Shi Irradiated Polymer Nanocomposites: A Literature Review

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Abstract

The techniques that have been used to synthesized $BaTiO_3$ and (1-x)PVDF/(x)$BaTiO_3$ nanocomposite films have been described in detail in this chapter. Also, this chapter describes the prominent techniques for structural, electrical and magnetic characterization employed in the present investigations. These techniques include X-ray diffraction (XRD) for phase identification, field emission scanning electron microscopy (FESEM) using secondary electron imaging mode for investigating the surface morphology, Fourier Transform Infra- Red (FTIR) spectrometer for the bonding vibrations and change in conformation of PVDF as a result of incorporation of $BaTiO_3$ nanoparticles, P–E loop tracer for the ferroelectricity, Chemical Impedance analyzer for dielectric properties measurements, and potentiostat for cyclic voltammetry (CV) and Electrochemical Impedance Spectroscopy (EIS) etc.

Keywords: SHI, Polymer, Review of Literature

Introduction: Staudinger in the 1920s has published a milestone concept of 'Macromolecule' as a long chain of small repeating monomer units linked via covalent bonds [5] and commercialized the polymers as a revolutionary material. Many classic materials like wood, steel, etc. have been replaced by polymers due to their low density, light-weight, and good mechanical properties etc. However, the use of polymer as an engineering material is still limited due to their low dielectric constant, low stiffness and low thermal stability etc. It is, therefore, necessary to develop a new technology that can answer to the requirements, such as enhanced dielectric constant, improved thermal properties, and flexibility etc.

The integration of polymers with functional nanomaterials, resulting in a new class of materials known as polymer nanocomposite, is a potential approach in designing the light- weight materials with better performances than both polymer matrix and nano-fillers or nano-reinforcements [6]. By definition, polymer nanocomposites are polymer-based composites that contain materials having at least one dimension below or equal to 100 nm [7].

Review of Literature

In the last two decades, polymer nanocomposite became a topic of intense research and development in both academia and industry due to its excellent endurance, high dielectric constant, low dielectric loss, high flexibility, wide working temperature range etc. [1]. These composites have lower manufacturing costs and can be easily prepared in a variety of shapes by various methods e.g. solvent casting, compression molding, hot pressing, filling the drilled holes in blocks of poled ceramic with polymer, ball milling etc. [1]. The properties can be tailored by changing the composition of the constituents as per the requirement [3]

Nanomaterial, in particular, nano-reinforcement for polymer composite is an influential subdivision of the Nanotechnology. In a momentous talk by Nobel Laureate Richard Feynman in 1959 on the top-down approach of Nanotechnology entitled '*There're plenty of rooms at the bottom*', he first predicted the concept of nanomaterials and nano-manufacturing methods [4]. He foresaw that the nanomaterials should have very small dimensions and exhibits some remarkable properties due to their small size.

SHI irradiation is a proven path for tailoring the structural and physicochemical properties of polymer nanocomposites, in order to broaden their applicability. Irradiation induced morphological and electrical changes are of profound interest for numerous device applications. As discussed in section 1.5, the physiochemical process that happens due to SHI irradiation is correlated with the crosslinking of polymer, recrystallization, emissions, defect sites and tracks formation etc. [5]. The target composition along with various ion beam parameters, such as the nature of the ions, fluence, and energy etc. perform a significant role in concluding the extent of modifications. A background presenting the effect of SHI irradiation on polymer nanocomposite systems is reviewed below.

Y. K. Mishra et al (2010) irradiated Ag-polyethylene terephthalate (PET) nanocomposite films with 120 MeV Ni ion beam at ion fluences 1×10^{10} to 3×10^{11} ions/cm^2. It has been observed that the FWHM of the transmission band for the pristine sample was ~ 60 nm, which was decreased to ~ 30 nm after irradiation [6]. When S. Sharma et al (2011) irradiated ZnO/PMMA nanocomposite films using 100 MeV Ni^{8+} at a fluence = 1×10^{11} ions/cm^2, an enhanced luminosity of ZnO/PMMA nanocomposite has been observed due to the irradiation-induced change in the microstructure of PMMA matrix [6]. Similarly, S. Kumar et al (2014) found the amorphous nature and bandgap energy value decreases at higher fluences for the 60 MeV Ni ion irradiated nano-CdS/polystyrene composite films [2]. In another work, the influence of 100 MeV O ions on PANI/SWNTs nanocomposite has been studied by H. K. Patil (2017). They found that with increasing the fluence, the root mean square roughness of the nanocomposite decreases, which further results in the diffusion of more electronic energy by the creation of new bands [3].

