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Electrical and mechanical behavior of polymethyl methacrylate/cadmium sulphide composites

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ABSTRACT

In the present investigation, electrical and mechanical behavior of cadmium sulphide (CdS) doped polymethyl methacrylate (PMMA) have been studied using different techniques. Dip casting technique was used for preparing free standing films of pristine and CdS doped PMMA at different compositions (*i.e.* 1 and 5 wt%). Optical absorbance as a function of wavelength was studied, by UV–visible spectroscopy, to find the impact of CdS doping on the optical band gap of synthesized PMMA/CdS composite. DC and AC conductivities were measured as a function of dopant concentration and temperature. Considerable increase in electrical conductivity was observed with the increase of CdS contents in polymer matrix. Overall electrical conduction mechanism in PMMA/CdS composites was attributed to movement of electrons through the uniformly distributed CdS aggregates within the matrix of PMMA. Mechanical properties, such as Young's modulus, tensile strength, elongation and ductility, of PMMA/CdS composites were determined and relevant responsible phenomena were discussed.

1. Introduction

During past few years, much work has been published on polymer composites, as it provides an alternate route to develop a new material with tailored properties [1–5]. At present, many researchers are preferring polymers, such as, polyvinyl alcohol [6,7], polyvinyl chloride [8], polystyrene [9], polymethyl methacrylate [10–12], polyvinyl carbazol [13], etc, as a suitable matrices for developing polymer nano-composite systems because of their longer life, more flexibility, less weight, easy to synthesize, environmental stability, ability to offer good adhesion to dopants/fillers, better mechanical properties, *etc*. Among them, PMMA has been reported as one of the lightest transparent polymer, which has unique optical, thermal, and mechanical properties [10–12,14–17]. Otsuka et al. [12] has reported the great potential of PMMA/ZrO_2 nanocomposites for application in optical and mechanical fields, due to its excellent optical properties and high thermal stability. Recently, highly conductive PMMA/reduced graphene oxide composites have been prepared by a research group of Korea [11].

Semiconductor such as cadmium sulphide (CdS) is a significant material owing to its inherent properties of small optical bandgap and better chemical stability, and its applications in catalysis, microelectronics, optoelectronics, photovoltaic's, non-linear optics, photoelectrochemistry, etc. [18–20]. Different research groups have already investigated the incorporation of CdS in different polymer matrices such as polyvinyl-alcohol/CdS [21], polystyrene/CdS [22], polyvinyl-carbazol/CdS [23], etc., and revealed the hybrid-composite material with better optical, thermal, mechanical and electrical properties. Kuljanin-Jakovljevic *et. al.* has reported the improvement of thermal properties of PMMA by filling micro-particles of CdS [24]. Recently, Padmaja *et.al.* has tuned the optical band gap of CdS:PMMA nanocomposites and proposed it for optoelectronic device applications [25]. However, the electrical conduction mechanism and mechanical behavior of PMMA loaded with chalcogenide semiconductor CdS is still quite obscure issue. So, an attempt has been made to prepare PMMA/CdS composite *via* solution casting technique and to understand the effect of CdS contents on electrical and mechanical properties of developed composite material.

2. Experimental method

2.1. Sample preparation

Research grade PMMA resins with 99% purity and CdS in powder form (~particle size 300 nm) were purchased from LOBA Chemie and were used without any further purification. PMMA resin was dissolved in chloroform (*i.e.* 5 g/100 mL) by constant stirring for 24 h, at ~50 °C.

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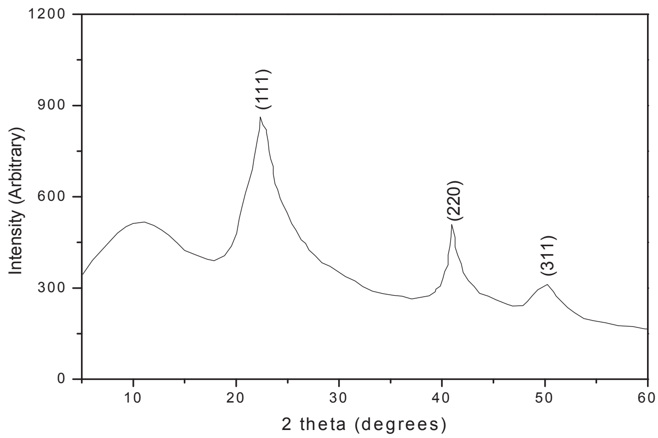

Fig. 1. XRD plot of PMMA/CdS composite.

