A Noise Suppressing Saturable Absorber at 1550nm Based on Carbon Nanotube Technology

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Abstract: We present an ultra-fast saturable absorber device based on single-walled carbon nanotubes. The saturable absorbing effect was observed using 1ps optical pulses at 80GHz. This device possesses promising characteristics for applications such as a noise suppresser or a mode-locker.

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1. Introduction

Recently, passive saturable absorbers have attracted increasing attention for their applications in extending the bit-rates and error-free transmission distances of periodically amplified optical transmission systems [1-4]. Saturable absorber devices offer a potentially simple and cost effective solution for passive optical regeneration. The noise suppression capability of such devices can attenuate the accumulated amplified spontaneous emission (ASE) noise more than the higher-power signal component, thereby increasing the signal-to-noise ratio (SNR). Currently reported and demonstrated saturable absorber devices, for such applications are mostly, semiconductor-based multi-quantum-well (MQW) devices [1-4]. Such MQW devices require complex and costly fabrication systems like MOCVD or MOVPE to grow, and may require additional substrate removal process. Furthermore, high-energy (4MeV~12MeV) heavy-ion implantation is required to reduce the device recovery time from a few nanoseconds to ~5ps. The MQW saturable absorber must also be used in reflection mode for polarization-independent operation, therefore requiring an optical circulator, which increases the total device insertion loss to > 6dB [2,4]. Additionally, MQW-based devices may require expensive hermetic packaging for long-term environmental stability, and may not withstand high optical input powers. So far, there was no other alternative material for saturable absorber at 1550nm to challenge the MQW-based saturable absorbers.

Carbon nanotubes, discovered in 1991 by Iijima[5], are unique nanostructures with fascinating electrical, mechanical, chemical and optical properties[6]. Amongst all these remarkable properties, there has been relatively little experimental work on the optical properties of carbon nanotubes. The saturable absorption property of single-walled carbon nanotubes (SWNT) was first observed by Sakakibara et al.[7]. Recently, Chen et al.[8] has also reported the third-order nonlinear polarizability, and optical-induced transparency effects in SWNT polymer composite, with an exciton decay time < 1ps, for all-optical switching applications.

We experimentally studied a thin layer of SWNT spray coated on a glass substrate using 1ps pulses at 1550nm, and measured its saturable absorption characteristics using the z-scan power measurement and also spectral measurement. The sample possesses ultra-fast response time (<1ps), is polarization insensitive, and can be used in transmission mode. Additionally, since carbon nanotubes are known to possess resilient mechanical properties and are chemically stable, special hermetic packaging is not required, and an exceptionally high optical damage threshold is expected. Moreover, the fabrication cost and complexity of carbon nanotubes are potentially much lower than that of the MQW devices. In this paper, we present the results confirming the properties of carbon nanotubes as an ultra-fast saturable absorber, for applications such as a noise suppresser.

2. Fabrication of Carbon Nanotubes

The carbon nanotubes samples used are SWNTs synthesized by a laser ablation method [9]. High energy laser pulses from a Nd:YAG laser were used to ablate a metal catalyzed carbon target placed in a quartz tube filled with 500 Torr of Ar gas. The quartz tube was heated in an electric furnace. By careful control of the furnace temperature and the adoption of specific catalysts with appropriate relative concentrations, diameter-selective SWNTs with a mean diameter at ~1.1nm were grown [10]. The SWNTs were dispersed in ethanol and then sprayed onto the surface of a 1mm thick quartz substrate using an airbrush forming a thin film of SWNTs (~1µm). A section of the substrate is not coated to serve as a reference region.

