



University of Belgrade, Technical Faculty in Bor



ECOENTER

**30th International Conference Ecological Truth
& Environmental Research
2023**

Proceedings

**Editor
Prof. Dr Snežana Šerbula**





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PREFACE

The 30th international conference Ecological Truth & Environmental Research – EcoTER'23 kept three areas in focus: ecology, environmental protection and sustainable development. The conference will be held on Mt Stara Planina in hotel Stara Planina, Serbia, 20–23 June 2023. The monograph is published on the occasion of the 30th anniversary of the conference. On behalf of the scientific and organizing committee, it is a great honor and pleasure to wish all the participants a warm welcome to the conference.

The monograph is published on the occasion of the 30th anniversary of the conference.

We hope to convey the message of the conference, which is that a transformation of attitudes and behavior would bring the necessary changes. This is also an opportunity for the participants who are experts in this field to exchange their experiences, expertise and ideas, and also to consider the possibilities for their collaborative research.

The 30th international conference Ecological Truth & Environmental Research – EcoTER'23 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology, the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica, the University of Zagreb, Faculty of Metallurgy – Sisak, the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Association of Young Researchers, Bor.

These Proceedings 103 papers from the authors coming from the universities, research institutes and industries in 11 countries: Australia, USA, Brazil, Spain, Portugal, Libya, Italy, Bulgaria, Bosnia and Herzegovina, North Macedonia, and Serbia.

As a part of this year's conference, the 5th Student Session – EcoTERS'23 is being held. We appreciate the contribution of the students and their mentors who have also participated in the conference.

The support of the Gold donor and their willingness and ability to cooperate has been of great importance for the success of the EcoTER'23. The organizing committee would like to extend their appreciation and gratitude to the Gold donor of the conference for their donation and support.

We appreciate the effort of all the authors who have contributed to these Proceedings. We would also like to express our gratitude to the members of the scientific and organizing committees, reviewers, speakers, chairpersons and all the conference participants for their support to the EcoTER'23. Sincere thanks go to all the people who have contributed to the successful organization of the EcoTER'23.

Prof. Snežana Šerbula,

President of the scientific and organizing committee

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MICROSTRUCTURAL AND THERMAL CHARACTERIZATION OF Bi-Sb-Sn ALLOYS FOR ECOLOGICAL APPLICATION

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Abstract

Bi-Sb-Sn alloys have gained attention as potential replacements for lead-tin (Pb-Sn) alloys due to their desirable properties and reduced environmental impact. These alloys offer a combination of low toxicity, low melting point, good solder ability, and mechanical strength, making them suitable for various applications in electronics and soldering. This work carried out the microstructural and thermal characterization of three-component alloys from the Bi-Sb-Sn system. Microstructural characterization of lead-free solder is essential as it provides crucial insights into the composition, distribution, and morphology of phases within the solder material. Thermal characterization of Bi-Sb-Sn alloys involves evaluating their thermal properties, including thermal diffusivity, specific heat capacity, and thermal conductivity. These properties play a crucial role in determining the performance and suitability of these alloys for various applications. Ongoing research and development in this field are expected to uncover further ecological applications for these alloys.

Keywords: Bi-Sb-Sn, lead-free solder, microstructural characterization, thermal diffusivity.

INTRODUCTION

Lead-free alternatives have become a significant area of research and development due to the harmful effects of lead on human health and the environment [1–4]. Bi-Sb-Sn alloys have gained considerable attention recently due to their potential ecological applications [5–11]. These alloys offer several environmentally friendly characteristics and find utility in various fields [7,9–12].

One of the primary motivations for exploring Bi-Sb-Sn alloys is their potential to replace lead-based solder materials [5,8,9,11,13]. Lead is a toxic element that poses severe health risks and environmental hazards [3,4]. Implementing lead-free solders has become crucial due to environmental concerns regarding the toxicity of lead-based solder materials [12,14]. Bi-Sb-Sn alloys offer a promising alternative, exhibiting low melting points, desirable mechanical properties, and good wetting behaviour on different substrates [10,12,15–18].

Bi-Sb-Sn alloys have been used in low-temperature applications, such as cryogenic systems and superconducting devices [19,20]. These alloys can exhibit good mechanical and thermal properties at extremely low temperatures, making them useful in research, medical, and space-related applications.

Bi-Sb-Sn alloys are relatively non-toxic compared to lead and other heavy metals. This property makes them suitable for applications where human and environmental safety is concerned. Using these alloys helps minimize the release of harmful substances into the ecosystem [12,21,22].

