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Novel X-rays attenuation by (PMMA-PS-WC) New Nanocompsites: Fabrication, Structural, Optical Characterizations and X-Ray Shielding Application

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ABSTRACT

In this paper, novel shields for x-rays attenuation are synthesized by using poly-methyl methacrylate (PMMA), polystyrene (PS) and tungsten carbide (WC) nanoparticles. The prepared nanocomposites have light weight, high corrosion resistance, low cost and high attenuation. The effect of tungsten carbide on structural and optical properties of (PMMA-PS) blend was studied for x-rays shielding. The structural properties included the FTIR analysis and optical microscope images. The results showed that the fabricated nanocomposites have high absorbance for high energies which can be used for flexible electronic applications and flexible shielding. The absorbance, absorption coefficient, extinction coefficient, refractive index, dielectric constants and optical conductivity of (PMMA-PS) blend are increased while the transmittance and energy band gap are decreased with the increase in WC nanoparticles concentrations. The results of applications showed the (PMMA-PS-WC) nanocomposites have high attenuation for x-rays.

Key words: tungsten carbide, PMMA, PS, attenuation, optical properties, x-ray.

1.INTRODUCTION

Radiation is defined as the energy that can be travel through the matter and space. It is caused by self-transmutation of nuclei and can be classified as ionizing and non-ionizing according to its energy. Non-ionizing radiation has low energy while ionizing radiation like alpha, beta particles and gamma, X rays has high energy. The radiation with high energy can ionize atoms of the interacting matter. Hence to protect human and environment from harmful effects of high energy ionizing radiation appropriate shielding materials are used. Shielding material reduces the exposured dose by interacting the radiation itself and reducing the intensity of the radiation. There is no need of special shielding materials for particle radiation such as alpha and beta particles since they interact with matter strongly that makes their penetrating ability weak. However high penetrating electromagnetic radiation such as gamma and X-ray must be shielded by special materials. At the present time the most widely used electromagnetic radiation shielding materials are high density materials such as lead bricks and high density concrete. Other metal based shielding materials like tungsten, copper, bismuth, steel etc. are used as shielding material but lead superior over them due to its high density, high atomic number and low cost. Besides these lead have many important disadvantages that limits its application areas and usage such as really high toxicity and heaviness, low mechanic and chemical stability and inflexibility. Thus at the present it is an important need to improve new shielding materials and also to develop properties of the conventional shielding materials [1]. Electromagnetic radiation which can cause ionisation, such as gamma rays and x-rays are dangerous to human health. People can get exposed to gamma and x-radiations from different types of sources, which find use in industries, medical diagnostic centres, nuclear research establishments, nuclear reactors, research involving radio-isotopes and nuclear weapon development facilities. In order to protect personnel and sensitive electronic equipment from such ionising radiation, shielding is necessary. Radiation shielding is the practice of protecting people and the environment from harmful effect of ionising radiation. Exposure to radiation is one of the major concerns when setting up nuclear power plants, the use of strong (high activity) radioisotopes in ‘spin-off’ applications like food preservation and cancer treatment, particle accelerator facilities as well as medical X-ray diagnostic systems, in order to prevent radiation from causing significant health problems among the users of these radiation based facilities. So, many types of shielding materials are installed at work places using radioactive and x-ray sources, in order to make the work place a safe zone for humans. Metallic lead (Pb) has been used most often as the radiation shielding material due to its high atomic number (Z), high density, low cost, easy process ability and mainly because, it provides effective shielding against penetrative gamma radiation. However, Pb is known for its toxicity, environmental pollution and extremely low level of neutron absorption. It has now become a priority to try and find materials that can effectively replace Pb as a radiation shielding material. Polymer composites doped with high Z constituents (other than Pb) can be used as shielding materials. Such alternative radiation shielding materials have lower effective density, but they provide sufficient, sometimes an improved protection against exposure to dangerous radiation. They even find applications in dosimetry and are also effective in the absorption of neutrons (say, from a nuclear reactor). One of the most exciting areas in material sciences is the field of polymeric materials. In the last two decades, polymeric materials have become a part of the everyday life of a human being in the civilized world. This is due to the large number of their applications, in industrial, biological, consumer and medical fields. Polymeric materials have gained the attention of many scientists due to their unique properties such as reasonable cost, light weight, flexibility, good mechanical strength and interesting optical as well as electrical properties [2]. Poly-methyl methacrylate (PMMA) has been widely used in architecture, automobile, air and railway transport systems due to its superior optical and mechanical properties. This wide range of applications of PMMA can be even more extended by incorporation of filler into PMMA matrix, because well dispersed filler may enhance various physical properties of PMMA [4]. Polystyrene has attracted the attention of scientists for its interesting features and its superior physical and chemical properties. Polystyrene (PS) is amorphous polymer with bulky side groups. Major characteristics of PS include rigidity, transparency, high refractive index, good electrical insulation characteristics, low water absorption, and ease of processing which makes important for many applications in industry. Moreover, PS is traditionally considered as an excellent host material for composites[3]. Transition metal carbides belong to group VI having similar chemical and electronic properties alike of Pt mostly investigated for hydrogen evolution reactions. Thus, these group elements are being used as fuel cell and they are under study also. Many studies and developments based on transition metal carbides used as fuel cell electro catalyst have been reported earlier. Certain transition metal carbides have some special properties such as high melting point, oxidation resistance, good electrical conductivity and a superior hardness. These properties make them most desirable materials for potential applications such as cutting tools, forming dies, and other wear applications [5]. Tungsten carbide (WC) is very desirable material due to its attractive mechanical, physical and chemical properties such as high hardness, high melting point, good electrical and thermal conductivity, and high corrosion resistance [6]. So, carbides used for thermal energy storage and release [7,8], enhancement the optical and electrical properties of polymers [9-17]. The effect of particles addition on DC electrical, dielectric and optical properties of polymer were studied to improve the properties for suitable application [18-32]. In this paper, fabrication of novel (PMMA-PS-WC) nanocomposites and studying their structural and optical properties for X-ray shielding .

