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Monolithic All-PM Femtosecond Yb-doped Fiber Laser Using Photonic Bandgap Fibers

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***Abstract*—We present a monolithic Yb fiber laser, dispersion-managed by an all-solid photonic bandgap fiber, and pulse-compressed in a hollow-core photonic crystal fiber. The laser delivers 9 nJ, 275-fs long pulses at 1035 nm.**

I. Introduction

Recently, there were notable achievements in the pulse duration and the pulse energy of femtosecond Yb-doped fiber lasers [1]. Most demonstrated solutions used the free-space coupling between the laser elements. Only few of the demonstrated Yb fiber lasers allowed direct fiber-end delivery of femtosecond pulses. Here, we demonstrate a stable all-fiber laser, with the intra-cavity dispersion managed by a novel PM all-solid photonic bandgap fiber (PM SC-PBG) [2], which is spliced into the cavity. The ex-cavity final pulse compression is realized by a spliced-on PM hollow-core photonic crystal fiber (PM HC-PCF) [3].

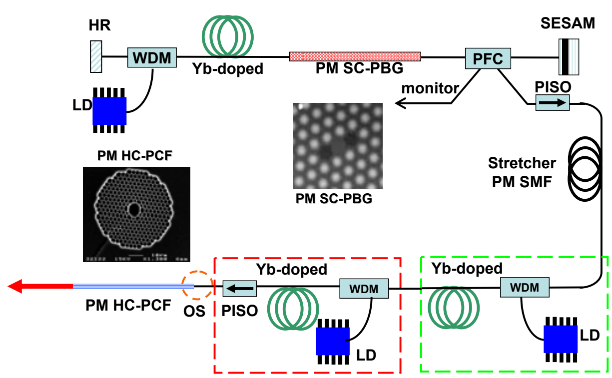

Fig. 1. Laser layout. HR - high-reflectivity pigtailed mirror, WDM - 980/1030 wavelength division multiplexer,PM SC-PBG - PM all-solid photonic bandgap fiber, SESAM - semiconductor saturable absorber mirror, PFC - polarization filter coupler, LD - pump laser diode at 974 nm, PISO - polarization-maintaining isolator, PM SMF - polarization-maintaining single-mode fiber, PM HC-PCF - polarization-maintaining hollow-core photonic crystal fiber, OS - optimized splice. Inset: SEM images of SC-PBG and HC-PCF separately. SC-PBG and HC-PCF are courtesy of Crystal Fibre A/S.

II. Laser Design and Performance

Our fiber laser system, shown in Fig. 1, consists of a modelocked linear cavity oscillator, a pre-amplifier, a power amplifier, and a spliced-on HC-PCF, which are separated by fiber optic isolators. Using such a spliced-on HC-PCF the output laser pulse can be compressed down to femtosecond duration with low loss and a high degree of polarization stability [4].

The Yb-fiber linear oscillator cavity consists of a WDM, 0.32 m PM Yb-doped fiber, a 1.21 m PM SC-PBG, a PM 80/20 2x2 filter coupler and a PM single mode (SM) fiber, which are confined between a high-reflectivity broadband fiber-pigtailed mirror and a fast SESAM with 24% modulation depth. The SESAM ensures stable and self-starting modelocking of the laser. The total cavity length is 3.7 m and provides a oscillator repetition of 26.7 MHz. The cavity is pumped by a 974 nm SM laser diode.

The PM hybrid TIR/bandgap all-solid PCF [2] with anomalous dispersion is used for cavity dispersion compensation. The TIR guidance in one plane of the fiber is provided by the undoped silica core and Boron-doped silica stress rods. The bandgap guidance in another plane of the fiber is provided by an array of Ge-doped rods embedded in a undoped silica host medium surrounding a silica core. The undoped, Ge-doped, and Boron-doped silica regions are seen in the SEM inage as grey, light grey, and black areas, respectively. Stress rods provide the needed birefringence within the transparency window of the fiber at 1000 - 1075 nm, whereas the PBG structure provides the anomalous dispersion (see Fig. 2(a)). The dispersion of PM SMF and HC-PCF, also used in this laser, are also shown in this figure. These dispersion curves are measured with the low coherence interferometry method [5].

