, and rare earth solubility. They do not exhibit "clustering", are insensitive to concentration quenching and exhibit low upconversion losses. Double-clad fiber lasers have a number of novel or unusual attributes, stemming from the fact that they represent the extreme case of a long, thin laser cavity. Conventional fused silica fiber laser single mode output powers of greater than 110 watts have been reported [1,2]. Kigre has invented new rare earth doped phosphate laser glass materials (designated QX) that exhibit nearly two orders of magnitude higher laser performance improvements over its predecessors [3]. Many aspects of the phosphate glass material offers unique advantages for those who wish to produce optimized high power fiber lasers with new innovative architectures. [4,5] Fiber lasers made from highly doped-phosphate laser glass may be designed to be short enough to direct side pump with linear diode arrays. In a recent experiment, a diode-pumped erbium/ytterbium QX glass fiber laser generated powers greater than 1 watt/mm of length: This experiment demonstrates the ability of fiber laser architectures made with this highly-doped phosphate glass material to generate very high power levels with relatively short segments of fiber. Conventional fiber lasers made with silica fiber, require meters of fiber length to generate powers up to 10 watts. In three to eight millisecond bursts, we have demonstrated outputs greater than 4 watts in a fiber laser only 4 millimeters long. Sustained operation at these power levels may be achieved with gain elements only centimeters in length, instead of the 10s of meters required for conventional silica fibers. Figure 1 illustrates the sustained 5-watt output level of a 4 mm long fiber laser at differing pump widths, using a 30-watt 943nm diode pump.

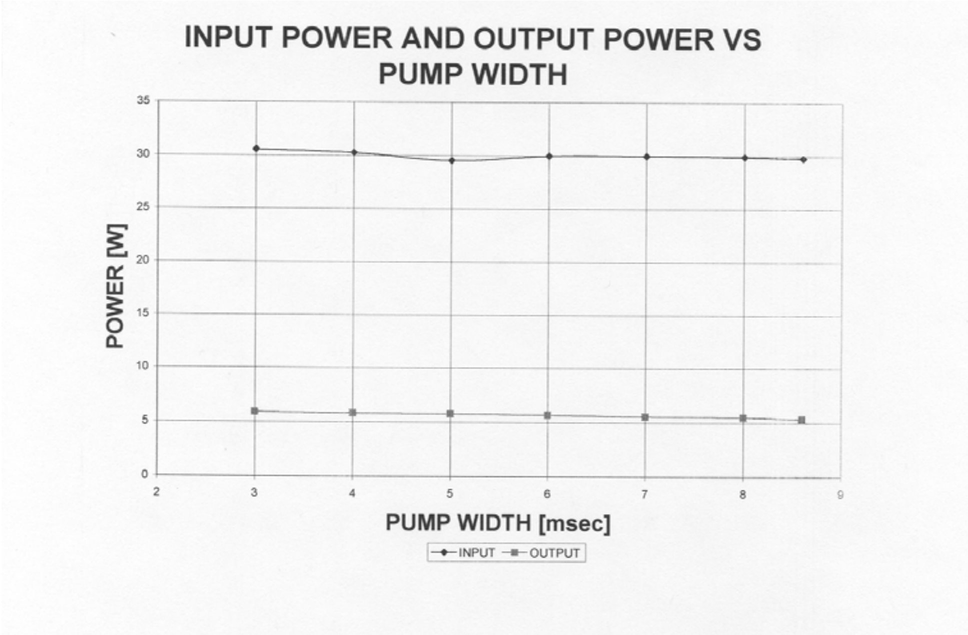

Fig. 1

2. DOUBLE CLAD LMA ERBIUM-YTTERBIUM FIBER

We have recently started evaluation of a double clad large mode area fiber manufactured with an undoped square 400 x 400um QX glass inner cladding and a 25um diameter QX/Er core containing erbium and ytterbium. The core of this fiber has an index of 1.535, the square cladding has an index of 1.531 and the outer polymer coating has in index of 1.398. This results in a core-square cladding numerical aperture of 0.11 and a NA of 0.62 for the square cladding and polymer overcoat. The design was chosen to facilitate comparative testing against a conventional erbium doped fused silica DC fiber. Figure 2 shows a picture of the end face (cross sectional view) of this QX/Er fiber.