2.MATERIALS AND METHODS

The (PMMA-PS-WC) nanocomposites were prepared from poly-methyl methacrylate (PMMA) and polystyrene (PS) as matrix and tungsten carbide (WC) nanoparticles as additive by using casting method. The (PMMA-PS) blend prepared by using 1gm of polymer with concentration: 50 wt.% / 50 wt.% was dissolved in 20ml of chloroform by using magnetic stirrer to mix the polymers for 1 hour to obtain more homogeneous solution. The WC nanoparticles were added to the blend with concentrations are (2, 4 and 6) wt.%. FTIR spectra of nanocomposites were recorded by FTIR (Bruker company, German origin, type vertex -70) Fourier transform infrared spectrometer in wave number range (500 – 4000)cm^{-1}. The optical properties of nanocomposites were measured by using the double beam spectrophotometer (shimadzu, UV -1800^{0}A) in wavelength (200-800) nm.

The absorption coefficient (α) was calculated using the equation [33]:

$$\alpha=2.303A/t \qquad \text{……….} (1)$$

Where A: is the absorbance and t: the sample thickness in cm. The non-direct transition model for amorphous semiconductors was determined by the equation [34]:

$$\alpha h\upsilon = B(h\upsilon - E_g)^r \text{..............................}(2)$$

Where B is a constant, hυ is the photon energy , E_g is the band gap, r=2,or 3 for allowed and forbidden indirect transition.

The extinction coefficient (k) of nanocomposites is given by using the equation [35]:

$$K=\alpha\lambda/4\pi \qquad \text{…………} (3)$$

The refractive index (n) was calculated by using the equation [36]:

$$n= (1+R^{1/2})/ (1-R^{1/2}) \qquad \text{………} (4)$$

The real and imaginary parts of dielectric constant (ε_1 and ε_2) are given by using equations [36]:

$$\varepsilon_1=n^2-k^2 \qquad \text{…..... } (5)$$

$$\varepsilon_2=2nk \qquad \text{…… } (6)$$

The optical conductivity is given by using the equation [37]:

$$\sigma = \frac{\alpha nc}{4\pi} \text{...}(7)$$

The x-ray shielding application of (PMMA-PS-WC) nanocomposites have been performed to investigate attenuation properties of x-ray for the samples with different concentrations of WC nanoparticles.

The attenuation of radiation is characterized by [38]:

$$N = N_0e^{-\mu t} \qquad \text{…………………}(8)$$

N_0 is the number of particles of radiation counted during a certain time, duration without any absorber, μ is the attenuation coefficient of x-ray and N is the number counted during the same time, with a thickness of sample t.

3.RESULTS AND DISCUSSION

FTIR spectra of (PMMA-PS-WC) nanocomposites are shown in Figure 1. The FTIR studies showed that there is no interactions between (PMMA-PS) blend and WC nanoparticles. The absorbance of (PMMA-PS) blend and (PMMA-PS-WC) nanocomposites is shown in Figure 1. The (PMMA-PS) blend film is highly transparent in nature because its spectrum does not display any peak in the visible region but it displays a peak in ultraviolet region of electromagnetic spectrum, so it can be used as a polarizer[39], flexible electronic applications and high energy shielding. All samples of (PMMA-PS-WC) nanocomposites have higher absorbance at UV region which is related to the energy of photon enough to interact with atoms; the electron excites from a lower to higher energy level by absorbing a photon of known energy, this behavior consistent with the results . By increasing the loadings of WC nanoparticles, the tranmittance of (PMMA-PS) blend was further decreased as shown in Figure 2. The absorbance of (PMMA-PS) blend is increased and the transmittance with an increase in WC nanoparticles concentrations, this is due to increase the number of free electrons which absorbs the incident light [44], as shown in Figure 3. The figure shows that the WC nanoparticles are aggregated as a clusters at lower concentrations. When increasing the concentrations of WC nanoparticles, the nanoparticles form a continuous network inside the (PMMA-PS) blend.

Figure 5 represents the absorption coefficient of nanocomposites as a function of photon energy of the incident light. The absorption coefficient is calculated to know the nature of electron transition. When the values of the absorption coefficient of nanocomposites are high ($\alpha > 10^4$) $(cm)^{-1}$, it is direct transition of electron. When the values of the absorption coefficient of nanocomposites are low ($\alpha < 10^4$) $(cm)^{-1}$, it is indirect transition of electron. So, the (PMMA-PS-WC) nanocomposites have indirect transitions. The absorption coefficient of (PMMA-PS-WC) nanocomposites is increased with the increase in the concentrations of WC nanoparticles, which is attributed to the increase in the number of charge carriers [45]. The energies gaps for allowed indirect transitions of (PMMA-PS-WC) nanocomposites are shown in Figure 6. The energies gaps for forbidden indirect transitions of nanocomposites are shown in Figure 7. As is shown in the figures, the energies gaps for allowed and forbidden indirect transitions of nanocomposites are decreased with the increasing of the WC nanoparticles concentrations, this behavior is due to the creation of levels in the energy gap; the transition of electron in this case is conducted in two stages that involve the transition from the valence band to the local levels in energy gap and to the conduction band as a result of increasing the WC nanoparticles concentrations; the electronic conduction depends on nanoparticles concentrations [46]. Figure 8 represents the extinction coefficient of nanocomposites as a function of the photon wavelength. The extinction coefficient indicates the amount of absorption loss when electromagnetic wave propagates through a material, which is a measure of the fraction of light lost owing to the scattering and absorption per unit distance of a penetration medium. The extinction coefficient is directly related to the absorption of a material and to the absorption coefficient. From Figure7, the exponential decrease in the extinction coefficient with an increase in the photon energy represents that the fraction of light lost owing to the scattering and absorbance increases. In addition, the loss factor decreases, as the photon energy increases. Figure 9 shows the relationship between the refractive index of nanocomposites and the wavelength. It can be observed that the refractive index of an as-synthesized material decreases, as the photon energy increases. This reflects that the synthesized polymeric samples represent the normal dispersion behavior. The variation in n values with the photon energy shows that the interaction between a photon and electrons takes place. Thus, one can get the desired material for fabricating the optoelectronics devices, by estimating the photon energy, as the internal energy of a device depends on the photon energy. The decrease in the extinction coefficient and refractive index with an increase in the photon energy may be correlated with an increase in the absorption coefficient and a decrease in the transmittance. The complex dielectric constant is the basic intrinsic property of materials. The real part of the dielectric constant represents how much it will slow down the velocity of light in the material, whereas, the imaginary part of the dielectric constant indicates how a dielectric material absorbs the energy from an electric field owing to the dipole motion [47].

