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# SYNTHESİS, CHARACTERİZATİON, AND PERFORMANCE OF $Sb_2(S, Se)_3$ BASED COMPOSİTES.

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**Abstract**

Thermal evaporation method was used to create the $Sb_2(S,Se)_3$ compounds. This finding emphasizes $Sb_2(S,Se)_3$'s promise as a new photovoltaic material. It has achieved good power conversion rates of 6.5% to 8%. Further efficiency improvement seems to be required for upcoming real-world applications. $Sb_2Se_3$-GaSe eutectic composites are synthesized by the vertical Bridgman method. XRD analysis and structural study of $Sb_2Se_3$-GaSe eutectics show that $Sb_2Se_3$ inclusions are uniformly distributed in the GaSe matrice. Three eutectic points were studied in the $Sb_2Se_3$-GaSe system. It was determined that the composition of the three eutectics formed in the $Sb_2Se_3$-GaSe systems is 80 wt %; 55wt % and 40wt % $Sb_2Se_3$, melt points were 776K, 725K and 698K respectively.

**Keywords:** XRD, SEM and EDX analysis, eutectic system, raman spectra, photovoltaic material, solar cell

## 1. Introduction

The structure of semiconductor-based composite materials is just as important as their content in determining their controllable physical characteristics. When developing composites, it's critical to consider the phases' size, shape, and distribution as well as the interface characteristics [1–9]. The creation of novel microstructures frequently results in notable enhancements to the new characteristics of composite materials. Eutectics is a paradigm of composite materials with extremely small microstructures that can optimize physical qualities by combining the properties of each component [8]. Due to the isomorphy of $Sb_2S_3$ and $Sb_2Se_3$, the antimony sulfide-selenide $Sb_2(S,Se)_3$ can be considered a binary metal chalcogenide semiconductor. They have a lot of elemental storage, are nontoxic, have good moisture stability at high temperatures, and have the right physical characteristics for materials used in solar cells to absorb light. Numerous efforts have been made thus far in the areas of device production, photovoltaic property research, and materials synthesis. This family of materials has been used in either sensitized-architecture or planar heterojunction solar cells, benefiting from earlier research in thin film solar cells and new generation nanostructured solar cells. Good power conversion rates between 6.5% and 8% have been attained. It appears that additional efficiency enhancement is needed for future real-world applications.

Because of their important applications in the fields of optics, electronics, mechanics, energy, and the environment, $Sb_2(S,Se)_3$ has received increasing attention in the physics of solid-state materials [6–7]. These applications include sensors, functional smart coatings, smart membranes and separation devices, micro-optical and photonic components, and a new generation of photovoltaics and photo-catalysts [11]. By directly converting solar energy into electrical power, photovoltaic solar cells are thought to be the most effective method of utilizing solar energy among its various applications [11-14].

$Sb_2(S,Se)_3$ has garnered a lot of attention lately because of its photovoltaic capabilities and thermoelectric efficiency [9]. As a result, solar panels with unique coatings and cooling systems that use optical and thermoelectric technology have unique properties. GaSe crystals are frequently found in non-linear optical and photoconductive materials [8]. GaSe has significant absorption behavior in the UV-visible wavelength, making them excellent candidates for use in photodetector. Eutectic systems maintain the physical characteristics of the chemicals that make them up [13], and these characteristics can be controlled [12, 18]. Consequently, it is crucial to investigate $Sb_2Se_3$-GaSe eutectic systems that incorporate the characteristics of both components because of the significant qualities of $Sb_2Se_3$ and GaSe compounds [12–18]. Here, we examine the structures, raman scattering, physical-chemical characteristics, volt-ampere characterisation, and applications of Sb2Se3-GaSe eutectic systems.

