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Incorporation of inorganic nanoparticles into an organic polymer matrix for data storage application

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ABSTRACT

The demand of polymer nanocomposite based energy storage devices is in ever increasing stage. Present work demonstrates the application of hybrid polymer nanocomposite (CdSe nanoparticles embedded in poly(*N*-vinyl carbazole) (PVK) matrix) for data storage devices. CdSe/PVK nanocomposite has been successfully synthesized by ex-situ chemical method. From X-Ray diffraction analysis, Zinc blende structure of CdSe nanoparticles with (111), (220) and (311) cubic crystal planes has been observed. TEM micrograph of CdSe/PVK nanocomposite shows the spherical CdSe nanoparticles having average particle size 6–7 nm, homogeneously dispersed in PVK matrix. CdSe/PVK nanocomposite shows photoluminescence due to the CdSe nanoparticles and p-PVK conformation of PVK. The average surface roughness of the nanocomposite film calculated by using AFM analysis is 45.12 nm. Two-terminal conductivity switching device, structured Al/(CdSe/PVK)/Ag, has been fabricated and characterized. Conductivity switching is due to electron trapping and tunnelling in CdSe nanoparticles and through PVK matrix, respectively. Write-read-erase cycles show a good stability of the device with ON/OFF ratio ~10^4. Obtained results reveal the application of CdSe/PVK nanocomposite in data storage devices.

1. Introduction

The inorganic nanoparticles (NPs) incorporated into organic polymers, called hybrid nanocomposites; represent a new class of innovative materials having applications in several fields such as optoelectronic devices [1], solar cells [2], sensors [3] and memory devices [4]. In hybrid nanocomposite, the properties of polymer material are combined with the unique size-tunable properties of the NPs [5]. Over the past decades, the silicon industry has made exponential growth in terms of both productivity and performance. However, as the device size approaches nano-scale, its production is becoming increasingly difficult as well as expensive [6]. The non-volatile memories of nano size with high density, low power consumption, good retention and thermal stability are the challenges for present technology [7]. The electronics based on polymer nanocomposites offer several advantages such as device structure simplicity, light weight, wide area production, low power consumption, device flexibility and is also inexpensive [8]. The synthesis technique used for the preparation of polymer nanocomposites play an important role on the properties of the device. For nanoparticle (NP) synthesis, the surfactants are usually used, which not only control their growth during synthesis but also prevent their agglomeration [9,10]. The choice of suitable surfactant (polar or non-polar) for NP synthesis depends on various factors: NP material, the solvent used during synthesis and the required application for which the NPs are synthesized. For polymer nanocomposite synthesis, the proper incorporation of NPs into the polymer matrix is a crucial factor. As reported in the literature, the synthesis of NPs in organic solvents is very complicated or complex plus the chemicals used during synthesis are toxic as well as expensive [11]. So, the phase transfer technique is generally used to transfer the phase of NPs from polar to a non-polar solvent which avoids the complicated processes involved during organic NP synthesis [12]. In addition to this, the quantity of NP loading into the polymer matrix can be controlled using this method.

Cadmium selenide (CdSe), a direct bandgap material (E_g ~ 1.74 eV) is a significant semiconductor [13]. In modern technology, the size tunable property of CdSe found applications in various fields such as LEDs, photovoltaic devices, memory devices and biomedical devices, etc [14–16]. Li et al. [17] have studied the mechanism of bistable memory device based on CdSe/ZnSe core-

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shell quantum dots conjugated with multi-walled carbon nanotubes (MWCNTs). They observed that the charge transfer efficiency of the devices have been improved with MWCNTs conjugation. Sahu et al. [18] have studied the memory phenomena of CdSe NPs capped with mercaptoacetic acid (MAA) and poly (diallyl dimethyl ammonium chloride) (PDDA) due to the charge confinement in CdSe NPs. CdSe/polymethylmethacrylate (PMMA) as a tunnelling layer have been utilized by Kim et al. [19] to improve the performance of organic memory device. Even though, literature is available regarding the data storage ability of different polymer nanocomposites [20,21], but due to the lack of clear understanding about the switching mechanism, the research on this topic is still in the exploratory stage. As various mechanisms such as electric field induced filament formation, charge trapping & detrapping and electric field induced charge transfer, etc are available to explain their switching behaviors. But still now, no unified mechanism is established resulting in difficulties in their commercialization. There are many important device parameters such as high performance which includes high speed & density, endurance and low power consumption which needs improvement. Research in this direction should be carried out for the better understanding of device switching mechanisms. This paper reports data on the synthesis of CdSe/PVK nanocomposite and its application for data storage devices. The reason behind the choice of PVK is its high resistant to oxygen and moisture as compared to other organic polymers [22]. The electrical properties of the fabricated device based on CdSe/PVK nanocomposite have been studied by I-V measurements. The data storage property of the device has been confirmed from write-read-erase cycles and endurance tests.