Figure 10 shows the variation of the real part of dielectric constant with the wavelength for nanocomposites as a function of wavelength. The effect of WC nanoparticles concentrations on imaginary part of dielectric constant is shown in figure 11. The figures show that the real and imaginary parts of dielectric constant of (PMMA-PS) blend increase with increase in WC nanoparticles concentrations, this behavior attributed to the increase of electrical polarization due to contribution of WC nanoparticles concentration in the sample i.e., the increase in the dielectric constant of polymer blend represents a fractional increase in charges within the polymers. As shown in the figures, the real and imaginary parts of dielectric constant of blend change with the wavelength, this is due to the real part of dielectric constant depends on refractive index because the effect of extinction coefficient is very small and the imaginary part of dielectric constant depends on extinction coefficient especially in the visible and near infrared regions of wavelength where the refractive index is approximately constant while extinction coefficient increases with the increase of the wavelength [48].

Figure 12 shows the variation of optical conductivity with the wavelength for (PMMA-PS-WC) nanocomposites. From the figure, the optical conductivity of nanocomposites is increased with the increase of WC nanoparticles concentrations, this behavior related to the creation of localized levels in the energy gap; the increase of WC nanoparticles concentrations increasing the density of localized stages in the band structure, hence, increase the optical conductivity of nanocomposites [49].

Figure 13 shows the variation of (N/N_0) for (PMMA-PS) blend with different concentrations of WC nanoparticles. As shown in the figure, the transmission radiation decreases with increasing of the WC nanoparticles concentrations which attributed to the increase of the attenuation radiation. Figure 14 shows the variation of attenuation coefficients of gamma radiation for (PMMA-PS) blend as a function of WC nanoparticles concentrations. From the figure, the attenuation coefficients increase with the increase of WC nanoparticles concentrations, this is due to the absorption or reflection of gamma radiation by nanocomposites shielding materials. By comparing the results with concrete, it showed very close results, however, (PMMA-PS-WC) nanocomposites have an advantage over concrete because of its mobility and less electrical properties. It neither makes magnetic nor electrical field influencing human health of the users and/or patients [50].

4.CONCLUSION

The (PMMA-PS-WC) nanocomposites were prepared for x-rays shielding with light weight, high corrosion resistance, low cost and high attenuation. The effect of tungsten carbide on structural and optical properties of (PMMA-PS) blend was studied. The results showed that the (PMMA-PS-WC) nanocomposites have high absorbance for high energies which can be used for flexible electronic applications and flexible high energy shielding. The optical parameters (absorbance, absorption coefficient, extinction coefficient, refractive index, dielectric constants and optical conductivity) of (PMMA-PS) blend are increased while the transmittance and energy band gap are decreased with the increase in WC nanoparticles concentrations. The results of applications showed the (PMMA-PS-WC) nanocomposites have high attenuation for x-rays.

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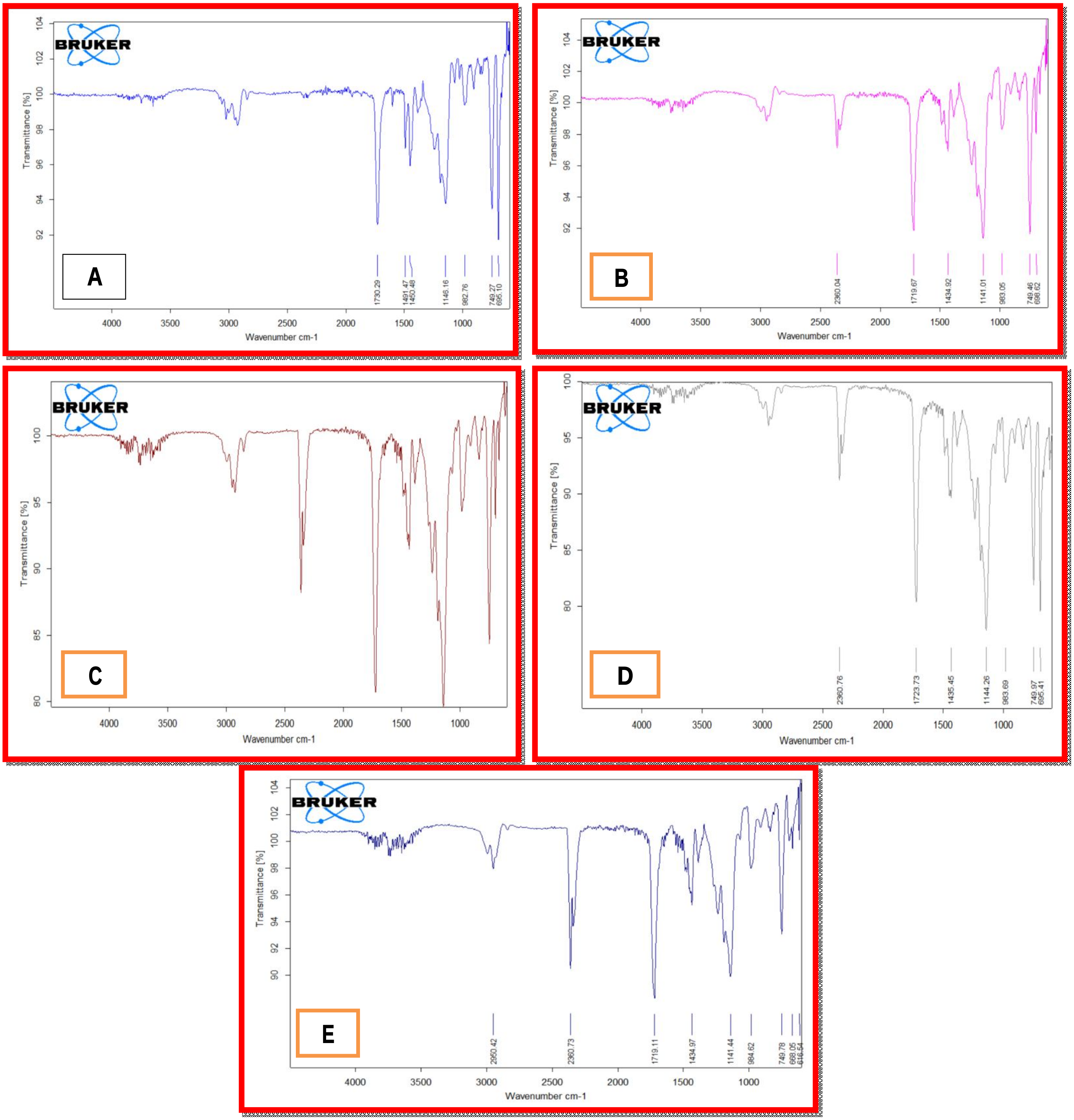

