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Lasers Operating at Room Temperature

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**Tunable, CW, Multicolor Visible Upconversion Fiber Lasers
Operating at Room Temperature**

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ABSTRACT

By pumping with either a single Ti:sapphire laser or a single diode laser, upconversion laser output from a praseodymium-ytterbium codoped ZBLAN fiber has been obtained in the red, orange, green, and blue spectral regions.

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We describe continuous-wave, red, orange, green, and blue upconversion laser output for various lengths of ZBLAN fluorozirconate fiber doped with trivalent praseodymium and ytterbium ions. The lasers operate at room temperature, are modestly tunable, and are pumped either with a single Ti:sapphire laser tuned anywhere in the 780-880-nm wavelength region, or a single 860-nm semiconductor diode laser. An unusually efficient photon-avalanche mechanism is responsible for filling of the $\text{Pr}^{3+} {}^3\text{P}_{0,1}$ upper states.¹ To our knowledge, the 300-mW output power we obtained at 635 nm while pumping with the Ti:sapphire laser is the highest yet observed for a room-temperature upconversion laser.

Two fiber-laser cavity configurations are used in the experiments. In configuration 1, dielectric mirrors selective for one of the four output wavelengths are butted against the fiber ends; one of these serves as an output coupler while the other serves as a high reflector. Configuration 2 is similar to configuration 1, except that a collimating ball lens and an intracavity prism are interposed between the output coupler and fiber end in order to provide wavelength discrimination sharper than that provided by the mirror coatings. We used configuration 2 in order to perform the tuning experiments, as well as to further suppress feedback at unwanted wavelengths.

The laser-active medium used in our experiments is a ZBLAN fiber doped with 3,000 ppm by weight Pr^{3+} and 20,000 ppm by weight Yb^{3+} . Its core and cladding diameters are 3 μm and 125 μm , respectively. The fiber has a numerical aperture of 0.3 and a cut-off wavelength of 1.17 μm . A variety of fiber lengths ranging from 20 cm to 10 m were prepared in order to investigate laser operation.

For a Ti:sapphire pump wavelength fixed at 860 nm, the performance of representative upconversion fiber lasers is summarized in Table 1. The slope efficiencies and the threshold pump powers given in the Table are determined with respect to the launched power, a quantity estimated in our experiments to be about 40% of the pump power incident on the pump focusing objective. Highlights from the Table include 300 mW output power at 635 nm, 52% slope efficiency at 635 nm, and tuning at green wavelengths over a range of 23 nm. Table 2 shows analogous data for pumping with a 200-mW diode laser operating at 860 nm.

The performance of these lasers has by no means been optimized. Aside from investigations into the kinetics of the population flows, optimization of the output coupling, fiber length, and pump geometry need to be examined more systematically. At the very least, green upconversion output of perhaps 100 mW should be possible with an optimized fiber and a watt or less of pump power. Potential ap-

plications of this multicolor upconversion laser include high-resolution color printing, confocal microscopy, and projection displays.

TABLE 1

PERFORMANCE SUMMARY OF UPCONVERSION FIBER LASERS; TI:SAPPHIRE PUMPING

laser wavelength (nm)	635 ($^3P_0 \rightarrow ^3F_2$)	615 ($^3P_0 \rightarrow ^3H_6$)	520 ($^3P_1 \rightarrow ^3H_5$)	491 ($^3P_0 \rightarrow ^3H_4$)
threshold (mW)	42	29	21	60
slope efficiency	52%	11.5%	12.4%	3%
maximum output (launched power)	300 mW (760 mW)	44 mW (430 mW)	20 mW (200 mW)	4 mW (200 mW)
cavity configuration*	1	2	1	1
fiber length (cm)	60	60	42	26
output coupling (% transmission)	96	5	3	3
tuning range (nm)**	635-637	605-622	517-540	491-493

*See text for descriptions of cavity designs.

**Cavity configuration 2.

TABLE 2

PERFORMANCE SUMMARY OF UPCONVERSION FIBER LASERS; DIODE-LASER PUMPING

laser wavelength (nm)	635 ($^3P_0 \rightarrow ^3F_2$)	615 ($^3P_0 \rightarrow ^3H_6$)	520 ($^3P_1 \rightarrow ^3H_5$)	491 ($^3P_0 \rightarrow ^3H_4$)
threshold (mW)	44	36	32	56
slope efficiency	49%	10%	16%	6%
maximum output (launched power)	20 mW (88 mW)	5 mW (88 mW)	10 mW (88 mW)	2 mW (88 mW)
cavity configuration*	1	2	1	1
fiber length (cm)	25	25	25	25
output coupling (% transmission)	96	5	3	3

*See text for descriptions of cavity designs.

REFERENCES

1. Ping Xie and T. R. Gosnell, Optics Lett. **20**, 1014 (1995).