Emission Beyond 4 μm and Mid-infrared Lasing from a Dy^{3+}:InF_3 Fiber

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Abstract: We present a dysprosium-doped InF_3 fiber exhibiting emission beyond 4 microns; the longest wavelength to date from a fluoride-based fiber. Laser emission around 3 μm is also demonstrated.© 2018 The Author(s)

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1. Main Text

Laser sources in the the mid-infrared (mid-IR) spectral region are finding increased application across a wide variety of disciplines. Specifically, fluoride glass fiber lasers have made great progress both in terms of output power and pushing emission wavelengths further into the infrared [1]. To this point, these fiber lasers have been based on ZrF_4 glass (ZBLAN) which exhibits significant attenuation at wavelengths beyond 4 μm, representing a distinct limitation in further wavelength scalability. Indeed the longest lasing emission yet demonstrated has been 3.9 μm [2]; requiring cryogenic cooling, and characterized by low efficiency. As a promising alternative to zirconium-based glasses, InF_3 (fluoroindate) possesses a reduced phonon energy [3], leading to an increased transparency window [4] approaching 5 μm. In particular, dysprosium doped InF_3 has been suggested as a promising candidate for mid-IR emission beyond 4 μm [5]. Here we present for the first time to our knowledge, emission from a dysprosium doped InF_3 fiber in the 4 μm region. We also demonstrate active lasing in this same fiber from the 3 μm transition.

From the simplified energy level diagram of dysprosium seen in Fig.1(a), to pump the 4 μm directly requires a pump source at 1.7 μm. To accomplish this we constructed a Raman fiber laser (RFL) consisting of standard telecommunications fiber pumped by an Er/Yb source emitting around 1570 nm. The experimental setup for the dysprosium fiber is presented in Fig.1(b): pump light is coupled into the core of a 30 cm section of fiber, with butt-coupled dichroic mirrors closing the cavity for laser experiments. Emission from the output end of the fiber is collimated by an aspheric lens, and a monochromator is used to record the optical spectrum.

With the laser cavity mirrors removed, we first record the fluorescence emission around 4 μm as seen in Fig.2. The influence of the increased transparency of InF_3 as compared to ZBLAN is immediately clear as we are able to observe distinct fluorescence at room temperature from a 30 cm length of fiber at an injected pump power of nominally 1 W. The emission spans from 4 to 4.4 μm, showing this transition to be quite broad, with the peak emission located at 4.25 μm.

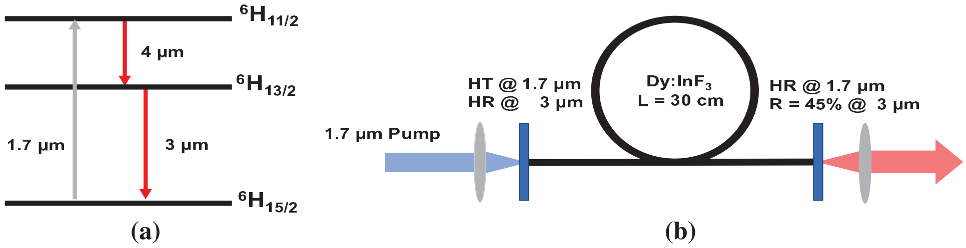


Fig. 1. (a) Simplified energy level diagram of dysprosium showing ground state pump absorption and both mid-IR radiative transitions. (b) Experimental schematic; indicated dichroic cavity mirrors are removed for 4 μm emission measurement.

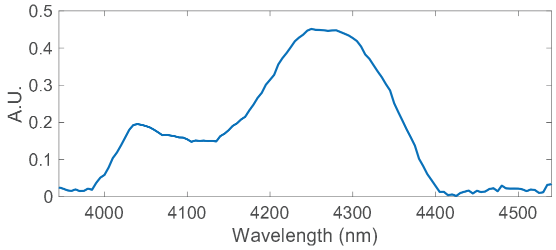
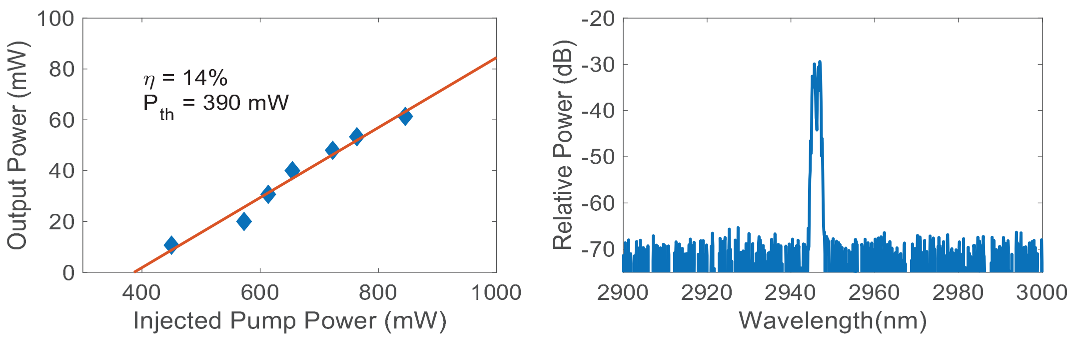


Fig. 2. Monochromator measurement of emission beyond 4 μm from the Dy^{3+}:InF_3 fiber

As the lifetime of the 4-micron level is substantially shorter than the lower 3-micron level, laser action on this transition would generally be self-terminating. To overcome this, cascade lasing on the 3-micron transition has been suggested [5]. Though 3-micron laser emission from dysprosium has been demonstrated previously in ZBLAN [6], lasing from any rare earth doped InF_3 fiber has until this work not been seen. To maximize the efficiency of this system, we choose a fairly high-Q cavity with an output coupler reflectivity of 45%. The output characteristic as a function of injected pump power is seen in Fig.3(a). The slope efficiency achieved is 14%, which is comparable to previous demonstrations of Dy:ZBLAN fiber lasers also pumped in the near-infrared. The oscillation threshold was reasonably low at 390 mW, allowing for power scaling up to 60 mW of mid-IR output for our maximum available pump power. The optical spectrum of the output is seen in Fig.3(b), where the emission is observed to be narrow-band centered around 2945 nm.

In conclusion, we have demonstrated here for the first time emission beyond 4 μm from a fluoride glass fiber by pumping the 4-micron level of dysprosium directly with a near-infrared Raman fiber laser. This emission from an InF_3 fiber exceeds the traditional transparency window of the much more widely used ZBLAN fiber, and shows potential as a 4-micron laser source. Additionally, we have also demonstrated coherent laser emission on the 3-micron transition. This is to our knowledge the first laser emission from an InF_3 fiber, and would be a key component of the cascade lasing schemes proposed to achieve efficient 4-micron laser emission from this system.



(a) (b)

Fig. 3. (a) 3 μm output power as a function of injected pump power; slope efficiency (η) is 14% with an oscillation threshold of 390 mW (b) Measured optical spectrum of the 3 μm output; emission is centered around 2945 nm.

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