



MME SEE

CONGRESS 2023

**5th Metallurgical & Materials Engineering
Congress of South-East Europe
Trebinje, Bosnia and Herzegovina
7-10th June 2023**



CONGRESS PROCEEDINGS

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PROCEEDINGS**

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MICROSTRUCTURE AND THERMAL CONDUCTIVITY OF THE Ag–Bi–Sn TERNARY ALLOYS

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The Ag–Bi–Sn ternary alloys represent an important material for the development of lead-free solders. In this work, the effect of tin content on the thermal properties of the Ag–Bi–Sn ternary alloys was investigated. Five Ag–Bi–Sn ternary alloys with tin content ranging from 12.8 to 75.1 mass% and nearly equal mass contents of silver and bismuth were prepared and experimentally studied. Microstructures of as-solidified alloy samples were examined using scanning electron microscopy with energy-dispersive X-ray spectrometry (SEM-EDS) and X-ray diffraction (XRD) analysis. The observed constitutive phases were Ag₃Sn, (Sn), and (Bi) phases as well as ternary (Sn)+(Bi)+Ag₃Sn eutectic. Thermal diffusivity measurements in the temperature range from 25 to 100 °C were performed using the flash method. Thermal conductivities of the solid Ag–Bi–Sn alloys were obtained using the measured values of thermal diffusivity. Thermal conductivity of the studied Ag–Bi–Sn ternary alloys considerably increases with increasing tin concentration and slightly decreases with increasing temperature. The measured thermal diffusivity at room temperature extends from 8.00 to 27.80 mm²s⁻¹ and thermal conductivity extends from 14.24 to 45.77 Wm⁻¹K⁻¹ with increasing Sn content. Chemical and phase compositions have a strong effect on the thermal diffusivity and thermal conductivity of the studied Ag–Bi–Sn alloys. It was found that an increase in the phase fractions of the (Bi) solid solution phase and Ag₃Sn intermetallic compound hinders heat transfer and decreases thermal conductivity.

Keywords: Ag–Bi–Sn alloys, microstructure, thermal conductivity

Introduction

For a long time, Sn–Pb solder has been widely used in the field of electronic packaging because of its excellent characteristics, such as low melting point (183 °C), good wettability, and low price [1]. However, due to the toxicity of lead, its use has been significantly reduced, which has led to the research of new, Pb-free solder materials. Several Sn-based lead-free solders such as Sn–Cu, Sn–Ag, Sn–Zn, Sn–Bi, and Sn–Ag–Cu have been developed in recent decades [1–3]. However, there is still no universal lead-free soldering alloy, and the selection among them is based on the specific requests of an application [4]. The ternary Sn–Bi–Ag represents important lead-free solder material [2]. According to the literature thermal conductivities of the alloys of this ternary system have been determined only in several alloys with a thin composition interval [5]. This investigation aims to establish the influence of Sn content on the microstructure and thermal properties of the Ag–Bi–Sn alloys. Because of that, Ag–Bi–Sn alloys with nearly equal silver and bismuth concentrations and variable tin concentrations (from 12.8 to 75.1 mass.%) were obtained by induction melting of pure starting metals. After casting, solid Ag–Bi–Sn alloys were subjected to microstructure characterization and thermal conductivity determination.

Materials and methods

Five samples of investigated Ag–Bi–Sn system were obtained by melting the calculated amounts of Ag, Bi, and Sn (99.99 mass% purity) in a high-frequency induction furnace "Over" under a high-purity argon atmosphere. During the melting, the eddy currents caused a good stirring of the melt. After melting, the molten alloys solidified into graphite crucibles. This procedure was repeated several times to assure homogeneous compositions.

Experimentally determined compositions of the studied alloys were: 44.3Ag–42.9Bi–12.8Sn, 34.0Ag–33.4Bi–32.6Sn, 22.5Ag–23.9Bi–53.6Sn, 19.7Ag–18.5Bi–61.8Sn, and 12.0Ag–12.9Bi–75.1Sn (in mass%).

Investigation of microstructural properties was performed by using scanning electron microscopy (SEM, Vega3 LMU, Tescan, Czech Republic) and energy dispersive X-ray spectroscopy (EDS, X-act, Oxford Instruments, UK) and XRD analysis (Rigaku MiniFlex 600 powder diffractometer equipped with the D/teXUltra 250 detector and ceramic X-ray Cu tube (KFL-Cu-2K) in a 2θ range from 3° to 90° with a step size of 0.02° , Japan). Thermal conductivities of the investigated alloys were determined using the discovery xenon flash instrument (DXF - 500, TA Instruments, Germany). The experimental procedure is explained in detail in our previous studies [4,6].

Results and discussion

Microstructure of the Ag-Bi-Sn alloys

The results of the SEM-EDS analysis are presented in Table 1.