Figure 1: FTIR spectra for nanocomposites: (A) for pure blend (B) for 1.5 wt.% WC, (C) for 3 wt.% WC, (D) for 4.5 wt. % WC, (E) for 6 wt. % WC

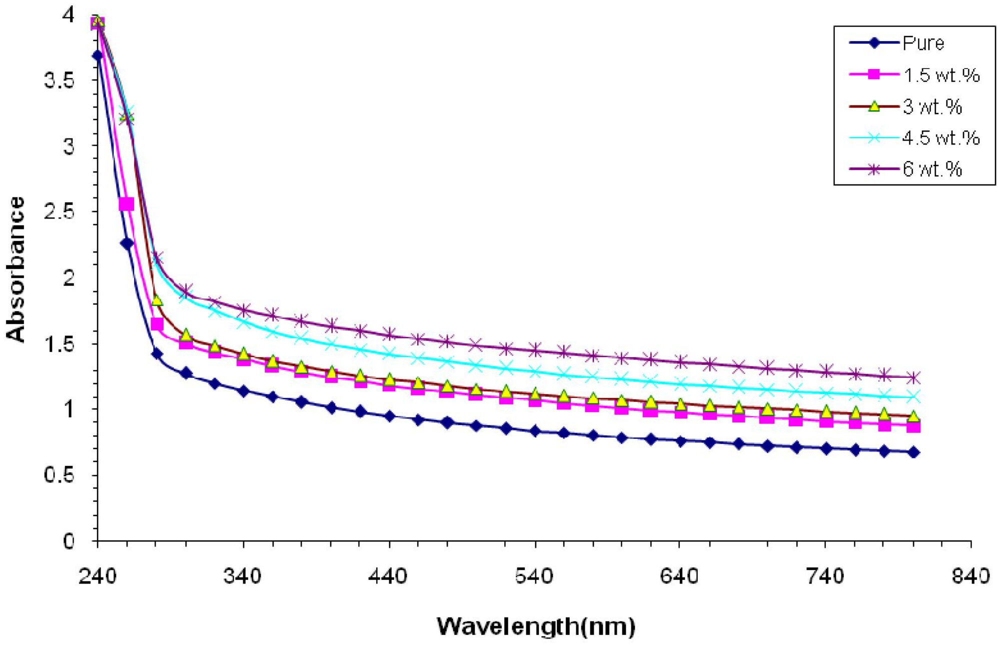

Figure 2: Absorbance spectra of (PMMA-PS-WC) nanocomposites

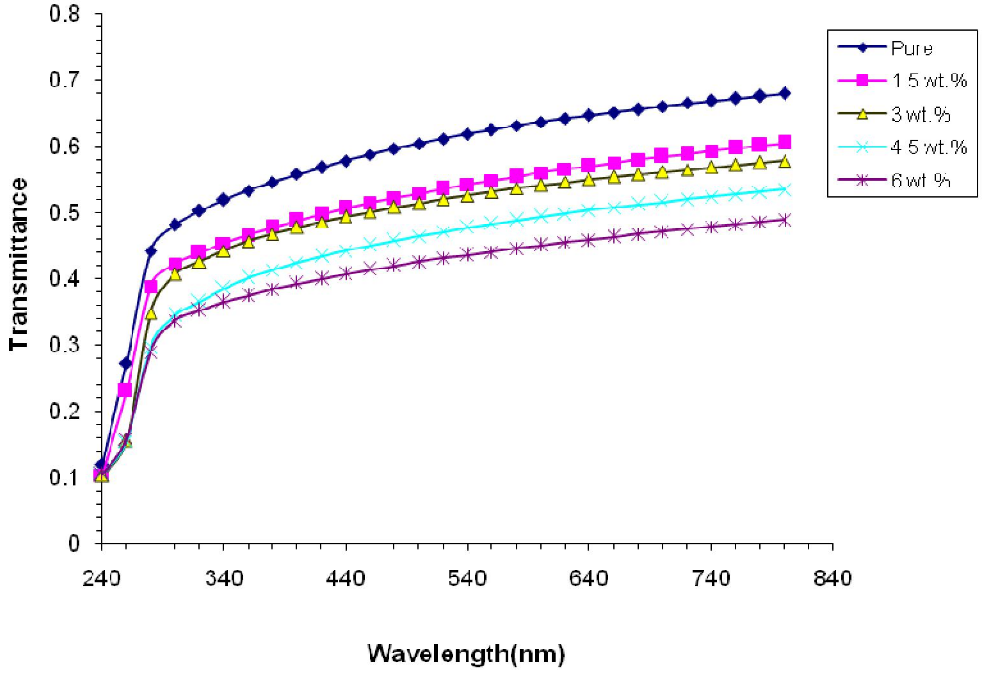

Figure 3: Transmittance spectra of (PMMA-PS-WC) nanocomposites

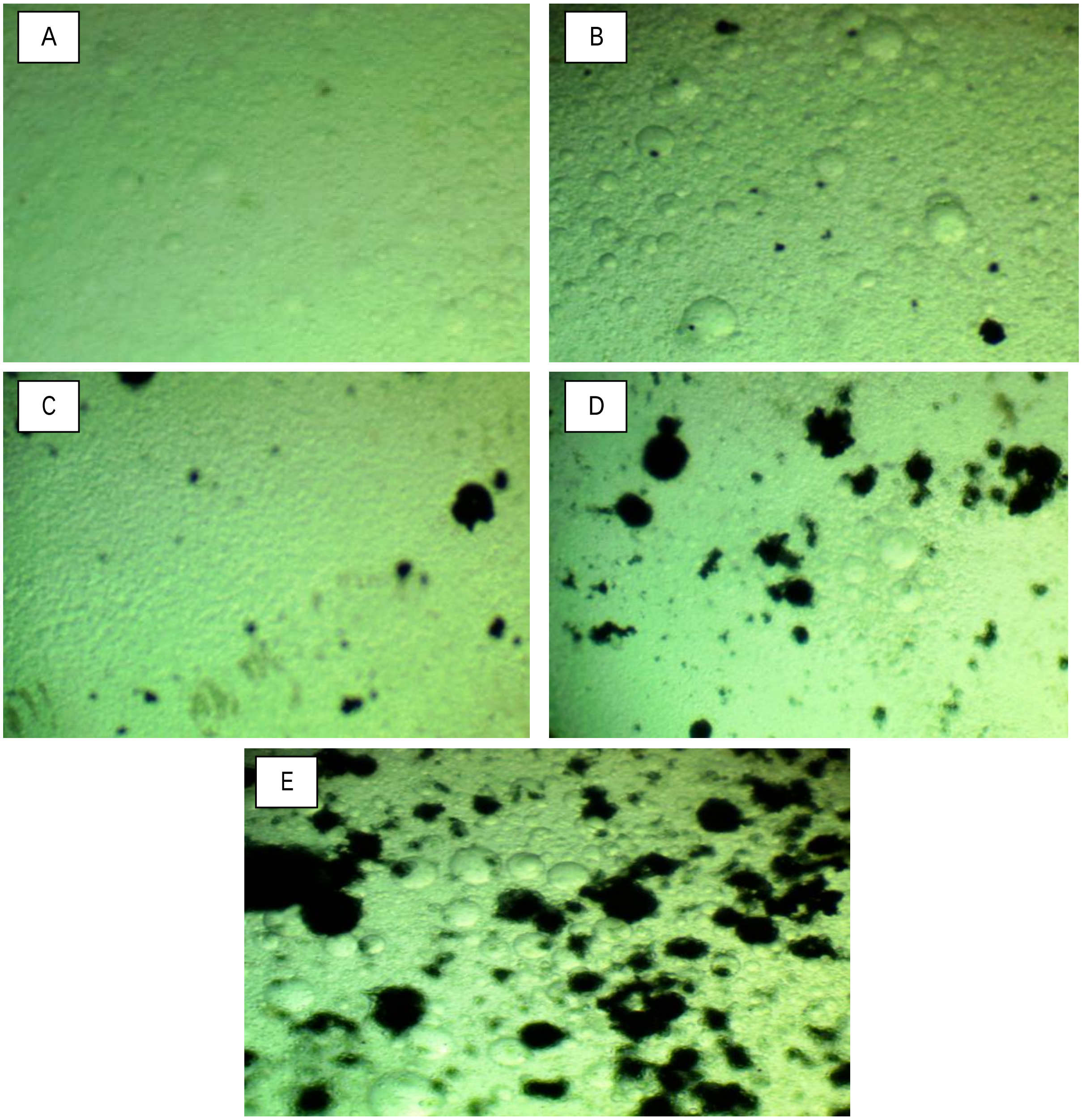

