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Synthesis of New Films From SiO_2–$SrTiO_3$-Nanoparticles-Doped Polystyrene for Environmental and Biomedical Applications

Arshad Fadhil Kadhim and Ahmed Hashim

College of Education for Pure Sciences,
Department of Physics,
University of Babylon,
Hillah, Iraq

The PS/SiO_2–$SrTiO_3$ nanocomposites are prepared by casting method with different concentrations of SiO_2–$SrTiO_3$ nanoparticles of 0, 1.6, 3.4, 4.8, 6.4 wt.%. The PS/SiO_2–$SrTiO_3$ nanocomposites are tested for antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*. The results show that the PS/SiO_2–$SrTiO_3$ nanocomposites have high antibacterial activity. The gamma-ray shielding application of PS/SiO_2–$SrTiO_3$ nanocomposites is also tested. The results indicate that the PS/SiO_2–$SrTiO_3$ nanocomposites have the high attenuation coefficients for gamma-rays. The attenuation coefficients increase with the increase of the SiO_2–$SrTiO_3$ nanoparticles' concentration.

Нанокомпозити полістирол/наночастинки SiO_2–$SrTiO_3$ (ПС/SiO_2–$SrTiO_3$) одержують методом лиття з різними концентраціями наночастинок SiO_2–$SrTiO_3$: 0, 1,6, 3,4, 4,8, 6,4 мас.%. Нанокомпозити ПС/SiO_2–$SrTiO_3$ перевірено на антибактеріяльну активність проти золотистого стафілокока та кишкової палички. Результати показують, що нанокомпозити ПС/SiO_2–$SrTiO_3$ мають високу антибактеріяльну активність. Також протестовано застосування нанокомпозитів ПС/SiO_2–$SrTiO_3$ для екранування γ-променів. Одержані результати свідчать про те, що нанокомпозити ПС/SiO_2–$SrTiO_3$ мають високі коефіцієнти згасання для γ-променів. Коефіцієнти згасання зростають зі збільшенням концентрації наночастинок SiO_2–$SrTiO_3$.

Key words: nanocomposites, polystyrene, SiO_2, $SrTiO_3$, antibacterial defence, radiation shielding.

Ключові слова: нанокомпозити, полістирол, SiO_2, $SrTiO_3$, антибактеріяльний захист, радіаційний захист.

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1. INTRODUCTION

Nanocomposites are generally more advantageous than conventional composites in many aspects; they have several advantages including improving the physical, electrical, optical, and thermal properties, *etc.* [1].

One of the greatest polymers, polystyrene (PS), finds use in a wide range of products, including packaging, electronics, household appliances, Petri dishes, test tubes, and medical devices like test kit housing. Its properties may be altered in a variety of ways, including physical mixing with other materials and copolymerization. Currently, physical alteration is frequently accomplished by combining several polymers. The styrene component of PS has a variety of characteristics, including solvent resistance, toughening, and flame resistance. Since it is amorphous in form and is being chemically attacked by aromatic and chlorinated hydrocarbons, which present several issues in application areas, its applications are limited. In medicine, test tubes, diagnostic components, and other medical equipment are sterilized using it [2].

PS is valued for its acceptable dimensional stability, acceptable density, adaptability of processing techniques, the potential for food contact for particular grades, *etc.* PS for general use is atactic and incapable of crystallizing. The comparatively high glass-transition temperature (T_g) and high refractive-index value are caused by the presence of phenyl groups (about 1.57 to 1.6). Additionally, the presence of phenyl groups in the polymer structure prevents the chain from rotating, which makes the polymer rigid and brittle. 1.05 g/cm^3 is the density of polystyrene [3], which has a density that is greater than both polyethylene and polypropylene. PS lacks an obvious melting point since it is amorphous. This is shown in the material gradually weakening across a large temperature range. The PS T_g ranges from 74°C to 105°C. Heating-sensitive properties include impact strength and elongation at break. PS has fair mechanical characteristics that include modest elongations at break and brittle behaviour at room temperature. Because general-purpose PS is inherently quite transparent, several grades are expressly created for suitable optical applications. Haze can have a concentration as low as 0.65 and light transmission ranges from 80% to 98%. Polystyrene is a weak gas barrier and has poor moisture barrier properties [4].

