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ELECTRICAL RESISTIVITY OF THE AL-BI-GE TERNARY ALLOYS

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Abstract
In this work, the ternary system Al-Bi-Ge has been studied. Twelve ternary samples were prepared and used for experimental testing of electrical conductivity. Based on those experimental results electrical resistivity was calculated. This information, were used for graphical presentation of the electrical resistivity of the ternary Al-Bi-Ge alloys depending on the mole fraction of different components.

***Keywords**: Bi-Ge-Pb ternary system, experimental characterization, electrical resistivity*

1. INTRODUCTION

Ternary Al-Bi-Ge alloys belong to the group of ternary monotectic Al alloys [1-3]. These alloys are promising for different applications because of very specific microstructure development during solidification [4]. They have a great potential to be used as plain bearing alloys [4-6]. A typical plain bearing alloy consists of three main materials, the hard matrix material aluminum, soft components and small amounts of various additives. Additives are important to modify the structure and properties of the matrix metal [7]. The practical use of these materials strongly depends on their properties (physical, structural and thermal characteristics). Therefore, a fundamental knowledge of the phase relationships of the respective alloy system is of great importance.

The ternary Al-Bi-Ge system was studied by Minic et al. extensively [8]. In this study results of the electrical resistivity were presented. The results of the electrical resistivity were calculated using the appropriate formula. For this calculation experimental results of electrical conductivity were used.

2. EXPERIMENTAL

Experimentally investigated samples with a wide range of compositions were prepared from high purity metals Al, Bi and Ge (99.99 %). In total 12 ternary samples were weighed, mixed and melted in an electric arc furnace under high-purity argon atmosphere. The samples were melted and re-melted five times until homogeneity was maintained. The average weight loss during melting and re-melting was abouth 0.5 mass %. After it samples were metallographically prepared for electrical conductivity measurements. The electrical conductivity measurements were carried out at frequency of f=120 kHz using the SIGMATEST 2.069 eddy current meter from Foerster.

3. RESULTS AND DISCUSSION

The ternary Al-Bi-Ge system consists of three binary systems. The constitutive binary phase diagrams are Al-Bi, Al-Ge and Bi-Ge. According to the literature, the solid phases that could be expected in the ternary system are summarized in Table 1 [9-11].

Table 1. Considered phase, their crystallographic data and database names for the solid phases of the ternary Al-Bi-Ge system [9-11]

Thermodynamic database name	Phase	Pearson symbol	Space group	Refs.
FCC_A1	(Al)	*cF4*	$Fm\bar{3}m$	[9]
DIAMOND_A4	(Ge)	*cF8*	$Fd\bar{3}m$	[10]
RHOMBO_A7	(Bi)	*hR2*	$R\bar{3}m$	[11]

Beside three solid phases (Al), (Bi) and (Ge) solid solution in ternary system liquid phase L should appear and no ternary compound.

Electrical conductivity measurements were performed on the samples (No. 1 to 12) and the results are summarized in Table 2.

Table 2. Electrical conductivity (EC) of the alloys of the ternary Al-Bi-Ge system

No.	Mole fraction			Electrical conductivity (EC), MS/m					Mean value of EC, MS/m
	x(Al)	x(Bi)	x(Ge)	1	2	3	4	5	
1.	0.2	0.4	0.4	0.661	0.663	0.684	0.653	0.680	0.668±0.013
2.	0.4	0.3	0.3	0.513	0.507	0.504	0.519	0.528	0.514±0.009
3.	0.6	0.2	0.2	10.303	10.228	10.274	10.320	10.140	10.253±0.072
4.	0.8	0.1	0.1	14.834	14.764	14.631	14.909	14.851	14.798±0.107
	1	0	0						38 [20]
5.	0.4	0.2	0.4	6.428	6.184	6.724	6.126	6.254	6.343±0.241
6.	0.3	0.4	0.3	0.575	0.588	0.584	0.581	0.579	0.582±0.005
7.	0.2	0.6	0.2	0.538	0.517	0.525	0.543	0.519	0.528±0.012
8.	0.1	0.8	0.1	0.534	0.559	0.533	0.538	0.513	0.536±0.016
	0	1	0						0.77[20]
9.	0.4	0.4	0.2	0.635	0.651	0.644	0.650	0.641	0.644±0.007
10.	0.3	0.3	0.4	0.490	0.472	0.492	0.501	0.505	0.492±0.013
11.	0.2	0.2	0.6	1.083	0.879	0.994	1.113	1.087	1.031±0.096
12.	0.1	0.1	0.8	0.715	0.718	0.653	0.695	0.732	0.702±0.031
	0	0	1						0.002 [20]