3. Experimental setup

The experimental setup is shown in Fig. 1. The laser source was a fiber laser operating at 1550nm, similar to that reported in [11], which produced 80GHz, 1ps soliton pulse bunches (~120 pulses), with a cavity round-trip frequency of 4.4MHz. A variable optical attenuator (VOA) was employed to control the power of the laser. The average optical power was 3.8dBm, when the attenuator level was set at 0dB. The laser pulses were launched through a fiber collimator, passed through an aspherical lens (f=2.5) and focused onto the surface of the sample coated with SWNT film. Depending on the z-position of the SWNT sample, the spot size of the focusing beam passing through the SWNT film could be varied from ~200µm down to a minimum of ~10µm, when it was positioned at the focal point (z=0mm). Another set of aspherical lens and fiber collimator was used to collect the outgoing beam from the sample back into a short piece of fiber connected to either an optical power meter or an optical spectrum analyzer.

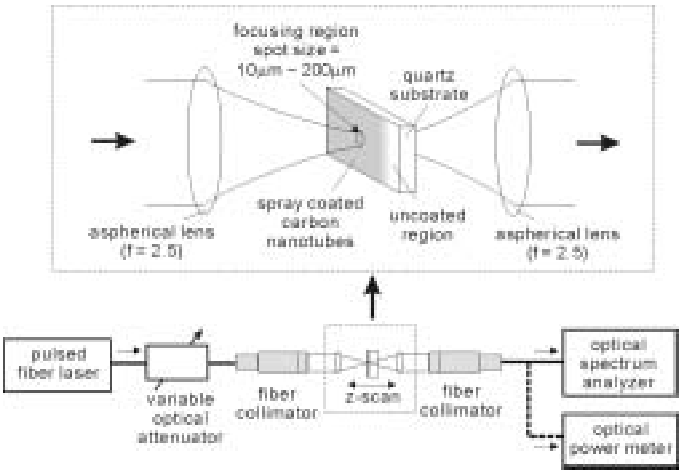

Fig. 1. Z-scan experimental setup.

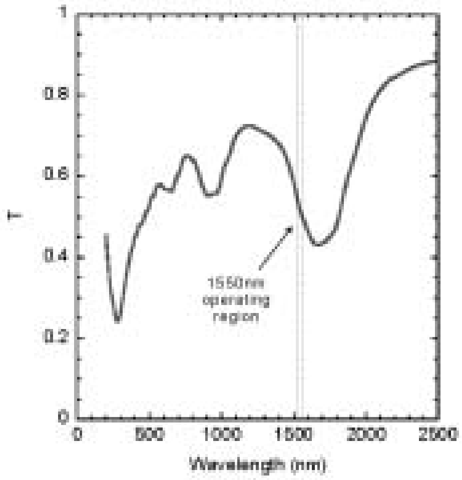

Fig. 2. Broadband transmission spectrum of the sample.

4. Results and discussions

The broadband transmission spectrum of the sample is shown in Fig. 2. The first absorption band is located around 1680nm, corresponding to a gap energy of 0.738eV and a nanotube diameter of ~1.1nm, according the Kataura plot [12]. A z-scan experiment [13] was carried out, whereby the z-position of the sample was varied to achieve different spot sizes, and hence optical intensity, passing through the SWNT film. The results of the z-scan experiment with different laser launch powers are shown in Fig. 3. When the laser intensity was low, at z = -1.0mm (ø=100µm), the transmission of the SWNTs (reference with the uncoated substrate) was measured to be ~63% (-2dB), similar to the linear transmission of the sample measured using a broadband source. However, the transmission of the sample increased when the laser intensity was raised, by moving the sample to positions with smaller spot sizes. The transmission was at a maximum at z = 0mm, where the spot size was at its minimum of ~10µm, and the laser intensity was at a maximum (estimated at 5.8µJ/cm^2 per pulse, peak intensity=5.8MW/ cm^2). The z-scan experiment was repeated with different optical launch powers by changing the attenuator level of the VOA. As expected, the transmission peak at z=0mm decreased as the optical power was reduced (Fig. 3). These phenomena were not observed when the laser pulses were launched through the uncoated part of the substrate. The transmission or loss of the sample is evidently dependent on the optical power of the input light, the property of a saturable absorber. This phenomenon occurs because there is a finite number of SWNTs in a thin layer that absorb light through excitonic absorption. The absorption is saturated when a large number of incoming photons exhaust the available SWNT excitonic absorption centers.

