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Ljubiša Balanović
Dejan Tanikić

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PREFACE

On behalf of the Organizing Committee, it is a great honor and pleasure to welcome all esteemed participants of the 54th International October Conference on Mining and Metallurgy (IOC 2023), scheduled to take place at the picturesque Bor Lake, Serbia, from October18th to 21st 2023.

The collaborative efforts of the University of Belgrade, the Technical Faculty in Bor, and the Mining and Metallurgy Institute Bor have meticulously organized this year's IOC. Our focus remains unwavering on showcasing the latest research findings and advancements in geology, mining, metallurgy, materials science, technology, environmental protection, and other engineering disciplines. Our primary objective is to foster a dynamic environment where academics, researchers, and industry professionals can come together to share their knowledge, experiences, and innovative ideas while exploring opportunities for collaborative research endeavors.

Our conference agenda is rich and diverse, encompassing plenary sessions, engaging invited lectures, technical presentations, enlightening oral and poster sessions, informative technical tours, a diverse exhibition, and memorable social gatherings. At the heart of this event lies our strong commitment to sustainable development within the mining and metallurgy sector. We are dedicated to exploring ecologically conscious methodologies, responsible resource extraction practices, and cutting-edge technologies that reduce the industry's environmental impact and enhance the well-being of local communities.

The conference proceedings comprise 129 papers authored by individuals from universities, research institutes, and industries in 22 countries. We are proud to welcome participants from Bosnia and Herzegovina, Bulgaria, Canada, China, Croatia, Germany, Greece, India, Iran, Kazakhstan, Libya, North Macedonia, Montenegro, Morocco, Romania, Russia, Slovakia, South Africa, Spain, Turkey, United States, and, of course, Serbia.

We are excited to host the 8th International Student Conference on Technical Sciences (ISC 2023) as part of IOC 2023. This event offers students from Serbia and the wider region a unique chance to showcase their research and discuss the future of their fields with experts.

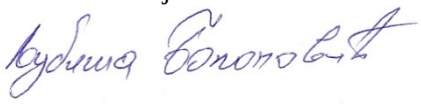
We sincerely thank the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia for their generous financial support. In addition, we express our profound gratitude to all our sponsors, exhibitors, and friends of the Conference for their contributions and unwavering support for playing a pivotal role in ensuring the success of IOC 2023.

We would like to express our heartfelt thanks to all authors, committees, reviewers, speakers, and chairpersons for their invaluable contributions in shaping IOC 2023.

We look forward to welcoming you to the 55th International October Conference on Mining and Metallurgy (IOC 2024), which will be held in October 2024.

On behalf of the 54th IOC Organizing Committee,

Prof. dr Ljubiša Balanović



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MECHANICAL AND ELECTRICAL PROPERTIES OF THE TERNARY Ag-Ge-Sn ALLOYS

Aleksandar Đorđević[1], Milena Zečević[1], Duško Minić[1], Dragan Manasijević[2]

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Abstract
This study presents the results of experimental and analytical tests. Experimental part includes results of the hardness and electrical properties of the selected ternary Ag-Ge-Sn alloys. In the experimental part of the study, alloys of selected compositions were prepared and then examined using scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS), X-ray powder diffraction (XRD), hardness measurements by Brinell method and electrical conductivity measurements. Analytical part includes, calculations of equilibrium phase diagram of the Ag-Ge-Sn ternary system by using the Calphad method and the corresponding thermodynamic program (Pandat ver. 8.1). The results include calculated characteristic isothermal sections. Isothermal section of the ternary Ag-Ge-Sn system at 25 °C have been extrapolated using optimized thermodynamic parameters from literature. Experimentally obtained results were compared with the results of thermodynamic calculation of phase diagrams. Good overall agreement between experimental and calculated values was obtained. Hardness and electrical conductivity of selected alloys were measured and by using appropriated mathematical model these properties were predicted in the whole composition range.

