UNIVERSITY OF BELGRADE

TECHNICAL FACULTY BOR

52nd International October Conference on Mining and Metallurgy

PROCEEDINGS

Edited by

Saša Stojadinović

and

Dejan Petrović

November 29th – 30th 2021

Bor, Serbia

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PUBLISHER:
UNIVERSITY OF BELGRADE - TECHNICAL FACULTY IN BOR, BOR, NOVEMBER 2021

FOR THE PUBLISHER:
DEAN: Prof. dr Nada Štrbac

EDITORS:
Prof. dr Saša Stojadinović
Doc. dr Dejan Petrović

TECHNICAL EDITOR
Pavle Stojković, MSc.

PRINTED BY:
»Štamparija Atlantis d.o.o.« Niš

CIRCULATION: 100 Copies

CIP – Каталогизација у публикацији –

Народна библиотека Србије, Београд

622(082)
669(082)

INTERNATIONAL October Conference on Mining and Metallurgy (52 ; 2021 ; Bor)
Proceedings / 52nd International October Conference on Mining and Metallurgy - IOC 2021, November 29th - 30th 2021 Bor, Serbia ; [organizer] University of Belgrade, Technical Faculty in Bor ; [co-organizer Institute for Mining and Metallurgy Bor] ; edited by Saša Stojadinović and Dejan Petrović. - Bor : University of Belgrade, Technical Faculty, 2021 (Niš : Atlantis). - V, 228 str. : ilustr. ; 25 cm

Tiraž 100. - Bibliografija uz svaki rad.

ISBN 978-86-6305-119-5

а) Рударство -- Зборници б) Металургија -- Зборници

COBISS.SR-ID 52072201

ORGANIZER:

UNIVERSITY OF BELGRADE – TECHNICAL FACULTY IN BOR

Co-ORGANIZER:

INSTITUTE FOR MINING AND METALLURGY BOR

Under the Auspice of:

The Ministry of Education, Science and Technological Development of the Republic of Serbia

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November 29th – 30th, 2021
www.ioc.tfbor.bg.ac.rs

STUDY OF TEMPERATURE PHASE TRANSFORMATION OF THETERNARY Bi-Cu-Ge SYSTEM

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Abstract
Decades of scientific work dedicated to the investigation of phase diagrams gave significant benefit to industry and science. After all those years of phase diagram investigation still there is missing information about phase diagram of some ternary systems. One of those systems is Bi-Cu-Ge. It is known importance of Cu-based alloys and Ge-based alloys in electro industry. Since such combination is not tested before this work will provide information about phase diagram of the three vertical sections from ternary Bi-Cu-Ge system. From each vertical sections (Bi-CuGe, Cu-BiGe and Ge-BiCu), 4 alloys were prepared and tested by DTA. Experimentally obtained results were compared with corresponding vertical sections. Experimental temperatures of phase transformation shows close value with calculated one. Temperatures of liquidus curve and primary crystallization were determined.

Keywords:*ternary Bi-Cu-Ge system, DTA analysis, vertical sections.*

1. INTRODUCTION

In recent period ternary alloys based on Bi-Ge attracted attention. Our group tested ternary systemssuch as Bi-Ge-Zn,Ga,In,Sn,Ag,Sb [1-3]. On other side copper is recyclable without any loss of quality and can easily make alloys with a lot of elements beside it Cu and Cu-based alloys are wide used in building industry, electronic industry, transportation and many others. So, chosen system Bi-Cu-Ge is important due to the possible application in electronic industry and it is not tested before.In this work studied ternary alloys were from three vertical sections. Used experimental techniques included differential thermal analysis (DTA). The experimental results were compared with the calculated phase diagrams of the selected vertical sections.Reasonable agreement between the calculated phase diagrams and the experimental data was obtained.

2. EXPERIMENTAL

In total 12 ternary alloys were prepared by using high purity Bi, Cu and Ge produced by Alfa Aesar, Germany. Samples were measured in different molar ration and the total mass of each sample were 4 g. Weighed masses of the samples were arc-melted and re-melted six times under high-purity argon atmosphere. The average weight loss was about 0.5 mass %.

Such samples were tested by DTA method with DTG-60H (Shimadzu). Alumina crucibles were used and measurements were performed under flowing argon atmosphere. Samples weighing between 20 and 30 mg were investigated at a heating rate of 5 °C/min.