Figure 4: Microscope images (10x) for nanocomposites: (A) for pure blend (B) for 1.5 wt.% WC, (C) for 3 wt.% WC, (D) for 4.5 wt. % WC, (E) for 6 wt. % WC

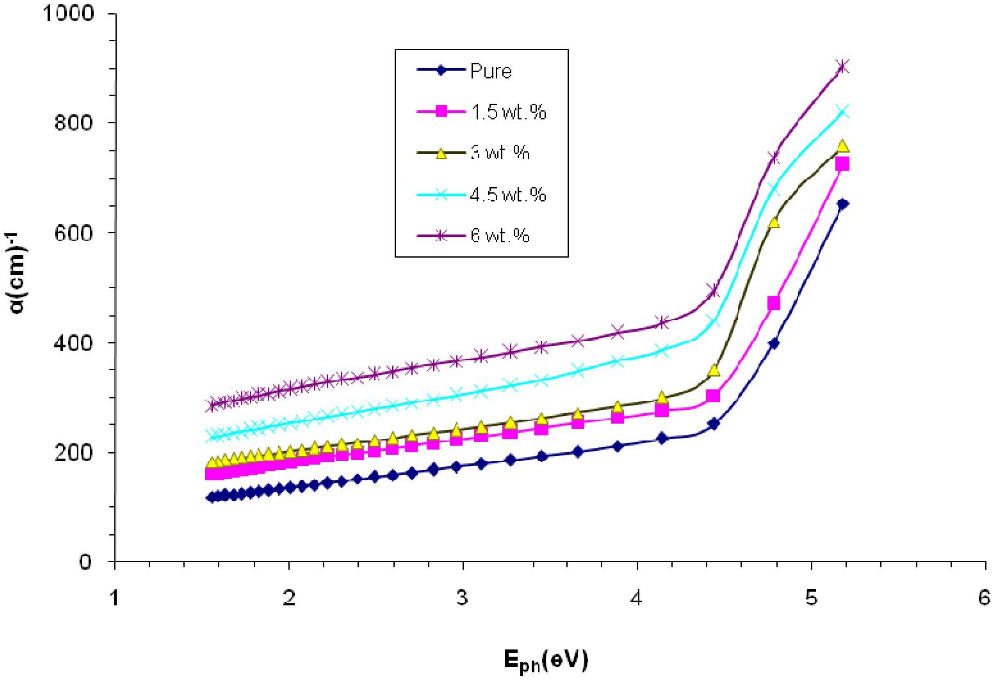

Figure 5: Absorption coefficient of nanocomposites as a function of photon energy of the incident light

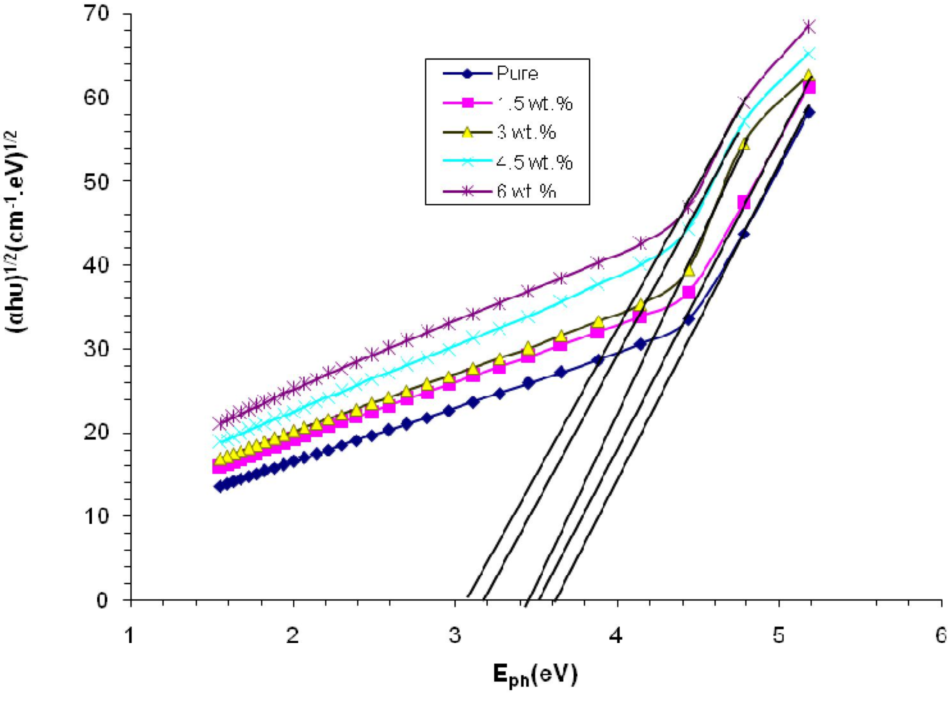

Figure 6: Energies gaps for allowed indirect transitions of (PMMA-PS-WC) nanocomposites

