Optical properties of carbon nanotubes and their applications to photonic devices

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ABSTRACT

Recent discovery of ultra-fast optical saturable absorption in single-walled carbon nanotubes (SWNTs) have found several photonic applications, amongst which the most practical application is for laser passive mode-locking. We review the optical properties of SWNT, and introduce our research on passively mode-locked fiber lasers.

1. INTRODUCTION

Carbon nanotubes have many interesting and versatile physical properties [1]. However, relatively little attention has been paid for their optical properties until quite recently. Recently, authors have proposed and demonstrated a saturable absorber incorporating carbon nanotubes [2-5] which offers several key advantages such as: ultra-fast recovery time, polarization insensitivity, high optical damage threshold, mechanical and environmental robustness, chemical stability, and the ability to operate both in transmission, reflection and bi-directional modes. In this paper, we review the optical properties of SWNT, and introduce our research on passively mode-locked fiber lasers.

2. OPTICAL PROPERTIES OF SWNT

Carbon nanotube is a nanostructure of carbon, discovered in 1991 by S. Iijima. It is an extension to the carbon bucky-balls discovered by R.E.Smalley, and a third kind of carbon beside graphite and diamond. Carbon nanotubes are classified into multi-walled and single-walled nanotubes (MWNT and SWNT), and interesting optical properties are in SWNTs. Structure of SWNTs is determined by a single parameter, called chirality [1]. Depending on the chirality, SWNTs exhibit two different electrical properties, metallic or semiconducting. Semiconducting SWNTs has energy bandgaps like in ordinary semiconductors, and photons having corresponding wavelength are absorbed by the SWNT. This absorption is saturable, and its recovery time is quite fast due to multi-phonon emission process, faster than 1ps [6,7]. Good thing is that the bandgap energy in semiconducting SWNTs can be controlled by the tube diameter. A tube diameter of ~1.2nm gives absorption at wavelength around 1550nm. However, it is not yet possible to synthesize only one chirality selectively in any method. Therefore, the sample is a mixture of several types of SWNTs.

3. FABRICATION OF PHOTONIC DEVICE

The SWNT-based photonic devices have been fabricated through several processes. First, the SWNTs were synthesized. There are several synthesis methods of SWNTs, including laser ablation, and HiPco (High Pressure carbon-monoxide). After a series of purifying processes, the high-purity SWNTs were dispersed in ethanol and then sprayed onto the surface of quartz substrate. These processes, however, are time-consuming and low-throughput.

We demonstrated a new fabrication technique of SWNT-based photonic devices [8, 9]. It is based on the low-temperature alcohol catalytic CVD method [10], and can synthesize high-quality SWNTs directly onto the quartz substrates and the single-mode fiber (SMF) ends. Figs.1 show the FE-SEM image of the synthesized SWNTs directly onto the cleaved end of SMFs

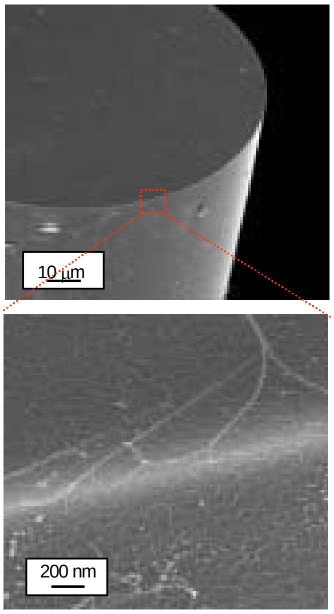


Fig.1 FE-SEM image of SWNT directly synthesized onto cleaved end

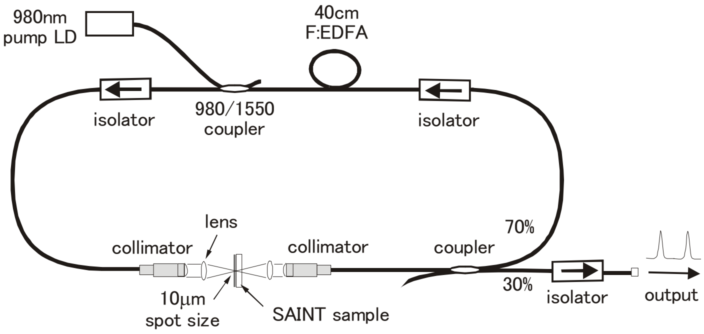
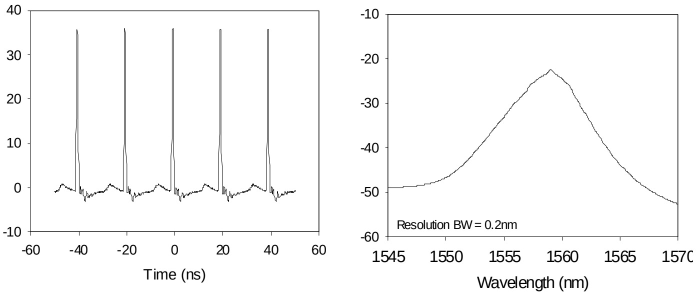


Fig.2 Mode-locked fiber laser with directly synthesized



(a) (b)

Fig.3 Laser output. (a) Pulse waveform (b) Spectrum

4. APPLICATION TO FIBER LASERS

We have applied the SWNT-based saturable absorber in passively mode-locked fiber lasers [2-5,8,9]. Here we show the results using the directly synthesized SWNT in Sec.3 [8,9].

The schematics of the mode-locked fiber ring laser are shown in Fig. 2. A very short length (40cm) of flouride-based Er-doped fiber (EDF) is used as the laser gain medium. We used the SAINT directly synthesized onto quartz substrate, fiber-coupled with fiber collimators and a focusing aspherical lens.

With a pump power of around 17mW, the laser self-starts to mode lock and produce single pulses in a round trip time, as shown in Fig.3(a). The fundamental repetition rate is of 50.4MHz. The output average optical power is about -7dBm. The output spectrum is shown in Fig.3(b), showing that the 3dB spectral width is ~3.0nm. We also measured autocorrelation trace, and inferred full-width half-maximum (FWHM) width is estimated to be 0.9psec. The resulting time-bandwidth product of 0.34 indicates that the pulses are transform-limited.

We also achieved very short (~2cm) passively mode-locked fiber laser whose pulse repetition rate is as high as 5GHz [11].

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