***Keywords**: Ag-Ge-Sn system; hardness; electrical conductivity; mathematical model.*

1. INTRODUCTION

The study of ternary systems based on Ge-Sn attracts a lot of attention. Increased attention to the research of these alloys can be attributed to the specific properties of the Ge and Sn elements, such as good insulating properties, easy machinability, forging and many others. The ternary Ag-Ge-Sn system has been investigated previously by our group [1]. In our previous study reliable thermodynamic data set has been proposed and experimentally confirmed with experimental investigation alloys from three vertical sections (Ag-GeSn, Ge-AgSn and Sn-AgGe) and two isothermal sections at 200 and 300 °C. Since reliable thermodynamic data set has been obtained by previous study [1], in the current study same thermodynamic parameters has been used for calculation of the isothermal section at 25 °C. Thermodynamic calculation of the isothermal section were performed by using Pandat software [2]. Calculated phase diagram of the isothermal section were compared with experimental results done in current study. The following experimental techniques were used for experimental trials of this ternary system: scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS), X-ray powder diffraction (XRD), hardness measurements by Brinell method and electrical conductivity measurements. In addition to the experimental test, the thermodynamic calculation of equilibrium diagrams of the state of ternary system was performed using the CALPHAD method. For each phase present in the examined system, the thermodynamic model and the values of thermodynamic parameters that occur in it were determined. For better insight into the properties of the Ag-Ge-Sn alloys, hardness and electrical conductivity were investigated in the current study. Based on experimental results and by using appropriated mathematical model these properties were predicted along whole composition range.

2. EXPERIMENTAL PROCEDURE

High-purity Ag, Ge and Sn produced by Alfa Aesar (Germany) were used for preparation of investigated binary and ternary alloys. Used elements were carefully measured in different molar ratio. Total mass of sample were 3 g. Such samples were melted and re-melted five times in an induction furnace under high purity Ar atmosphere. The average weight loss of the sample during melting was about 1 mass %. Samples were used for SEM-EDS, XRD, hardness tests and electrical conductivity measurements. Samples are prepared by classical experimental procedure as it is deskripcion in our previous paper [3].

3. RESULTS AND DISCUSSIONS

3.1 Microstructural analysis

Twelve ternary samples were selected to SEM-EDS test. Overall compositions of samples were situated along three vertical sections (samples 1 to 4, along Ag-GeSn vertical section, samples 5-8 along Ge-AgSn vertical section and samples from 9-12 along Sn-AgGe vertical section).
As a result, it shown that in ten samples same three phases are detected. Detected phases are marked as (Ge), (βSn) and ε. Two SEM microstructures of samples 1 and 5 are presented as an illustration in Figure 1a) and 1b). In microstructure of sample 3, three phase are detected. By EDS composition of phases, it is determined that detected phases are (Ge), ε and ζ. Microstructure of sample 3 is given on Figure 1c). Sample 4, have two phases in microstructure. Presented phases are determined to be (Ge) and ζ. Microstructure of sample 4 is given on Figure 1d).

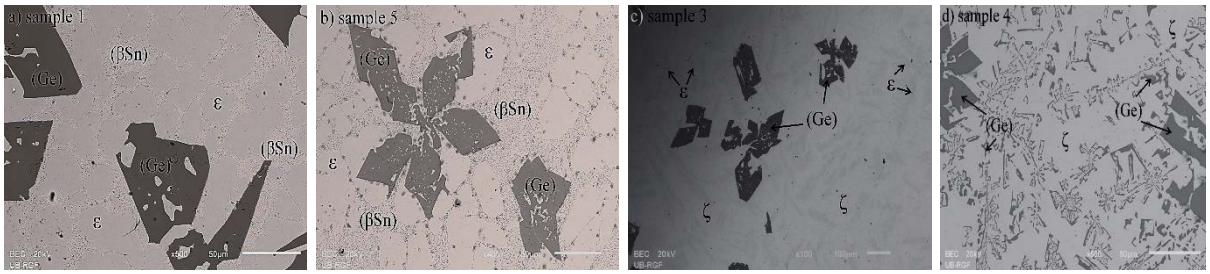

Figure 1 - SEM micrographs of the a) sample 1, b) sample 5, c) sample 3 and d) sample 4.

3.2 Brinell hardness measurements

Twelve ternary samples were subjected to the Brinell hardness measurements. Brinell hardness measurements for all tested alloy samples were performed at room conditions. Relation between mean value of Brinell hardness and alloy composition are presented graficaly on Figure 2.

