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Flexible and passive photo sensor based on perylene/graphene composite

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ABSTRACT

Graphene-based composites represent a new class of materials with potential for many electronic applications. Especially, any polymer's property can be tuned by attaching it to graphene. In this paper, we propose a passive photo sensor based on a single layer of perylene/graphene composite, which is deposited in comb type silver electrodes separated as 50 μm spacing. The electrical conductivity of perylene is increased by blending with graphene. Photo sensing layer (120 nm thick) and Silver electrodes (50 μm width and 350 nm thick) are deposited on poly(ethylene terephthalate) (PET) substrate through electro-hydrodynamic (EHD) system, which is cost effective, environmentally friendly, and non-vacuum e-printing technology. The proposed photo sensor detects a terminal resistance inversely varied by an incident light in the range between 78 GΩ in dark and 25 GΩ at light intensity of 400 lux. The device response is maximum on wavelength range 465–535 nm at blue light. The device exhibited bendability up to 4 mm diameter for 1000 endurance cycles. The surface morphology analysis is carried out with FE-SEM and microscope.

1. Introduction

Since the discovery of conducting polymers [1], organic materials have been researched for biomedical and electronic applications including OLEDs, organic solar cells, organic transistors, memories, and sensors [2–6]. By a direct printing, organic-based electronic devices and integrated circuits are developed for eco-friendly system, easy and low-cost fabrication and flexibility [7–10]. Among organic electronic based devices many photo sensors [11] are also extensively researched by using different materials carrying photoconductive property [12,13]. Most of them are active sensors based on photo transistor and photodiode [14] and some are integrated with resonant circuits [15]. Various materials those having photo conductive property has been also reported to fabricate a photo detector [13,16–18]. Especially, graphene (2D material) is emerging material which is considered to be the replacement of silicon in near future [19]. It is extensively researched to improve photo detectors [20,21].

Photoconductive material Perylene has been widely applied in various optical devices due to excellent photophysical properties of high absorption coefficient and high fluorescence quantum yield, charge transfer properties, as well as outstanding chemical, thermal and photochemical stability [22]. By attaching any other material with it, the property of attaching material can be changed in both cases, optically and electrically [23,24]. Perylene has been researched in phototransistors [25], solar cells [26], and it is researched for its derivatives to achieve optical and electrical enhancement [27,28]. Perylene has very high resistivity thus when it is used in passive devices, the resistance is very high which cannot be interface with external electronic circuitary. Perylene have versatile properties which can be achieve by synthesizing it or blending with other material that can enhance its property either optically or electrically [29].

In this paper, we propose a passive photo sensor based on thin film of perylene/graphene composite. Graphene/perylene film is deposited on plastic substrate and then silver electrodes are deposited on the photo sensing film. Electrodes are fabricated very closed to each other (50 μm) so that it can detect a small change in the light intensity which varies the resistance of photo sensing layer inversely proportional. The incident light intensity produces a small change in the resistance of the sensing layer, this small change in resistance is enhanced with comb type electrodes. Because the comb type electrodes collects resistance of the film at each 50 μm throughout the film same as resistances in parallel, hence increase

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the sensitivity of the sensor as much area is sensing the incident light. In case of two electrodes the resistance of film is very high which is not interfaceable with external circuitary but multiple electrodes of comb shape solves this problem. By increasing the number of electrodes of comb sensitivity of the sensor increases.

Furthermore, graphene is mixed with perylene to enhance the electrical properties and achieve good resolution of photo detection. The proposed photo sensor changes its resistance along the light intensity in wavelength range 465 nm and 535 nm. The resistances are detected in between 25 GΩ for 400 lux and 78 GΩ for dark. The proposed device is passive type sensor which does not require biasing voltage for operation like transistor, hence it saves the static power consumption and provides a simple fabrication. Whenever light detection is required it can be connect to measuring unit and current value of light intensity can be read. Active type sensors including photo transistors and diodes require biasing voltage, that draw current all the time and consumes power [14].

In order to fabricate a printed electronic device there are several fabrication techniques each of them require a particular process for fabrication including heat, light, and vacuum chamber. These parameters directly affect materials during the fabrication of an organic device. In particular, the properties of organic materials are sensitively changed due to temperature and light. A suitable environment in the fabrication process is required in all kind of organic materials and devices [9,30]. There is a variety of fabrication techniques for organic printed electronic components and circuits such as atomic layer deposition, sol–gel method, anodization, spin coating, thermal evaporation, roll to plate, screen printing, electro-hydro-dynamic (EHD), and electro-static spray deposition (ESD) [31–34]. The EHD and ESD techniques are good candidates for fabrication of printed electronic device due to their advantages over other fabrication techniques. It is a direct printing technique working at room temperature and normal air pressure, environment friendly, and good for prototyping and mass production as well. Also multiple devices in different scales and multiple layers can be fabricated on the same single substrate with very good surface morphology by using EHD atomization technique [35,37].