## 2. Experimental

The $Sb_2(S,Se)_3$ compounds were produced by the thermal evaporation method. The prepared $Sb_2S_3$ thin film's energy dispersive X-ray examination revealed that the atomic percentage ratios were Sb = 41.3% and S = 58.7%. $Sb_2Se_3$-GaSe eutectic composites were prepared by using the vertical Bridgman method. The rate of the crystallization front was about 1.7 mm/min. The X-ray spectra of the $Sb_2Se_3$-GaSe eutectic systems were made by the Advance-D8 diffractometer ("Bruker"). The source of radiation was the CuKα-anode, operating at a voltage of 40kV and a current of 40 mA. The wavelength of the radiation was $\lambda$=1.5406Å, and the angle between the falling X-rays and the sample was $2\Theta=5\div80$. A Zeiss ΣIGMA Field Emission Scanning Electron Microscope (FESEM) were used to characterize the morphology of the specimens and to obtain qualitative information on the elemental composition of the samples, respectively. Raman scattering was studied using a Nanofinder 30 confocal setup (Tokyo Instruments, Japan) with a diffraction grating of 1800 lines/mm and a spectral resolution of 0.5 $cm^{-1}$ . Scattering was excited at a wavelength of 532 nm by the second harmonic of a Nd:YAG laser with a maximum power of 10 mW. Thermal analysis in the $Sb_2Se_3$-GaSe eutectic systems was performed in an inert gas environment (argon) on a NETZSCH DSC 204 F1 (Germany) differential scanning calorimeter. Nitrogen is used as shielding gas. A composite sample with a mass of 40 mg is placed in an aluminum socket. In the same slot, a sapphire is placed as a standard sample and in completely identical conditions both cells are heated at a rate of 10 K/min. Inert gas the flow rate is chosen to be 20 ml/min and the studies are carried out in the temperature range of 273-873K according to the purpose of the work.



## 3. Results and discussion

The Sb2Se3-GaSe systems are obtained in the form of light grey compact ingots. Three eutectic points were studied in the $Sb_2Se_3$-GaSe system. Diffraction patterns of the $Sb_2Se_3$-GaSe eutectic composite are shown in Fig. 1. Analysis of XRD spectra confirmed that this system is diphasic: the most intense peaks corresponding to the (020), (120), (130), (230), (240), (211), (301), (041), (141), (520), (002), (061), Muller index are identical to the $Sb_2Se_3$, and orthorhombic structure with lattice parameters of a = 3.81, b = 12.82, c = 15.06 while the weak peaks found at $2\theta = 22^0$, $34^0$, $45.5^0$, $58^0$ and $71^0$ coincide with the GaSe lines.