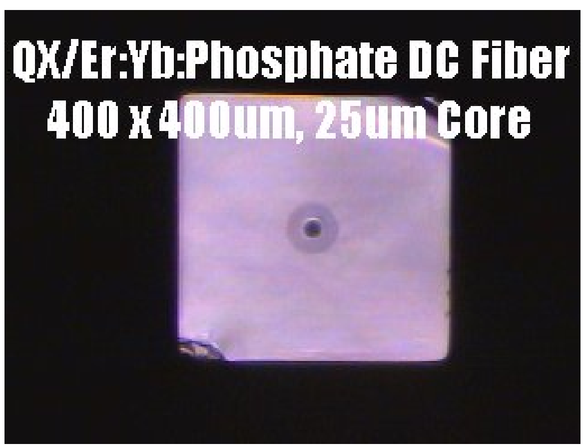

Fig. 2.

A 30cm long sample of the QX/Er fiber was mounted on aluminum V-channel and end pumped with a 30 watt 943nm CW diode laser coupled to a 600um diameter delivery fiber. The resonator consisted of a HR@1.54um/HT@940nm coated optic on the end with the pump input end a HR@940nm/HT@1.54um coated optic on the laser output end. Fresnel reflections from the fiber's output face were used as the resonator's output coupler. Performance data is shown in figure 3. Figure 4 shows the fiber laser laboratory setup. Note the green upconversion from the Er^{+3} 2H9/2–4I13/2 transition. The slope and optical efficiency for the test data shown in figure 3 is calculated to be ~ 30%.