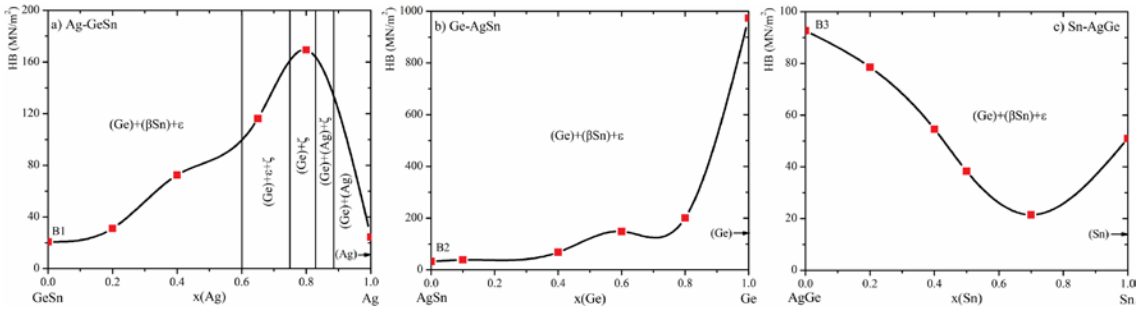

Figure 2 - Graphical presentation of Brinell hardness depending on the composition vertical section: a) Ag-GeSn, b) Ge-AgSn and c) Sn-AgGe.

Experimental results shows that ternary alloy Ag10Ge80Sn10, sample 8 have highest hardness in comparison with other ternary alloys. Detected hardness is 201 MN/m2. High percent of (Ge) phase inside sample 8 is responsible for high value of Brinell hardness. In microstructures of samples 1,2, 5-12, the same three phases are present as in sample 8. The hardness value determined in these samples have a decreasing trend in comparison with hardness of sample 8. Reason for this

trend can be related to the dominant presence of (βSn) and ε phase. In microstructure of samples 3 and 4, different phases are detected in comparison with all other ternary samples. Sample 3, have (Ge)+ε+ζ three phase structure.Sample 4, have two phase structure. In general, can be concluded that percent of (Ge) phase influence on hardness values and that sample 8, have the highest hardness in comparison with other ternary samples. Also it is clear that phase ζ is responsible for high hardness, since this phase is dominant in sample 4. Based on the obtained results, and appropriate mathematical model it can be predicted bihavior of Brinell hardness allong all composition range. The final equation of the predictive model in terms of real components is:

Ln (HB) =3.94623547x(Ag) +6.70578429x(Ge)+3.7583475x(Sn)-7.8742816x(Ge)x(Sn) (1)

Iso-lines contour plot for Brinell hardness of alloys defined by equation 1 is shown in Figure 3.

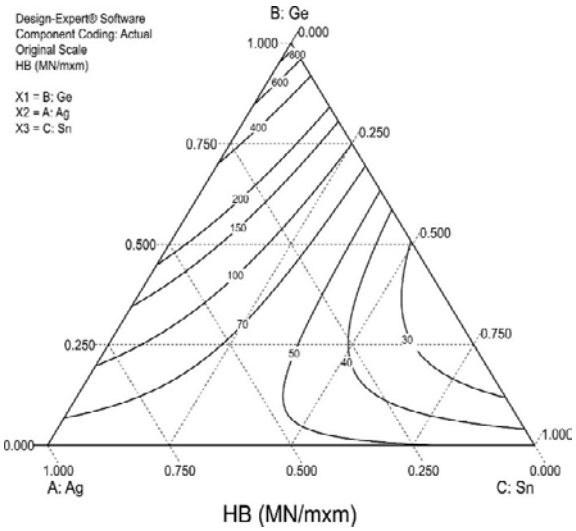

Figure 3 - Calculated iso-lines of Brinell hardness in ternary Ag-Ge-Sn system.

3.3 Electrical conductivity measurements

Electrical conductivity was measured in the same samples as Brinell test. The obtained results of electrical conductivity are also presented graphically. Figure 4 shows a graphical representation of the relationship between electrical conductivity of the tested alloys and the composition of the alloys.

