Characterization of the Ga-InSb system: experimental investigation of thermal, structural, mechanical and electrical properties

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The materials based on gallium-antimonide are widely used in electronic industry in the production of various electronic devices. The results of characterization of selected alloys in the Ga-InSb system obtained by experimental investigation of some thermal, structural, mechanical and electrical properties are presented in this paper. Applied experimental techniques included: differential thermal analysis, light optical microscopy, scanning electron microscopy with EDX, hardness, micro hardness and electrical conductivity measurements.

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1. Introduction

The Ga-InSb alloys belong to the group of GaSb-based materials and are widely used in electronics in the form of thin films for the production of various electronic devices. They also find the application in the manufacture of semiconductor devices - infrared detectors, infrared and light emitting diodes, while alloy $Ga_{1-x}In_xSb$ with x≈0.2 is used for microwave oscillators based on Gunn-effect [1].

Due to the fact that these alloys belong to the family of III-IV semiconductors in the multicomponent In-Ga-Al-Sb-As system with a wide range of applications, the Ga-In-Sb system was studied in both experimental and theoretical way [2]. Its liquidus projection [3] and calculated isothermal section at 823K [4] are shown in Fig. 1.

Different researches have studied phase equilibria in the Ga-In-Sb system [2-15], and also its thermodynamics [2-4,15-18], but materials properties were studied only for solid solutions (In,Ga)Sb in the form of epitaxially grown films [1,5,6,19].

Therefore, the results of characterization of Ga-InSb alloys are presented in the frame of this paper, contributing to the experimental data knowledge for this GaSb-based material.

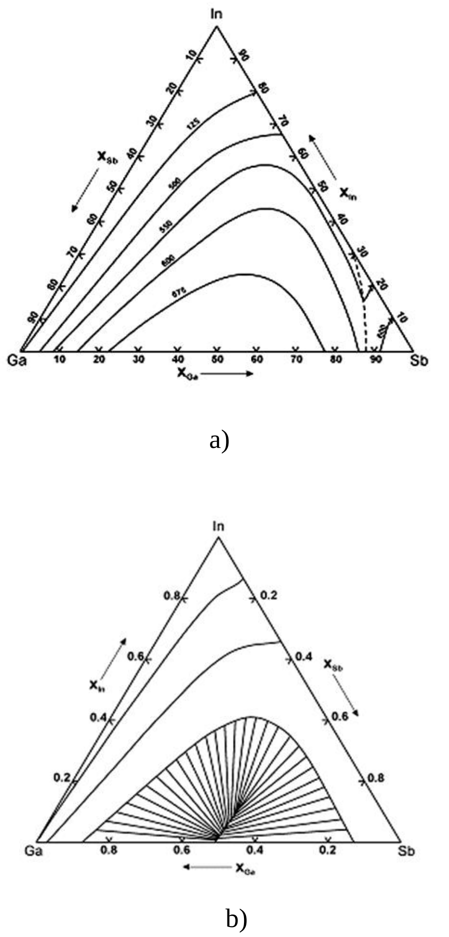


Fig. 1. The Ga-In-Sb system – (a) liquidus projection [3] and (b) calculated isothermal section at 823K [4].

2. Experimental

The samples used for the investigations were prepared using metals - gallium, indium and antimony of 99.99% purity. The composition and masses of selected samples are given in Table 1.

Table 1. Composition and masses of the investigated samples.

Alloy	x_{Ga}	x_{In}	x_{Sb}	m_{Ga} (g)	m_{In} (g)	m_{Sb} (g)
A1	0	0.5	0.5	0	1.69	1.793
A2	0.2	0.4	0.4	0.437	1.44	1.528
A3	0.4	0.3	0.3	0.935	1.155	1.226
A4	0.6	0.2	0.2	1.508	0.828	0.878
A5	0.8	0.1	0.1	2.173	0.447	0.475

Differential thermal analysis (DTA) measurements have been carried out using Derivatograph 1500 (MOM Budapest) apparatus, under following conditions - air atmosphere, heating rate 10°C/min, and T_{max} = 1073K. Al_2O_3 was used as a referent material during the measurements. The precision of the measurement in the investigated temperature interval was ± 5 °C.