According to the experiments and predictions, the electrical conductivity in the ternary Al-Bi-Ge alloys increases towards the aluminum corner. Since it has been shown [8], that all ternary alloys have the same three phases in all composition ranges at 25 °C, the proportions of these three phases significantly influence the electrical conductivity. Thus, if the proportion of the (Al) phase is dominant, the electrical conductivity is high. The ternary alloy 4, $Al_{80}Bi_{10}Ge_{10}$, have an electrical conductivity of 14.798±0.107 MS/m, which is due to the 80 % proportion of the (Al) phase in the alloy.

The experimentally determined value of electrical conductivity, which is given in Table 2, is used to calculate the electrical resistivity. The electrical conductivity is the reciprocal of the electrical resistivity and the calculated values are given in Table 3.

Table 3. Calculated value of electrical resistivity based on experimental value of electrical conductivity given in table 6 for ternary Al-Bi-Ge alloys

No.	Mole fraction			Electrical resistivity, μΩ·m					Mean value, μΩ·m
	x(Al)	x(Bi)	x(Ge)	1	2	3	4	5	
1.	**0.2**	0.4	0.4	1.513	1.508	1.462	1.532	1.470	1.497±0.030
2.	**0.4**	0.3	0.3	1.949	1.973	1.983	1.928	1.895	1.946±0.035
3.	**0.6**	0.2	0.2	0.097	0.098	0.097	0.097	0.099	0.098±0.001
4.	**0.8**	0.1	0.1	0.067	0.068	0.068	0.067	0.067	0.068±0.001
	1	0	0						0.0263 [21]
5.	0.4	**0.2**	0.4	0.156	0.162	0.149	0.163	0.160	0.158±0.006
6.	0.3	**0.4**	0.3	1.738	1.700	1.712	1.720	1.728	1.719±0.014
7.	0.2	**0.6**	0.2	1.859	1.935	1.905	1.843	1.928	1.894±0.41
8.	0.1	**0.8**	0.1	1.872	1.789	1.874	1.859	1.950	1.869±0.057
	0	**1**	0						1.2987 [21]
9.	0.4	0.4	**0.2**	1.576	1.535	1.553	1.539	1.560	1.553±0.016
10.	0.3	0.3	**0.4**	2.039	2.117	2.031	1.996	1.978	2.032±0.054
11.	0.2	0.2	**0.6**	0.923	1.138	1.006	0.898	0.920	0.977±0.099
12.	0.1	0.1	**0.8**	1.399	1.394	1.532	1.439	1.366	1.426±0.065

Mean values of electrical resistivity are graphically presented in Figure 1.

