Femtosecond All-In-Fibre Laser Based On Chirped Pulse Amplification

J.-B. Lecourt, C. Duterte, Y. Hernandez, and D. Giannone

Multitel, Applied Photonics Department, 2 rue Pierre et Marie Curie, 7000 Mons, Belgium

We present a fibre laser dedicated to THz generation with DAST/DSTMS organic antennaes. The setup is based on an all-fibred polarization maintaining Chirped Pulse Amplification configuration. The oscillator, passively mode-locked by SESAM, operates at a central wavelength of 1560nm with a repetition rate of 50MHz. The signal is then amplified by a highly Erbium-doped fiber. During amplification, the optical spectrum is highly broadened up to about 30nm. Finally the optical pulses are compressed into a 15µm/NA=0,08 fibre. The output pulses have duration of 75fs with an average output power of about 100mW, suitable for an efficient broadband THz generation.

Introduction

Ultra-short pulses are required for many applications such as medical imagery, microsurgery, micromachining or TeraHertz generation. Among the sources of ultra-short pulses, fiber lasers become more and more attractive because of their reliability, low cost and maintenance-free operation. In a lot of cases, high-power ultra-short pulse fiber lasers are built with free space optic devices which are able to sustain high level of power and perform functions difficult to achieve with fibers such as dispersion compensation without non-linear effects [1].

Interesting configurations have already been published demonstrating high peak power oscillators [2], new devices for saturable absorption [3] or new fibres for compensation dispersion [4].

In recent work [5] 56fs pulse duration, 2,6nJ pulse energy at repetition rate of 40 MHz has been demonstrated amplifying a mode-locked laser based on Non-linear Polarisation Evolution (NPE) with a Large Mode Area (LMA) Er-doped fiber. This configuration permitted to obtain high peak power values but with a randomly polarized output. Moreover the authors do not mention the core size of the LMA fiber and then single transverse mode operation is not clear. In the reference [6], 44kW peak power, 80fs pulse duration at a repetition rate of 48MHz have been demonstrated but the compression of the pulses takes place in a 25µm multimode fiber resulting in a probably low spatial quality beam. In this experiment the polarization is maintained linear with the use of free-space beam splitters. With the help of Raman solitonic compression which shifts wavelength operation, ultra-short pulses have also been demonstrated. For example with a non-Polarisation Maintaining (PM) setup combined to free space optics, 35kW peak power, 100fs pulse duration at a repetition rate of 52MHz are generated in a multimode Er/Yb-doped fiber [7]. Even if only the fundamental mode is amplified, the experiment has to be conducted with a lot of care regarding beam coupling in the fiber and handling. In another work using Raman solitonic compression in an all-fibered setup, pulse duration of 82fs with average power of 131mW at a repetition rate of 50MHz have been demonstrated but the laser output is not employing PM fibres and is probably

slightly multimode due to the use of a 17µm-core (NA= 0,13) LMA Erbium doped fiber [8].
In this paper we propose a PM all-fibered laser operating at 1,55µm delivering ultra-short pulses and high peak power. The laser combines linear polarization, in a fully-fibered configuration and a Gaussian beam quality at the same time. This laser will be therefore a suitable source for broadband TeraHertz Generation [9].

Experimental setup

The experimental setup is shown on figure 1. The laser is based on an all-fibred Chirped Pulse Amplification (CPA) method.

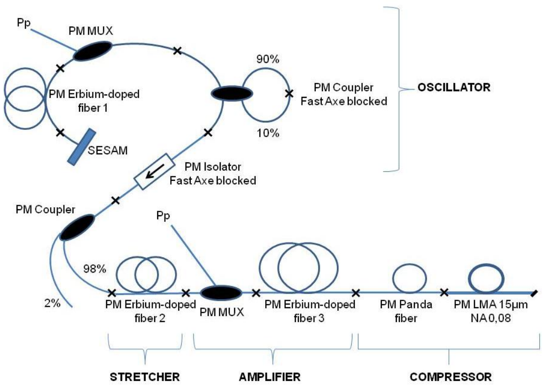

Figure 1: Experimental Setup.