Bi-Sb-Sn alloys also possess good thermoelectric properties. Thermoelectric materials can convert waste heat into valuable electrical energy, offering sustainable energy generation and waste heat recovery opportunities [11,16,20,23,24].

Understanding the microstructure of Bi-Sb-Sn alloys is essential for evaluating lead-free solder's performance, reliability, and suitability in various applications [5–7,10,11,25,26]. On the other hand, thermal diffusivity is an important property to consider in solder materials as it influences their thermal management capabilities and ability to dissipate heat from electronic devices [27,28].

MATERIALS AND METHODS

The raw metals used in the study (Bi, Sb, and Sn, with a purity of 99.999 wt.%) were melted in an induction furnace with an argon atmosphere to prevent oxidation and contamination. After the melting and cooling process, the alloys from the Bi-Sb-Sn system were further processed by pressing them into the shape of a disk. The specific dimensions of the disk were a thickness of 2.50 mm and a diameter of 12.70 mm. The samples were annealed at a temperature of 100°C for three hours to eliminate internal stresses and further enhance the homogeneity of the alloy. The prepared sample's total mass was approximately 6 g. Investigated samples (S1, S2, and S3) from the Bi-Sb-Sn ternary system were with composition 0, 40, and 60 at.% of Sb and ratios Bi/Sn=1. Two sets of each sample were prepared. One set was used for microstructural characterization, and the other for thermal diffusivity measurements. Samples intended for microstructural analysis were prepared by grinding on papers with different granulations, mechanical polishing with aqueous alumina suspension, and etching with aqueous ferric chloride solution. For measuring thermal diffusivity, the upper and lower surfaces of the samples were covered with a thin layer of graphite to prevent heat dissipation and better heat absorption on the lower surface of the sample.

The microstructural properties of the alloys were investigated using scanning electron microscopy – SEM (TESCAN VEGA3 LMU) in combination with energy-dispersive X-ray spectroscopy – EDS (Oxford Instruments X-act). The thermal diffusivity of the investigated alloys was determined using the xenon-flash method at temperatures of 25°C, 50°C, and 100°C. This method is a well-established technique for measuring thermal conductivity [29]. The thermal diffusivity measurements were conducted on the Discovery Xenon Flash (DXF) 500, TA Instruments. The specific heat capacity can be determined using differential scanning calorimetry (DSC) or heat flow calorimetry. The temperature difference can determine the specific heat capacity for unknown materials, that is, by comparing the increase in the temperature of the samples with the increase in the temperature of the reference sample of known specific heat capacity. Both samples must be tested in the same differential mode [28,29]. Thermal conductivity describes the ability of a substance to conduct heat; that is, the

higher the thermal conductivity, the greater the amount of heat that can be transferred through the same cross-section at the same time [30]. As defined by Parker et al. [28,30], thermal conductivity, for homogeneous materials, after measuring the thermal diffusivity and determining the specific heat capacity, can be calculated as $\lambda = \alpha \cdot \rho \cdot C_p$. Where: λ is thermal conductivity (W/m·K), α is thermal diffusivity (m²/s), ρ is density (kg/m), and C_p is specific heat capacity (J/kg·K).

The specific details of the experimental procedures for microstructural characterization and thermal conductivity measurements can be found in previous papers [28,31]. Combining SEM-EDS for microstructural characterization and the Xenon-flash method for thermal conductivity measurements provides valuable insights into the microstructure and thermal properties of the studied Bi-Sb-Sn alloys.

RESULTS AND DISCUSSION

Microstructural Characterization

The following figures show SEM microphotographs of investigated alloys S1, S2, and S3 at different magnifications a) 200x, b) 500x, c) 1000x, d) 2000x.