Due to their chemical and thermal stability, low toxicity, capacity to be functionalized with a variety of chemicals and polymers, biocompatibility, physiological degradability, low cost, *etc.*, silica nanoparticles (SiO_2 NPs) are an appealing material. The scientific biomedical community is paying increasing attention to mesoporous silica NPs for their application in cell imaging, diagnostics, and drug/gene/protein delivery systems because of their enormous surface area and pores, which allow entrapping of huge numbers of cargo molecules. Nanosilica may also be utilized extensively in many other industries of environmental protection, including batteries, paints, adhesives, cosmetics, glass, steel, chemical fibres, plexiglass, and many more. Rubber and polymers that have silica nanoparticles scattered in them have much better strength, hardness, wear, and ageing resistance [5].

The ferroelectricity of strontium titanate ($SrTiO_3$) nanoparticles is maintained at low temperatures by quantum functions, making them incipient ferroelectric materials. They are renowned for their capacity to function as resistive high-temperature oxygen sensors and take on a transitional state to non-ferroelectric properties at lower temperatures. From 104 K to 2300 K, strontium titanate is stable without recrystallizing across a large temperature range. A high dielectric constant characterizes $SrTiO_3$. These characteristics are explained by their special characteristics, which include high breakdown strength, low leakage current density, low dielectric loss, tunability, and high dielectric constant [6].

Potential uses for $SrTiO_3$ include environmental clean-up and renewable energy generation. It also functions as a photocatalyst. These photocatalysts create electron/hole (e^-/h^+), when they are activated. With a gap energy of around 3.2 eV, it can absorb UV light [7], has superior corrosion resistance, a stronger flat band potential, and other advantages. $SrTiO_3$ can be used in oxygen sensors, photocatalysis, organic thin film transistors, dye-sensitized solar cells (DSSCs), and other applications because of its exceptional features [8]. There are several studies on applications of nanocomposites and composites included sensors and piezoelectric [9–19], optical, electronics and optoelectronics applications [20–40].

This work deals with preparation of PS/SiO_2–$SrTiO_3$ nanocomposites' films for antibacterial and gamma-ray shielding.

2. MATERIALS AND METHODS

The PS/SiO_2–$SrTiO_3$ nanocomposites were prepared by dissolving 1 gm of polystyrene (PS) in 30 ml of chloroform alcohol, and a magnetic stirrer was used to mix the material and obtain a complete dissolution of the solution. Thus, the first sample (pure) was prepared, and then, the SiO_2 and $SrTiO_3$ nanoparticles were added to polymer with different concentrations, which are of 1.6, 3.2, 4.8 and 6.4 wt.%. The casting method is used to prepare the samples of PS/SiO_2–$SrTiO_3$ nanocomposites in the template (Petri dish) and left to dry. The PS/SiO_2–$SrTiO_3$ nanocomposites' films were tested by optical microscope. The antibacterial activity was done against of gram-positive (*Staphylococcus aureus*) and gram-negative (*Escherichia coli*) organisms.

Gamma-ray shielding measurements of PS/SiO_2–$SrTiO_3$ nanocomposites have been carried out to examine gamma-ray attenuation for the samples with various concentrations of SiO_2–$SrTiO_3$ nanoparticles. The gamma-ray source (Cs-137, 5 μci) was placed in front of test samples, which were set up in various concentrations. The nanocomposite sample is placed at a distance of 1 cm from the gamma-ray source, which is located at 3 cm away from the detector. Geiger counter measurements of the transmitted gamma-ray fluxes