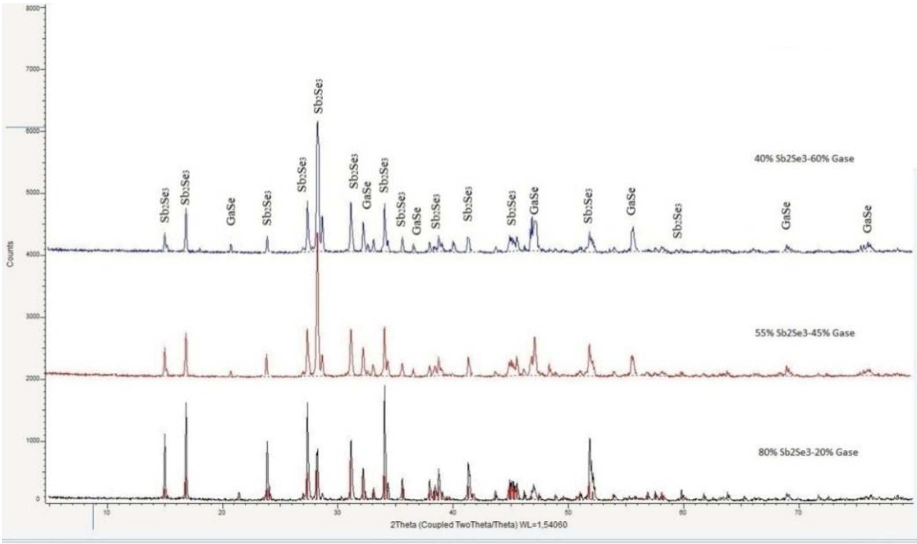


Fig. 1. XRD patterns of $Sb_2Se_3$-GaSe eutectic systems

Gallium monoselenide melts congruently at 960ºC and is crystallized in a hexagonal syngony with lattice parameters: a=b=0.375 nm, c=1.591 nm, Z=4, space group P63/mmc-D4 6h, density ρ = 5,03 g/cm3. It was determined that the composition of the three eutectics formed in the $Sb_2Se_3$-GaSe systems is 80 wt %; 55wt % and 40wt % $Sb_2Se_3$, melt points were 776K, 725K and 698K respectively. The structure of $Sb_2Se_3$-GaSe eutectic systems was studied with an electron microscope (FESEM) and X-ray spectrograph (Fig.2). SEM and EDX analysis show that the obtained eutectics present two phase systems. Figure 2 shows a image of the $Sb_2Se_3$-GaSe systems contains Sb = 51.03wt%, Se = 47.01 wt%, and Ga = 1.96 wt% . The data correspond to the stoichiometric composition of the matrix and inclusions.



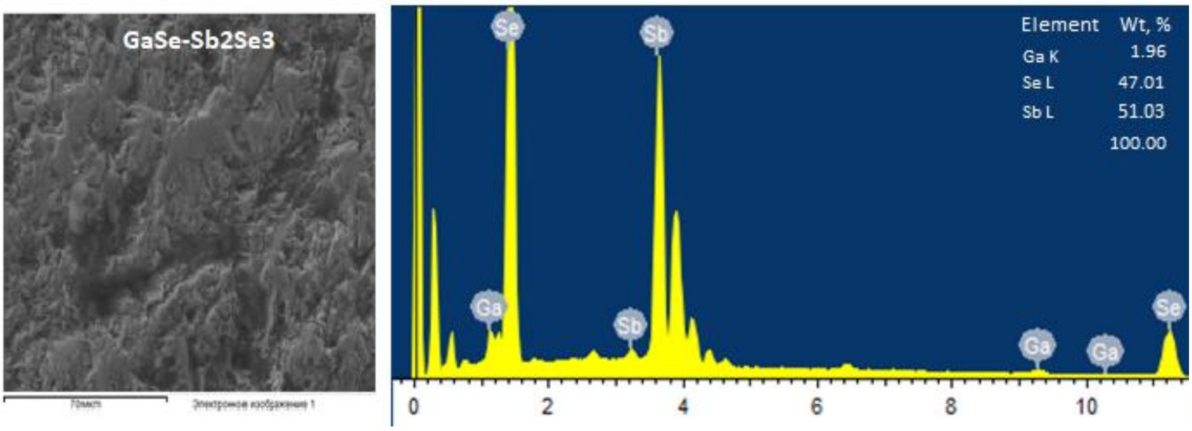


Fig. 2. X-ray spectra of $Sb_2Se_3$-GaSe systems obtained with SEM–EDX

Two phases and interphases in GaSe-$Sb_2Se_3$ eutectic composite Raman spectra for both GaSe- $Sb_2Se_3$, $Sb_2S_3$, and $Sb_2Se_3$ at room temperature were investigated to confirm the presence of the zones. Figure 4 shows the Raman spectra of the $Sb_2Se_3$ compound and, Figure-5 shows the Raman spectra of the GaSe- $Sb_2Se_3$eutectic system.