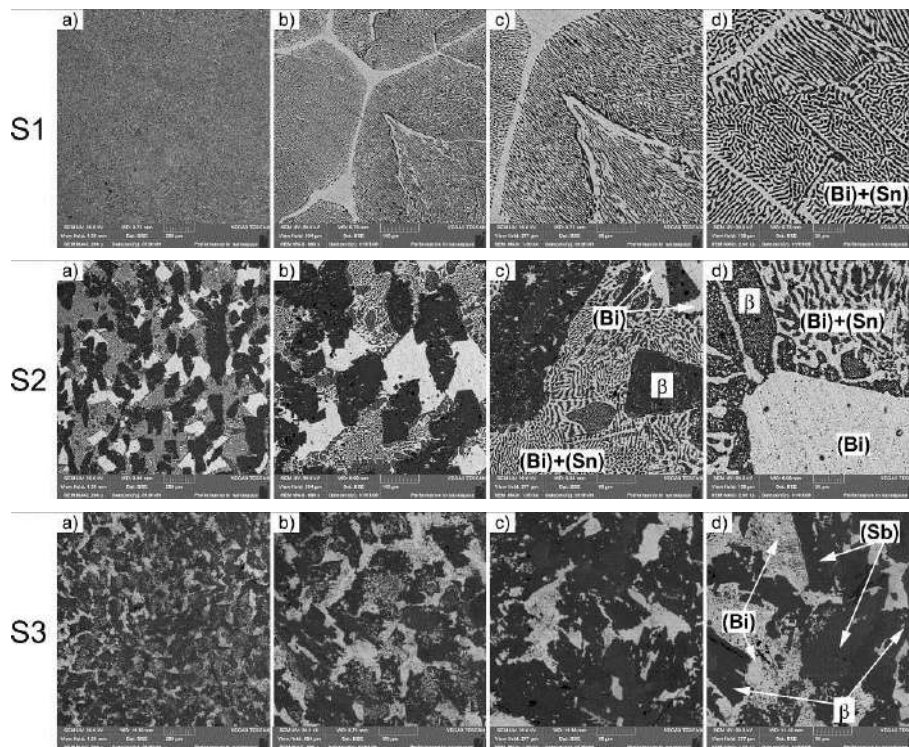


Figure 1 SEM microphotographs of the investigated alloy S1, S2 and S3 at different magnifications a) 200x, b) 500x, c) 1000x, d) 2000x

The provided SEM microphotographs of the investigated Bi-Sb-Sn alloys (S1, S2, and S3) reveal essential insights into the microstructure and phase composition. Based on the observed microstructural features and the EDS analysis of the present phases, the following observations can be made. A lamellar eutectic structure is evident in the SEM

microphotographs of alloy S1 at 200x magnification. This structure consists of alternating light lamellae rich in bismuth (Bi) and dark lamellae rich in tin (Sn). The lamellar structure becomes more clearly visible at higher magnifications (500x, 1000x, and 2000x), indicating well-defined boundaries between the different phases. In the SEM microphotographs of alloy S2, the microstructure reveals the presence of three distinct phases. The dark gray phase corresponds to the β phase, the light gray phase represents a solid solution based on bismuth (Bi), and the lamellar eutectic crystal composed of the bismuth and tin (Bi)+(Sn) is also observed. In the SEM microphotographs of alloy S3, a microstructure with three phases is observed. The dark gray phase corresponds to a solid solution based on antimony (Sb), the black β phase is present, and the light gray phase represents a solid solution based on bismuth (Bi). Based on the composition of the present phases determined by EDS analysis and theoretically calculated, we note a higher solubility of bismuth 10.89 at.% in solid solution based on antimony, and also higher solubility of bismuth 3.28 at.% and antimony 55.47 at.% in the β phase.

Thermal Characterization

Table 1 shows experimentally obtained thermal diffusivity results, specific heat capacity, and thermal conductivity for alloys.

Table 1 Obtained results of thermal diffusivity, specific heat capacity, and thermal conductivity for investigated alloys S1, S2, and S3 at 25 °C, 50 °C, and 100 °C

Properties	Samples			
	Temperature	S1	S2	S3
Thermal diffusivity (cm ² /s)	25°C	0.0847	0.1227	0.1427
	50°C	0.0962	0.1364	0.1584
	100°C	0.1098	0.1511	0.1661
Specific heat capacity (J/(kg·K))	25°C	159.9689	167.4150	184.9377
	50°C	161.8067	169.2722	186.8094
	100°C	166.2126	173.4360	190.3570
Thermal conductivity (W/m·k)	25°C	11.2549	16.5539	20.3573
	50°C	12.9299	18.6063	22.8257
	100°C	15.1597	21.1186	24.3899

Based on the provided data from Table 1, the thermal diffusivity, specific heat capacity, and thermal conductivity of the examined Bi-Sb-Sn alloys (S1, S2, and S3) can be analyzed, and the following observations can be made. The thermal diffusivity values range from 0.0847 cm²/s to 0.1661 cm²/s in the examined alloys. Alloy S1 exhibits the lowest thermal diffusivity at 25°C, with a value of 0.0847 cm²/s. On the other hand, alloy S3 shows the highest thermal diffusivity at 100°C, with a value of 0.1661 cm²/s. The specific heat capacity values range from 159.9689 J/kg·K to 190.3570 J/kg·K in the examined alloys. Alloy S1 exhibits the lowest measured specific heat capacity at 25°C, with a value of 159.9689 J/kg·K. In contrast, alloy S3 shows the highest specific heat capacity at 100°C, with a value of 190.3570 J/kg·K.