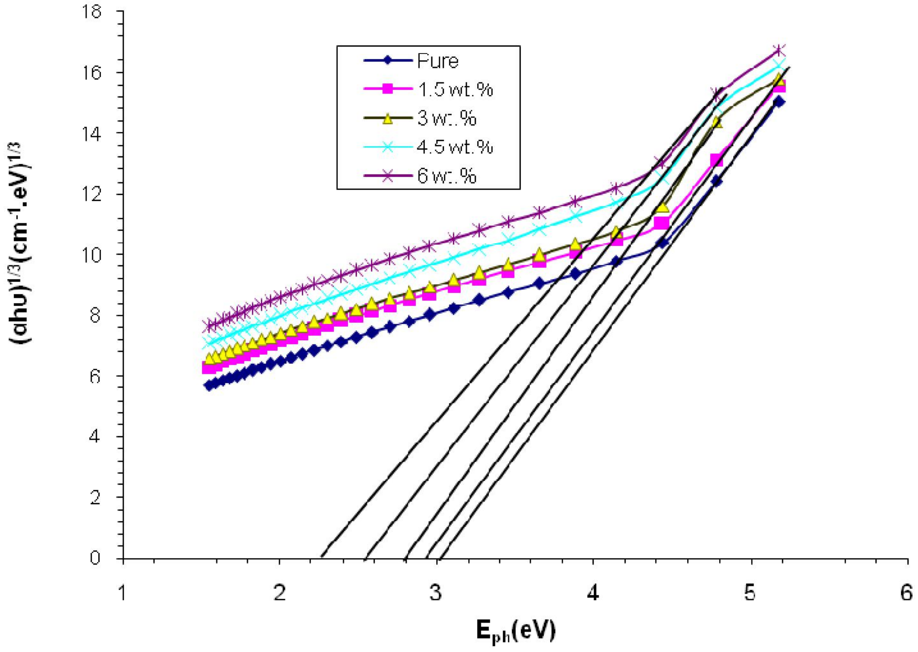

Figure 7: Energies gaps for forbidden indirect transitions of nanocomposites

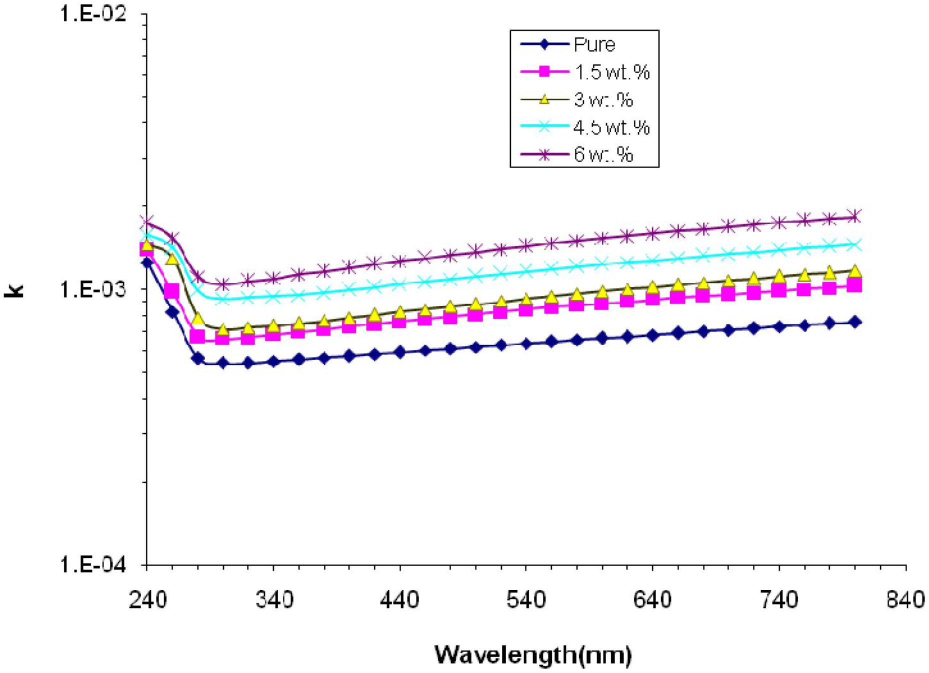

Figure 8: Extinction coefficient of nanocomposites as a function of the photon wavelength

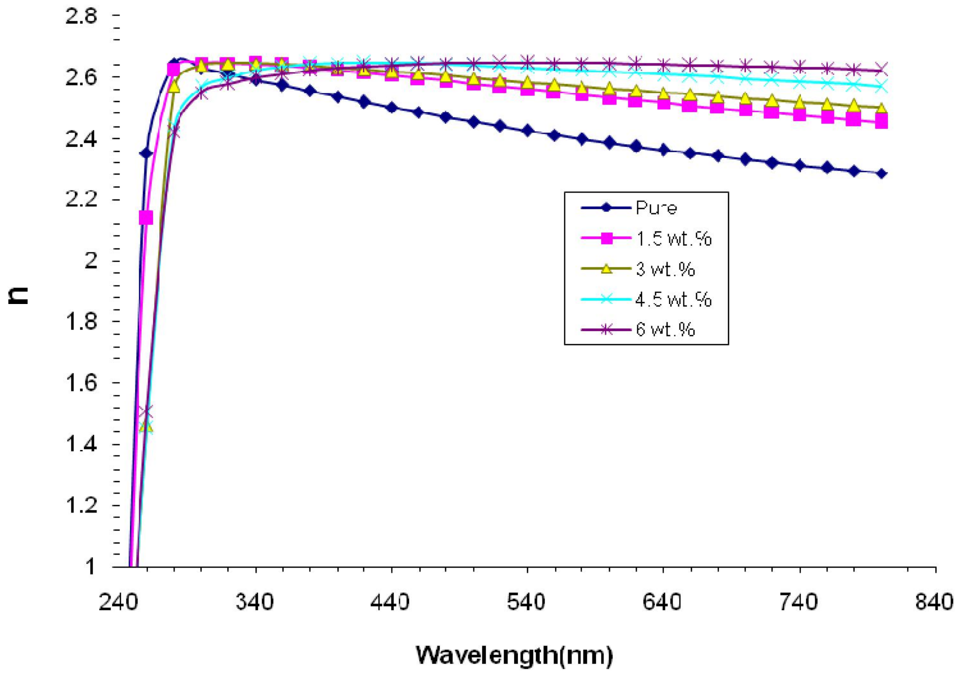

Figure 9: Relationship between the refractive index of nanocomposites and the wavelength

