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Investigation of optical and dispersion parameters of electrospinning grown activated carbon nanofiber (ACNF) layer

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ABSTRACT

Activated carbon nanofiber (ACNF) layers are prepared by electrospinning method. We have investigated the optical properties of ACNF layer using UV–vis-NIR spectrophotometer. The optical constants such as refractive index, extinction coefficient and dielectric constants were evaluated using reflectance and transmittance spectra for ACNF layer. The optical energy gap of ACNF layer was determined as 1.07 eV. The refractive index dispersion of ACNF layer was analyzed by using the single oscillator model proposed by Wemple and DiDomenico. The dispersion parameters such as oscillator energy and dispersion energy values of ACNF layer were determined. Several dispersion parameters such as optical dielectric constant at higher frequency, lattice dielectric constant, oscillator average wavelength, oscillator average strength and the ratio of carrier concentration to the effective mass were also determined by analysis of refractive index dispersion. Furthermore, the optical conductivity of ACNF layer was evaluated from the analysis of optical dielectric constants.

1. Introduction

Among the carbon nanostructures (e.g., graphenes, carbon nanotubes (CNTs), carbon nanofibers (CNFs), activated carbon nanofibers (ACNFs), and C60), graphenes present new opportunities in photocatalysis and photovoltaic (PV) conversion by the hybrid structures with a variety of nanomaterials, due to their beneficial electrical conductivity, a major specific surface area, and ideal charge carrier mobility [1,2]. Ultra fast photoresponses and new optical functionalities have been achieved with semiconductor nanowires/nanorods grown on the few layer graphene (FLG) and single layer (SLG) substrates for multifunctional optoelectronic device applications [3,4]. CNTs are known as excellent light absorbers [5]. Also, CNTs have excellent advantages in chemical stability, thermal and electric conductivity. The use of CNTs has been recommended for diverse applications such as components of PV devices, energy storage devices, chemical sensors, actuators, and metrology-probe tips [6,7]. Carbon nanofibers (CNFs) have received much attention due to their various potential applications such as rechargeable battery [8], hydrogen storage [9], electrode materials in electrochemical capacitor cells [10], gate materials in nanoelectronics [11], etc. B. Réti et al. reported that the CNFs also play a role in extending the absorption edge and enhancing photoelectric activities. This unique nanostructures hold great promise for potential applications in solar cells because of their excellent optical and electronic transport properties [12].

Recently, activated carbon nanofibers (ACNFs) have attracted considerable attention because of their various applications, such as energy storage devices, capacitors [13] or lithium ion second batteries [14]. Nowadays, these carbons are produced from precursors, such as poly(L-lactic acid) (PLLA) [15], polyacrylonitrile (PAN)-based fibers [16], rayon-based fibers [17], etc. Amongest the different fabrication methods of carbon nanofibers [18–20], electrospinning method is still the dominant technique for the production of large amounts of nanofibers [20]. Electrospinning method is a simple technique for producing nanofibers from organic polymers and inorganic oxide materials. ACNF has been fabricated by the electrospinning approach followed by subsequented heat treatment steps. Because the diameter of the prepared electrospun nanofibers ranges from sub-microns to nanometers scales, this type of material should display various effective benefits such as remarkable mechanical properties, excellent porosity and high specific surface area [21–23].

In earlier work of our other group, they have reported the performances of nanofiber and nanofiber/nanoparticles on proton exchange membrane (PEM) fuel cell [24] and the use of ACNF in microbial fuel

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cells (MFCs) [25]. While mechanical, thermal, and electrical properties of carbon nano structures are very well studied in literature [1–25], to the best of our knowledge, there is no report on the optical and dispersion properties of ACNFs fabricated using electrospinning for use in optoelectronic applications. The present study aims to prepare high quality thin films of ACNFs by low cost technique, i.e. electrospinning. Furthermore, an optical absorption and dispersion characteristics to extract the most important parameters that controls the optoelectronic application of the film are presented. Moreover, we have charaterized them by Scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), and UV–vis-NIR spectroscopy.

2. Experimental

2.1. Fabrication

To make a 14 wt.% polyacrylonitrile (PAN) in dimethylformamide (DMF) solution, PAN and DMF have been used. The solution has been stirred by constant at 60 °C for 2 h. The charged PAN solution has been dispensed by the syringe pump onto a rounded collector drum at a constant rate of 1 cc/h and rotating at 70 rpm. The tip to collector distance was 18 cm and the applied voltage was 20 kV. The precursor mats have been spun under a relative humidity of 10–20% at room temperature. Schematic diagram of the electrospinning experimental setup is given in Ref. 24.