Table 1 The average results of SEM-EDS analysis [7]

Sample / mass%	Microstructure	Identified microconstituents	Average composition / mass%		
			Ag	Bi	Sn
44.3Ag-42.9Bi-12.8Sn	Ag ₃ Sn dendrites in the (Bi) base	Ag ₃ Sn	75.4	2.2	22.4
		(Bi)	-	98.5	1.5
34.0Ag-33.4Bi-32.6Sn	Ag ₃ Sn grains, (Bi) dendrites, and ternary eutectic in the interdendritic regions	Ag ₃ Sn	75.1	-	24.9
		(Bi)	-	100.0	-
		(Sn)+(Bi)+Ag ₃ Sn eutectic	2.3	30.7	67.0
22.5Ag-23.9Bi-53.6Sn	Ag ₃ Sn dendrites and eutectic (Sn)+(Bi)+Ag ₃ Sn in the interdendritic regions	Ag ₃ Sn	75.2		24.8
		(Sn)+(Bi)+Ag ₃ Sn eutectic	2.2	24.4	73.4
19.7Ag-18.5Bi-61.8Sn	Ag ₃ Sn dendrites with (Sn) phase and coarse and fine regions of ternary (Sn)+(Bi)+Ag ₃ Sn eutectic in the base	Ag ₃ Sn	75.6	-	24.4
		(Sn)	-	3.9	96.1
		(Sn)+(Bi)+Ag ₃ Sn eutectic	2.3	20.3	77.4
12.0Ag-12.9Bi-75.1Sn	Ag ₃ Sn dendrites with (Sn) phase and coarse and fine regions of ternary (Sn)+(Bi)+Ag ₃ Sn eutectic in the base	Ag ₃ Sn	75.5	-	24.5
		(Sn)	-	4.5	95.5
		(Sn)+(Bi)+Ag ₃ Sn eutectic	2.6	13.9	83.5

Fig. 1 illustrates typical microstructures of three studied Ag-Bi-Sn alloys.