The oscillator delivers sub-ps pulses centered at 1032.2 nm with a FWHM bandwidth of 8.6 nm, as shown in Fig. 2(b). The spectrum after the amplification but before HC-PCF compression is broadened to approximately 11 nm at FWHM.the spectral shape of the laser pulse before and after HC-PCF compression does not change, which indicates a very small nonlinearity of the HC-PCF at this pulse energies. When the oscillator pump power increases, the oscillator output spectral central wavelength will shift towards longer wavelengths, which indicates the tendency of formation of stronger and longer pulses in the cavity, conforming to the higher negative net cavity dispersion.

The oscillator output is first stretched in a 35 m standard PM SMF, then preamplified in a single-mode amplifier, and finally end-amplified in a booster amplifier. The stretcher is necessary to avoid significant nonlinearity in the amplifier such as self phase modulation (SPM). The preamplifier is used to achieve a high contrast between the laser output and amplified

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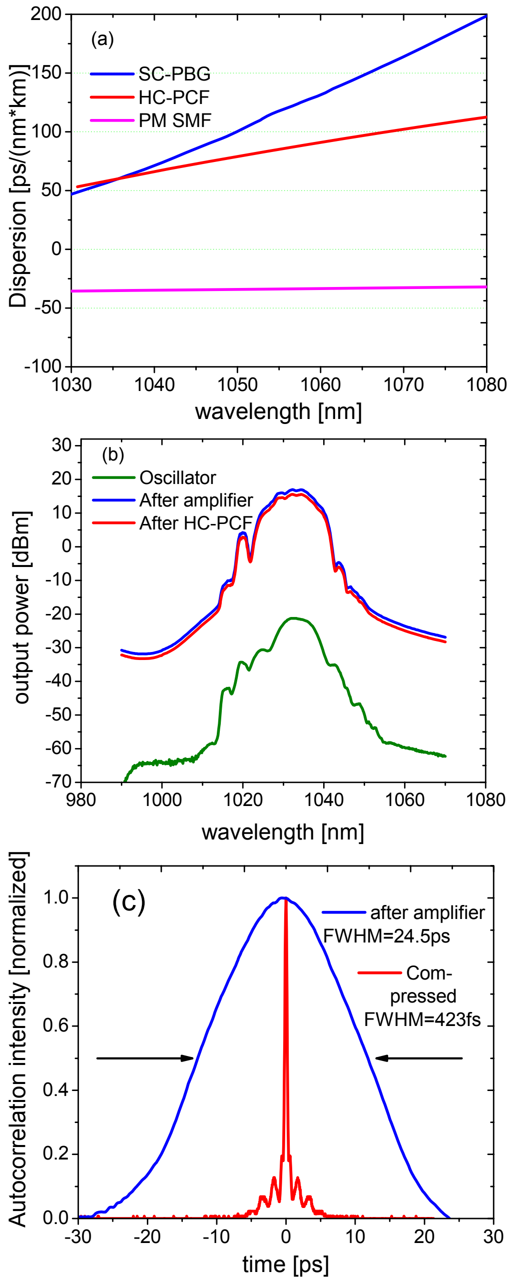

Fig. 2. (a) Dispersion of SC-PBG, HC-PCF and PM SMF in the fiber laser system. (b) Laser spectra measured from the oscillator, after the amplifier and at the output end of the laser. (c) Autocorrelation trace of the laser pulses at the end of the amplifier, and at the output end of the laser.

spontaneous emission in Yb before launching the signal into the end-amplifier. The broadband laser output is then isolated and compressed by a PM HC-PCF [3] using an optimized splicing procedure [6] which gives the splice loss as low as 0.54 dB.

The measured autocorrelation duration of the laser pulse after the end-amplifier but before HC-PCF compression is 24.5 ps at FWHM, which corresponds to around 15.9 ps pulse duration. After compression in 18.5 m of spliced-on HC-PCF, the autocorrelation of the laser pulse is reduced to 423 fs at FWHM. This would correspond to an estimated pulse duration of about 275 fs. The output pulse energy is 9 nJ.

Our laser demonstrates a very stable performance. No Q-switch events are observed during hundreds of hours of test operation. At room temperature the oscillator output power fluctuates by only 0.25%. Also, the temperature stability test was performed, that revealed a hysteresis-free decrease of laser output power by approximately 10% when the temperature was sweeped from 10^{o}C up to 40^{o}C. At any temperature, the stable modelocking operation of the laser was maintained.

III. Conclusion

We have demonstrated an all-fiber, very stable, all-PM femtosecond Yb-fiber laser using SC-PBG for intra-cavity dispersion compensation and HC-PCF for final pulse compression. Directly from the fiber end, our laser delivers 9 nJ pulse with the duration of about 275 fs.

Acknowledgment

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