3. RESULTS AND DISCUSSION

Twelve ternary samples were selected for DTA tests. The samples were placed in alumina crucibles and characteristic temperatures were recorded under protective flowing Ar atmosphere. Weights of the analyzed alloy samples were between 30 and 40 mg and a reference material was an empty alumina crucible. Determination of phase transition temperatures was carried out according to recommendations from the literature [4,5].The liquidus and temperatures of monovariant phase transitions were determinedfrom peak maxima while the solidus temperatures and the temperatures of invariant reactions were determined from onset temperatures of the corresponding peaks.Such determined temperatures from DTA heating curves from 12 samples are summarized in Table 1.

Table 1. Phase transition temperatures of the studied alloys from the ternary Bi-Cu-Ge system determined by DTA at pressure p = 0.1 MPa.

Number	Composition (at. %)		Identified phase transition temperature in °C		
	Nominal	EDS	Ternary eutectic reaction	Ternary transition reaction	Liquidus
Vertical section Bi-CuGe					
1	$Bi_{20}Cu_{40}Ge_{40}$	$Bi_{20.15}Cu_{39.18}Ge_{40.67}$	279.47	613.53/636.21/701.3	849.09
2	$Bi_{30}Cu_{35}Ge_{35}$	$Bi_{29.11}Cu_{35.48}Ge_{35.41}$	269.09	610.34/629.30	933.10
3	$Bi_{50}Cu_{25}Ge_{25}$	$Bi_{49.81}Cu_{25.13}Ge_{25.06}$	275.24	610.19/634.16	979.54
4	$Bi_{70}Cu_{15}Ge_{15}$	$Bi_{70.02}Cu_{14.81}Ge_{15.17}$	278.22	-/622.34	918.92
Vertical section Cu-BiGe					
5	$Bi_{45}Cu_{10}Ge_{45}$	$Bi_{45.01}Cu_{9.81}Ge_{45.18}$	278.10	613.80/627.10	778.90
6	$Bi_{35}Cu_{30}Ge_{35}$	$Bi_{35.52}Cu_{29.61}Ge_{34.87}$	279.14	614.87/633.78	938.19
7	$Bi_{27.5}Cu_{45}Ge_{27.5}$	$Bi_{27.43}Cu_{44.87}Ge_{27.70}$	277.33	612.70/629.23	1035.74
8	$Bi_{20}Cu_{60}Ge_{20}$	$Bi_{19.73}Cu_{61.12}Ge_{19.15}$	277.02	681.20/727.20	1041.80
Vertical section Ge-BiCu					
9	$Bi_{45}Cu_{45}Ge_{10}$	$Bi_{45.08}Cu_{44.87}Ge_{10.05}$	278.31	548.90/723.90/765.61	1128.92
10	$Bi_{35}Cu_{35}Ge_{30}$	$Bi_{34.98}Cu_{35.09}Ge_{29.93}$	279.11	615.19/631.20	1024.90
11	$Bi_{20}Cu_{20}Ge_{60}$	$Bi_{19.35}Cu_{20.87}Ge_{59.78}$	280.10	615.70/631.67	768.62
12	$Bi_5Cu_5Ge_{90}$	$Bi_{4.35}Cu_{4.91}Ge_{90.74}$	277.78	615.30/628.10/733.10	915.90

From recorded DTA results in Table 1, it is visible that on three samples five peaks are detected, on eight samples four peaks and on sample $Bi_{70}Cu_{15}Ge_{15}$ three peaks. It can be notice that first detected peak ofeach sample have similar value of temperatures and it can be assumed that detected temperatures are related to the same transformation. Last detected temperature on all samples is liquidus temperature while peaks in-between are ternary transition reaction. Experimental temperatures from Table 1 are compared with calculated vertical sections. Calculated vertical sections are Bi-CuGe, Cu-BiGe and Ge-BiCu respectively presented on Figure 1.