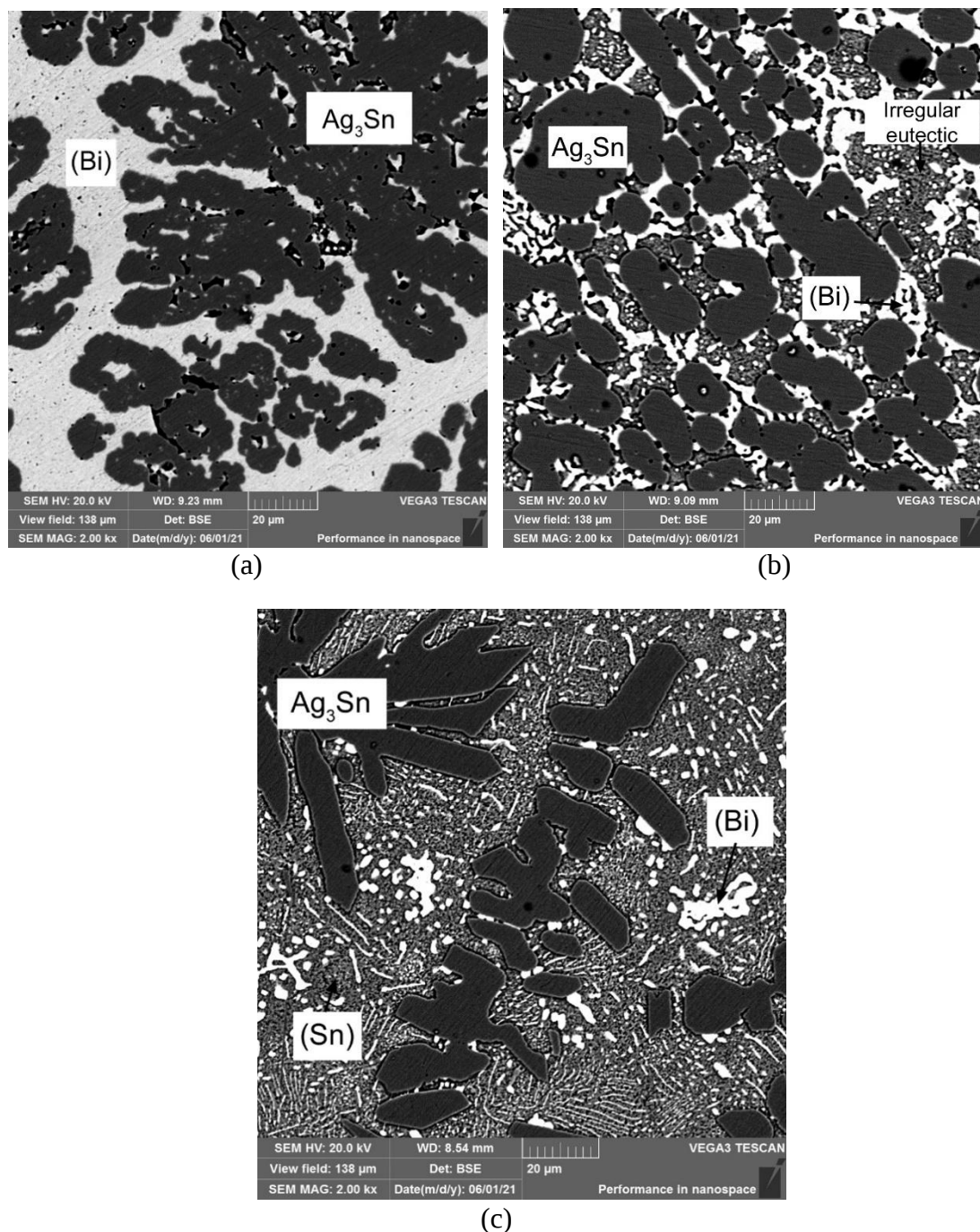


Figure 1 SEM micrograph: (a) 44.3Ag-42.9Bi-12.8Sn alloy (b) 34.0Ag-33.4Bi-32.6Sn alloy; (c) 19.7Ag-18.5Bi-61.8Sn alloy

The phases identified by SEM-EDS analysis were additionally confirmed by the results of XRD analysis. The identified phases were Ag₃Sn intermetallic phase and (Bi) and (Sn) solid solutions. The results of thermodynamic calculations and microstructural analysis also reveal that with the increase of tin content, phase fractions of Ag₃Sn and (Bi) phases decrease while the phase fraction of the (Sn) phase increases.

Thermal conductivity of the Ag-Bi-Sn alloys

The flash method was used for directly measuring the thermal diffusivity of investigated alloys in the temperature range from 25 to 100 °C. Densities of all alloys at room temperature were measured using Archimedes' law of buoyancy. The measured density values for the 44.3Ag-42.9Bi-12.8Sn alloy was 9.73 gcm⁻³, for 34.0Ag-33.4Bi-32.6Sn alloy was 9.03 gcm⁻³, for 22.5Ag-23.9Bi-53.6Sn alloy was 8.19 gcm⁻³, for 19.7Ag-18.5Bi-61.8Sn alloy was 8.01 gcm⁻³, and for 12.0Ag-12.9Bi-75.1Sn alloy was 7.73 gcm⁻³. Specific heat capacities of the studied Ag-Bi-Sn alloys were calculated using the optimized thermodynamic parameters from [8] and the CALPHAD (CALculation of PHase Diagrams) method [9]. Thermal diffusivity and thermal conductivity dependences on Sn content for the studied alloys at 25 and 100 °C are presented in Figs. 2 and 3, respectively. The measured thermal diffusivity values of the investigated Ag-Bi-Sn alloys at room temperature increase with an increase in Sn content from 8.0 to 27.8 mm²s⁻¹. Similarly the thermal conductivity values increase from 14.2 to 45.8 Wm⁻¹K⁻¹ with an increase in Sn content. It can be seen that both thermal diffusivity and thermal conductivity values slightly decrease with an increase in temperature.

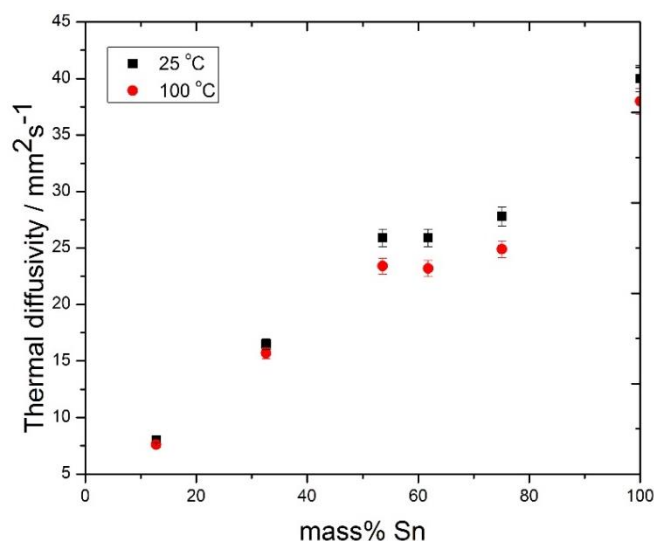


Figure 2 Thermal diffusivity variation with Sn content for the studied Ag-Bi-Sn alloys

