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Research paper

Optical characterization of tip bended Vertically Aligned Carbon Nanotubes array

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HIGHLIGHTS

- Refractive index of the tip bended Vertically Aligned Carbon Nanotubes array (VACNT) has been calculated to be ∼1.8.
- Optical reflectance of the tip bended VACNT array surface depends on both the polarization state and the angle of incidence.
- The finding of this research could help in the future to develop an angle sensing device that can measure the two angular positions simultaneously.

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ABSTRACT

Vertically Aligned Carbon Nanotube arrays (also termed as VACNTs or CNT forest) have recently found to be transformable to a reflective mirror from a naturally black absorber. The feature of improved reflectance can be attained by the controllable tip bending process using the bottom surface of a rotated cylindrical tool (the process called micro-mechanical bending (M2B)). In this paper, the polarized light reflectance of bent and compacted region of the CNT forest using M2B method has been investigated. We observed that reflectance from the processed CNT zone was highly dependent on the angle of incidence and polarization state of the incident laser. For the first time, the refractive index of the tip bent CNT forests by M2B method was investigated and found to be in a range of ∼1.8.

1. Introduction

Carbon Nanotubes (CNTs) and Vertically Aligned Carbon Nanotubes (VACNTs) are well known for their individual and collective nanostructure property[1]. CNTs are being applied in various engineering fields which include high strength materials [2], nanotube transistors [3], cooling fins [4], solar energy collectors [5], and so on. It is also useful in the optical application. The National Aeronautics and Space Administration (NASA) made use of VACNTs array as a light absorber because of its high optical absorption property [6 7]. However, recently, the behavior of structurally modified CNT forest as a reflector has been demonstrated by Saleh et al. [8]. They have shown that the top surface of the CNT forest could be transformed into a reflective mirror after mechanically bending and flatten the tips of the CNTs inside the VACNTs array. The increase in reflection was significant from 0.045% [7] to 10–15% [8] across a wide range of the spectrum (570–1100 nm). The method mentioned above, called Micro-mechanical bending (M2B) was thoroughly studied and characterized for its usefulness in 3-dimensional and free-form micro-patterning of VACNTs array by Asyraf et al.[9]. In the same paper [9] we showed the influence of different parameters of the M2B process such as tool's rotational speed, step size, and lateral speed on the properties of the resultant surface such as white light reflectivity, structural integrity, and surface roughness. However, in this paper, we are further reporting the polarization dependent optical reflectance of the tip bent CNT forest for a monochromatic green laser (532 nm). The reflectance was investigated by varying both the state of polarization and the angle of incidence.

2. Methodology

CNTs forest used in this study were purchased from a company named Timesnano [10]. The array of multiwalled CNTs were grown on a monocrystalline Silicon substrate of 1 cm by 1 cm base size. The

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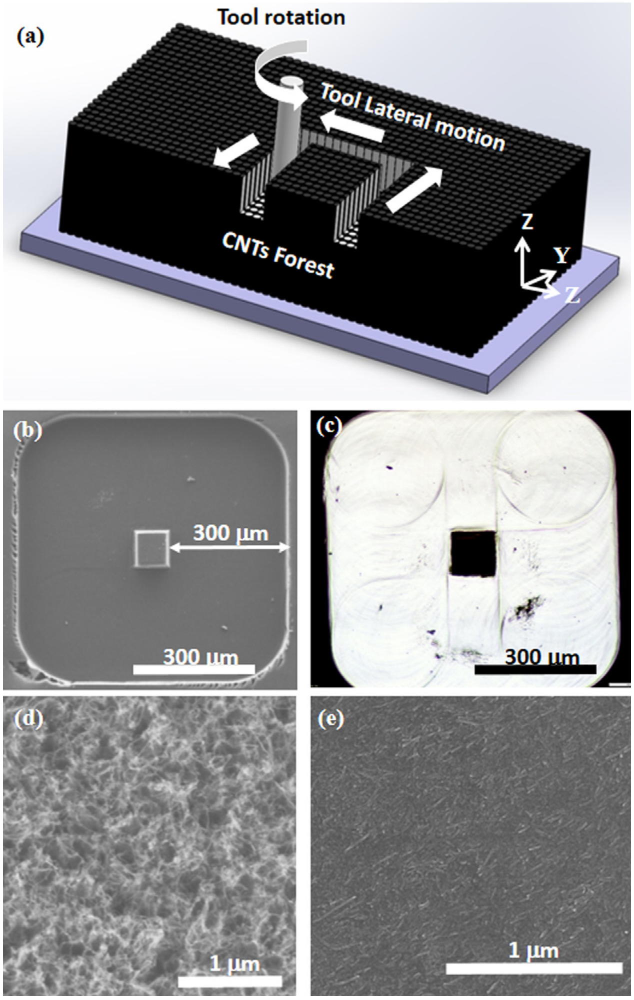

Fig. 1. (a) Schematic diagram of M2B method. (b) FESEM image of a typical square pattern created by the M2B method [9]. (c) Demonstrates white light reflected from the bent CNT forest zone. (d) Untreated CNT forests viewed from top to show the porosity. (e) CNT forest's transformation after undergone the M2B process.

purity of the CNTs was 98%, and the density of the CNT forest was ≤0.3 g/cm3. The diameter of each nanotube varied from 3 nm to 10 nm. The forests of vertically aligned multiwall CNTs had a height up to several 100′s of μm.