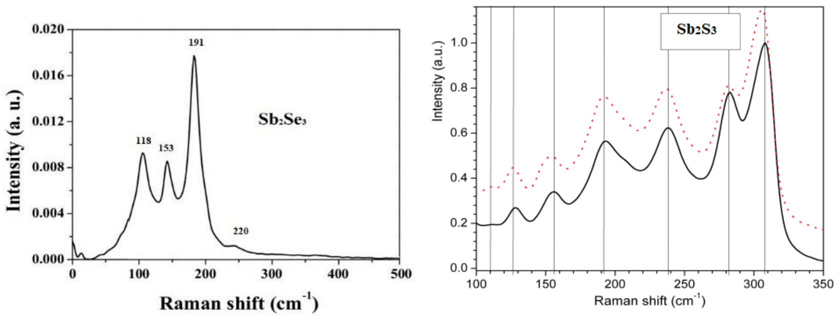


Fig. 3 Raman spectrum of $Sb_2Se_3$ and $Sb_2S_3$ powders

Raman analysis was applied to the samples to investigate the structure. Raman spectra (see Fig. 3) show more intense peaks around 153 and 191.3 $cm^{-1}$, which are usually attributed to the $Sb_2Se_3$ phase; in particular, the first belongs to the $A_{2u}$ mode of the Sb-Sb bond, and the second to the $A_g$ mode of the Sb-Se-Sb mode. In contrast to the Raman spectra published for the $Sb_2S_3$ molecule, the most intense band in the current work is located at around 307 $cm^{-1}$ rather than 281 $cm^{-1}$.



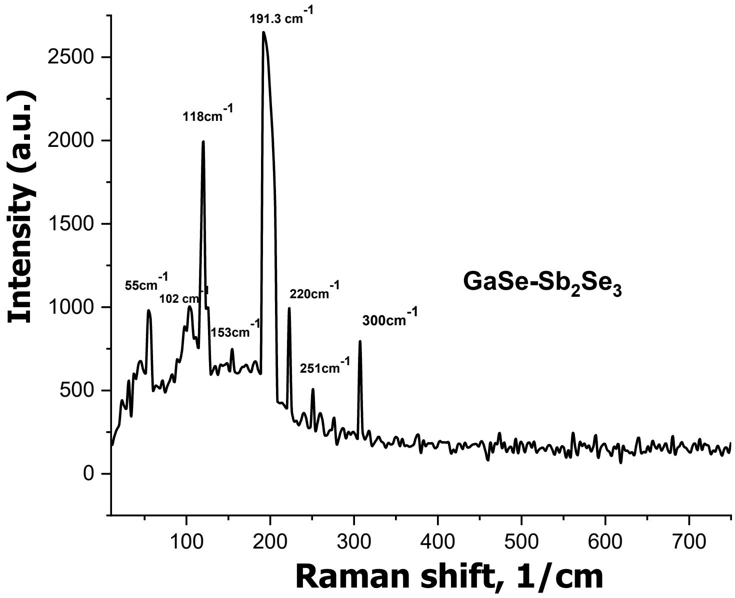


Fig. 4 Raman spectrum of $Sb_2Se_3$-GaSe eutectic system

Peaks at 220 $cm^{-1}$ were detected in $Sb_2Se_3$ and were attributed to strong Sb-Se modes. The Raman modes at 102 and 118 $cm^{-1}$ are assigned to the Se-Se bond [10]. Peaks at 251 and 300 $cm^{-1}$ were detected and were attributed to a strong GaSe compound [14,17]. Absence of any peaks related to the supplement phases reaffirm the purity of the synthesized material.

## 4. Conclusions

In summary, we have investigated the structural and electrophysical properties of $Sb_2Se_3$-GaSe eutectic systems, taking into account all possible configurations. Two congruent melting compounds were obtained in the $Sb_2Se_3$-GaSe system. The composition of the three eutectics formed in the system is 40, 55, and 80 mol% $Sb_2Se_3$, and their temperatures are 470, 425, and 450 °C, respectively. The electron microscopy (SEM) and XRD studies of $Sb_2Se_3$-GaSe eutectic have confirmed that the systems consist of a semiconductor matrix and oriented inclusions [19]. Applications of $Sb_2(S, Se)_3$ compounds in optoelectronics have drawn more attention. Technology intervention, however, necessitates a material-specific comprehension of the responsiveness to various surroundings.

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