1. INTRODUCTION

Over the past twenty years, since the semiconductor saturable absorber mirrors (SESAMs) were successfully developed [1], there has been a great interest on the investigation of passively mode-locked solid-state lasers for the generation of ultrashort pulses, due to their attractive applications in many fields and their advantages including compactness, flexibility, and a wide spectrum ranging from the visible to the infrared. SESAMs have been well proved as a promising device for passive mode locking in many kinds of solid-state lasers [2–5]. SESAMs are grown by metal-organic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE) on Bragg mirrors. In addition to strict fabrication requirements, they often undergo high-energy heavy-ion implantation to create defects in order to reduce the recovery time [6]. Furthermore, SESAMs typically cover a narrow operation wavelength range. Hence, new materials with strong ultrafast optical nonlinearities, broad operating range, and simple fabrication are in demand.

Carbon nanotubes (CNTs) are one of the most important materials due to their unique electric mechanic and optical properties and have been widely investigated since their discovery [7]. Especially, single-walled CNTs (SWCNTs) exhibit fast recovery times, chemical stability, and broad spectral range, roughly between 1 and 2 \( \mu \)m [8–10]. Semiconducting SWCNTs turned out to be a promising material for saturable absorbers for laser mode locking [11–14]. SWCNT-based saturable absorbers can be fabricated in a much simpler and cost-efficient way with well-known techniques such as spray [15], spin coating [16] or horizontal evaporation methods [17, 18].

In 2002, Shimoda et al. [19] fabricated carbon nanotubes at atmosphere and found them appear some extent of alignment, which will help to laser polarization absorption. Kim et al. [20] made Carbon nanotubes of in-plane orientation by Langmuir–Blodgett method and measured the polarized UV-Vis-Nir absorption spectra. However, Expensive device is needed in Langmuir–Blodgett method. Furthermore, for vertical evaporation at atmosphere, too much time (about two to three weeks) will be taken to finish the growth. In this letter we demonstrated a kind of single wall carbon nanotube absorber grown on glass by the method of vertical evaporation in an oven. Detailed nonlinear characteristics as an absorber such as modulation depth, lifetime were measured. To our knowledge similar work has not been reported by far.

2. FABRICATION AND MEASUREMENT

The SWCNT material was purchased from Golden Innovation Business Company. The diameter of the SWCNTs is about 1.5 nm and the length distribution was from 1 to 5 \( \mu \)m. The SWCNTs were processed by \( \text{H}_2\text{SO}_4/\text{HNO}_3 \) so that they could dissolve into the water. First, 1 mg SWCNT powder was put into 10 ml 0.1% SDS (sodium dodecyl sulfate) aqueous solution. Here SDS is used as surfactant. In order to get SWCNT aqueous dispersion with high absorption, SWCNT aqueous solution was ultrasonic agitated for 6 to 30 h. As Fig. 1 shows, the absorption of the dispersion at 1060 nm increases with the ultrasonic time at the first 6 h and doesn’t change at the next 30 h. We consider that the absorption of the solution will get higher when the SWCNTs disperse better. After the ultrasonic process, the SWCNT dispersed solution was centrifuged to induce sedimentation of large SWCNT bundles. After decanting the upper portion of the centrifuged solution, the SWCNT dispersion was prepared for the film fabrication. Then, the SWCNTs dispersion were poured into 10 × 10 × 45 mm\(^3\) polystyrene cell inserted with hydrophilic glass substrate as Fig. 2. The polystyrene cell was then put into an oven and gradually evaporates. The oven was kept at 40°C during the evaporation process. The cell will dry after
about 3 days, which was much shorter than evaporation at atmosphere. The latter usually takes two to three weeks. Sometimes the SWCNTs will aggregate in the dispersion in several weeks.

We designed a Pump-Probe setup for nonlinear measurement of the SWCNT absorber as Fig. 3. The pump-probe apparatus is driven by a series of ultrafast laser system from Spectra-Physics Corporation, including Tsunami femtosecond laser, Spitfire Pro amplifier and TOPAS-C OPA system. The laser sys-

**Fig. 1.** Dependence of absorption at 1060 nm on ultrasonic time.

**Fig. 2.** A schematic illustration of the vertical evaporation process. SWCNTs were dispersed in deionized water to form a suspension into which a hydrophilic glass was insert along the diagonal line of the cell. With gradual evaporation of the water in an oven, the SWCNT stayed on the glass substrate around the air/water/substrate triple line [16].

**Fig. 3.** Pump-probe setup for nonlinear parameter measurement of the SWCNT absorber.