Sub-ps erbium doped fiber laser with nanotube mode-locker

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Abstract: We fabricate a sub-ps erbium doped fiber laser using a carbon nanotube-polymer composite mode-locker. The spectral and pulse width data are analysed to evaluate the contribution of different physical process into ultra-short lasing.

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1. Introduction

Carbon Nanotubes (CNT) are rolled up graphene sheets. Their electronic properties depend on diameter and chirality, i.e. the twist angle along the tube axis [1]. Semiconducting tubes have a band gap, which varies inversely with their diameter [1]. CNTs are one-dimensional objects so their electronic density of states and absorption spectra consist of series of strong one-dimensional singularities. Nanotubes of different diameter and/or chirality have different absorption energies. The CNTs one-dimensionality and heterogeneity is the basis for their potential application as fast optical switches [2,3]. For example, the strong saturable absorption of CNTs was used to make amplified spontaneous noise suppression filters [5]. Recently, a passively mode-locked Erbium Doped Fiber (EDF) laser, incorporating a CNT-mode-locker, was reported [4,5]. However, no detailed spectrum analysis was presented.

The easy and cheap processing of CNTs into films or composites, as well as their good radiation and thermal stability, can make them the best candidates for the replacement of semiconductor saturable absorption mirrors (SESAM), which are commonly used in passively mode-locked ultra-fast lasers [6]. Most SESAMs are currently made by depositing superlattices of InGaAs and InP, followed by further ion implantation to reduce their recovery time [6]. Here, we present an EDF laser using CNT–polymer composites as mode lockers and report its lasing properties as a function of inter-cavity power.

2. Experimental

We use single wall carbon nanotubes (SWNT) deposited by laser ablation, synthesised with Ar as flow gas, 1 atom % Ni and Co as catalysts and an oven temperature of 1000°C, as described in ref. 7. The as-prepared soot is further purified by using dimethylformamide to wash out fullerenes, amorphous carbon and some of the metal

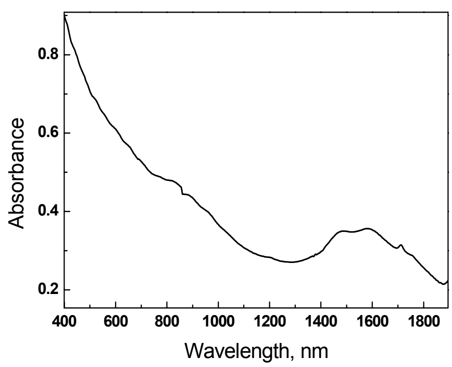

Fig.1. Optical absorbance of CNT-PVA composite.

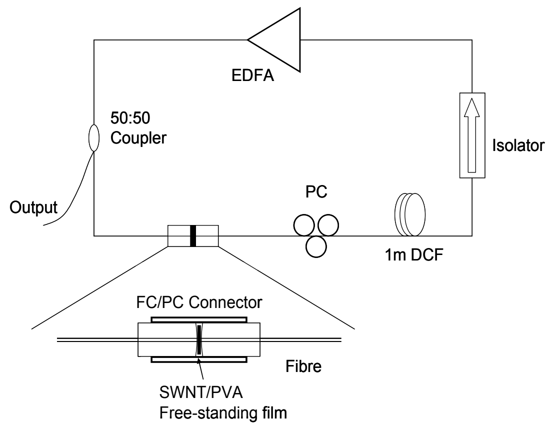

Fig.2. EDF laser scheme.

content, as for ref. 8. The material is then dissolved in water by using sodium dodecylbenzene sulphonate (SDBS) surfactant-assisted ultrasonication (Bioruptor ultrasonic processor, Diagenode). Next, the CNT water solution is mixed with polyvinyl alcohol (PVA) and the resulting solution evaporated in air. This allows us to get ~50 µm free-standing CNT-PVA composite films. Their absorption spectrum is shown in Fig. 1 and has a broad optical

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absorption band centred at ~1.5 µm. The CNT-based mode-locker is then fabricated by sandwiching the CNT-polymer composite in a FC/PC connector after depositing an index matching gel to both fiber ends. This device is then placed in a fiber ring cavity. The laser scheme is shown in Fig. 2. The main constituent of the cavity is the EDF amplifier (EDFA) (PMA 32, HighWave Optical Technologies Corporation), which is pumped by a 980 nm semiconductor laser. Other components of the cavity are a fiber polarization controller (PC), an isolator, a 50/50 fiber coupler and 1 meter of dispersion compensated fiber (DCF) as dispersion compensation component. We use one port of the 50/50 coupler to have a feed-back into the cavity, while the second port is used to study the fundamental cavity repetition rate (Textronix oscilloscope, TDS 2024), autocorrelation trace (Inrad autocorrelator, 5-14-LDA), pulse spectrum (HP optical spectrum analyzer, 86140A) and output power.