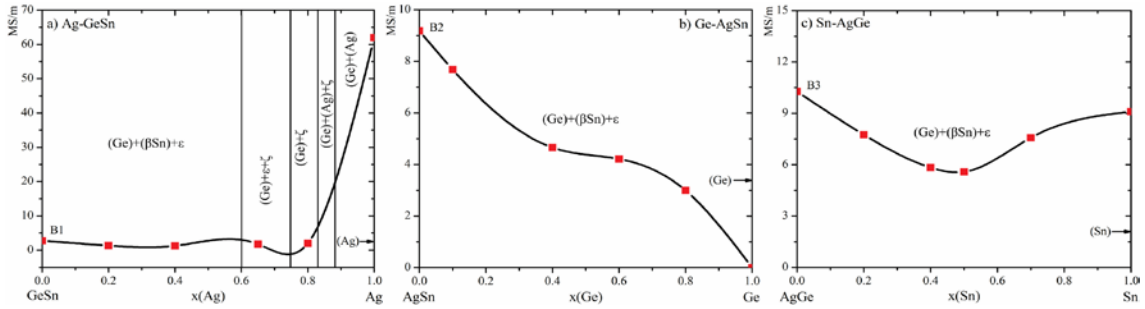

Figure 4 - Graphical presentation of electrical conductivity dependence of composition and phase fraction vertical section a) Ag-GeSn, b) Ge-AgSn and c) Sn-AgGe.

From results shown in Figure 4a), it can be seen that the values for electrical conductivity are very small and quite uniform. While value of electrical conductivity of samples 5 to 12 are higher than for samples 1 to 4. In the microstructure of samples 5 to 12 same three phases are presented (βSn)+(Ge)+ε. Different phase fraction in responsible for slight changes in electrical conductivity. It can be concluded that high percent of ε is mostly responsible for high value of electrical conductivity in ternary alloys. On the other hang beside ε phase, (βSn) phase is also responsible for high value of electrical conductivity.

The final equation of the predictive model in terms of Real components is:

Ln(EP+1.00) =4.036388638x(Ag) 0.137064739x(Ge)+2.175797172x(Sn)+0.463525434x(Ag) x(Ge)-4.099509193x(Ag)x(Sn)-16.81004221x(Ag)x(Ge)x(Ag-Ge)-11.38241626x(Ag) x(Sn)x(Ag-Sn) (2)

Iso-lines contour plot for Electrical conductivity of Ag-Ge-Sn alloys defined by equation 2 is shown in Figure 5.

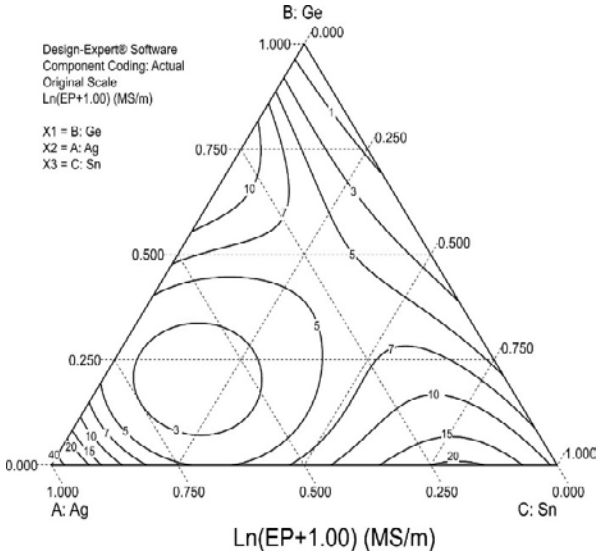

Figure 5 - Calculated iso-lines of Electrical conductivity in ternary Ag-Ge-Sn system.

4. CONCLUSION

The ternary Ag-Ge-Sn system has been experimentally investigated by using several experimental techniques: SEM-EDS, XRD, hardness measurements by Brinell method and electrical conductivity measurements. Experimentally determined phases by XRD analysis were compared with calculated isothermal section at 25 °C and agreement between the results was reached. Experimentally determined compositions of coexisting phases were in good agreement with related calculated compositions. Conducted experiments did not indicate any new ternary phases or large solubility of third element in binary phases. Microstructural, hardness, electrical conductivity tests were performed on twelve ternary alloys. Results of Brinell hardness and electrical conductivity measurements were presented and discussed with respect to alloys compositions and phase constituents. By using appropriated mathematical model these properties were predicted in the whole composition range.

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