

Synthesis of GaInSb ternary semiconductor nanoparticles using spark discharge method under Argon gas atmosphere

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ABSTRACT

The alloy semiconductor nanoparticles, with variable band gap, have potential applications in advanced electronic, optoelectronics, infrared detectors and thermophotovoltaic devices. In this paper, nanoparticles of Gallium Indium Antimonide (Ga_{0.5}In_{0.5}Sb) were synthesized using spark discharge generated between two electrodes of Ga_{0.5}In_{0.5}Sb bulk crystals grown using vertical directional solidification (VDS) technique. The spark discharge between two electrodes at 700 V and current of 5 mA was maintained for 25 minutes. The Argon gas pressure of 20 Torr was maintained constant during the experiment. The nanoparticles formed were directly deposited on quartz substrate kept at 5 cm away from spark discharge. The composition ratio was confirmed using energy dispersive X-ray (EDX) analysis. The energy band gap using Fourier transform infrared spectroscopy (FTIR) was around 0.63 eV. The average crystalline size obtained using XRD peaks broadening was 39 nm. The variation of practical size distribution with time has been studied and discussed in this paper.

Keywords: GaInSb, spark discharge, nanoparticles.

INTRODUCTION

Gallium Indium Antimonide (GaInSb) is a well-known III-IV ternary semiconductor. With variation in relative content of Indium and Gallium, the band gaps varies continuously from 0.17 eV for InSb to 0.726 eV for GaSb at 300 °K and the room-temperature electron mobility of 78,000 cm²/Vs for InSb to 3000 cm²/Vs for GaSb.

These properties make GaInSb a potential candidate for applications in infrared detectors, magnetic sensors, thermoelectric power generation, high-speed field-effect transistors, and low-power device applications. However, due to technological challenges of synthesis, GaInSb materials have been rarely studied. In this paper, we present synthesis of GaInSb ternary semiconductor nanoparticles using spark discharge method under Argon gas atmosphere. The spark discharge method of nanoparticle production had been introduced in [1] and has been applied by a number of research groups [2,3,4]. However, there is still a lack of information about the optimization of various physical parameters for ternary alloy materials using this method.

METHODOLOGY

In this work, the polycrystalline wafers of $\text{Ga}_{0.5}\text{In}_{0.5}\text{Sb}$ bulk crystals grown using vertical directional solidification (VDS) technique [5] were used as a electrodes material. To maintain the inert atmosphere, we have used HINDHIVAC BC 300 vacuum evaporation system. Initially, chamber was evacuated up to 10^{-5} Torr using rotary and diffusion pump. To avoid oxidation, chamber was flashed with Argon gas for three times. The Argon gas pressure of 20 Torr was maintained constant during spark discharge. The diameter of GaInSb wafer used for electrode was 12 mm with thickness of 1 mm. The separation of electrode was kept 0.5 cm. The spark discharge streamer between two electrodes start at DC voltage of 700 V and current of 5 mA was maintained for 25 minutes. The nanoparticles formed due to coalition of molecules eradiated into vapor state were directly deposited on quartz and glass substrates kept at 5 cm away from spark discharge glow. For removal of strain, the as grown nanoparticles were kept at 300°C in inert Argon atmosphere furnace for 20 hours.

RESULTS AND DISCUSSION

Compositional and structural analysis:

The compositional analysis of nanoparticles was done by EDAX Model: FEI Quanta 200 ESEM system. The

relative atomic percentage of Gallium, Indium and Antimony was found to be 22:22:56 (fig.1).

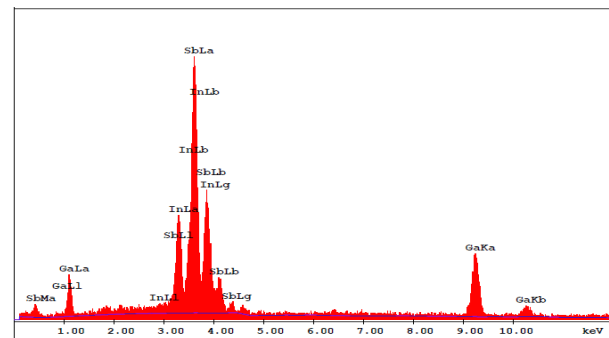


Figure.1. EDAX spectra of nanoparticles

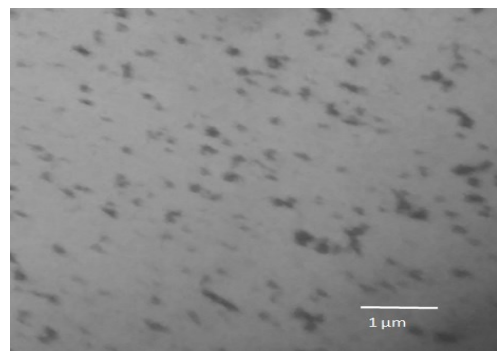


Figure.2. SEM image of nanoparticles after spark discharge time of 25 minutes.