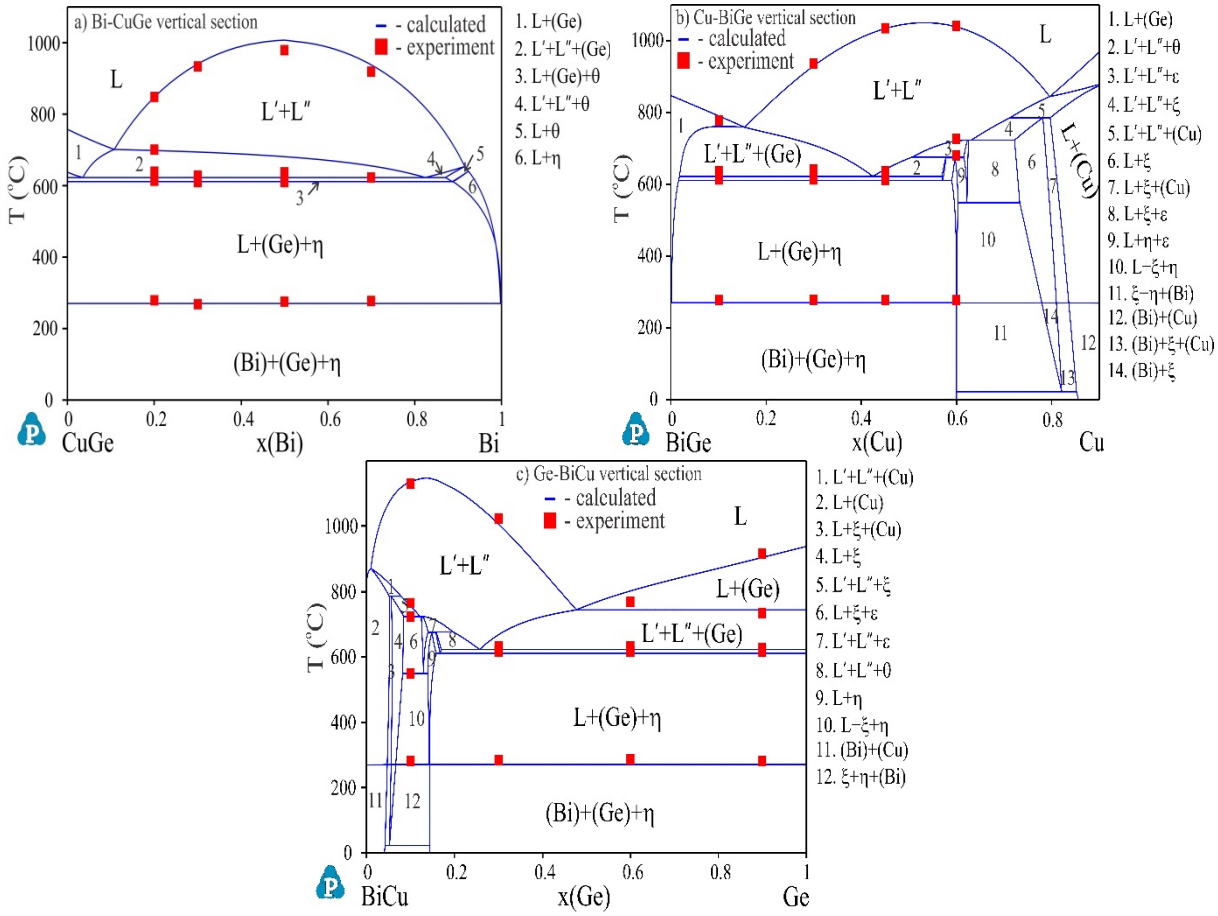

Figure 1. Calculated vertical sections of the ternary Bi-Cu-Ge system compared with DTA experimental results: a) Bi-CuGe, b) Cu-BiGe and c) Ge-BiCu.

From figure 1, good agreement with calculation and experimental resultscan be noticed.Figure 1a) presents calculated vertical section Bi-CuGe compared with experimental result of four samples 1-4. From calculation it is clear that first detected temperature of all samples is related to the same transformation which is related to the ternary eutectic reaction L→(Ge)+(Bi)+η. According to the calculation reaction appears at 271.07 °C, while experimental temperature is in range of 269.09 to the 279.47 °C, which are close to calculated value. Second detected temperature on samples 1, 2 and 3 is related to the θ→L+(Ge)+η calculated at 611.64 °C while experimental are 610.19 to the 613.53 °C which are close to each other. This transformation wasn't confirmed on sample 4 while according to the calculation it should be. Third detected temperatures on all samples is related to the L→L+(Ge)+θ with calculated temperature at 623.05 °C. Experimentally determined temperatures are 622.34, 629.30, 634.16 and 636.21 °C which are slightly higher than calculated one. On sample $Bi_{20.15}Cu_{39.18}Ge_{40.67}$ is also determined temperature of transformation L'+L"→L'+L"+(Ge) at 701.30 °C. Last temperature on all samples is liquidus temperature and all experimental temperatures agree well with calculated.