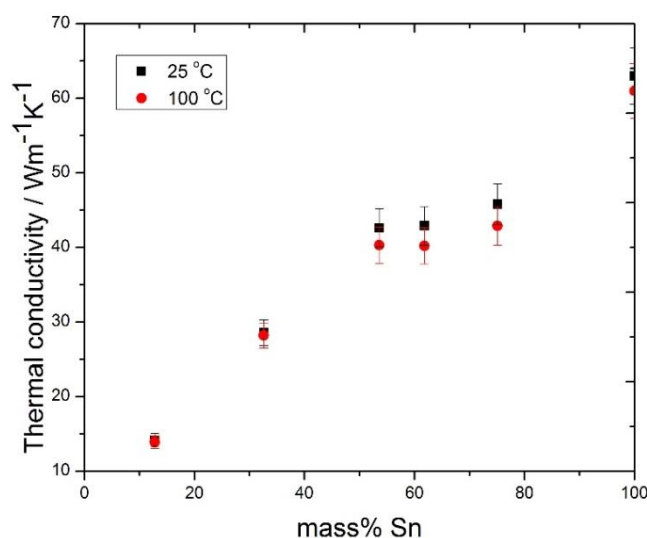


Figure 3 Thermal conductivity variation with Sn content for the studied Ag-Bi-Sn alloys

Conclusion

The main conclusions are summarized as follows:

- a) The microstructure of the 44.3Ag-42.9Bi-12.8Sn alloy has consisted of Ag₃Sn and (Bi) phases. Other investigated alloys have consisted of three phases in the microstructure: Ag₃Sn, (Bi), and (Sn). The irregular (Sn)+Ag₃Sn+(Bi) ternary eutectic is observed in the microstructure of the studied alloys. With an increase in Sn content, the phase fractions of Ag₃Sn and (Bi) phases decrease while the phase fraction of (Sn) increases.
- b) With an increase in Sn content, density values decrease and specific heat capacity values increase.
- c) The measured thermal diffusivity and thermal conductivity both increase with increasing Sn content and slightly decrease at 100 °C. Thermal diffusivity and thermal conductivity are both considerably influenced by the chemical and phase compositions of the investigated Ag–Bi–Sn alloys. An increase in phase fractions of the (Bi) solid solution phase and Ag₃Sn intermetallic phase obstructs the heat transfer and decreases the thermal conductivity of studied alloys.

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References

1. Xu, Kai-Kai, Liang Zhang, Li-Li Gao, Nan Jiang, Lei Zhang, and Su-Juan Zhong. "Review of microstructure and properties of low temperature lead-free solder in electronic packaging." *Science and Technology of Advanced Materials* 21, no. 1 (2020): 689-711.
2. Li, Yulong, Zhiliang Wang, Xuewen Li, and Min Lei. "Effect of temperature and substrate surface roughness on wetting behavior and interfacial structure between Sn–35Bi–1Ag solder and Cu substrate." *Journal of Materials Science: Materials in Electronics* 31 (2020): 4224-4236.
3. Kotadia, Hiren R., Philip D. Howes, and Samjid H. Mannan. "A review: On the development of low melting temperature Pb-free solders." *Microelectronics Reliability* 54, no. 6-7 (2014): 1253-1273.
4. Manasijević, Dragan, Ljubiša Balanović, Ivana Marković, Milan Gorgievski, Uroš Stamenković, Aleksandar Đorđević, Duško Minić, and Vladan Ćosović. "Structural and thermal properties of Sn–Ag alloys." *Solid State Sciences* 119 (2021): 106685.
5. Aksöz, Namık, Esra Öztürk, Ümit Bayram, Sezen Aksöz, Selçuk Kervan, Ahmet Ülgen, and Necmettin Maraşlı. "Thermal conductivity variation with temperature for lead-free ternary eutectic solders." *Journal of Electronic Materials* 42 (2013): 3573-3581.
6. Manasijević, Dragan, Ljubiša Balanović, Ivana Marković, Milan Gorgievski, Uroš Stamenković, and Kristina Božinović. "Microstructure, melting behavior and thermal conductivity of the Sn–Zn alloys." *Thermochimica Acta* 702 (2021): 178978.
7. Manasijević, Dragan, Ljubiša Balanović, Ivana Marković, Milan Gorgievski, Uroš Stamenković, Kristina Božinović, Duško Minić, and Milena Premović. "Microstructural analysis and thermal conductivity of the Ag–Bi–Sn alloys." *Thermochimica Acta* 717 (2022): 179344.
8. Zabdyr, Leszek A., and G. Garzel. "Critical assessment of the Ag–Bi–Sn ternary system." *Calphad* 33, no. 1 (2009): 187-191.
9. Sundman, Bo, H. L. Lukas, and S. G. Fries. *Computational thermodynamics: the Calphad method*. Cambridge: Cambridge university press, 2007.

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