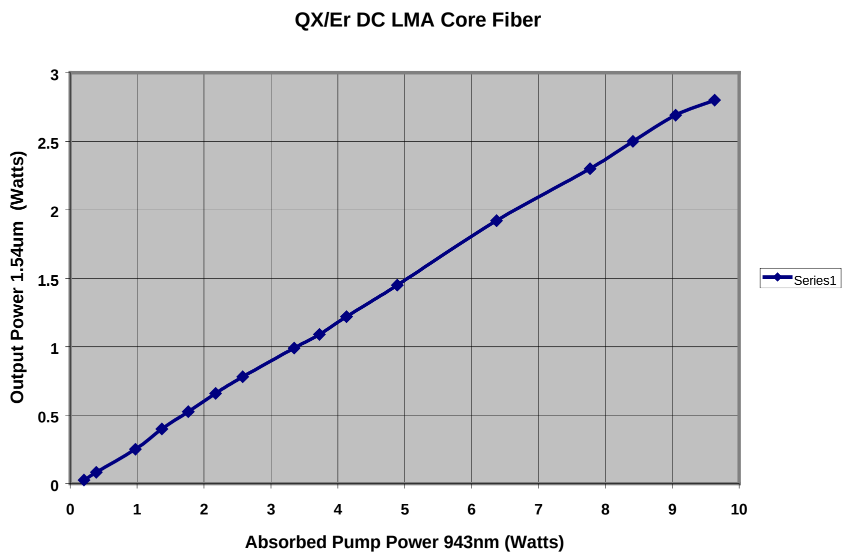

Fig. 3

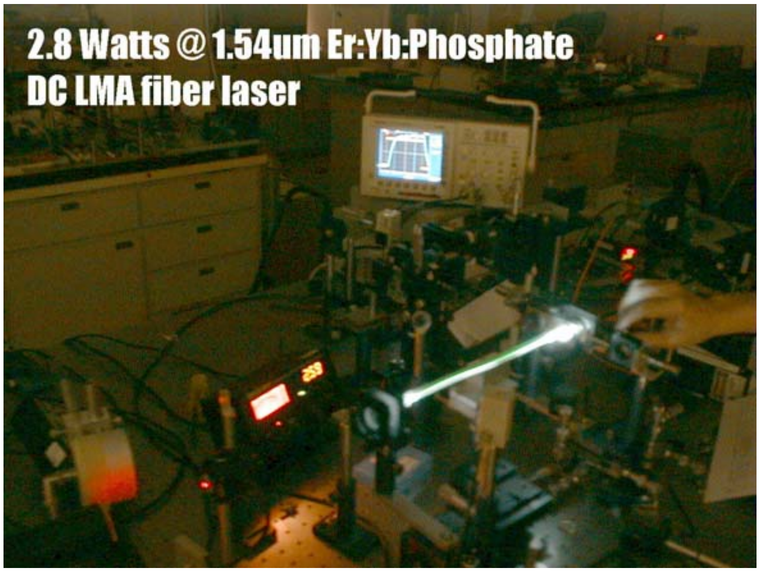

Fig. 4

3. DOUBLE CLAD LMA YTTERBIUM FIBER

We have also begun evaluation of a double clad large mode area fiber manufactured with an undoped square 400 x 400um QX glass inner cladding and a 25um diameter QX/Yb core containing a very high concentration of ytterbium. The core of this fiber has an index of 1.529, the square cladding has an index of 1.522 and the outer polymer coating has in index of 1.398. This results in a core-square cladding numerical aperture of 0.14 and a NA of 0.60 for the square cladding and polymer overcoat. The design was chosen to facilitate comparative testing against a conventional ytterbium doped fused silica DC fiber. Figure 5 shows a picture of the end face (cross sectional view) this fiber.

Fig. 5

Fiber yield from the drawing of this 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 (~ 250um to 370um square) rather than the targeted 400um square cladding design. Figure 6 & 7 show the setup and initial lasing of the DC LMA Yb:phosphate fiber laser. Note strong blue glow emission that appears to be upconversion in figure 7. The unexplained excited Yb emission may be due to the presence of Yb^{2+} ions or impurities such as other rare earth contaminants.