The Polarization Maintaining (PM) oscillator is based on a very simple configuration. The pump power supplied by a 980nm laser diode is launched into the cavity through a PM multiplexer. The amplifier medium is a PM highly Er-doped fiber exhibiting a high absorption of 55dB/m @ 1530nm. Self-starting mode-lock operation is ensured by a high contrast (ΔR=30%) and very fast (τ=2ps) SEmiconductor Saturable Absorber Mirror (SESAM). On the other side of the Fabry-Perot cavity, a 90/10 PM coupler, is used as a loop mirror. It acts as a mirror with a net reflection of 36% and as a polarizer since the fast axis is blocked. To our knowledge, such a configuration to build PM mode-locked fiber lasers has never been published elsewhere even if a similar configuration has been reported but only with single-mode fibers [10]. The total dispersion of the cavity is estimated to be 0,03ps/nm and thus remains anomalous. It is well-known that this kind of lasers called solitonic lasers emits Fourier-limited pulses with low energy [11]. In our case the average output power is 3mW, the repetition rate is 52MHz and pulse duration is about 300fs, leading to pulse energy of 58pJ and peak powers close to 200W.

A PM isolator with fast axis blocked and a 98/02 PM coupler are spliced at the output of the cavity in order to respectively avoid any reflection back from the amplifier and to check the oscillator operation during the amplification.

A PM slightly Erbium-doped fiber exhibiting negative chromatic dispersion has been spliced before the amplifier in order to increase pulses duration and to induce a negative chirp to the optical pulses. Note that pulse duration also increases during amplification under the effect of the negative chromatic dispersion.

Amplification occurs in a highly doped PM Erbium fiber exhibiting negative chromatic dispersion. All along the fiber, the interplay between non-linear effects and the chromatic

dispersion broadens the optical spectrum leading to deliver highly-chirped pulses with duration of few picoseconds at the output of the amplifier.
For pulse compression, instead of using bulk gratings [12] or Photonics Crystal Fiber (PCF) [13], we use a 15µm core PM Large Mode Area (LMA) fiber with a Numerical Aperture (NA) of 0,08 exhibiting positive dispersion. The core area, significantly larger than one of a standard fiber, permits to reach higher peak powers without loosing the advantage of a high beam quality.

Results

Laser efficiency, represented on figure 2, is linear as observed in numerous works before. The laser can deliver up to 125mW of average output power with a repetition rate of 52MHz. This means that the highest pulse energy available is 2,4nJ.

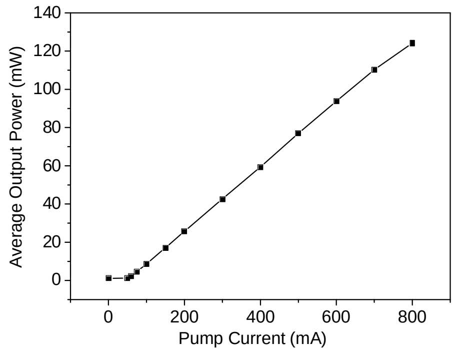

Figure 2: Laser efficiency.

The optical spectrum broadens all along the fiber amplifier from 10nm to 40nm depending on the pump power. A span of 15µm LMA fiber has been spliced at the output. The length of this fiber has been optimized to compensate for the positive chirp accumulated by the optical pulse in the amplifier. The shortest pulse duration obtained is 72fs which corresponds to the Fourier limit. The related peak power is 27kW. The autocorrelation trace of the optical pulse is represented in figure 3. There is a small pedestal demonstrating that the output pulse has not a purely linear chirp. This is mainly due to the non-linear effects and the higher-order chromatic dispersion occurring in the fiber.

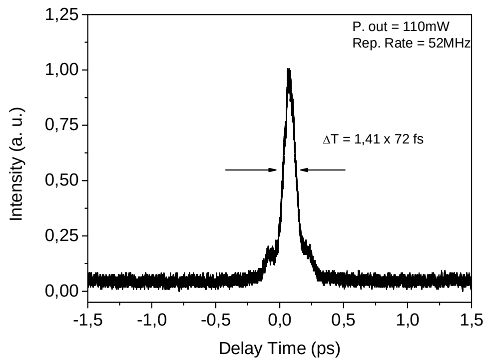

Figure 3: Autocorrelation trace for 700mA pump current.

We think that the laser peak power is limited by the core diameter of the 15µm fiber. To improve these results larger core LMA fibres would be required. Nevertheless, to sustain a single transverse mode, the NA of the LMA fibres has to be decreased in order not to loose the advantage of the fiber approach. Others improvements could be done using fibers exhibiting higher chromatic dispersion for the compression, limiting then the length of the LMA fiber required to recompress the optical pulse and avoiding the appearance of non-linear effects.

Conclusion

We have demonstrated a PM fibered ultrashort pulsed laser for TeraHertz generation. The PM oscillator is based on a new configuration which has never been reported so far to our knowledge. With a fiber amplifier and LMA-based compressor, the laser delivers 75fs pulses at 52MHz with an average power up to 100mW.

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