Microstructural analysis of investigated samples was performed by light optical microscopy (LOM), using a Reichert MeF2 microscope (magnification up to 500x) and by Scanning-electron microscopy (SEM) with Energy dispersive spectroscopy (EDX) analysis performed on electronic microscope JEOL JSM-6610LV with resolution of 10 nm on 20kV, accelerating voltage of 0.2-30 kV and magnification up to 300000 x. Prior to metallographic analysis, surfaces of the polished samples were etched with $HF:H_2O_2:H_2O$=1:1:4 solution to reveal the structure of the investigated alloys.

Hardness measurements were done using standard procedure according to Brinell, with ball diameter of 20 mm and load of 15.6 kP. Microhardness was measured using instrument PTM-3 with 50 - 150 grams load, depending on a phase.

Electrical conductivity of investigated materials was measured using SIGMATEST 2.069 (Foerster) eddy current instrument for measurements of electrical conductivity of non-ferromagnetic metals based on complex impedance of the measuring probe with 8mm probe diameter.

3. Results and discussion

As already stated, selected alloys from Ga-InSb system were characterized using different experimental techniques. The results of the DTA measurements for chosen samples are presented in Table 2. Obtained temperatures for characteristic liquidus temperatures are in accordance with available literature data [2,3].

Table 2. DTA results of the investigated Ga-In-Sb alloys.

ALLOY	Characteristic peak temperatures (in °C)	
	Other phase transformations	Liquidus
A1	-	503
A2	130, 514	620
A3	205, 496	570
A4	138	490

Structural analysis of the selected Ga-InSb alloys was done using LOM and SEM-EDX. Characteristic microphotographs recorded by LOM of the samples with 0; 20; and 40 at% Ga are given in Fig. 2. SEM images with marked points of EDX chemical analysis of the investigated samples A1 and A2 are presented in Fig. 3, while the results of experimental determination of composition by EDX are presented in Table 3.

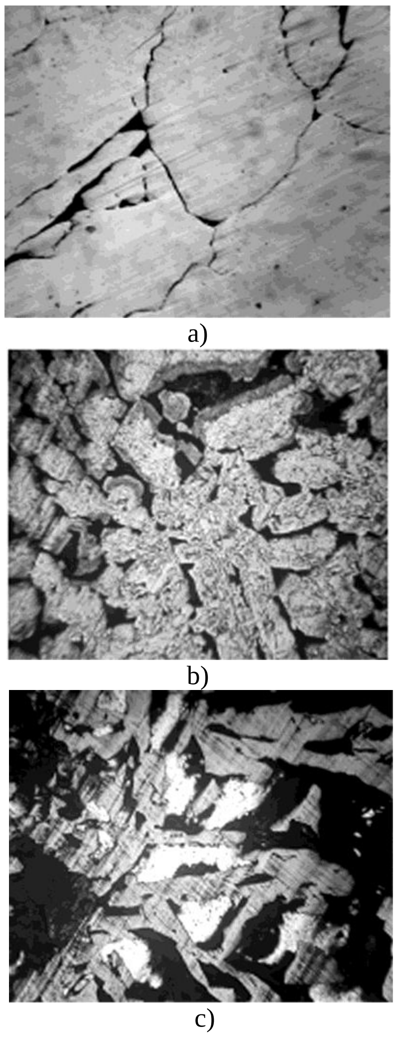
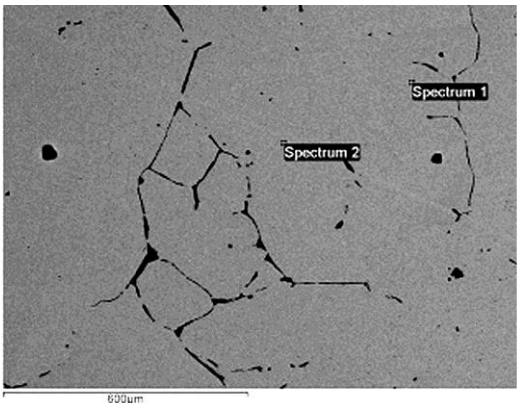
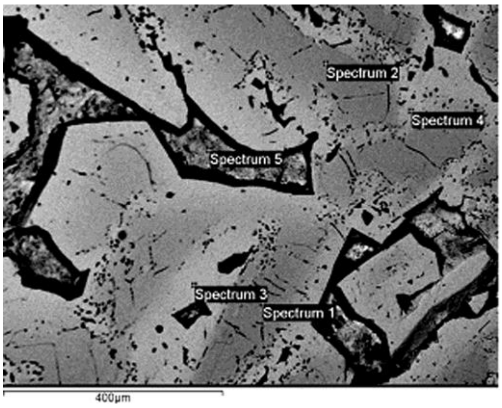


Fig. 2. Characteristic optical microphotographs of: a) A1 (80x), b) A2 (40x) and c) A3(100x).



a)



b)

Fig. 3. SEM images (with investigated points) of the samples a) A1 and b) A2.

