Subpicosecond As_2S_3 Fiber Ring Laser

Thibault North and Martin Rochette
Department of Electrical and Computer Engineering
McGill University, Montreal, Qc, Canada
e-mail: thibault.north@mail.mcgill.ca

***Abstract*—We demonstrate the operation of a fiber ring laser using a short segment of chalcogenide fiber. The laser is passively mode-locked via nonlinear polarization rotation and provides two different operation regimes of subpicosecond transform-limited pulses.**

***Index Terms*—chalcogenide, nonlinear polarization rotation, passive mode-locking**

I. Introduction

Fiber ring lasers are known to produce short and powerful pulses when passively mode-locked using nonlinear polarization rotation (NPR) [1], saturable absorbers [2] or other additive pulse mode-locking techniques [3]. A polarizer can take advantage of NPR to shorten circulating pulses by letting their highest intensity components pass through and attenuate their wings [4]. Indeed, the combined effects of cross-phase modulation (XPM) and self-phase modulation (SPM) lead to a nonuniform rotation of the polarization state across the pulse. However, in order to avoid the deterioration of pulses and stability issues, the nonlinear phase shift should remain under a maximum of 2π [5], [6]. It has been shown that the total dispersion in a ring dictates the minimum achievable pulse width [7], and pulses as short as 77 fs have been demonstrated in a short fiber cavity [8].

In this paper, we make a first demonstration of using chalcogenide glass as the nonlinear medium for NPR in a fiber ring laser. The high nonlinearity provided by chalcogenide enables the formation of nonlinear pulses with low peak power. This is a step forward to the conception of compact and low power consumption laser sources. In addition to its nonlinearity, chalcogenide glass is also transparent in the mid-infrared (M-IR) and thus can serve to make pulsed laser sources in this wavelength range. We provide a theoretical basis to support the dynamics of this laser and a complete set of experimental results.

II. Experimental setup

Figure 1 shows a schematic of the As_2S_3 fiber ring laser. It comprises an erbium-doped fiber amplifier (EDFA), a highly nonlinear fiber (HNLF), two polarization controllers (PCs), and a polarizer. A coupler O_1 extracts 1% of the power out of the loop for monitoring purposes. The HNLF is a single-mode As_2S_3 fiber of $19.5\,\mathrm{cm}$ in length with a waveguide nonlinear parameter $\gamma = 0.16\,\mathrm{W^{-1}\,m^{-1}}$ and a dispersion coefficient $D = 410\,\mathrm{ps\,nm^{-1}\,km^{-1}}$. NPR takes place in that segment of fiber having a γ parameter ~ 1000 times that of standard silica fiber. The As_2S_3 fiber is pigtailed to standard silica

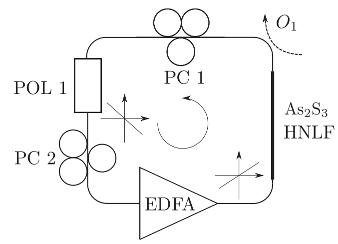

Fig. 1. Schematic of the As_2S_3 fiber ring laser and its polarization states.

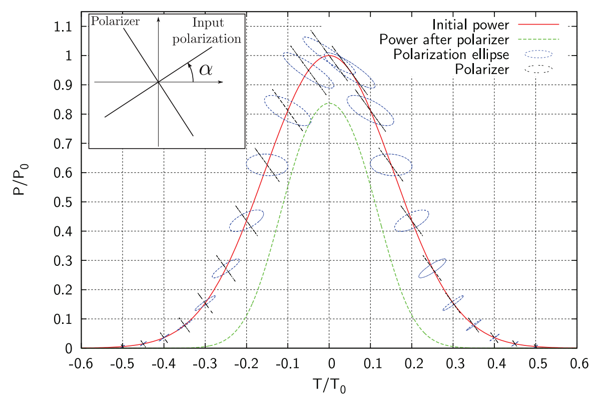

Fig. 2. The propagation of a Gaussian and linearly polarized pulse of angle α experiences NPR in a nondispersive medium. The polarization ellipses are shown at different positions of the pulse. Then, a polarizer of angle $\alpha + \pi/2$ is added and illustrates the resulting pulse shortening.

fibers using UV-cured epoxy, leading to a total insertion loss of $4.5\,\mathrm{dB}$. The EDFA is composed of $10\,\mathrm{m}$ of erbium-doped fiber, with a normal-dispersion propagation parameter $D_{\mathrm{edfa}} = -4\,\mathrm{ps\,nm^{-1}\,km^{-1}}$. The EDFA has a built-in isolator which conveniently ensure self-starting of the laser cavity [5]. With a proper alignment of the two PCs and an EDFA gain of $20\,\mathrm{dB}$, increasing the losses for continuous-wave (CW) state, pulsing occurs. Figure 2 illustrates the mechanism of NPR along the pulse profile which after passing through a polarizer leads to pulse shortening.

