100 µJ picosecond pulses from a single-stage fluoride fiber amplifier at 2.86 µm

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Laser radiation around 3 µm shows strong absorption in biomaterials because of the resonance with OH vibrational modes of water, therefore finding an increasing number of applications in biomedical research [1,2]. For such applications, 3 µm lasers sources are generally operated in the pulsed regime to reduce thermal effects. While Er:YAG solid state lasers are good candidates for efficient pulse generation, the pulse duration of such lasers (100s of microseconds) is longer than the average thermal relaxation of water in biological materials, which is estimated to about a few µs [3]. Although these lasers can be operated in Q-switch configuration where the pulse duration is reduced to dozens of nanosecond, generation of sub-ns pulses is not efficient due to low gain of short length crystals. Novel approaches are therefore needed to achieve short pulses with high energy levels. In this work, we report the demonstration of a 2.86 µm Ho^{3+}, Pr^{3+} co-doped fiber amplifier based on one-stage amplification. The amplifier delivers 113 µJ, 500 ps pulses at 1 kHz repetition rate with a peak power estimated to 225 kW (113 mW average power) and is pumped around 915 nm using widely available InGaAs laser diodes. This result sets a record for the highest pulse energy emitted from a single-stage fluoride fiber amplifier.

The experimental setup of the laser system is shown in Fig.1 (a). The seed signal is generated by an optical parametric generation (OPG) source (*Light Matter Interaction Inc.*), which produces 800 ps pulses at a central wavelength of 2.86 µm with 10 mW of average power and a repetition rate of 1 kHz. The one-stage amplifier is based on a 1 m of Ho^{3+}, Pr^{3+} co-doped fluoride gain fiber (85/190 µm, with a core doping level of 4.5 mol.% in Ho^{3+} and 0.5 mol.% in Pr^{3+}, *Le Verre Fluoré*) pumped at 915 nm from both sides. Short endcaps (L ≈ 600 µm) made with an AlF_3-based multi-mode fluoride fiber are spliced on both fiber tips to slow down the OH diffusion process and avoid fiber tip damage at high peak powers. In the middle of the amplifier, the doped fiber is stripped from its coating over ~6 cm and a high-index acrylate (n=1.54) is applied to suppress backward pump and protect the OPG source from the unabsorbed pump power. ZnSe aspheric lenses are used to launch both pumps and the seed signal in the amplifier. The 5 mW seed signal launched in the gain fiber is amplified up to 14 mW by pumping from the forward side only. When the gain fiber is pumped from the backward side with 4.6 W, the amplified signal reaches 113 mW of average power with a pulse energy of 113 µJ and a pulse duration of 500 ps. The output power and pulse energy with respect to launched pump power are shown in Fig. 1(b), while the spectrum of the seed source and amplified signal are presented in Fig. 1(c).

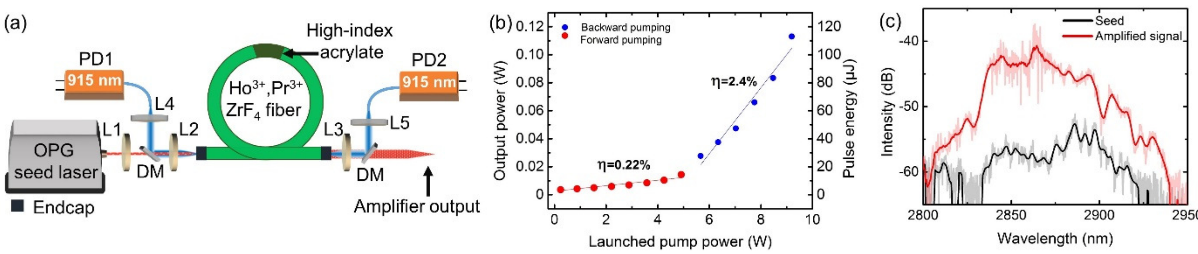

Fig. 1. (a) Experimental setup of the laser amplifier; L1-L2-L3, ZnSe aspheric lenses; L4-L5, silica lenses; DM, dichroic mirrors (HR at 915 and 980, HT at 2850 nm); PD1-PD2, pump diodes. (b) Output power and pulse energy with respect to launched pump power (for bidirectional pumping). (c) Spectrum of the seed source and evolution of the spectrum after amplification.

In summary, we demonstrated a 2.86 µm high pulse energy source based on amplification in a Ho^{3+}, Pr^{3+} fluoride fiber. The system delivers 500 ps at 1 kHz with a pulse energy of 113 µJ, the highest ever produced from a single-stage fluoride fiber amplifier operating around 3 µm. Our study demonstrates the potential of future mid-IR fiber amplifiers as high energy laser sources for biomedical applications. In this talk, the advantages and challenges of one- and multi-stage 3 µm fluoride fiber amplifiers will be discussed.

References

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