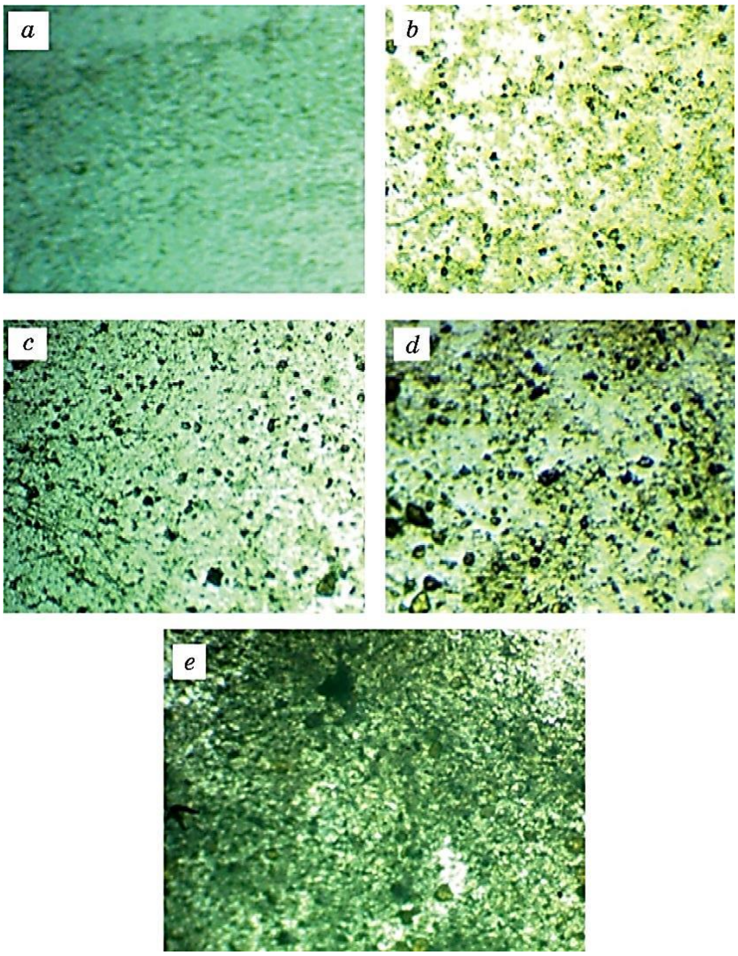

Fig. 1. Microscopy images of PS/SiO_2–$SrTiO_3$ nanocomposites: (*a*) for PS, (*b*) 1.6 wt.% SiO_2–$SrTiO_3$, (*c*) 3.2 wt.% SiO_2–$SrTiO_3$, (*d*) 4.8 wt.% SiO_2–$SrTiO_3$, and (*e*) 6.4 wt.% SiO_2–$SrTiO_3$.

through the samples were used to calculate the linear attenuation coefficients.

3. RESULTS AND DISCUSSION

Figure 1 shows the optical microscopy of PS/SiO_2–$SrTiO_3$ nanocomposites. It can be noticed that, at the low concentrations, the SiO_2–$SrTiO_3$ NPs form of clusters. With increasing concentrations of NPs, a connected network will form inside the nanocomposites [41–44].

Figures 2, 3 show the antibacterial properties of the PS/SiO_2–

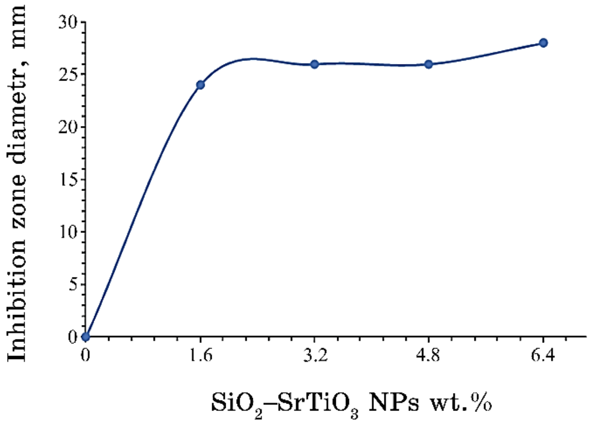

Fig. 2. Antibacterial activity of the PS/SiO_2–$SrTiO_3$ nanocomposites against *S. aureus*.

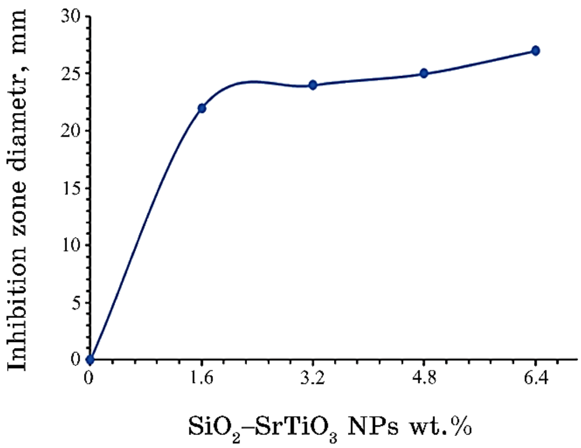

Fig. 3. Antibacterial activity of the PS/SiO_2–$SrTiO_3$ nanocomposites against *E. coli*.