2. Experimental details

2.1. Synthesis of CdSe/PVK nanocomposite

CdSe/PVK nanocomposite was prepared by utilizing aqueous to organic phase transfer technique as reported in our previous work [23]. Here, the organic solvent used is toluene instead of DMF. Schematic synthesis route for the CdSe/PVK nanocomposite is shown in Fig. 1.

2.2. Device fabrication

Two terminal conductivity switching device with CdSe/PVK nanocomposite as an active layer was fabricated by using Al substrate as a bottom electrode and Ag as a top electrode. Bottom substrates were washed with distilled water and KOH solution prior to nanocomposite thin film formation. CdSe/PVK nanocomposite film was deposited on Al substrate of dimensions 1×1 cm^2 by drop casting method utilizing 1 ml of polymer nanocomposite solution. The films were dried under ambient conditions for 2 days and the thickness of the CdSe/PVK nanocomposite films is ~10 μm. Finally, the Ag top electrode of thickness ~100 nm was deposited by using silver paste covering surface area of 16 square micrometre.

2.3. Instrumentation

Structural characterization of the nanocomposite was studied by using a Phillips PW-1710 X-ray diffractometer using CuKα radiation. Structural refinement was carried out by Rietveld method using the program Full Prof and Pseudo-voigt function. Morphological analysis was carried out by using Hitachi H7500 electron microscope, operating voltage ~90 kV and magnification ~40,000×. Surface morphology and the smoothness of the CdSe/PVK nanocomposite films was characterized by using TT-AFM V 2.1. The absorption spectra was recorded by using Labindia Analytical UV 3000$^+$ UV–vis spectrophotometer. Shimadzu Spectrofluorophotometer RF-5301PC spectrometer was used for recording the Photoluminescence (PL) spectrum at an excitation wavelength of 320 nm. For memory device characterization, computer controlled Keithley 6517 A electrometer was used for all electrical measurements which were carried out at room temperature (300 K).

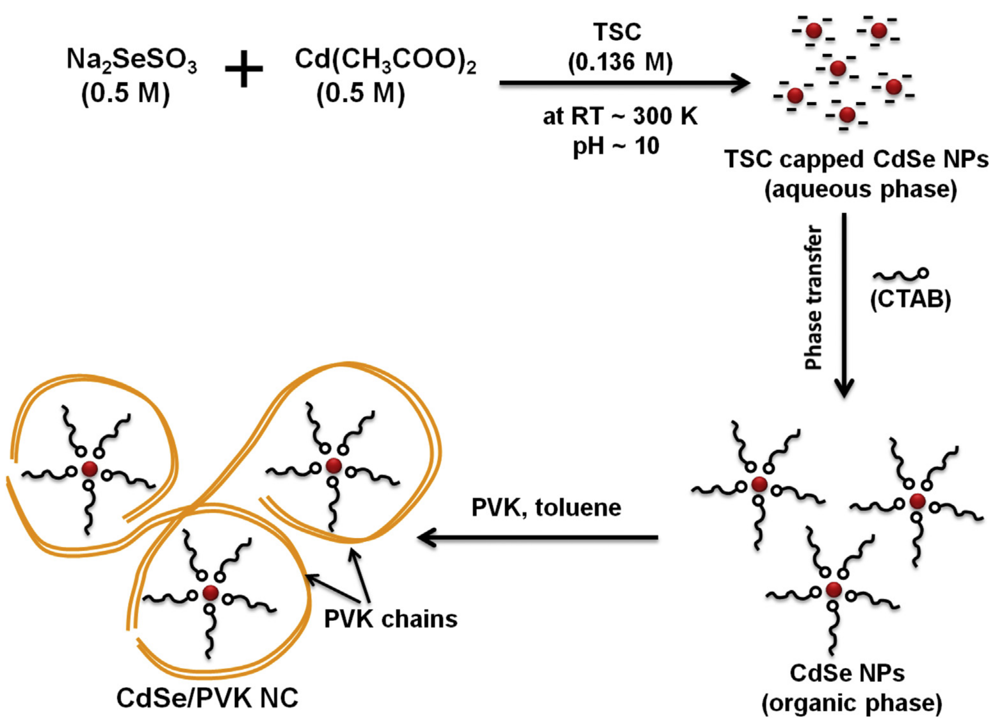

Fig. 1. Schematic representation of the synthesis of CdSe/PVK nanocomposite.

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