Tested samples from vertical section Cu-BiGe are marked with numbers 5, 6, 7 and 8. On each sample four temperatures were detected. By compering DTA results and calculated vertical section Figure 1b), it can be noticed that all four temperatures detected with samples 5, 6 and 7 corresponds to the same phase transformation on each sample. First temperatures are related to the ternary eutectic reaction L→(Ge)+(Bi)+η calculated at 271.07 °C. Experimentally detected temperatures of this reaction are 278.10, 279.14 and 277.33 °C which are close to calculated one. Second detected temperatures are 613.80, 614.87 and 612.70 °C which are related to the ternary phase transformation θ→L+(Ge)+η calculated at 611.64 °C. Third temperature on samples 5,

6and 7 are 627.10, 633.78 and 629.23 °C respectively. This temperatures are related to the L→L+(Ge)+θ phase transformation calculated temperature at 623.05 °C. Last temperatures on those samples are liquidus temperature. Sample 8, from same vertical section as samples 5 to 7, detected different phase transformations than samples 5 to 7. Fist temperature is related to the transformation of L+η→ξ+(Bi), second to the L+ε→L+ξ, third to the L'+L"→L'+L"+(Ge) and last one to the liquid temperature.

Four samples from vertical section Ge-BiCu are tested and marked with numbers 9 to 12. Sample 9 detected five phase transformations. First one is related to the L+η→ξ+(Bi) reaction calculated at 270.46 °C while experimental one is at 278.31 °C, next temperature is detected at 548.90 °C and it is corresponding to the L+ε→ξ+η reaction with calculated temperature at 549.31 °C. Third temperature detected with sample 9 is at 723.90 °C while calculated is at 723.67 °C, this temperature corresponds to the reaction L'→L"+ξ+ε. Next temperature detected at 765.61 °C is related to the solidification of ξ phase while end temperature is liquidus. Samples 10 and 11 detected temperatures of same transformations. First at both samples is relate to the ternary eutectic reaction L→(Ge)+(Bi)+η calculated at 271.07 °C while experimental are 279.11 and 280.10 °C. Second temperature is related to the reaction θ→L+(Ge)+η calculated at 611.64 °C while experimental are 615.19 and 615.70 °C. Third detected temperatures on samples are 631.20 and 631.67 °C which are related to the L'→L"+(Ge)+θ with calculated temperature at 623.05 °C. Last temperatures are liquid. Sample 12 detected five temperatures. First three one are related to the L→(Ge)+(Bi)+η calculated at 271.07 °C, θ→L+(Ge)+η calculated at 611.64 °C and L'→L"+(Ge)+θ calculated at 623.05 °C reactions, experimentally detected at 277.78, 615.30 and 628.10 °C, respectively. Forth temperature is at 733.10 related to the transformation of L+(Ge) into L'+L"+(Ge) while last one is liquid temperature.

As general conclusion after comparison of experimental temperatures and calculated vertical sections good agreement with temperatures is reached in most cases.

4. CONCLUSION

The ternary Bi-Cu-Ge system was experimentally tested. Twelve ternary samples were prepared and test by using DTA.Three vertical sections were calculated from each corner Bi, Cu and Ge. Each vertical section was tested with four samples by DTA. DTA test shows temperatures of phase transformation which were in good agreement with calculated temperatures.In general it can be concluded that phase equilibria of ternary Bi-Cu-Ge system presented in this paper is confirmed by experiments

ACKNOWLEDGEMENTS

This work has been supported by the National Nature Science Foundation of China (project No.51950410600) and the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. OI172037).

REFERENCES

[1] A. Djordjevic, M.Premovic, D. Minic, V. Cosovic, D. Manasijevic, J. Chem. Thermodynamics 142 (2020) 106000.
[2] A. Djordjević, D. Minić, M.Premović, D. Manasijević, V. Ćosović, Inter. J.Thermophysics (2019) 29-40.
[3] P. Fima, A. Gazda, J. Therm. Anal. Calorim., 112 (2013) 731–737.
[4] W.J. Boettinger, U.R. Kattner, K.W. Moon, J.H. Perepezko, in DTA and Heat-Flux DSC Measurements of Alloy Melting and Freezing (NIST recommended practice guide, Special publication 960-15, NIST, (2006).

ISBN 978-86-6305-119-5