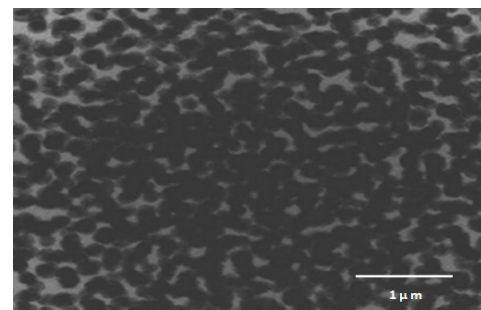


Figure.3. SEM image of agglomerated nanoparticles after spark discharge time of 70 minutes

The SEM microscopy image (fig.2) showed the growth of nanoparticles after 25 minute spark discharge. After spark discharge time of 70 minutes, large number of agglomerated clusters was formed.

X-ray analysis:

The structural analysis is done using Rigaku X-Ray Diffractometer operated at 30 kV (with $\text{CuK}\alpha$ radiation at 0.154 nm). The X-ray spectra (Fig. 4) revealed the phase formation of $\text{Ga}_{0.5}\text{In}_{0.5}\text{Sb}$, with lattice constant 6.485 \AA . The XRD spectra shown cubic symmetry with zinc blende structure with peaks

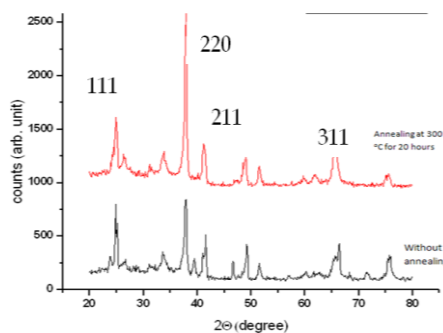


Fig.4: XRD spectra of nanoparticles for spark discharge of 25 minutes.

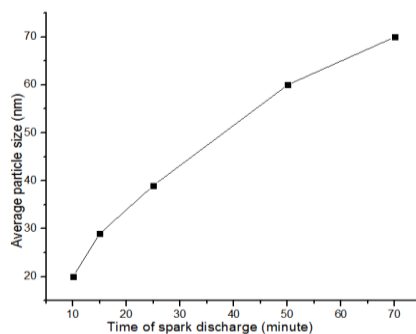


Fig.5 Average particle size with spark discharge time.

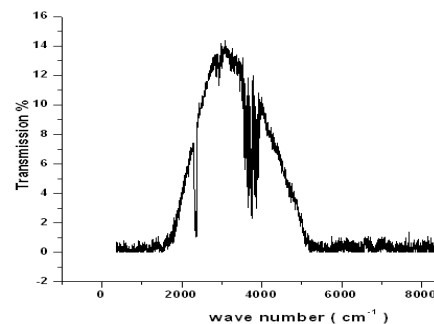


Fig.6 FTIR spectra of GaInSb nanoparticles after 25 minutes spark discharge.

corresponds to the directions of (111), (211), (220), (311) and (422). The peaks in graph (figure.3) are consistent with JCPD data.

The average size of nanoparticles is calculated using the Debye-Scherrer formula given by

$$D = k\lambda / \beta \cos\theta$$

Here, D is the crystallite size, k is the shape factor (~ 1), λ is the wavelength of the $\text{CuK}\alpha$ radiations (~ 0.154 nm), β is the integral broadening of XRD peaks in radians and θ is half angle at peak. The variation of average particle size with spark discharge time is shown in fig.5.

FTIR Analysis:

Band gap analysis using Perkin Elmer FTIR-Spectrum-2, showed the band edge (fig.6) with band gap of 0.63eV. This shows that the band gap of nanoparticles increases by 0.18 eV, as compare to band gap of bulk materials used for electrodes (0.45 eV).

CONCLUSION

From this work, we have demonstrated the applicability of spark discharge method for novel synthesis of ternary $\text{Ga}_{0.5}\text{In}_{0.5}\text{Sb}$ semiconductor nanoparticles. This work is also proved cleaner, faster and cheaper way of synthesise ternary semiconductor nanoparticles with tuned band gap, controlled particle size, as compared to other methods. This method provides future scope for study on particle size distribution, effect of inert gas pressure, substrate temperature, rate of sputtering and time of spark

discharge required for precise control of nanoparticles size of ternary semiconductor materials.

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Conflicts of interest: The authors stated that no conflicts of interest.

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