In this paper, the proposed photo sensor is fabricated through EHD system and cured at appropriate 120 °C temperature. The photo sensor based on Graphene/perylene composite layer fabricated through EHD atomization technique on a flexible substrate was demonstrated for the first time, which has a good characterization for electrically and mechanically. Fabrication and ink preparation of the proposed sensor is discussed in section 2, results and discussions about the characterization of the device electrically, mechanically, and surface morphology is discussed in section 3, section 4 presents the conclusion.

2. The proposed photo sensor

2.1. Material

Graphene platelets from Cheap Tubes (less than 4 layers and surface area greater than 750 m^2/g), and dichloromethane solvent and perylene powder assay 99.5% from Sigma Aldrich are used. The graphene platelets are dispersed in dichloromethane solvent by bath sonication 24 h and centrifugation for 4 h. The viscosity of the graphene dispersion is measured to be 15.8 mPa by using Viscometer VM-10A system. The surface tension of the dispersion is measured to be 54–57 mN/m. Surface-electro-optics (SEO)'s contact angle analyzer is used for the surface tension measurements. The electrical conductivity of graphene dispersion is 12.2 μS/cm measured by using conductivity meter (Cond6 + meter).

Perylene powder of 0.15 g is dispersed in 10 ml dichloromethane and magnetically stirred for 24 h. The prepared ink is filtered with

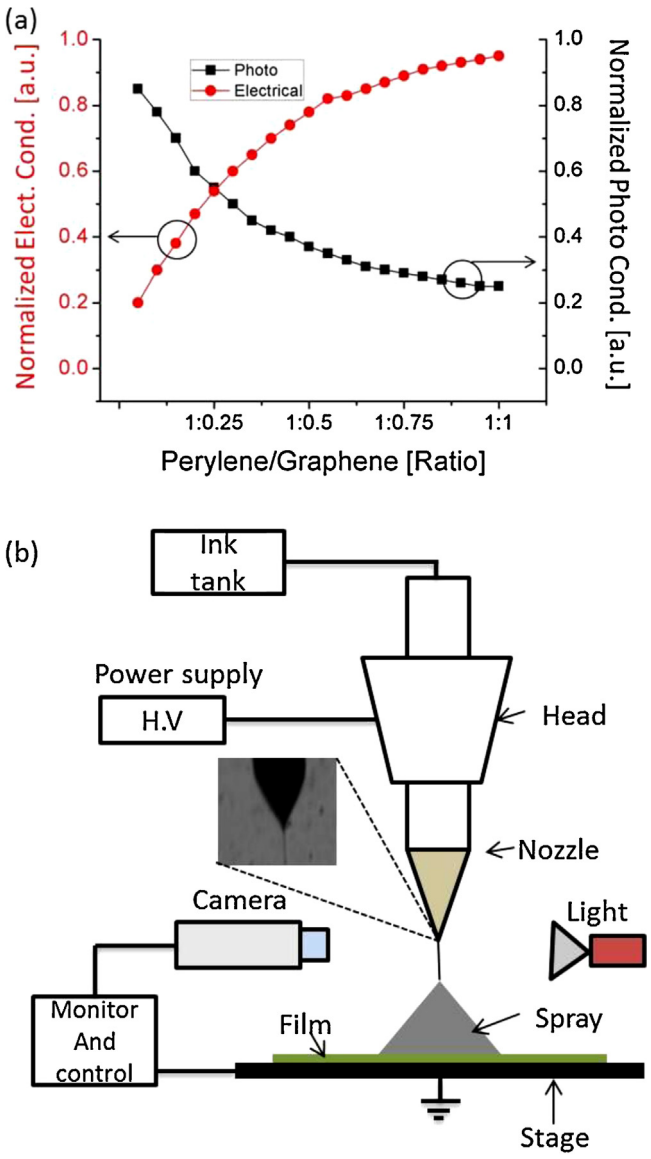

Fig. 1. (a) Electrical and photo conductance along the mixing ratios of perylene/graphene inks. (b) Schematic diagram of the EHD fabrication system.

5 μm filter to remove undispersed particles and then bath sonicated for 30 min prior to use. These two materials are prepared separately and then mixed with various ratios to achieve optimum results experimentally. As a rule of thumb, we found that 1:1/4 is optimal mixing ratio. The electrical conductance is increased along the ratio of graphene in the perylene ink, whereas the photo conductance is decreased as the relationship described in Fig. 1a. The mixing ratio (1:1/4) of perylene/graphene inks is optimum in term of a balanced performance both light sensing sensitivity and electrical conductance. Ink for silver electrodes is prepared as: Ag nano particle paste sigma Aldrich 50%wt is diluted in 10 ml ethylene glycol solvent and mixed for 1 h on magnetic stirrer and then 20 min bath sonication.

2.2. Fabrication

A schematic diagram of the EHD setup is shown in Fig. 1b. In the EHD system the ink is pumped through a nozzle at appropriate flow rate with the positive potential at the nozzle and ground at the substrate. Applying high DC voltage supply between nozzle and substrate the induction of the surface charges on the pendent