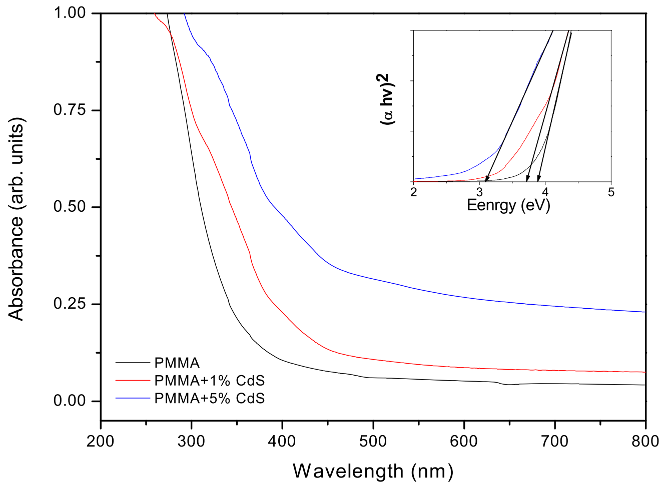

Fig. 2. Absorbance spectra of PMMA/CdS composites and inset are their direct bandgap energies.

After that, CdS particles were introduced at different concentration by weight *i.e.* 1% and 5%. Free standing films (~10 µm) of pristine and CdS doped PMMA were prepared using dip-casting technique. Three samples with different compositions *i.e.* 0%, 1% and 5% by weight of CdS in PMMA were prepared.

2.2. Characterization

XRD plot was recorded using X-Pert Pro PANanalytical, Netherland, in the range 05°-60° with step size of 0.02°. Shimadzu UV–Visible spectrometer was used to study absorption behavior of prepared samples in wavelength range 200–800 nm. DC electrical conductivity was recorded at room temperature with a Keithley-412 Picometer. However, AC electrical measurements were taken with a two-probe setup, using Hioki 3522-50 LCR HiTester, in frequency range 10 KHz – 1 MHz. The mechanical properties of investigated samples were determined by using a tensile testing machine ASTM D412. For analyzing electrical and mechanical behavior, average of five measurements were taken.

3. Results and discussion

3.1. XRD analysis

XRD curve of composite film (*i.e.* 5% by weight of CdS in PMMA) is shown in Fig. 1. Broad hump at 10° is revealing the amorphous nature of PMMA, whereas the peaks at 22°, 41° and 50° are representing (111), (220) and (311) planes, respectively, of CdS [24].

3.2. UV– visible analysis

The UV–visible spectra of PMMA/CdS composite films are shown in Fig. 2. It is observed that pristine PMMA film showed small but nearly constant absorbance over the wavelength range 350 nm - 800 nm and an absorbance edge at around 350 nm, which may be attributed to $\pi - \pi^*$ transitions due to C=O unsaturated bonds [26]. However, as CdS contents were doped in PMMA, absorption edge started shifting towards the red end of the spectrum, which may be due to decrease of optical bandgap energy with the increase of CdS concentration in PMMA/CdS composite system. Inset of Fig. 1 is revealing the direct band gap energies of pristine, 1% and 5% CdS doped PMMA films as 3.82eV, 3.72eV and 3.09eV respectively [26]. This result indicates the possible application of PMMA/CdS composite in optical switching devices, in visible region.

3.3. DC electrical conduction analysis

Fig. 3 is presenting the relation between dc conductivity (σ_{dc}) of PMMA/CdS composites with temperature. It can be seen that conductivity of pristine PMMA is lying in range ~10^{-14}-10^{-13} $\Omega^{-1}cm^{-1}$, which

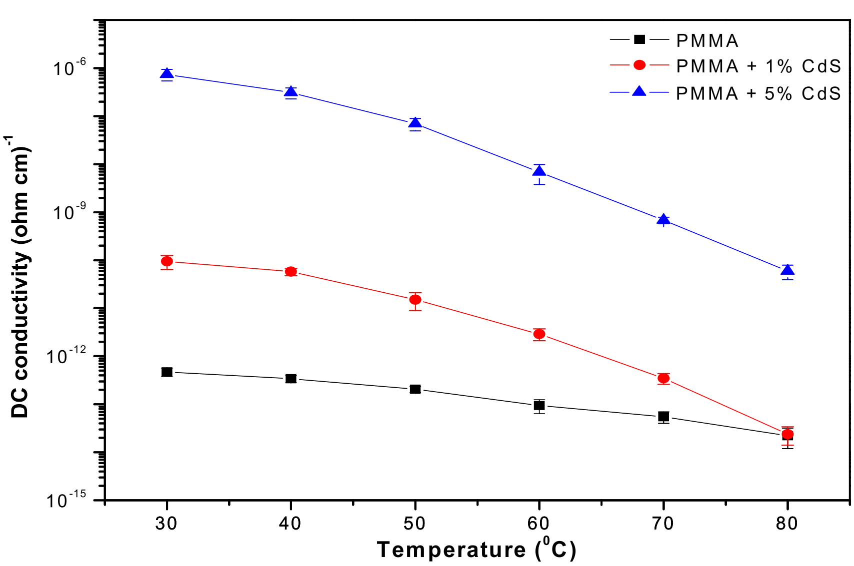

Fig. 3. Variation of DC conductivity of PMMA/CdS composites with temperature.