

***40 mW Single Transverse Mode Mid-IR (2.7  $\mu$ m) CW Output from a  
Simple Mirror-Free 780 nm Diode-Pumpable Fiber Laser***

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***Abstract***

We report relatively high output powers and operating efficiencies from a relatively simple uncoated-end Fresnel-reflection-based Er:ZBLAN fiber laser, whose output powers should be easily scalable to the Watt power level with commercially available 780 nm diode pumps.

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Compact and tunable, high efficiency mid-IR laser sources are critically needed for a variety of applications including: (i) surgical cuts enabled by the strong water absorption at 2.7  $\mu\text{m}$  in tissue<sup>1</sup>, (ii) mid-IR countermeasures, and (iii) environmental and industrial gases such as NO, H<sub>2</sub>S, and water vapor. The first two applications typically require Watts of mid-IR power and the latter requires a source that is tunable. The 2.7  $\mu\text{m}$  transition in Er:ZBLAN fibers<sup>2-5</sup> is a promising candidate for the above applications due to its broad tunability (over 50 nm) and the demonstrated power scalability of fiber lasers, particularly with the use of double-clad designs. In this paper, we report over 40 mW of unsaturated single transverse mode output power from an Er:ZBLAN fiber laser of relatively simple construction, enabled in part by the use of high Er concentrations (10,000 ppm) and in part by the choice of 780 nm (vs. 791 nm) as the pump wavelength. The output powers from this laser should be readily scalable to the Watt-power level with commercially available 780 nm diode pumps. As such, this work represents the first report of the use of a double-clad fiber for a mid-IR fiber laser.

Figure 1 shows the experimental arrangement used in the present work. The choice of the fiber was based on our plans to replace the currently-used 780 nm Ti:Al<sub>2</sub>O<sub>3</sub> laser pump with high power diode pumps of relatively low beam quality. As such, we used a 5.5 m long double-clad Er:ZBLAN fiber, with 10,000 ppm Er in a 6  $\mu\text{m}$  diameter, 0.15 NA single mode amplifier core surrounded by a concentric 125  $\mu\text{m}$  diameter diode pump-confining core (“inner clad”) of 0.3 numerical aperture. In contrast to previously reported work<sup>3,4</sup> in which relatively expensive multiresonant mirrors (high R at 1.6  $\mu\text{m}$  and 2.7  $\mu\text{m}$ , and high T at the relatively short 780-800 nm pump wavelength), we chose a much simpler cavity design comprising simply of the 4% Fresnel reflections at the two uncoated fiber ends. Output power from the fiber laser was monitored by completely attenuating the 780 nm pump with a 2.7  $\mu\text{m}$  (T=90%) transmitting filter.

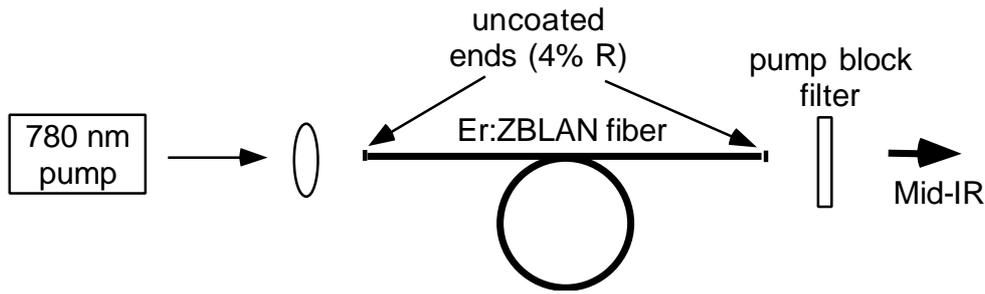


Fig.1: Schematic of the “mirror-free” Er:ZBLAN fiber laser

A key feature of the work reported here is the use of high Er concentrations to facilitate depopulation of the long-lived lower laser level by cross-relaxation processes<sup>7</sup>. A companion key feature of the work reported here is the use of a pump wavelength of 780 nm (compared to the 791 nm pump wavelength used previously for excitation of the  $^4I_{11/2}$  upper laser level via the  $^4I_{9/2}$  pathway) to alleviate ground state bleaching problems<sup>8</sup>; this choice of pump wavelength is demonstrated to be approximately 3 times more efficient than the use of a 791 nm pump in our laser design, as elaborated below.

Figure 2 shows the  $P_{\text{out}}$  vs.  $P_{\text{in}}$  curve for this fiber laser when pumped by 780 nm single transverse mode Ti:Sapphire pump radiation that is directly coupled to the 6  $\mu\text{m}$  amplifier core (coupling efficiency  $\sim 50\%$ ) corresponding to its current use as a simple “single clad” fiber. The vertical axis in Fig 2 corresponds to mid-IR power output from both ends of the fiber laser, and lasing threshold corresponds to a gain of 5.85 dB/round-trip at a pump power of  $\sim 25$  mW corresponding to a pump power density of  $\sim 400$  KW/cm<sup>2</sup>. Note that even at the highest pump power levels, there is no evidence of saturation of the output power from this 2.7  $\mu\text{m}$  fiber laser. As such, in a follow-on experiment currently in progress, comparable gains should be attainable with the use of  $\sim 20$  W of diode pump power (Optopower Corp.) coupled partially into the core and partially into the diode-pump confining 125  $\mu\text{m}$  inner