III. Results & Discussion

A proper adjustement of the polarization state leads to several self-pulsating regimes spawned by NPR. Two different regimes were observed, each with their own spectral and temporal properties. Regime 1 has a typical solitonic spectral shape with sidebands, while regime 2 has a wider and flat

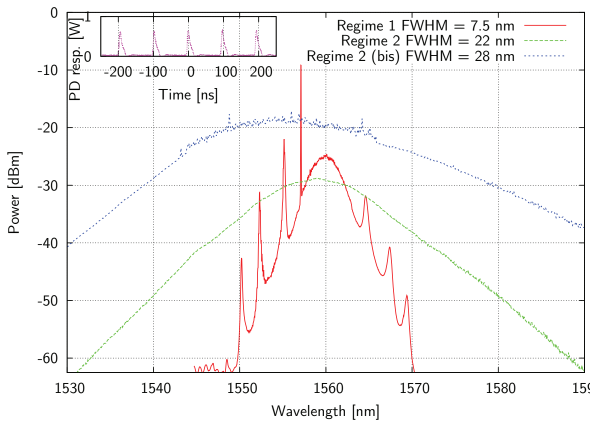

Fig. 3. *(solid)* Fiber laser spectrum operating in regime 1 *(dashed & dotted)* Operation in regime 2

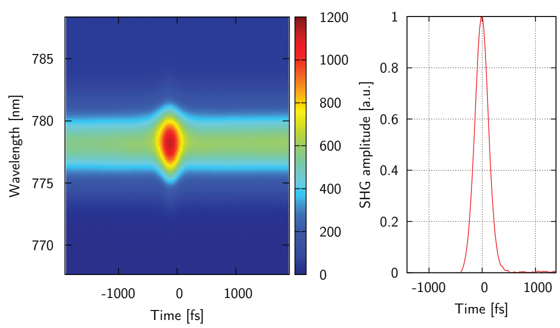

Fig. 4. Spectrogram and autocorrelation acquired using the FROG

spectrum. Both lead to transform limited pulses.

Figure 3 shows the spectrum of regime 1, centered at a wavelength of 1560 nm. Important sidebands are present; known to be a consequence of phase-matched dispersive waves emitted mostly at the polarizer, and other regions perturbing solitonic propagation. Indeed, fiber sections with gain or losses, sudden variations of both the dispersion and the nonlinearity prevent the soliton from adapting adiabatically [9], [10]. The sidebands are relatively strong, which is a good indication that the minimal pulse width has been reached. As confirmed by the frequency resolved optical gating (FROG), pulses corresponding to that pulsating regime are unchirped, and are as short as 380 fs according to the inverse fourier transform of the spectrum.

Regime 2 was observed by changing the polarization state at both PCs. It provides a spectrum that stretches with respect to regime 1, as illustrated by the dotted line of figure 3, and suggesting shorter pulses. Shorter corresponding pulses were indeed observed using the FROG. Extinction occurs within a few seconds, and a continuous tuning of the PCs was sometimes required to maintain that regime. The large bandwidth observed is due to SPM in the normal dispersion As_2S_3 fiber and to the fact that the associated pulses are shorter. Also, pulses are accompanied by a CW signal, as noted in the spectrogram of figure 4. Single pulses with a duration of 205 fs were observed.

The repetition rate of the laser was 10.42 MHz, which corresponds to a cavity length of 19.9 m. The measured peak power was of 96 W. The power is shared between the CW signal and the pulses, with a peak nonlinear phase shift of $\phi_{\mathrm{NL}} \cong \pi$, which has already been reported to lead to stable operation [11].

Passive mode-locking via NPR was achieved in a chalcogenide fiber, leading to subpicosecond pulses. It is known that both the average dispersion in the cavity and its length are particularly important in achieving the shortest possible pulses, and limit the spectral sidebands [7]. In our setup, the 20 dB gain of the EDFA, the corresponding losses from the As_2S_3 and the polarizer as well as the dispersion discontinuities in one round trip force the solitons to emit dispersive waves. However, chalcogenide fiber is a good candidate for a similar source in the M-IR due to its high transparency in this spectrum range. A gain media emitting in the M-IR, such as thulium-doped fibers providing amplification between 2 and 2.1 µm can be used for this purpose.

Acknowledgment

The authors gratefully thank the National Optics Institute (Qc) for financial support.

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