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Interferometrically-controlled electrical currents in carbon nanotubes coated by platinum nanoparticles

E. Jiménez-Marín [a], C. Torres-Torres [b,*], C. Mercado-Zúñiga [c], J.R. Vargas-García [a], M. Trejo-Valdez [d], F. Cervantes-Sodi [e], R. Torres-Martínez [f]

[a] Depto. Ing. Metalurgia y Materiales, ESIQIE, Instituto Politécnico Nacional, México, D.F. 07300, Mexico
[b] Sección de Estudios de Posgrado e Investigación, ESIME ZAC, Instituto Politécnico Nacional, México, D.F. 07738, Mexico
[c] Depto. Ing. Materiales, Tecnológico de Estudios Superiores de Coacalco, Coacalco de Berriozábal 55700, Edo. México, Mexico
[d] Escuela Superior de Ingeniería Química e Industrias Extractivas, Instituto Politécnico Nacional, México, D.F. 07738, Mexico
[e] Depto. Física y Matemáticas, Universidad Iberoamericana, Prol. Paseo de la Reforma 880, Lomas de Santa Fe, México, D.F. 01219, Mexico
[f] Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada Unidad Querétaro, Instituto Politécnico Nacional, Santiago de Querétaro, Querétaro 76090, Mexico

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ABSTRACT

Described herein is a spatially selective modification in the conductive effects exhibited by multi-wall carbon nanotubes decorated with platinum nanoparticles. The samples were prepared by a chemical vapor deposition processing route. The changes in the conductivity of the samples in thin film form were achieved and explored by a fringe irradiance pattern impinging on the nanohybrid materials. A vectorial two-wave mixing configuration was performed for varying the electrical behavior of the irradiated film. A noticeable reversible modification in the conductivity of the samples was induced by nanosecond pulses at a 532 nm wavelength in our experiments. The rotation of the angle between the planes of polarization of the incident waves allowed us to switch the electrical currents in a circuit with one input and two outputs. The current-conduction terminals were specifically monitored for cases where the incident beams were displaying parallel or mutually orthogonal polarizations. It was considered that functionalization and metallic decoration processes present opposite responsibilities for the evolution of the electrical phenomena in carbon nanotubes. Impedance spectroscopy measurements were undertaken and a strong dependence on electrical frequency that corresponds to an inductive action in the sample was observed. It was highlighted that the manipulation of the vectorial nature of light can be a useful tool for tuning the electrical response in nanosystems. Potential applications for developing photoconductive and filtering functions can be contemplated.

1. Introduction

In recent years, the use of carbon nanostructures has caused a motivating interest in different topics of science and technology regarding their fascinating physical properties [1]. Currently, carbon nanotubes (CNT) are between the mechanically strongest fiber-like elements [2]. Their exceptional structure, large surface area and morphology, certainly rule their unique electrical, optical and mechanical characteristics [3–6].

In general, CNT are endowed with high chemical stability, important photocatalytic ability and remarkable thermal conductivity [7]. Moreover, the use of CNT bundles to support metallic nanoparticles (NPs) seems to be a suitable alternative for tailoring numerous features [8,9]. Fuel cells, electronic signal modulation, photonic sensing, and nanomechanical actuators are some attractive functions that can succeed by using CNT enhanced by NPs decoration [10,11]. The surface engineering of CNT allows a superlative implementation of nanostructures as carbon/metal nanohybrid systems. Particularly, it has been noted the possibility to improve the electrical conditions of CNT by NPs deposition on their surface by sophisticated techniques [11].

In this direction, several preparation approaches have been carried out for decorating CNT with a diversity of NPs essentially conformed by metals [6,12]. The most commonly used methods for functionalizing CNT are derived from oxidation effects [9]. However, as a matter of fact, the gas phase processing routes have shown a major benefit taking into account an extraordinary homogeneous NPs dispersion and control in the NPs size [13].

Outstanding innovating systems based on CNT decorated with metallic NPs have been proposed for performing electrical

* Corresponding author.
E-mail addresses: ctorrest@ipn.mx, crstorres@yahoo.com.mx (C. Torres-Torres).

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transmission processes [14]. Furthermore, there have been reported many options to involve these carbon/metal structures for energy storage and ultrafast mechanisms [15]. A variety of potential applications can be envisioned by the combination of different NPs for designing optoelectronic pathways [16]. Impressive advantages in the use of CNT together to metallic NPs have enabled assembling low-dimensional devices in integrated configurations for performing biomedical tasks [17]. The development of optical and electronic platforms for building high-density architectures is still in progress [18].

In view of all of these considerations, this work has been devoted to study the electrical effects resulting from a totally nanostructured platinum coating on functionalized CNT irradiated by nanosecond pulses. An *in-situ* vapor-phase decomposition method was employed for depositing Platinum NPs on the tubes. An optically-controlled scheme capable to promote an electrical current bifurcation in a thin film sample was conducted by using a two-wave interferometric interaction. It was emphasized the highly sensitive electronic response of carbon/metal based nanostructures to polarization and irradiance of incident light.

2. Experimental

2.1. Sample preparation

Multi-wall CNT (MWCNT) were grown by chemical vapor deposition (CVD) at 850 °C using a vaporized toluene/ferrocene solution and Argon as gas carrier with flow rate of 2 l/min during 40 min. Full experiment details can be found elsewhere [19,20]. Subsequently, in order to induce defects and functional groups on the walls of the MWCNT, a surface modification process was carried out in the resulting samples. A solution with 10 ml of HNO_3 and 30 ml of H_2SO_4 (1:3 v/v) were mixed in a reflux at 80 °C to eliminate carbon amorphous traces in the samples and for obtaining the functionalized MWCNT (*f*-MWCNT) [21]. This thermal annealing process consisted of 6 h. by considering a systematic study performed in this work to discern induced defects without modification in the tubular structure of *f*-MWCNT. It is worth to mention that an interval of 12 h. of annealing generates a strong degradation of the MWCNT walls; while a treatment of 24 h. results in a complete deterioration of the MWCNT.