$SrTiO_3$ nanocomposites against gram-positive *Staphylococcus aureus* and gram-negative *Escherichia coli*. As shown in these figures, the inhibition zone diameter increases with the increase in SiO_2–$SrTiO_3$ nanoparticles' concentrations. The reason for the antibacterial activity of nanocomposites may be due to the presence of reactive oxygen species (ROS) generated by the concentrations of SiO_2 and $SrTiO_3$ nanoparticles that could damage DNA and proteins in bacteria. The possible mechanism of action is that PS/SiO_2–$SrTiO_3$ nanocomposites carry positive charges and bacteria have negative charges that create electromagnetic attraction between microbes and nanoparticles of nanocomposites. When the interaction takes place, the microbes oxidize and die instantly [45–49].

Table shows the inhibition-zone diameter of PS/SiO_2–$SrTiO_3$ nanocomposites against *Staphylococcus aureus* and *Escherichia coli* bacteria.

Figure 4 depicts the variation of N/N_0 with concentrations of PS/SiO_2–$SrTiO_3$ NPs. The attenuation of radiation increases as SiO_2–$SrTiO_3$ nanoparticles' concentrations rise that is why the transmission radiation drops.

TABLE. Inhibition zone diameter of PS/SiO_2–$SrTiO_3$ nanocomposites.

Concentrations of NPs, wt.%	*Staphylococcus aureus*, mm	*Escherichia coli*, mm
0	0	0
1.6	24	22
3.2	26	24
4.8	26	25
6.4	28	27

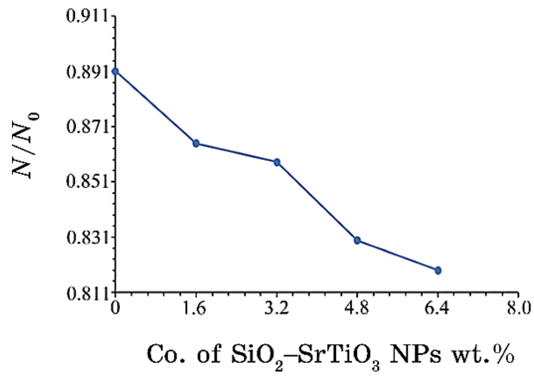

Fig. 4. Variation of N/N_0 for the PS/SiO_2–$SrTiO_3$ nanocomposites with different concentrations of SiO_2–$SrTiO_3$ nanoparticles.

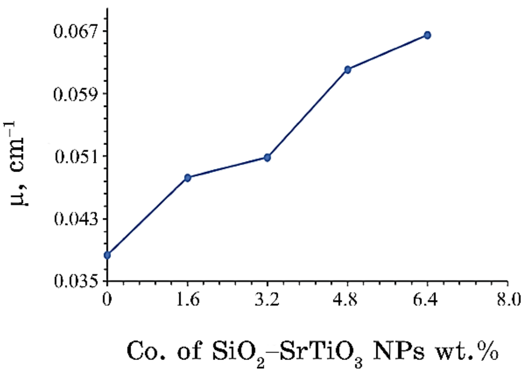

Fig. 5. Variation of attenuation coefficients of gamma-radiation for the PS/SiO_2–SrTiO3 nanocomposites with different concentrations of SiO_2–$SrTiO_3$ nanoparticles.

The attenuation coefficients of gamma-rays for the PS/SiO_2–$SrTiO_3$ nanocomposites are shown in Fig. 5. The attenuation coefficients rise as SiO_2–$SrTiO_3$ nanoparticles' concentrations rise because shielding materials used in nanocomposites either reflect or absorb gamma-radiation [50–55].

4. CONCLUSIONS

This work included preparation of PS/SiO_2–$SrTiO_3$ nanocomposites' films for antibacterial and gamma-ray shielding applications. The PS/SiO_2–$SrTiO_3$ nanocomposites were tested for antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*. The results showed that the PS/SiO_2–$SrTiO_3$ nanocomposites have high antibacterial activity. The gamma-ray shielding application of PS/SiO_2–$SrTiO_3$ nanocomposites was also tested. The results indicated that the PS/SiO_2–$SrTiO_3$ nanocomposites have high attenuation coefficients of gamma-rays. The attenuation coefficients increased with the increase of the SiO_2–$SrTiO_3$ nanoparticles' concentrations.

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