2.1. Micro-mechanical bending (M2B) process

The micromechanical bending (M2B) process [9] was performed using a servo-controlled 3-axis Micro-CNC system. This machine can move at 1-μm positioning resolution. First, a micro tool (made of tungsten) was shaped from a 500 μm diameter to 300 μm diameter using a method called wire-electro-discharge grinding (WEDG) [11]. The tip bending process of CNTs was carried out with this micro tool using the M2B method as explained in Fig. 1(a). In the process, the microtool was positioned just above the CNT forest using visual feedback to set the datum. Then, the microtool was programmed to move downward in the Z-direction with defined step size. Subsequently, the tool was moved in the lateral (X- and Y-) directions with a pre-defined translational and rotational speed. Fig. 1(b) shows a field emission scanning electron microscopic (FESEM) image of a square pattern that was produced by the M2B method with the 300 μm micro tool using the optimum parameter (2000 rpm of micro tool's rotational speed, 1 mm/min of lateral speed and 1 μm of step size for a total of 60 μm depth of bend) as identified by Asyraf et al.[9].

The M2B process modifies the morphology of the original CNT forests. Untreated CNT forests are a highly porous material which will trap any incident laser and behaves like a black body. The concept above of the CNT forest's absorption phenomenon was discussed by Rana et al. [12]. They [12] also revealed that closing the pores by densification process could also improve the reflectance. After experiencing the M2B process, the patterned area eventually becomes optically shiny like a reflective mirror as shown in Fig. 1(c). During the patterning process (by M2B) the individual nanotubes are bent and flattened to close the porous gaps at the top surface (Fig. 1(d)) of the CNT forest. As a result, the incident laser was unable to penetrate the VACNTs array hence, reflected from the patterned surface. This phenomenon was described in our previous work by Asyraf et al. [9]. The FESEM photograph of bent and flattened CNT forest surface is shown in the Fig. 1(e).

Previous researchers reported that light could transmit through only a few micrometers of CNTs ($<80\,\mu m$) [13] and can get reflected from the substrate, whereas the CNT forests samples used in this study has an average height in the range of $\sim$300 μm. Due to that, the reflection coming from the substrate (silicon wafer) could be ignored considering the thickness of the CNT forests.

2.2. Experimental setup for optical characterization

To conduct the optical characterization of the M2B processed CNT forest, an experimental setup was arranged as shown in the Fig. 2. The setup included a laser source (which was partially polarized), an iris, an attenuator, a polarizer, a lens, a photodetector and a power meter. The partially polarized laser source emits laser continuously with a constant wavelength (532 nm). Iris and attenuator were used to adjust the spot size and to filter the power of the laser. The polarizer was used to vary the polarization angle from S- to P- polarization. Experiments were

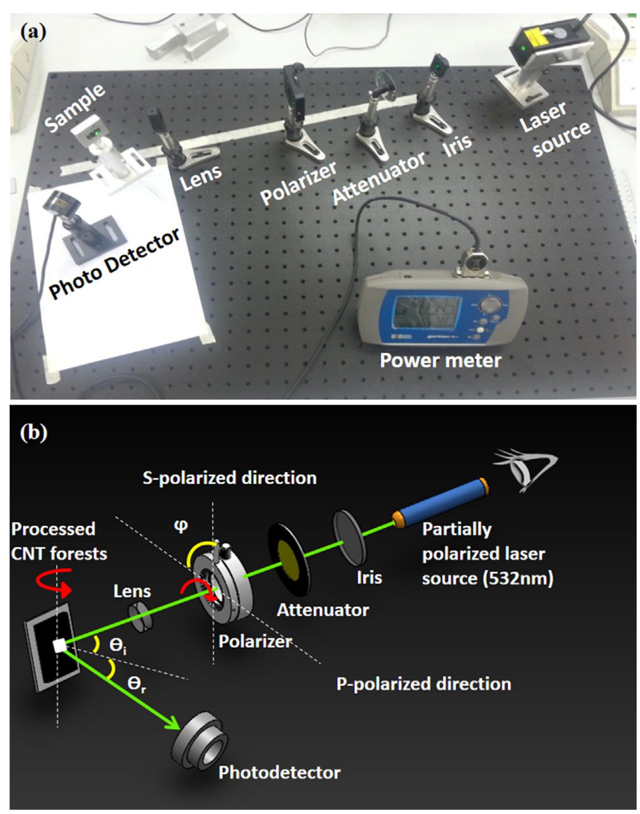

Fig. 2. (a) Describes the actual experimental setup used for this study. (b) Describes schematically the concept of different angular variation.