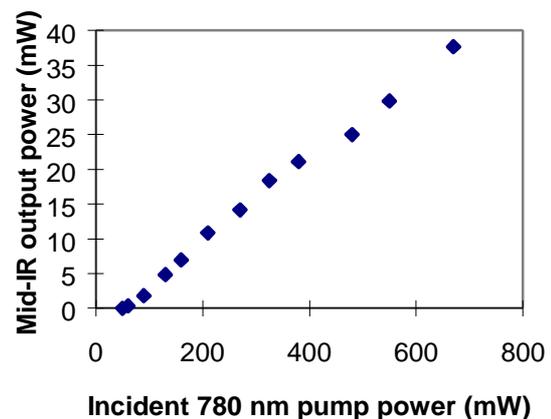


Fig. 2: Output power as a function of incident pump power at 780 nm

cladding; for this experiment, output power levels of the order of a Watt are anticipated.

Figure 3 shows the “excitation spectrum” of such a fiber laser in the vicinity of 780 nm. Note that in contrast to a previous report<sup>2</sup> on the output power of such a mid-IR fiber laser as a function of the pump wavelength, in our work 3 times greater output power was obtained with the use of the 780 nm excitation wavelength when compared to the use of the more traditional 791 nm pump wavelength<sup>2-4</sup>, despite the higher ground state ( $^4I_{15/2}$  to  $^4I_{9/2}$ ) absorption at 791 nm. We are studying this effect in detail, and we currently ascribe the observed behavior to reduction in ground state bleaching effects<sup>8</sup>, as well as to the reduction of deleterious effects caused by significantly lower ESA<sup>5,6</sup> (from the upper laser level  $^4I_{11/2}$  to  $^4F_{5/2}$ ) for 780 nm (instead of 791 nm), and the wavelength dependence of the “beneficial” lower-level ( $^4I_{13/2}$ ) depleting ESA to the  $^4H_{11/2}$  level<sup>5,6</sup>.

Results on diode-pumping and power scalability issues will also be presented in detail in this talk, as well as the detailed role of the various excited state absorption processes, and a comparison of the performance of this “mirror-free” laser with designs using traditional<sup>3-5</sup> multi-resonant mirrors for “cascade lasing” of such Er:ZBLAN fiber lasers.

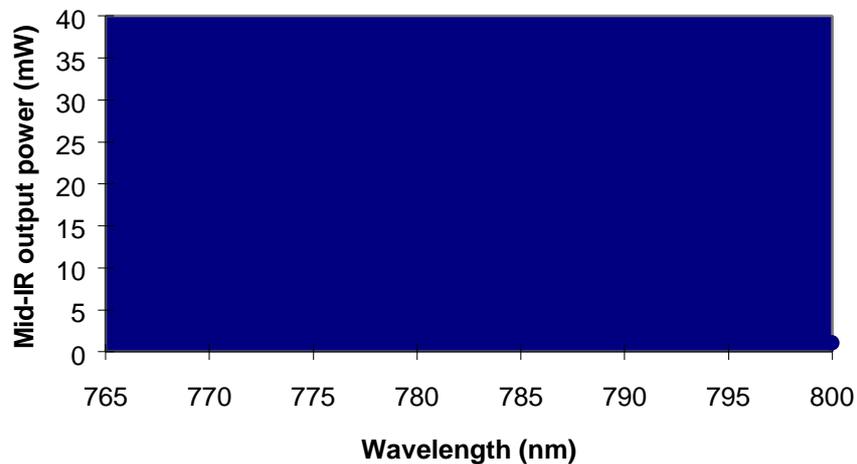


Fig. 3: Output power as a function of pump wavelength

### References:

1. L. Esterowitz, R. Allen, Proc. SPIE **1048**, 129 (1989)
2. R. Allen, L. Esterowitz, R.J. Ginther, Appl. Phys. Lett., **56**, 1635 (1990)

3. M. Pollnau, Ch. Ghisler, G. Bunea, W. Luthy, and H.P. Weber, *Appl. Phys. Lett.*, **66**, 26 (1995)
4. M. Pollnau, Ch. Ghisler, W. Luthy, H.P. Weber, J. Schneider, and U.B. Unrau, *Opt. Lett.*, **22**, 612 (1997)
5. M. Pollnau, R. Spring, Ch. Ghisler, S. Wittwer, W. Luthy, H.P. Weber, *IEEE J. Quant. Electron.*, **32**, 657 (1996)
6. T.J. Whitley, C.A. Miller, R. Wyatt, M.C. Brierly, D. Szebesta, *Electron. Lett.*, **27**, 1785 (1991)
7. G.J. Kintz, R. Allen, and L. Esterowitz, *Appl. Phys. Lett.*, **50**, 1553 (1987)
8. S. Bedo, M. Pollnau, W. Luthy, H.P. Weber, *Opt. Commn.*, **116**, 81 (1995)