The incorporation of Pt onto *f*-MWCNT (MWCNT-Pt) was carried out by an *in-situ* vapor-phase decomposition method described in Ref. [22]. The experimental conditions for annealing the Pt precursor and *f*-MWCNT inside a tubular reactor under a 0.1 l/min Ar flow were 180 °C for 10 min followed by 400 °C for 10 min.

2.2. Structural and morphological characterization

The techniques used within this work included X-Ray Diffraction (XRD; Bruker D8 Focus), Scanning Electron Microscopy (SEM; JEOL JSM-6701F) and Transmission Electron Microscopy at 200 kV in brightfield mode (TEM; JEOL JEM-2200FS). Compositional analysis was performed by Energy Dispersive X-ray Spectroscopy (EDS; JEOL JSM-6701F). The quality of the samples was also studied by Raman Spectroscopy (LabRam HR800; Horiba Jobin Yvon, Argon laser at $\lambda = 514.5$ nm).

2.3. Optical and electrical measurements

Different samples containing 1 mg of MWCNT, *f*-MWCNT or MWCNT-Pt in 5 ml of ethanol suspensions were evaluated in a Perkin Elmer XLS spectrophotometer. Samples for electrical evaluations were prepared by drop casting of the obtained solutions on SiO_2 substrates. Obtained samples of approximately 1 μm thickness were selected. The impedance spectroscopy studies were carried out by using a 10 mV signal and an integration time of 1 s in an Autolab/PGSTAT302N high power potentiostat/galvanostat. Conductive carbon adhesive tape in direct contact with the sample was employed as electrodes for the electrical measurements. In order to evaluate the impedance dependence on electrical frequency, the electrodes were separated by a distance of 5 mm in the samples.

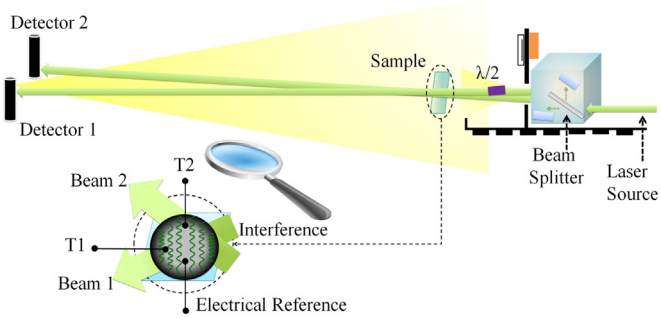

Fig. 1. Experimental two-wave mixing setup.

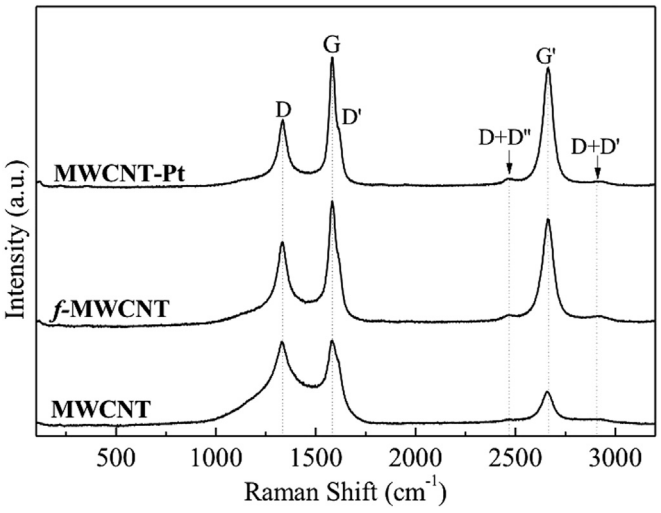

Fig. 2. Micro-Raman spectra of MWCNT, *f*-MWCNT and MWCNT-Pt. The graphitic (G) and defect (D, G′) bands are labeled.

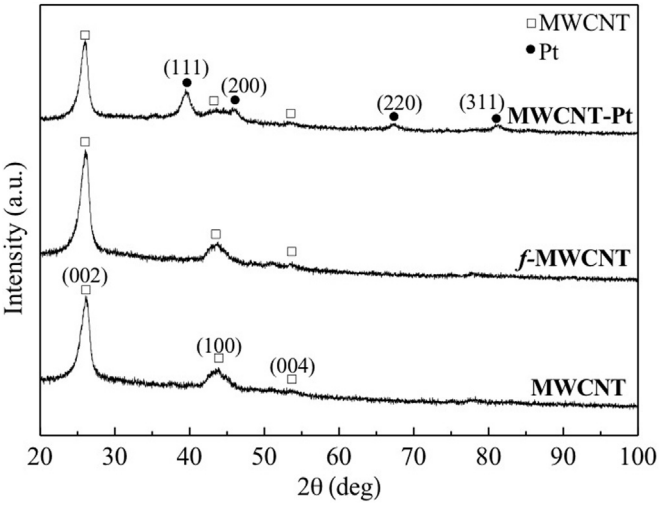

Fig. 3. XRD pattern of MWCNT, *f*-MWCNT and MWCNT-Pt showing the principal planes of MWCNT and polycrystalline Pt coating.