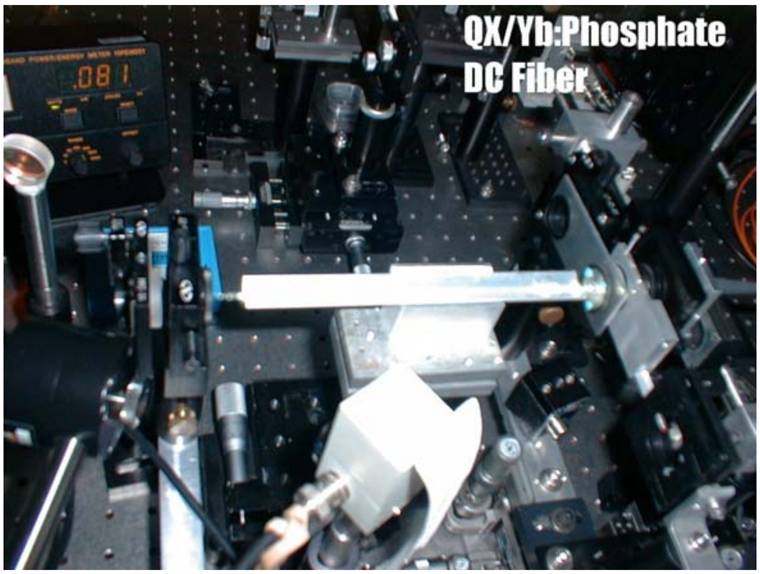

Fig. 6

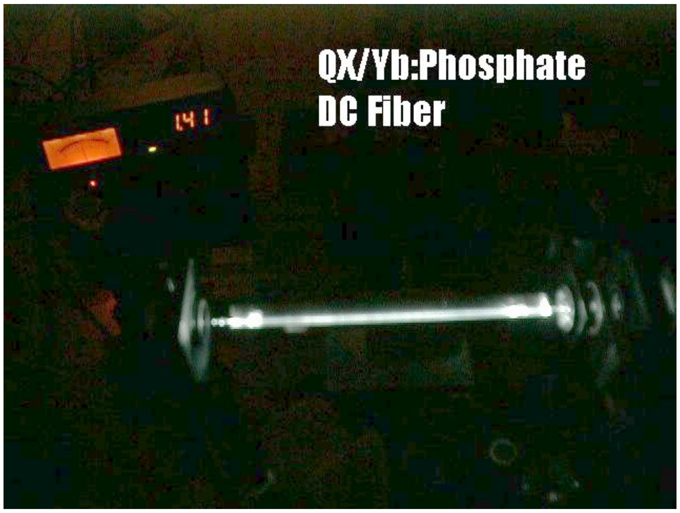

Fig. 7

Figure 8 shows a scope output emission trace for an 18cm long sample of the QX/Yb fiber output with a 3ms, 36mj (absorbed) 943nm pump pulse. The laser energy output is ~ 2mj. We suspect that the 1060 nm output wavelength is shifted by high intracavity losses from the 1032nm peak due to excessive scatter & fiber defect losses in the fiber sample [7].

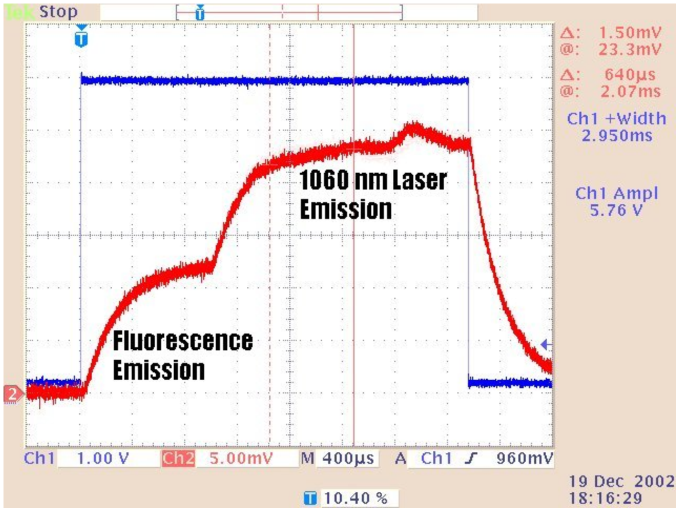

Fig. 8.

4. SUMMARY

We believe that this initial fiber laser performance data is encouraging when taking into account the non-optimized fiber materials, laser resonator, preform processing and fiber architecture. Figure 9 shows computer modeling that suggest that with proper resonator optimization and a decrease in the laser's intra-cavity losses, the optical efficiency of this QX/Er erbium-ytterbium fiber laser may be increased from ~30% to ~ 43%. The 943nm pump is attractive for military applications due to its insensitivity to pump wavelength changes caused by temperature variations. Pumping at 975nm instead of 943nm provides a smaller quantum defect, shorter absorption length and an optical efficiency value of ~ 48%.

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**	**%**

Fig. 9

Overall efficiencies of the DC LMA erbium/ytterbium phosphate 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-erbium energy transfer efficiency and shorten the pump absorption length that in turn contributes to overall pump containment efficiency [8].

5. FUTURE WORK

A second QX/Yb DC LMA fiber is being produced in light of problems encountered during the pulling of the first fiber and the resulting poor yield of quality fiber samples. A third neodymium doped DC fiber with multiple cores is designed for "supermode" laser emission at 1.053um. is currently in the final stages of fabrication. Performance data for this fiber will be taken and presented at a later date. New side-pump fiber and end pump double clad fiber architectures are under construction. The newer designs are optimized to take advantage of the phosphate glass attributes and minimize its deficiencies. Improvements in gain architecture and pump containment should result in a two to three fold increase in efficiency.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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