Mode-locking by nanotubes of a Raman laser based on a highly doped GeO_2 fiber

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Abstract: A mode-locked Raman laser, using 25 m of a GeO_2 doped fiber as the gain medium, is reported employing carbon nanotubes. The oscillator generates 850 ps chirped pulses, which are externally compressed to 185 ps.

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1. Introduction

Raman amplification in fiber lasers is a widely used technique to generate light sources from the visible to the near infrared. Unlike typical lasers based on rare-earth doped elements, such as erbium and ytterbium, the operation wavelength of a Raman laser is not limited to a specific emission band defined by an active doping element, and high-power continuous-wave (CW) Raman lasers were already developed at numerous wavelengths within the transparency window of silica [1, 2]. Furthermore, mode-locked lasers can also take advantage of Raman gain to generate wavelength versatile short-pulsed sources [3, 4], especially if a broadband saturable absorber is used, such as nanotubes [4-12] or graphene [13-15].

Here, we report a Raman laser passively mode-locked by a nanotube-based saturable absorber (CNT-SA) using only 25 m of a highly-doped GeO_2 fiber as the gain medium. Although doping silica fibers with GeO_2 to enhance nonlinearities has been routinely used for decades, concentrations higher than 50 mol.% have only been achieved in the last few years [16]. Such fibers usually present nonlinearities at least one order of magnitude higher than standard telecom fibers (STF), making them an attractive gain medium for the development of Raman lasers using shorter cavities [2]. In contrast to few hundred meter gain fibers used in previously reported ultrafast Raman lasers (e.g. 450m in Ref.[3], 100m in Ref. [4]) the results presented here indicate that mode-locked Raman lasers can potentially be made as short as rare-earth doped mode-locked fiber lasers, avoiding instability problems and low repetition rates related to very long cavities.

2. Experimental setup

The all-fiber geometry is shown in Fig. 1. The mode-locked cavity consists of 25 m single-mode normal-dispersion optical fiber, with an enhanced germanium oxide (GeO_2) concentration (75 mol.%) , core pumped through a wavelength-division multiplexer (WDM) by a CW Raman laser at 1455 nm, with no need for synchronous pumping.

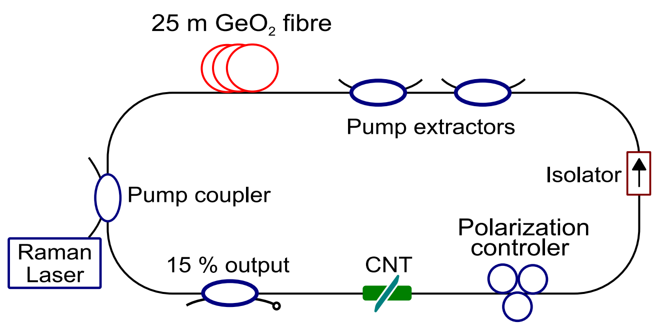

Fig. 1. Experimental setup. CNT: nanotube-based saturable absorber.

The saturable absorber interface is formed by a ~30 µm CNT polymer [4] composite integrated into the cavity between a pair of fiber connectors. A polarization insensitive inline optical isolator and a fiber-based polarization controller stabilize the mode-locking. Light is extracted from the unidirectional cavity through a 15% output coupler. In order to prevent high-levels of un-depleted pump power damaging the passive cavity components, two WDM couplers are used to extract the residual pump light after the gain fiber.

3. Results

Self-starting mode-locking is achieved for pump powers from 4.2 W up to 5 W, the maximum power available from our CW pump source. Fig. 2 shows the pulse trace and the spectrum obtained for laser operation just above threshold. The pulses at the output are 850 ps long with 0.4 mW average power. In contrast to few hundred kHz pulses generated in previous ultrafast Raman laser experiments [3,4] (e.g. 205 KHz in Ref. [3]), our pulse repetition rate is 4.85 MHz, corresponding to one pulse per round trip in the ~42 m cavity. The spectrum centered at 1553 nm has a 3 nm bandwidth and a squared shaped typical of lasers operating in the dissipative soliton regime. In order to verify the chirped nature of the pulses, expected in mode-locked lasers operating in the normal dispersion regime, 12.7 km of STF was spliced to the output of the laser providing anomalous group-velocity dispersion. The pulse trace and the spectrum after the STF are also shown in Fig. 2. The pulses were compressed to 185 ps and the spectrum remained largely unchanged, indicating that the compression was due to the linear dispersion induced by the STF and not due to nonlinear effects.

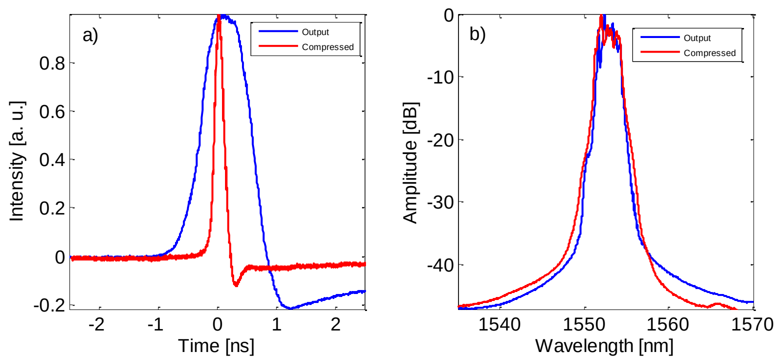

Fig. 2. (a) Oscilloscope trace of pulses before and after compression. (b) Corresponding spectra, before and after compression.

4. Conclusions

We have demonstrated a passively mode-locked Raman laser using as the gain medium only 25 meters of a highly doped GeO_2 fiber in an all-fiber configuration employing carbon nanotubes as the saturable absorber. The fundamental frequency of 4.85 MHz shows that ultrafast Raman lasers can present repetition rates comparable with rare-earth doped fibre systems. The net-normal dispersion cavity generated 850 ps long pulses at 1553 nm that were externally compressed by 12.7 km of STF to 185 ps, showing the chirped nature of the output pulses. Combining Raman gain and carbon nanotubes is an attractive technique to generate wavelength versatile short pulsed sources across the transparency window of silica fiber. Further characterization of the GeO_2 fiber parameters and an external compression closer to the transform-limit of the pulse is ongoing.

5. Acknowledgements

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