EFFECT OF HIGH-DOSE GAMMA RADIATION AND WS_2 NANOSHEETS ON THE SUPRAMOLECULAR STRUCTURE, FRACTAL MORPHOLOGY, AND INTERFACIAL BEHAVIOR OF PVDF BY SAXS

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In this study, PVDF nanocomposites reinforced with WS_2 nanosheets were fabricated and exposed to high-dose gamma irradiation. The objective of this work is to analyze changes in structural integrity, crystallinity, defect formation, radiation resistance, nanoparticle dispersion, and interfacial interactions within these nanocomposites, as well as to assess their long-term suitability for use in radiation-intensive environments. PVDF/WS_2 nanocomposite films are highly promising materials for a wide range of applications, including flexible energy storage devices, sensors, and energy harvesting systems [1]. By combining the piezoelectric properties of PVDF with the high surface area and electrochemical properties of WS_2, these composites show enhanced performance in energy storage and conversion, as well as mechanical flexibility for wearable and flexible electronics. In this work, the effect of high-dose ionizing gamma radiation (0–700 kGy) and WS_2 nanosheets at different concentrations (1%, 3%, 5%, 10%) on the supramolecular structure, crystal/amorphous interface, and fractal morphology of PVDF was systematically studied using SAXS (broad peak, two-power-law, correlation function) method [2-3].

It was established that the roughness of neat PVDF thin films of surface fractal ($p=3.21$, $D_s=2.79$) transforms into a diffuse interface ($p>4$), with increasing radiation dose, while interlamellar distance decreases monotonically from 9.57 nm to 8.33 nm (densification), with short-range order ($\xi\approx4.4–4.6$ nm) is preserved and the degree of crystallinity increases (WAXS: 36.2% → 44.6%). At the same time, it was found that PVDF is resistant to radiation and no destruction occurs in the bulk structure. Furthermore, it was determined that at 1–3% WS_2 concentration, the WS_2 nanosheets exhibit good dispersion and a nucleating effect in the polymer matrix. This leads to a sharp smoothing of the polymer crystal/amorphous interface ($D_s=2.79 \rightarrow 2.05$) and increment in lamellar spacing ($d=9.57 \rightarrow 10.12$ nm). At 5% WS_2 – the onset of aggregation, return of the surface to moderate roughness ($D_s\approx2.30$), lamellar densification ($d=9.22$ nm) and maximum correlation length ($\xi=46.6$ Å) – this concentration is optimal for piezoelectric applications. At 10% WS_2 – formation of large aggregates (crossover size ~113 nm), two-level fractal structure: large aggregates very rough ($D_s\approx2.92$), small structures moderately rough ($D_s\approx2.44$). The PVDF matrix is constrained, and its own lamellar structure weakens (Fig. 1.).

Additionally, it was found that in low-concentration composites WS_2 nanosheets delays the radiation-induced interface diffusion (e.g., in 5% WS_2 the diffuse interface appears at 500 kGy, whereas in neat PVDF it appears at 300 kGy). Despite the presence of agglomeration, the relatively homogeneous distribution of nanosheets around 10 wt% filler concentration leads to

more effective absorption and scattering of radiation energy. This shields the PVDF matrix from direct radiation damage, limiting crosslinking and chain scission, and thereby significantly enhances the radiation resistance of the nanocomposite. The SAXS results directly confirm this protective effect, as the fractal parameters remain stable over the 0–700 kGy dose range in this highly filled system.

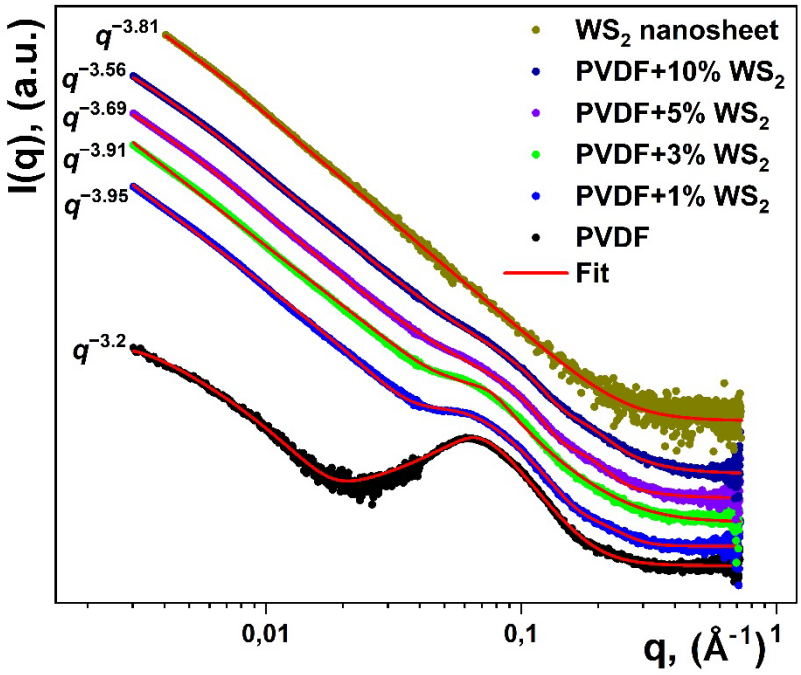

Fig. 1. Small-angle X-ray scattering plots of WS_2 nanosheets and PVDF+%WS_2 nanocomposite films

PVDF+5%WS_2 composite is recommended for optimal piezoelectric response, while 10% WS_2 is recommended for structural stability in radiation environments (sterilization, nuclear technology, aerospace industry). Nevertheless, several unsolved problems remain for the practical application of PVDF/WS_2 composites: potential increase in dielectric loss due to the diffuse interface, instability caused by aggregates, strong temperature dependence, and the difficulty of combining multiple functions (high piezoelectric response + low loss + radiation stability) in the same material. This work makes important contributions to both fundamental science (polymer physics, radiation chemistry) and practical materials science by quantitatively describing, through fractal analysis, the structural behavior of PVDF/WS_2 nanocomposites under radiation. The research provides a scientifically based guide for optimizing the WS_2 concentration and radiation dose according to the intended application area. Future work should focus particularly on determining the interface thickness, conducting in-situ studies, and establishing correlations with macroscopic properties. This approach will pave the way for the design of a new generation of multifunctional polymer nanocomposites.

[1] Arun Mondal, et al., (2024). High-performance flexible piezoelectric nanogenerator assisted by a three-phase PVDF/WS2/rGO nanocomposite, Nanotechnology 395401.

[2] A.A. Nabiyev, et al. (2020). Nano-ZrO_2 filled high-density polyethylene composites: Structure, thermal properties, and the influence γ-irradiation, Polymer Degradation. Stability 171

[3] A.A. Nabiyev, O.I. Ivankov, et al., (2026). High-dose gamma irradiation effects on HDPE/SiO_2 nanocomposite films: Structure, crystallinity, defects, radiation endurance, dispersion, and interfacial behavior, Polymer Degradation and Stability, 245, 111851.