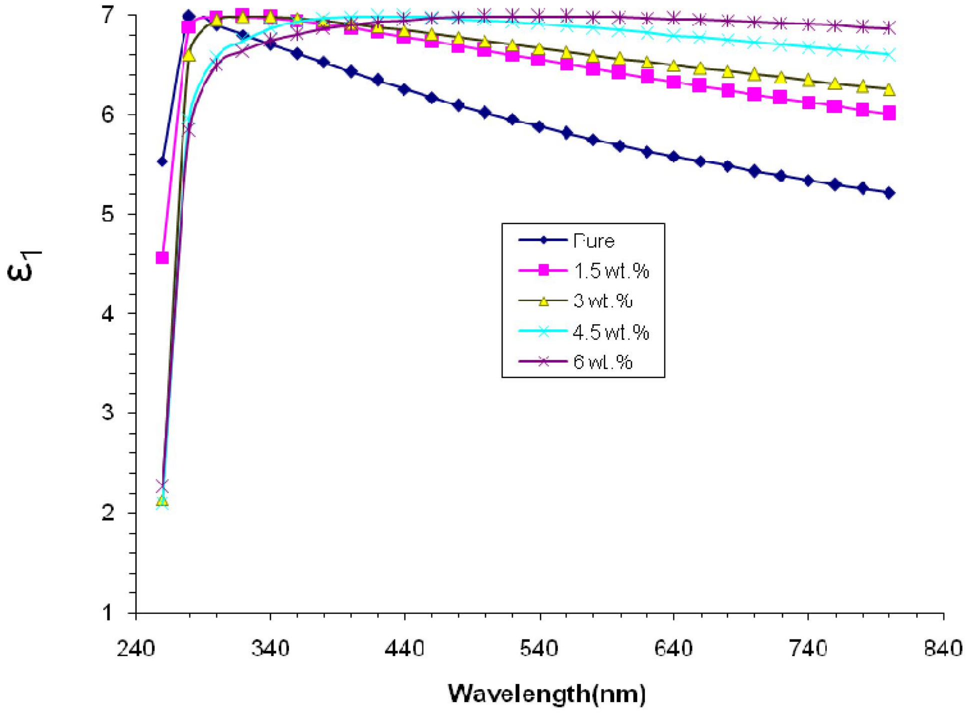

Figure 10: Variation of the real part of dielectric constant with the wavelength for nanocomposites as a function of wavelength

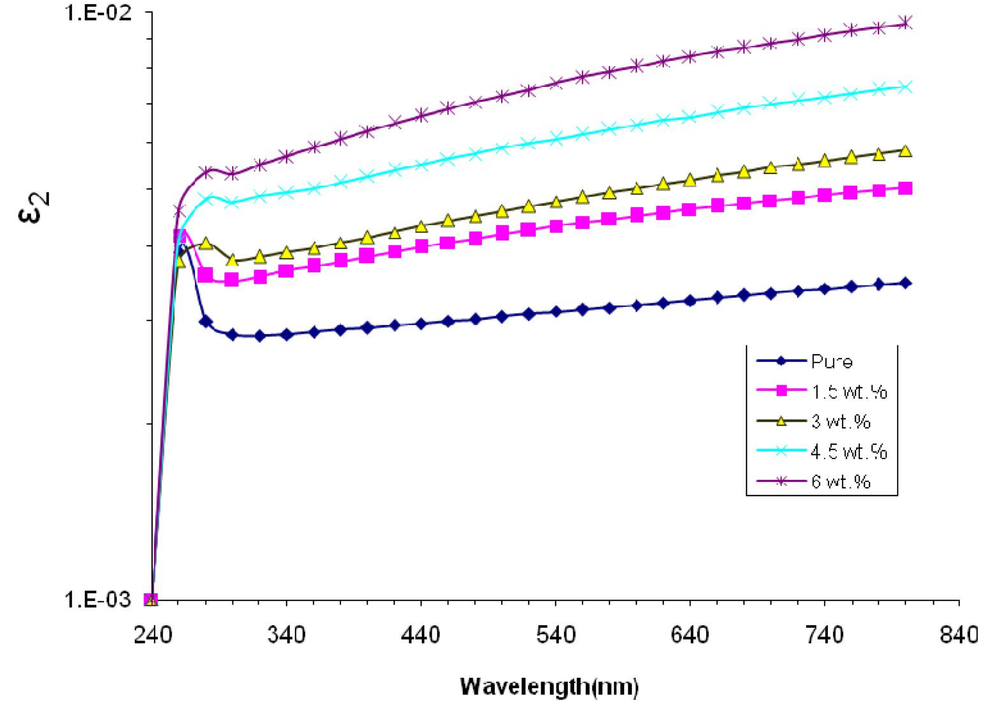

Figure 11: Effect of WC nanoparticles concentrations on imaginary part of dielectric constant