2.2. Characterization

The surface morphology of the nano-structured materials was examined by scanning electron microscopy (Hitachi, S-4700). Optical absorption measurements of the ACNF films was recorded using an UV–vis–NIR spectrophotometer (JASCO-V-670) in the wavelength range from 200 to 2000 nm and at room temperature. The thickness of ACNF layer was estimated using an AEP profilometer (Model no: Nanomap-500 LS). Fourier transform infrared (FTIR) spectra (4000–400 cm^{-1}) were acquired using an VERTEX 70 spectrophotometer (Bruker) at 4 cm^{-1} resolution and 16 scans at room temperature.

3. Results and discussion

3.1. SEM images of ACNF layer

Fig. 1 show the overall SEM photographs of electrospun fiber webs derived from ACNF. The SEM image of ACNF revealed a long and continuous cylindrical morphology. Fig. 1b shows the diameter distribution of the electrospun ACNF. The average diameter is 270 nm distributed from 223 to 396 nm. The comparising nanofibers are partially aligned along the winding direction of the drum winder.

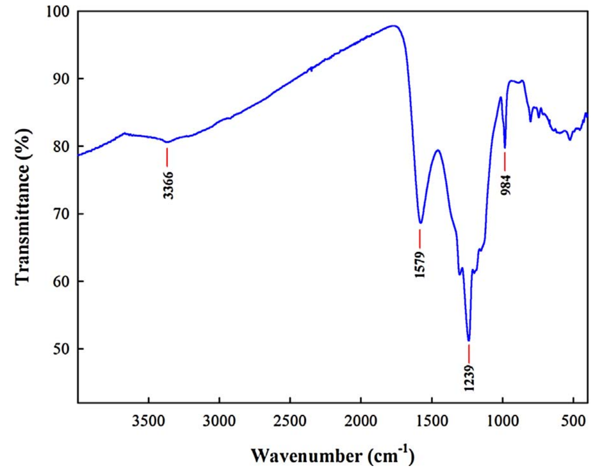

Fig. 2. FTIR spectrum of ACNF layer.

3.2. Fourier transform infrared (FTIR) spectroscopy

FTIR analysis was done to examine the functional groups on the carbon surface. The FTIR spectrum of ACNF layer in transmittance mode was shown in Fig. 2. The attenuated total reflection mode with a diamond crystal was used to scan the samples. FTIR analysis of the activated carbon nanofiber (ACNF) spectrum shows four distinct absorption bands at 3366, 1579, 1239 and 984 cm^{-1}. The FTIR spectrum of heat-treated PAN nanofiber (ACNF) is characterized by the absence of C≡N nitrile group which shows vibration around at 2240 cm^{-1}. The band around 1580 cm^{-1} is due to a mixture of C═N and C═C groups which is attributed to the cyclization and cross-linking. The broad peak around 3400 cm^{-1} corresponds to the presence of interstitial water and hydroxyl groups. The spectrum distinctive absorption bands at 1240 refers to (—O—C(O)—C stretching).

3.3. Transmission and reflection spectra of ACNF layer

The optical constants are obtained by using the transmission spectrum. The layer is assumed to be homogeneous with a uniform thickness. The reflectance (*R*) and transmittance (*T*) characteristics of the ACNF layer were obtained for the normal incidence of light between 200 and 2000 nm at room temperature. They can be expressed by the following relations [26–28]

$$R = \left(\frac{(n-1)^2 + k^2}{(n+1)^2 + k^2}\right) \tag{1}$$

and

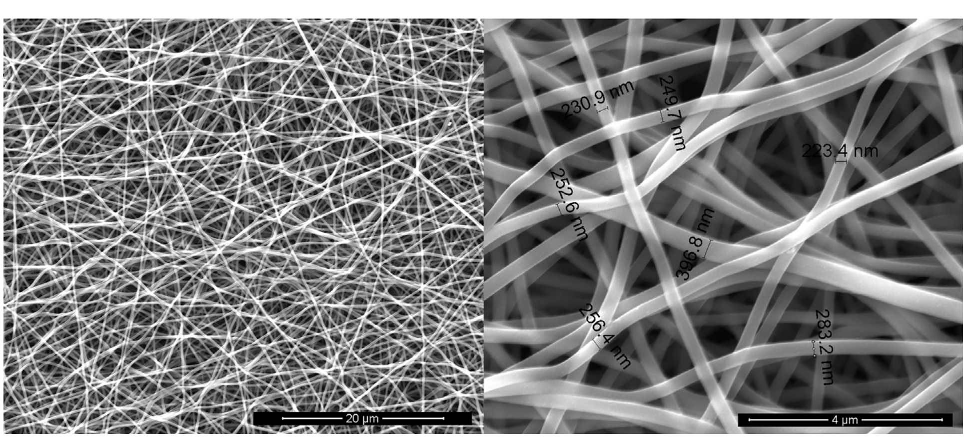

Fig. 1. SEM images showing the morphology of ACNF layer.