Results of SEM-EDX analysis confirm that sample A1 consist only of one phase - InSb intermetallic compound represented as dark gray crystals on Fig. 3a, while in sample A2 there are two phases. Spectrum 5 (Table 3.) corresponds to a In-based phase (dark phase on Fig. 3.b) and spectra 1-4 correspond to a Ga,In(Sb) solid solution formed from two presented intermetallic compounds InSb and GaSb due to their mutual solubility. Light gray phase on Fig. 3b represents phase richer in GaSb whereas dark gray phase is richer in InSb.

Table 3. Results of SEM/EDX analysis of investigated samples A1 and A2.

Alloy / Spectrum	A1			A2		
	Ga	In	Sb	Ga	In	Sb
Spectrum 1	0	50.84	49.16	37.44	12.83	49.74
Spectrum 2	0	50.63	49.37	37.79	12.33	49.88
Spectrum 3				9.31	41.33	49.35
Spectrum 4				12.19	38.40	49.42
Spectrum 5				0.00	97.51	2.49

Results of hardness measurements are presented in Table 4, while the results of micro hardness measurements are presented in Table 5.

Table 4. Hardness of some investigated Ga-In-Sb alloys.

Alloy	x_{Ga}	**HB**
A1	0	78,5
A2	0.2	65

Table 5. Microhardess of some investigated Ga-In-Sb alloys.

Alloy	x_{Ga}	H_μ	
		Dark gray phase	*Light gray phase*
A1	0	268,62	/
A2	0.2	346,48	30,58
A3	0.4	272,01	25,57

Values of hardness of the investigated A1 (InSb) and A2 alloys show decrease with increase of gallium content, which is in accordance with pure Ga hardness value of 60 MN/m^2 [20]. Microhardness measurements were carried out on the samples A1-A3. Since sample A1 doesn't contain gallium and has monophase composition, microhardness was measured only for InSb phase (signed as dark gray phase in Table 5.). It can be seen that phase 2, corresponding to light gray phase of Ga,In(Sb) solid solution richer in GaSb, shows lower values of microhardness compared to those of dark gray phase richer in InSb.

Conductivity is one of the important electrical properties of semiconductors, just as carrier concentration, carrier mobility, and the lifetime of excess carriers [21]. The results of electrical conductivity measurements of samples A2 and A3 are presented in Table 6 (three series of measurements).

Table 6. Measured values of electrical conductivity of the investigated Ga-In-Sb alloys.

Alloy	Electrical conductivity (MS/m)		
A2	0.7138	0.7236	0.7221
A3	0.7924	0.7515	0.7727

As it can be seen, the electrical conductivity increases with increasing gallium concentration in the investigated alloys, having average values (in MS/m) of A2 - 0.7198 and A3 – 0.7722, which is in accordance with electrical conductivity of pure Ga - 0.7143 [20].

Although, the applied method of electrical conductivity measurement is commonly used in semiconductor testing the obtained values were at the lower end of the measuring range of the used instrument.

Nevertheless, measured values give information about the trend of the electrical conductivity change in regard to the gallium content.

4. Conclusion

The Ga-In-Sb alloys has been investigated using different experimental methods, such as DTA, light optical microscopy, SEM-EDX, hardness, micro hardness and electrical conductivity measurements.

Results obtained by DTA measurements show agreement with existing literature data. The obtained experimental results have shown that the microstructure of the investigated Ga-InSb alloys consist of InSb phase, In-based phase and Ga,In(Sb) solid solution formed from two presented intermetallic compounds InSb and GaSb due to their mutual solubility.

The increase of the electrical conductivity of the investigated Ga-InSb alloys with increasing gallium concentration was observed as well as decrease of hardness.

The obtained results are part of broader continued and ongoing investigations of Ga-InSb alloys in the frame of our research group [17,18] and present a contribution to the better knowledge of the Ga-In-Sb system.

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