A. Biswas et al (2004) studied the characteristic nanostructural change in 2D and 3D arrays of vapour phase tandem deposited Au and diluted Ag clusters with Teflon AF layers after 120 MeV Au beam irradiation at ion fluences 1×10^{11} – 3×10^{12} ions/cm^2. They found that after irradiation the 2D distributed Au clusters were transformed into cluster helical chains in the Teflon matrix and diluted 3D arranged Ag nanoparticles were concentrated in the mesh of carbon-enriched nano-regions [4]. E.M. Abdelrazek et al (2017) exposed the (PEO/PVP) blend/Au nanocomposite to γ-radiations. It has been observed that the Au nanoparticles were dispersed in the polymer at a higher dose and the size of pores was increased with increasing the irradiation dose.

P. Mazumdar et al (2018) subjected the PMMA/nano graphite nanocomposites to irradiation using 80 MeV Ni ion beams at fluence between 10^{11} – 10^{12} ions/cm^2 and observed a significant increase in electrochemical capacitance compared to the pristine nanocomposite samples [5].

When N.L. Singh et al (2008) irradiated PMMA-ferric oxalate with 120 MeV Ni^{10+} ions, it has been found that the SHI irradiation increased the conductivity and hardness by developing the metal - PMMA bonding and converting the polymeric structure into hydrogen depleted carbon network [6]. An increase in electrical conductivity has also been analyzed by Amar Ratan et al (2020) while studying the 80 MeV C ion irradiation effects on MoS2- PVA films at different fluence. The electrical conductivity was increased due to the creation of conductive tracks and homogeneous dispersion on the surface after SHI irradiation. An increase in the film crystallinity at lower fluence i.e. 1×10^{10} ions/cm^2 has also been observed [7].

S. Shah et al (2007) irradiated PMMA/Ni composite with 3 MeV proton beam and shown that the crystallinity and crystalline size decreases after irradiation. The average surface roughness has been observed to change with the proton irradiation. [6]. When S. Bhavsar et al (2019) irradiated the polymer nanocomposites films of polystyrene/Al2O3 with 5 MeV proton beam at different fluences, a decrease in FTIR spectra band intensity has been observed after irradiation due to the chain scission/crosslinking. A decrease in bandgap and an increase in photoluminescence intensity have also been observed due to the creation of polycyclic aromatic hydrocarbon [9]. M. Kaur et al (2014) studied the effect of swift heavyion irradiation on in PLGA/clay nanocomposites. The observed results confirmed intercalation at high fluence. The bandgap energy has been decreased with the ion fluence in nanocomposites having low clay content (1 and 3 wt%), except the nanocomposites having a high clay content (5 wt%). The increment in bandgap at high clay concentration was due to the irradiation-induced aggregation of clay platelets into tactoids [7].

P. Shah et al (2020) irradiated the $CoFe_2O_4$/NG/PMMA nanocomposites with 80 MeV C^{6+} and 100 MeV O^{7+} ion beams and found a significant enhancement in the homogenization of nano-fillers after irradiation. A decrease in saturation magnetization and an increase in coercivity have been observed with an increase in fluence. They further found that 100 MeV O^{7+} irradiated nanocomposites at fluence 1×10^{12} ions/cm^2 exhibited strong broadband microwave absorption [71]. R. P. Chahal et al (2016) concluded that SHI irradiation in PVA/Ag nanocomposites resulted in a significant change in the energy gap and transmission due to the structural modifications. The transmission of irradiated nanocomposite showed that almost UV and a part of visible light were cut off at the highest fluence and hence can be used in UV radiation blocking applications.

J. Maniks et al (2014) studied the 150 MeV Kr ions irradiation effect on PP/ZnO nanocomposites at fluences 10^{11} and 10^{12} ions/cm^2. An increment in the luminescence intensity of PP/ZnO nanocomposite has been observed which can be attributed to the broken polymer bonds after irradiation [2]. According to G. K. Prajapati et al (2014), on irradiating PVA-H_3PO_4-Al_2O_3 nanocomposite thin films with 50 MeV Li^{3+} ions, a decrease in the degree of crystallinity with ion fluences has been observed. It has also been found that ε' and ε'' increase with ion fluences; while, after a critical fluence, they were decreased [7].

Apart from the above reviewed SHI irradiation effects on polymer nanocomposites, D. S. Grant et al (2018) presented the synthesis of polymer nanocomposites through the conversion of plasma polymerized polyterpenol thin films into graphitic-polymer nanocomposite using 55 MeV I^{9+} ions irradiation with ion fluence varied from $0.5\times10^{14} - 2\times10^{14}$ ions/cm^2 [7].

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