Monolithic stabilized Yb-fiber All-PM laser directly delivering nJ-level femtosecond pulses

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the intracavity components of the oscillator, as well as to a permanent damage to the subsequent amplifier stages.

In order to stabilize our laser against Q-switching, we employ a narrow-band fiber Bragg grating serving as an end mirror on one side of the cavity. Stronger pulses in optical fibers undergo stronger self-phase modulation, which leads to an increase in the spectral bandwidth of the pulse. Thus, the excess energy of the pulse will be spectrally redistributed to the shorter and longer wavelength sides of the pulse spectrum with respect to its central wavelength. Most of this excess energy, added to a pulse due to a strong intensity fluctuation, will leave the cavity past the narrow-band FBG, and the laser will be stabilized [2]. Therefore, the FBG in this case acts as an optical limiter. The separate and combined contributions of the SESAM and FBG to the total cavity loss are shown in Fig. 2. The laser enters a stable modelocking regime, when the maximum of the combined SESAM-FBG reflectivity is achieved, and the cavity has a minimal loss. The FBG also acts as a means of cavity dispersion management in our laser, since the spectrum of any FBG contains the positively and negatively chirping regions. In our laser the pulse is formed on the negatively chirping side of FBG reflectivity spectrum, and thus the effect of propagation through the positively chirping fibers of the cavity is being balanced [3].

Our laser is sequentially preamplified in a chain of single-mode amplifiers in order to achieve a high contrast between the laser output and amplified spontaneous emission in Yb, and finally end-amplified in a booster amplifier. The amplified output of the laser is launched into a long piece of a PM SMF, where its spectrum is broadened up to 11 nm of bandwidth, which permits femtosecond operation. The broadband laser output is then isolated and launched into a PM HC-PCF [4] using an optimized splicing procedure [5].

The SEM image of the HC-PCF used, the resulting mode shape of the laser, and measured and calculated autocorrelations (AC) of the laser pulse are presented in Fig. 3. The mode shape is near-perfect Gaussian with an elongated hexagonal pattern visible in the low-intensity part of the image, which is typical for the birefringent hollow-core PCFs [3], [5]. The measured AC could not be fitted with any parameterized function and had a FWHM duration of 615 fs. The comparison with calculated ACs of the Fourier-limited pulse (pulse shape FWHM of 370 fs, AC FWHM of 596 fs), and of the pulse resulting from a numerical propagation through a HC-PCF (pulse shape FWHM of 415 fs, AC FWHM of 729 fs) shows, that the experimental pulse has a FWHM duration very close to that of the Fourier-limited pulse, i.e. 370 fs. The longer duration of the pulse from HC-PCF propagation model can be explained by slightly lower than specified [4] 3rd order dispersion in the fiber used in our experiment. Combined loss of the HC-PCF compressor, comprising of the splice loss and the attenuation in the fiber, only amounted to 1.35 dB, and the resulting femtosecond pulse energy was 4 nJ.

Fig. 3. (a) SEM image of the HC-PCF. Courtesy of B.J. Mangan, Crystal Fibre A/S. (b) Measured far-field mode profile mode on the logarithmic intensity scale. (c) Measured (red) and calculated autocorrelations of Fourier-limited laser pulse (green), and the shortest pulse resulting from the HC-PCF compression modelling (blue).

III. CONCLUSION

We have presented a fully monolithic (i.e. without any free-space coupling) FBG-stabilized, all-PM femtosecond Yb-fiber laser highly stable against chaotic Q-switched modelocking. Compression of an amplified laser output in the spliced-on PM HC-PCF provides near-transform-limited pulses of around 370 fs duration and 4 nJ pulse energy, directly delivered from the fiber end with a high optical mode quality. Exceptional environmental stability of our laser suggests that it may be used as a compact and reliable seed source for the high power applications.

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