

Passively Mode-locked Ytterbium Fiber Laser with Integrated Hollow-Core Photonic Bandgap Fiber

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Abstract: An ytterbium fiber oscillator is demonstrated comprising a hollow-core photonic bandgap fiber fusion spliced to single-mode fibers in the cavity generating pulses of 4.1 nJ energy and pulse width of 210 fs.

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1. Introduction

Passively mode-locked Yb based fiber oscillators have gained high interest, recently. Such lasers have found numerous applications since they offer compact design with improved stability. However dispersion control in such lasers is critical since conventional single-mode fibers (SMF) all have normal dispersion below $1.3\mu\text{m}$. The application of hollow-core photonic bandgap fibers (HCF) for dispersion control is advantageous because in addition to their possibly anomalous group velocity dispersion (GVD) in the Yb wavelength range they have reduced nonlinearity compared to solid-core fibers. There have been experimental demonstrations of dispersion compensated fiber lasers utilizing intra-cavity HCF in the weakly stretched soliton [1] and in the similariton regimes [2]. However, for alignment-free operation and high stability an all-fiber setup is desired. Here we report a self-starting passively mode-locked fiber laser containing a HCF spliced into the cavity to provide anomalous GVD. To the best of our knowledge this is the first implementation of integrated HCF based intra-cavity dispersion control. This arrangement provides stable pulses with energy as large as 4.1 nJ, and they can be externally compressed to 210 fs. This paper is aimed to be a step towards all-fiber dispersion compensated lasers but further investigations on using fiber integrated mode-locking for the realization of an improved all-fiber setup are required.

2. Design of the cavity

The fiber laser (see Fig. 1) consists of a highly doped ytterbium gain fiber (YbF) pumped through a WDM by a 976 nm SMF coupled laser diode providing maximally 600 mW power, SMF pieces (HI1060), a 50/50 splitter used as an output coupler, a circulator (CIR), a saturable absorber mirror (SAM), a hollow-core photonic bandgap fiber (HC-1060-02, Crystal Fibre) for dispersion compensation, and an isolator (ISO). The length of the single-mode fibers added together is 5.2 m and of the HCF it is 1.3 m resulting in an estimate value of 0.07 ps^2 for the net cavity dispersion.

Fusion splicing of the HCF is carried out by a conventional electric-arc splicer (Ericsson, FSU 15FA). This is critical because of the possible collapse of the air holes and the different mode-field diameter compared to the SMF. With careful manual splicing the loss was reduced to less than 3 dB after 2 splices. Another problem was that Fresnel reflections at the HCF-SMF junctions disturb mode-locking. For this reason unidirectional cavity is desired and the reflections from the junctions have to be perfectly isolated. This was done by a circulator and an isolator in our setup. Unidirectional operation incorporating a SAM is not obvious. This is why a circulator was applied resulting in a σ -type cavity but introducing an additional 3 dB loss on each transmission.

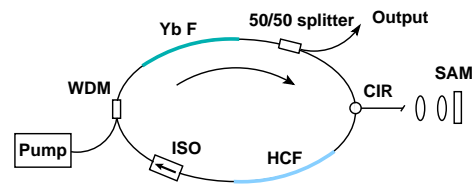


Fig. 1. Fiber laser setup

3. Results

Initially the output was coupled out on the 20% port of a 80/20 splitter that was placed between the isolator and the WDM assuming there the shortest pulse duration and the 50/50 splitter was missing from the setup. We observed stable mode-locking at 200-300 mW pumping with insignificant intensity modulation. Reduction of the pump power resulted in increasing Q-switching and at higher pumping levels double-pulsing occurred. The output power of this system was however too low to further processing without amplification (< 0.5 mW), so we decided to couple light out right after the gain fiber where the intensity is the highest in the cavity. In the final setup the 80/20 splitter was removed and a 50/50 broadband splitter was inserted and used as output coupler.

The output power reached 125 mW corresponding to 4.1 nJ pulse energy, when pumped at 600 mW. The spectrum was measured to be 8.6 nm (Fig. 2 (a)) and the corresponding pulse train showed stable single-pulse operation (Fig. 2 (b)).

It is to be mentioned that the back-reflection at the output fiber end has to be prevented otherwise the gain drops and the oscillator becomes unstable.

The pulse duration at the output is supposed to be of some 10 ps. The pulses were measured after dispersion compensation by a grating pair. The autocorrelation trace (Fig. 2 (c)) of the shortest pulses obtained by varying the grating separation had a width of 322 fs, implying about 210 fs pulsewidth.

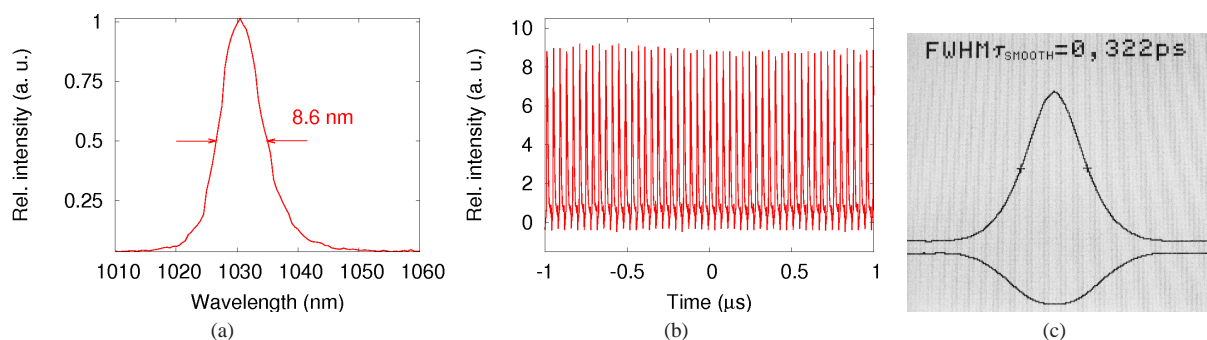


Fig. 2. Output spectrum, pulse train and autocorrelation trace at 600 mW pump power

In conclusion it is demonstrated that fusion spliced HCF is applicable for intracavity dispersion control in a passively mode-locked σ -type fiber laser which is a step towards an all fiber cavity. However it should be emphasized that stable laser operation can be established by adjusting the SAM. This means that mode-locking of such system with a fiber integrated SAM is not obvious.

Acknowledgement

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4. References

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