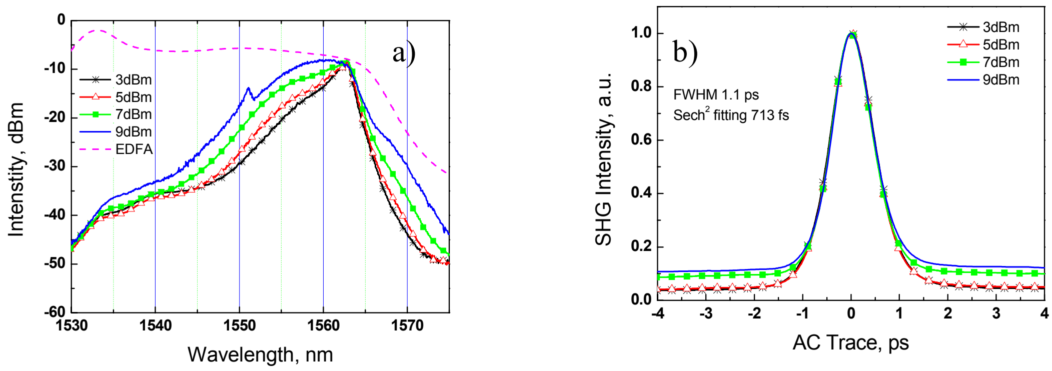

Fig.3. (a) Output optical pulse spectrum and (b) SHG autocorrelation trace.

Our laser shows stable mode-locking with fundamental repetition rate ~5-MHz and output power up to 9 dBm (8 mW). Figure 3 plots the output spectrum and the second harmonic generation (SHG) autocorrelation trace. The output optical pulse spectrum has a complex structure (Fig. 3a). The sharp intensity decrease in the long-wave spectral range is due to the limitation of our EDFA output spectrum (EDFA curve, Fig. 3a). With increasing EDFA output power the main band at ~1563 nm widens and other spectral futures at ~1552 and 1570 nm appear. The spectral broadening of the main band is caused by the decrease of the contributions due to continuous wave (cw) lasing. This could be a sign that the inter cavity power is not enough to fully saturate the CNT-mode-locker under low pumping power conditions (below 7 dBm), resulting in single mode lasing accompanied by cw lasing. On the other hand, the appearance of the sub-bands at ~1552 nm and 1570 nm (curves 7dBm and 9 dBm, Fig. 3a) proves that, under high power pumping, fiber non-linearities should be considered [6]. This is confirmed by the autocorrelation data in Fig. 3b. The pedestals are inherent for high output power data (curves 9dBm and 7dBm, Fig. 3b), showing the presence of noise floor in the cavity. The $sech^2$ fitting of the normalized autocorrelation data gives a pulse-width of ~713 fs.

In conclusion, we demonstrated a 713 fs pulse passive mode locked EDF laser, using CNT-polymer composites as mode-lockers. We also report the presence of additional dynamics in the spectrum.

Acknowledgments

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References

[1] R. Saito, G. Dresselhaus, M. S. Dresselhaus, "Physical Properties of Carbon Nanotubes" (Imperial College Press, London, 1998)
[2] Y.-C. Chen, N.R. Raravikar, L.S. Schadler, P.M. Ajayan, Y.-P. Zhao, T.-M. Lu,. G.-C Wang, X.-C. Zhang, 'Ultrafast optical switching properties of single-wall carbon nanotube polymer composites at 1.55 µm,' Appl. Phys. Lett. **81,** 975-977(2002).
[3] A.G. Rozhin, Y. Sakakibara, H. Kataura, S. Matsuzaki, K. Ishida, Y. Achiba, M Tokumoto, Chem. Phys Lett. **405**, 288-293 (2005)
[4] S.Y. Set, H. Yaguchi, M. Jablonski, Y. Tanaka, Y. Sakakibara, A.Rozhin, M. Tokumoto, H. Kataura, Y. Achiba, K. Kikuchi, Trends in Optics and Photonics (TOPS) Vol. **86**, Optical Society of America, Washington, 2003, pd. 44.
[5] Y. Sakakibara, A. G. Rozhin, H. Kataura, Y. Achiba, M Tokumoto, Jpn. J. Appl.Phys. **44**, 1621-1625 (2005).
[6] G.P. Agrawal, "Application of Nonlinear Fiber Optics" (Academic Press, San Diego. 2001)
[7] S. Lebedkin , P. Schweiss , B. Renker , S. Malik , F. Hennrich , M. Neumaier , C. Stoermer , M. M. Kappes, *Carbon* **40** (2000), 417-423.
[8] F. Hennrich, R. Wellmann, S. Malik, S. Lebedkin, M. M. Kappes, *Phys. Chem. Chem. Phys.* **5** (2003), 178–183.