DOI: 10.5937/IOC24307M Original Scientific Paper-Material Science

# LIQUID METAL ALLOYS BASED ON GALLIUM

**Aleksandra Milosavljević[1a], Ana Kostov[1b], Predrag Stolić[2]**

[1]Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia
[2]Technical Faculty Bor, University of Belgrade, V.J. 12, 19210 Bor, Serbia
[1a] aleksandra.milosavljevic@irmbor.co.rs, https://orcid.org/0000-0003-3841-7357;
[1b] ana.kostov@irmbor.co.rs, https://orcid.org/0000-0001-6436-9091;
[2] pstolic@tfbor.bg.ac.rs, https://orcid.org/0000-0002-2574-4765

## Abstract

*Liquid metal alloys based on gallium are materials of great interest due to their outstanding properties and wide range of applications. This paper provides an overview of the current state of research in the field of gallium-based liquid metal alloys, as well as applications in various industries. Examples of these materials with the lowest melting point are also given in this paper.*
***Keywords****: liquid metals, gallium, alloys*

## 1. INTRODUCTION

The so-called liquid metals (LM) have recently become very attractive, thanks to their properties, as well as due to the wide area of application. The term liquid metals means not only metals, yet all materials: metals and alloys that have lower melting point in comparison to commonly used metals. These materials retain their liquid state even at relatively low temperatures (lower than room temperature). Besides this fact, which is very important but not crucial, there are other properties (mechanical, electrical, electrochemical, etc.) that are causing the range of applications for these alloys to continuously expand.

The first liquid metal was mercury (Hg), and we are all familiar with Hg – thermometers which were widely used all over the world, as well as amalgams (Hg alloys) in dentistry. However, other options had to be considered due to the toxicity of mercury and investigations started with gallium, indium, zinc, tin etc. Gallium in combination with other element / elements gives us the whole spectra of usable alloys (LM). Pure gallium melts on about 30 °C, while alloying with indium and tin can lower the melting temperature even further (≈ 10 °C) as can be seen in Figure 1.

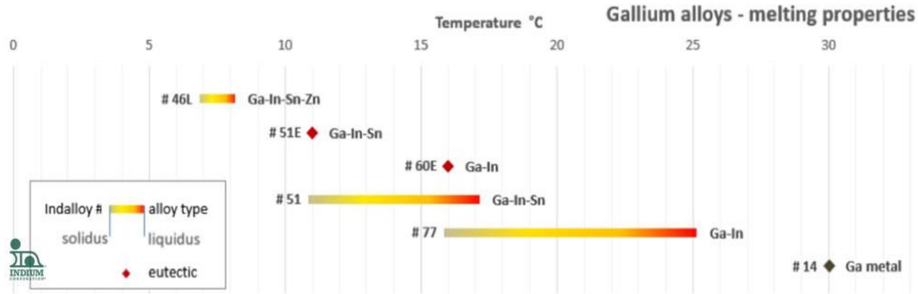


**Figure 1.** *Melting points of some available gallium alloys [1]*

## 2. EXAMPLES OF Ga-Me ALLOYS

As we mentioned, numerous investigations were done in the past, included phase diagrams, electrical and conductivity properties of Ga-Me (Me = In, Sn, Zn etc.). The first addition to gallium in order to decrease melting point, was indium as can be seen in Figure 2. Liquid alloys Ga-In [1, 2] have low melting point, low viscosity and good wetting properties.

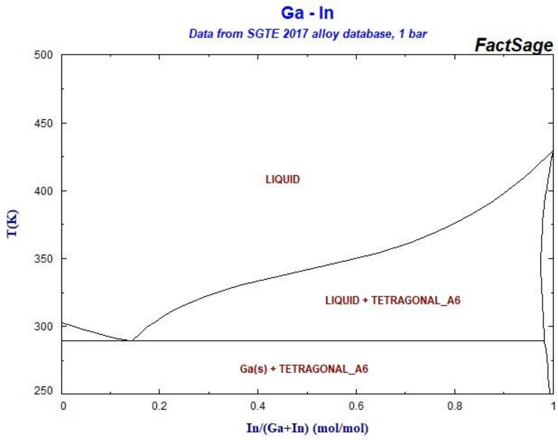


**Figure 2.** *Ga-In phase diagram [2]*

The melting point of the Ga-In-Sn ternary alloy is even lower than melting point of binary alloys [3]. For example, alloy with composition of 68.5% Ga, 21.5% In, 10% Sn, known as Galinstan has melting point about 11°C – 13 °C [3]. The phase diagram of Ga-In-Sn system is shown in Figure 3.