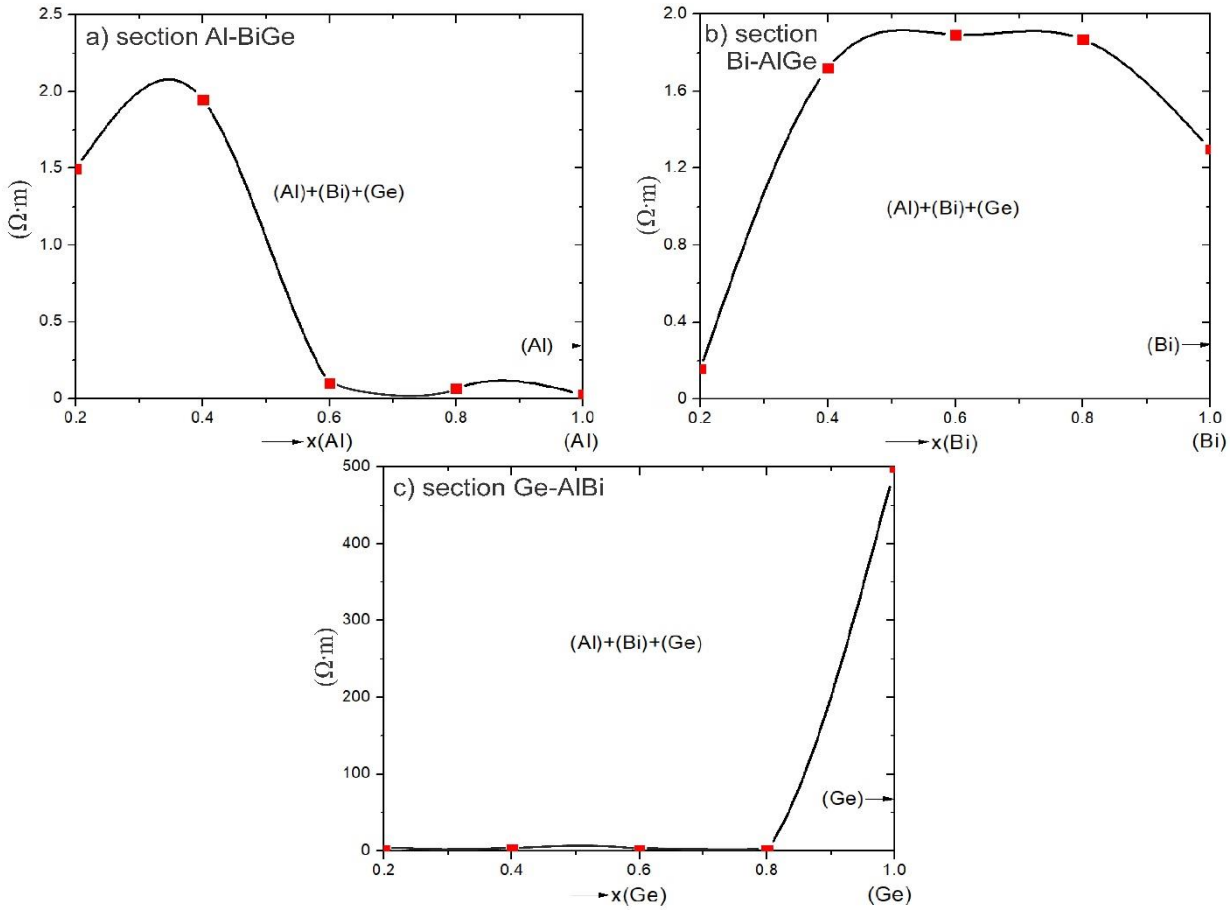

Figure 1. Graphical presentation of the electrical resistivity of the ternary Al-Bi-Ge alloys depending on the mole fraction of different components

For alloy 4, $Al_{80}Bi_{10}Ge_{10}$ resistivity was 0.068±0.001 μΩ·m, while the highest resistivity of 2.032±0.054 μΩ·m was obtained for alloy 10, $Al_{30}Bi_{30}Ge_{40}$.

4. CONCLUSION

Electrical conductivity of the ternary alloys was measured. For this test 12 ternary samples were prepared. Experimental tests shows that sample 4, Al80Bi10Ge10, had the best electrical conductivity of 14.798±0.107 MS/m. The electrical resistivity was calculated as reciprocal of electrical conductivity and the highest resistivity value of 2.032±0.054 μΩ·m refers to alloy 10, with nominal composition Al30Bi30Ge40.

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