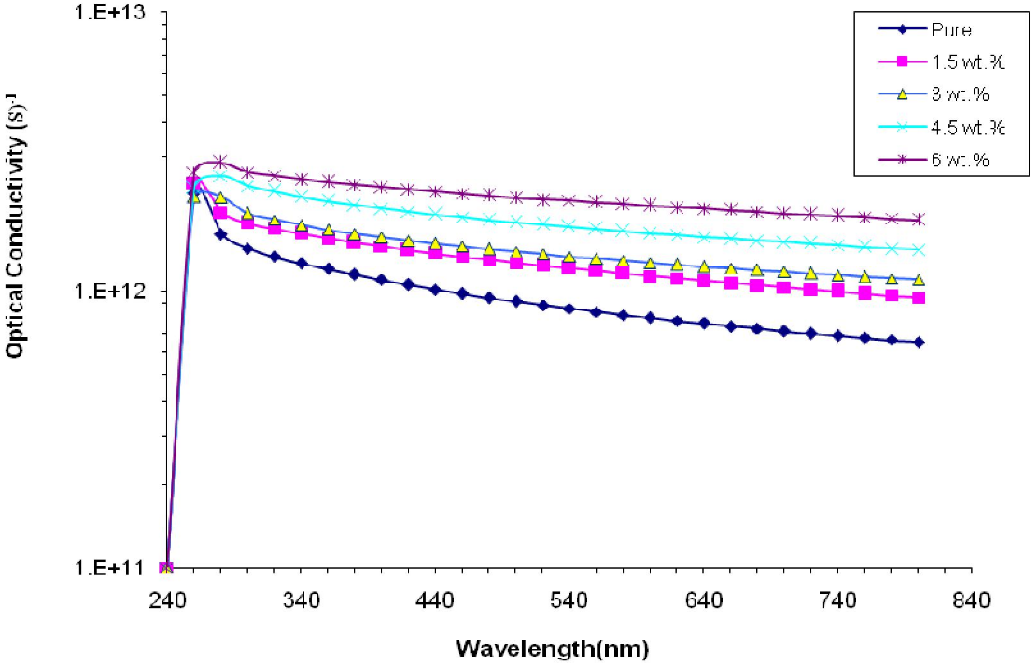

Figure 12: Variation of optical conductivity with the wavelength for (PMMA-PS-WC) nanocomposites

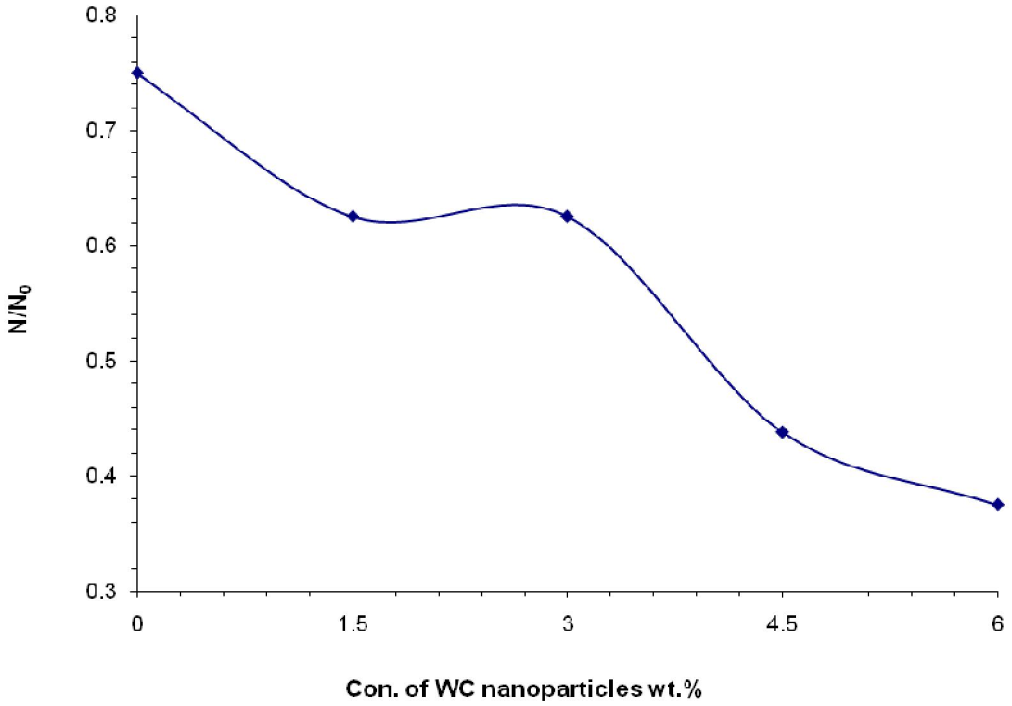

Figure 13: Variation of (N/N_0) for blend with different concentrations of WC nanoparticles

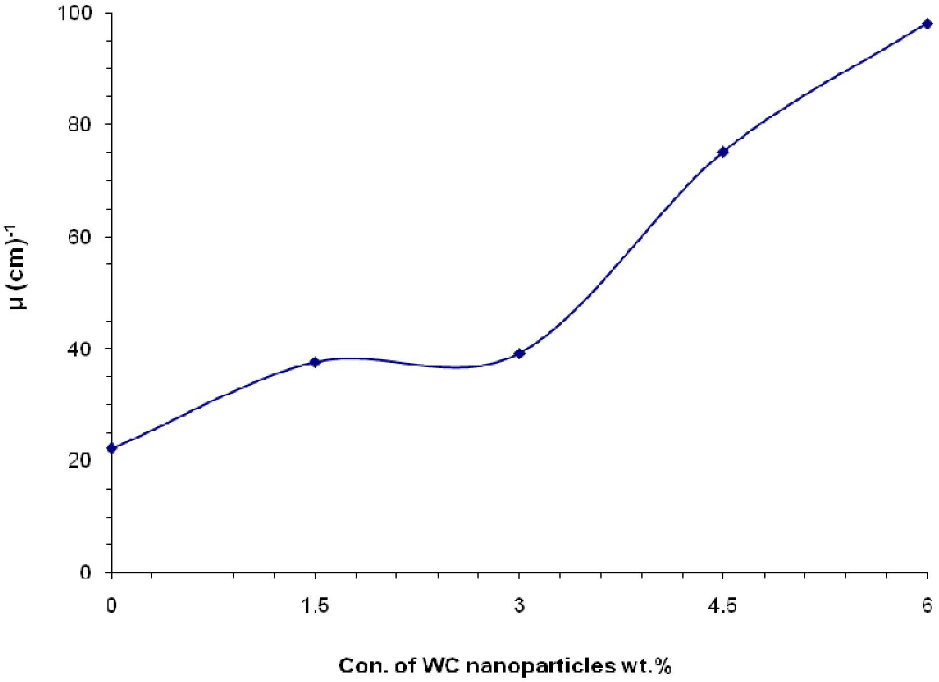

Figure 14: Variation of attenuation coefficients of gamma radiation for (PMMA-PS) blend as a function of WC nanoparticles concentrations