The thermal conductivity values show a similar trend to the thermal diffusivity and specific heat capacity. The lowest calculated thermal conductivity value is 11.2549 W/m·K at 25°C for alloy S1, while the highest thermal conductivity value is 24.3899 W/m·K obtained for alloy S3 at 100°C. Figure 2 presents the dependence of thermal diffusivity, thermal conductivity, and specific heat capacity on the antimony content in investigated alloys.

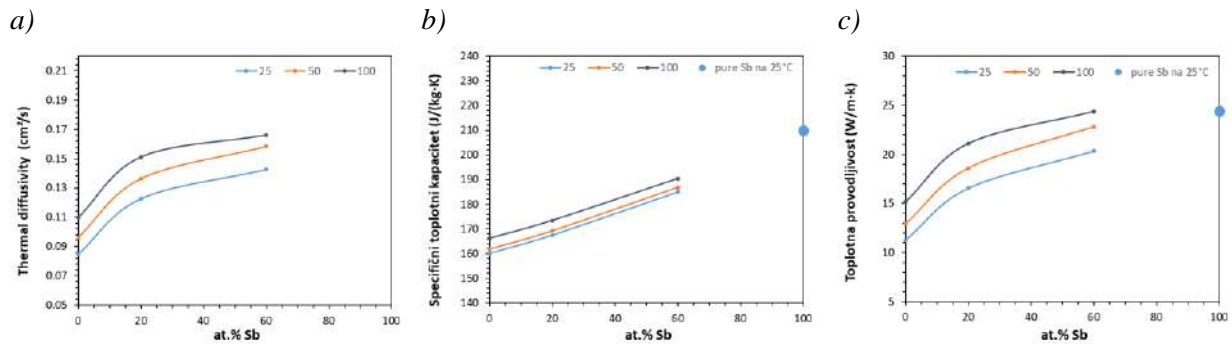


Figure 2 Dependence of a) thermal diffusivity, b) thermal conductivity, and c) specific heat capacity on antimony content in investigated alloys S1, S2, and S3 at 25 °C, 50 °C, and 100 °C

With an increase in the antimony content in investigated alloys, it is concluded that there is an increase in the value of thermal diffusivity, and the specific heat capacity also increases, as well as the thermal conductivity. This aligns with the known thermal conductivity values of the constituent elements. Antimony has a relatively high thermal conductivity of 24.4 W/m·K, bismuth has a lower value of 8.2 W/m·K, and tin has the highest thermal conductivity of 67 W/m·K. The higher thermal conductivity of antimony compared to bismuth contributes to the overall increase in thermal conductivity as the antimony content in the alloys increases.

CONCLUSION

The microstructure and thermal properties of the Bi-Sb-Sn ternary alloys were studied in this work. The provided SEM microphotographs of the investigated Bi-Sb-Sn alloys reveal essential insights into the microstructure and phase composition. Based on the composition of the present phases determined by EDS analysis and theoretically calculated, we note a higher solubility of bismuth 10.89 at.% in solid solution based on antimony, and also higher solubility of bismuth 3.28 at.% and antimony 55.47 at.% in the β phase. Regarding the thermal properties, the study found that increasing the antimony content in the Bi-Sb-Sn alloys led to an increase in thermal diffusivity, specific heat capacity, and thermal conductivity. The higher thermal diffusivity indicates improved heat transfer capabilities, while the increased specific heat capacity suggests a more remarkable ability to store thermal energy. Moreover, the higher thermal conductivity implies better heat conduction within the alloys. Bi-Sb-Sn alloys offer significant ecological advantages, including low toxicity, RoHS compliance, sustainable sourcing, soldering process and thermal interface efficiency, low melting point, and lead-free. By embracing Bi-Sb-Sn alloys, we can support environmental sustainability by reducing toxic materials, minimizing environmental impact, and promoting resource efficiency.

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