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Boosting the electrical properties of nano-structured ($Ga_{10}Se_{90}$)-MWCNT bilayer thin films

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Selenium-based chalcogenide semiconductors are of growing interest for optoelectronic applications due to their high DC conductivity, photoconductivity, and carrier mobility. In this work, $Ga_{10}Se_{90}$-MWCNT nanocomposite thin films were fabricated *via* thermal evaporation and subsequently modified using swift heavy ion (SHI) irradiation using 70 MeV Ni^{7+} ions at fluences of 1×10^{12} to 1×10^{13} ions per cm^2. SHI irradiation promoted the homogeneous mixing of CNTs within the GaSe matrix, enhancing the electrical properties through defect engineering and interfacial charge transfer. Characterization *via* FESEM, EDX, and FTIR confirmed uniform nanoparticle dispersion and strong GaSe–CNT interactions. Post-irradiation, DC conductivity increased from 2.11×10^{-4} to $2.97 \times 10^{-3}\ \Omega^{-1}\ cm^{-1}$, photoconductivity from 5.16×10^{-5} to $2.90 \times 10^{-3}\ \Omega^{-1}\ cm^{-1}$, and carrier mobility from 50.9 to 475.1 $cm^2\ V^{-1}\ s^{-1}$. These enhancements are attributed to improved charge transport *via* CNT networks and SHI-induced acceptor states. The results highlight the tunability of GaSe–CNT composites *via* SHI, supporting their potential use in advanced optoelectronic devices.

1 Introduction

Chalcogenides are versatile semiconducting materials, and the electrical properties of chalcogenide-based semiconductors are significant for a variety of electronic and optoelectronic applications. Their physical properties can be tailored by engineering their composition. Electrical conductivity is influenced by several factors, including the chalcogenide's composition and doping levels. They have attracted interest worldwide because of their unique optical and electrical properties, corresponding to a wide range of applications such as in energy storage devices, communication, photoconductors,[1] phase change memory devices,[2] photovoltaics, photodiodes, *etc.*[3,4] It has been demonstrated that incorporating doping elements in chalcogenide glasses can lead to significant modification of their physical properties. There are various techniques available for the deposition of thin films of chalcogenides such as chemical vapor deposition (CVD), chemical bath deposition (CBD), sol–gel synthesis, solvothermal techniques, pulsed laser deposition, *etc.* Thermal evaporation is one of the easiest and most cost-effective techniques for the deposition of thin films.[5,6] Gallium selenide (GaSe), a layered semiconductor monochalcogenide, due to its composition dependent properties has emerged as a vital semiconducting material in the fields of photonics and optoelectronics. It has a hexagonal structure, and finds various applications due to its novel optoelectronic properties.[7,8] Each individual layer of gallium selenide is made up of two sheets of Ga ions in the middle and two sheets of Se ions on the top and bottom. Similar to other layered 2D structures like graphene, adjacent GaSe layers are bound by weak van der Waals forces, which allows for the structure to be peeled off by mechanical or liquid exfoliation.[9] The ultra-thin few or single layer 2D gallium selenide nanosheets or nanoparticles that are produced have a wide range of applications, including in integrated optics, optical information communications, *etc.*[10–12] In layered gallium chalcogenide semiconductor crystal materials such as GaSe, GaS, and GaTe, free excitons play a vital role in optical, photoconductivity and luminescence properties. The exciton states have densities that are higher than those at the edges of the valence and conduction bands; the exciton maximum can be seen in the measured values of photoluminescence, absorption, reflection, and photoconductivity spectra. With a pseudo direct bandgap of the order of 2.1 eV and thickness dependent opto-electronic properties, GaSe has emerged as a promising candidate for the implementation of thin film transistors (TFTs), photodetectors and photoconductors with fast response and high sensitivity. Ga-Se, exhibiting novel optoelectronic properties, is a promising material for photoconductor and nonlinear optical applications. Non-linear optical materials are used in the frequency conversion of laser light.[13,14] A photoconductor is a light-

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