980nm - Diode-Pumped Power-Scalable Continuous Wave Mid-IR (2.7 mm) Fiber Laser

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We report a relatively efficient power-scalable mid-IR (2.7 μm) Er^{3+}:ZBLAN fiber laser pumped by readily available 980 nm laser diodes. The ~10 mW cw power levels demonstrated are significantly higher than those reported previously, presumably because the high Er concentrations (10,000 ppm) used enable a rapid depletion of the lower laser level through cross-relaxation processes.

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Compact and tunable, high-efficiency mid-infrared lasers are needed for numerous applications, including (1) field-usable spectroscopic sensors for environmental and industrial-process monitoring and (2) master oscillators in airborne or spaceborne high-power mid-IR MOPAs for various countermeasures applications. Lead-salt diode lasers are limited by the need for cryogenic cooling, low power, and spatial, temporal, and spectral instabilities. Sb-based and quantum cascade diode lasers seem to be more promising, but long-lived stable cw mid-IR outputs has not yet been achieved with these devices at room temperature. On the other hand, diode-pumped fiber lasers are an attractive alternative technology, delivering stable diffraction-limited cw room-temperature mid-IR emission, at least in limited wavelength ranges[1-3] (such as in bands around 2.7 µm and 3.5 µm). Figure 1 shows a vision for future compact field- usable tunable mid-IR fiber lasers suitable for the above-stated applications.

In this talk, we describe a relatively efficient power-scalable mid-IR (2.7 µm) Er^{3+}:ZBLAN fiber laser pumped by readily-available 980 nm laser diodes. The ~10 mW cw power levels demonstrated here are significantly higher than those reported previously from any Er^{3+}:ZBLAN diode-pumped mid-IR fiber laser, presumably because the high Er concentrations (10,000 ppm) used enable a rapid depletion of the lower laser level through cross-relaxation processes.

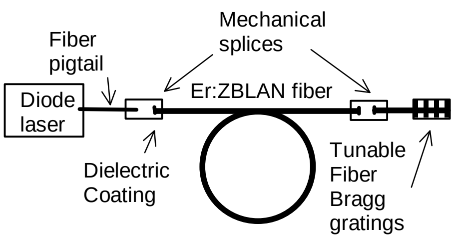

Figure 1. Schematic of a tunable, diode-pumped Er:ZBLAN mid -IR fiber laser

In our experiments, we used a nearly single transverse mode, 1 Watt 980 nm tapered amplifier diode laser[5] as the pump source, which was coupled by a free space lens into the Er:ZBLAN fiber. The fiber was double-clad, with a core diameter of 6 µm, a length of 5.5 m, an Er^{3+} concentration of 10,000 ppm (in the core), and an inner cladding diameter of 125 µm. The choice of a double-clad fiber was dictated by our plans for power scaling of the outputs of such a fiber laser with use of high power diode lasers. At the input end an HR mirror was butt-coupled to the fiber while the cleaved distal end was used as a 96% output coupler. Figure 2 shows the 2.7 µm output power as a function of launched pump power. The low lasing threshold of 30 mW for a 96% output coupler, and the fact that no saturation of the output power is observed even at the highest pump powers used indicates that this laser can be further optimized to yield much higher output powers.

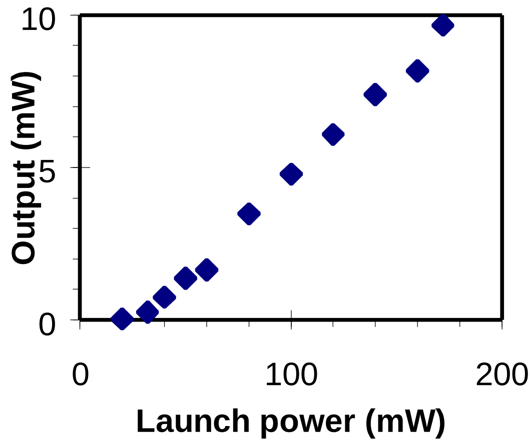

Figure 2. P_{out} vs P_{in} for cw pump

Our choice of a 980 nm pump wavelength for this work (instead of the more efficient 791 nm pumps traditionally used[1,3]) was dictated by the ready availability of multi-Watt power level 980 nm diode lasers (due to the relatively large market need for 1.55 µm EDFA pumps). A principal reason why 980 nm pumps are less efficient for the pumping of the 2.7 µm transition in Er is the lack of an appropriate 980 nm ESA process (as occurs with the 791 nm pump) to depopulate the lower laser level ($^4I_{13/2}$) whose lifetime (9.4 ms) is longer than that (7.5 ms) of the upper laser level ($^4I_{11/2}$). As such, the 2.7 µm Er:ZBLAN laser transition is expected (at first glance) to be self-terminating with the use of a 980 nm pump. The data presented here clearly demonstrates the possibility of relatively efficient cw operation, partly consistent with the theory of Quimby et al.[5], and partly because of the onset of a cross-relaxation mechanism which depletes the lower laser level ($^4I_{13/2}$) in one ion while upconverting the other ion to the $^4I_{11/2}$ state[6]; this high cross-relaxation rate is possible due to the high Er concentrations (10,000 ppm) used, and is being investigated in further detail. Nevertheless, the lack of saturation at the highest pump power levels used is particularly interesting, and bodes good promise for future power scaling experiments.

Work is currently in progress to demonstrate tuning of the output of such a laser with the use of a PZT-tuned fiber Bragg grating reflector similar to that shown in Fig 1. In our talk, we will also describe several other observations, including a natural tendency of the "untuned" laser to shift to longer wavelengths with increased pump power, and the onset of relaxation oscillations at frequencies varying from 5 kHz to 20 kHz (see Fig 3), when pumped with a chopped pump (at 100 Hz). Issues related to power scaling of such double clad fiber lasers with the use of high power multimode diode pumps will also be discussed.

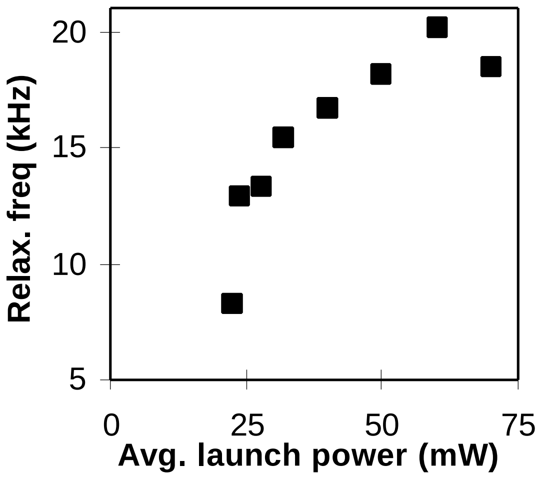

Figure 3. Relaxation oscillation frequency vs launched pump power

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