High-resolution spectral transmission measurements were also carried out to further confirm the saturable absorber property of the sample. The sample was fixed at z=0mm, where the z-scan results showed a maximum transmission. The output spectra were taken using an optical spectrum analyzer in high-sensitivity mode. The spectral transmission characteristics of the sample were taken on the SWNT-coated region. For reference, spectral data was also taken on the uncoated region of the quartz substrate. The effects measured were confirmed to be purely due to the SWNTs. The changes in transmission compared to the linear absorption are plotted in Fig. 4, for various optical launched powers. The linear absorption profile of the SWNTs, measured using a broadband ASE source, serves as a baseline reference (Fig. 4).

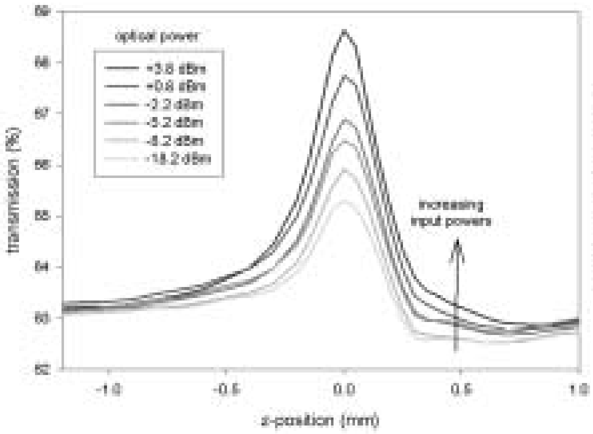

Fig. 3. Z-scan results with different launched powers.

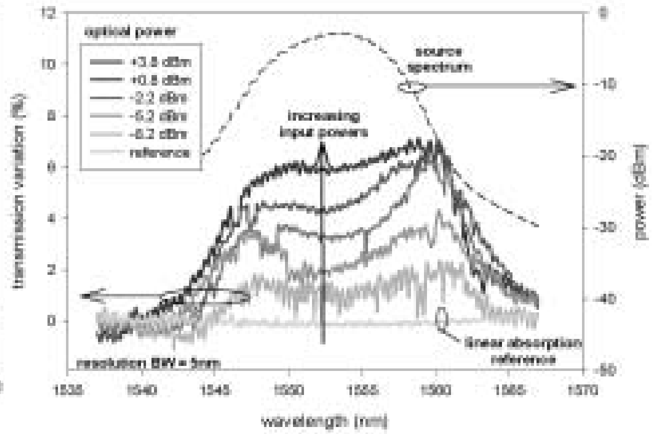

Fig. 4. Transmission spectra with different launched powers.

When the pulsed laser was used, the sample exhibited an increased transmission over the spectral region of the pulse source. As expected, an increasing launched power caused an increasing transmission (reduced loss) in the spectral region of the pulsed source. At the highest launched power of +3.8dBm (VOA=0dB), the transmission deviated from the linear case by up to >6% in the spectral region of the input pulses. This shows that the SWNT sample is capable of preferentially suppressing lower intensity noise components, such as the ASE noise (Fig. 4). The double-hump features on the spectral transmission correspond to the spectral contents or Fourier components of the pulse where its temporal intensity is high. The results are in agreement with our numerical simulation, where an intensity dependent loss, as in the case of a saturable absorber, gives rise to similar double-hump spectral transmission variation characteristics. Furthermore, the spectral results indicate that the sample has an inhomogeneously broadened absorption, which can respond to pulses on a timescale of 1ps.

5. Conclusion

A saturable absorber at 1550nm based on carbon nanotube technology was demonstrated. This new class of device offers many advantages over the traditional MQW-based devices, such as low manufacturing cost and complexity, physical resilience, environmental robustness, ultra-fast response time, and low loss. The performance we have shown in this initial sample is still far from its full potential. The carbon-nanotube-based saturable absorber is a promising candidate for applications like ultra-fast 2R regeneration, noise-suppression, and laser mode-locking.

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