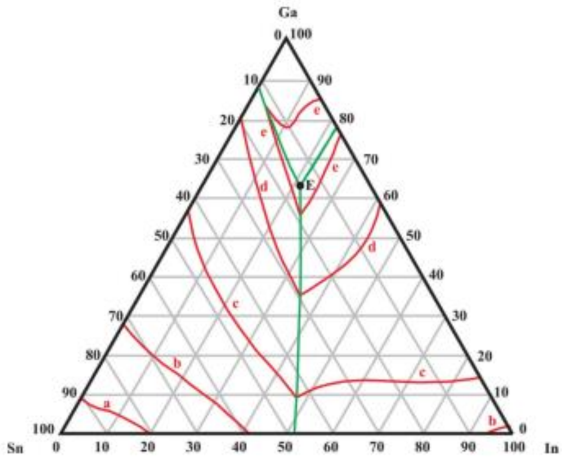


**Figure 3.** *Ga-In-Sn phase diagram: (a) 200°C, (b) 150°C, (c) 100°C, (d) 50°C, (e) 20°C [4]*

As can be seen in figures 2 and 3, there are various compositions of liquid metals; some of those are not investigated yet, some are already in practice. Their application is reflected primarily in electronics, but also in other areas. Consequently, integrated liquid cooling system is necessary in electronics today, so Galinstan alloy has emerged as one of the very good solutions [5]. Liquid metals possess superior thermal conductivity and thereby can cooperate with the temperature control in electronics [6]. They also show fluidity ad flexibility at room temperature, like Ga-In alloys.

LM like Ga-In, have also found application in biomedicine in elimination of cancer and tumor cells, as well as an encouraging substitute for the function of healing and nerve-repairing substance like Ga-In-Sn [6].

Storage systems are vital components of electronic devices, so overcoming limitations is a great challenge, but not an impossible achievement to obtain a fully flexible memory through introducing the oxidation and deoxidation behaviors of liquid metals [7]. By analogy with the human brain, with its memory and thinking capabilities, liquid materials should have the same attention in the field of storage. The brain is fully flexible memory relied on neural cells. Inspired by the polarizing and depolarizing behaviors observed in brain neural activity, scientists decided to try to use the properties of LM like oxidation and deoxidation of GLM (liquid metals based on Ga), which resulting in the realization of a new genre of erasable fully flexible random access memory (FlexRAM) [7].

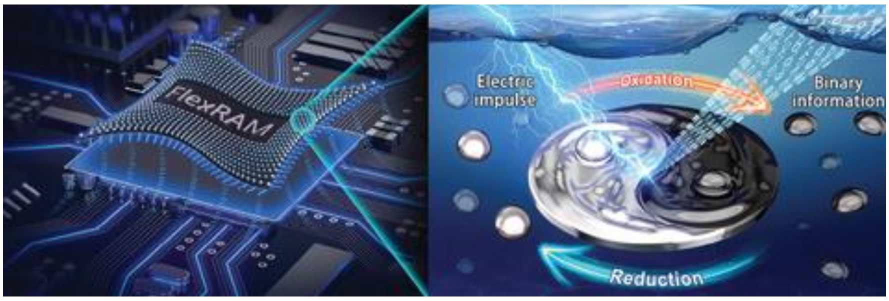


**Figure 4.** *Flexible random access memory based on GLM [7]*

Such an achievement overcomes existing limitations relied to electronic storage units but also gives us possibilities for future applications in soft robotics and artificial intelligence systems.

## 3. CONCLUSION

Gallium-based liquid metals are used in various industries, especially electronics due to their specific characteristics. In addition to this fact, these materials are also used in biomedicine, which makes them an inexhaustible field of research. Although some of them, such as eutectic alloys Ga-In and Ga-In-Sn are already used in practice, there are still many insufficiently tested ones. Consequently, environmental and economic acceptability should be taken into account.

Excellent properties of these materials covering wide application area, but there are some challenges that need to be faced and solved. Toxicology of LM is one important challenge because of biomedicine application. The other one is corrosion as well as stability on different temperatures.

The number of practically useful liquid metals is not remarkable. Hence, further research should be carried out in order to find novel materials. This is not simple, so experimental investigations are not sufficient and should be expanded by powerful advanced techniques such as prediction methods, simulations, artificial neural networks and machine learning. Continued research in this area can lead to significant innovations and improvements in various application fields in all aspects of life.

## ACKNOWLEDGEMENTS

*This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia. Contract on realization and financing of the scientific research work of the Mining and Metallurgy Institute Bor in 2024, Contract No.: 451-03-66/2024-03/ 200052 and University of Belgrade, Technical Faculty in Bor Contract No.: 451-03-65/2024-03/200131*

## REFERENCES

[1] https://www.indium.com
[2] https://www.crct.polymtl.ca
[3] J. Shentu, J. Pan, H. Chen, C. He, Y. Wang, G. Dodbiba, T. Fujita., Metals, 13 (2023) 615
[4] A. Prijić, Z. Prijić, B. Pešić, D. Pantić, S. Ristić, D. Mančić, Z. Petrušić., IEEE Transactions on Components and Packaging Technologies, 31 (4) (2008) 904
[5] J.Y. Zhu, S.Y. Tang, K. Khoshmanesh, K. Ghorbani., ACS Applied Materials & Interfaces, 8 (3) (2016) 2173
[6] S. Afrin, E. Haque, B. Ren, J.Z. Ou., Applied Materials Today, 31 (2023) 101746
[7] R. Yuan, Y. Cao, X. Zhu, X. Shan, B. Wang, H. Wang, S. Chen, J. Liu., Advanced Materials, 36 (2024) 2309182