International Journal of Emerging Technologies in Engineering Research (IJETER)
Volume 5, Issue 7, July (2017) www.ijeter.everscience.org

Green Technology of MEMS Packaging for Subsurface Monitoring of Geothermal Reservoirs

Ujala Nyola
Associate Professor, B K Birla Institute of Higher Education, Pilani (Rajasthan) India.

R. P. Sharma
Associate Professor and Principal, B K Birla Institute of Higher Education, Pilani (Rajasthan) India.

Abstract – Energy companies and policy makers recognise the huge global potential of geothermal energy as a renewable resource for sustainable development. The fast growing thoughts and demand for the environment friendly energy production is driving the researchers to develop green electronics for automation and control of process parameters. The micro electro mechanical systems (MEMS) for automotive control of the geothermal energy production process are playing key role in developing this sector of environment friendly energy. The high temperatures of the geothermal reservoirs emphasize on reliable packaging and strong lead attachments on MEMS devices. The source, channel and sink in MEMS devices are commonly fabricated in square shape. In this course of work isothermal solidification based packaging a Pb free technology using materials Au-In-Cu and Au-Sn-Ni combinations are developed and analyzed. The thermal and mechanical strengths of the interconnect specimen are tested and reported. The isothermal solidification morphology and crystallography are examined and discussed. Environment test results are also reported.

Index Terms – Geothermal Energy, Environment Friendly, Packaging, Pb Free Technology, Isothermal Solidification.

1. INTRODUCTION

A number of characteristics make geothermal energy an attractive option. It is a renewable resource, widely available around the globe [1-2]. It is suitable for diversified and distributed power generation under environment friendly conditions. The continuous monitoring and automotive control enhance the possibility of sustainable production of base-load electricity and heat supply from geothermal reservoirs in all the seasons and weather conditions [3]. To meet the fast growing global demand for renewable energy, researchers are driving their full efforts to develop micro electro mechanical systems (MEMS) for the continued analysis of production parameters. Subsurface monitoring of air and water temperatures, water flow, electricity consumption, and soil temperatures is possible with these devices in a geothermal system where manual observations are not possible. The high temperatures of these geothermal reservoirs emphasize on reliable packaging and strong lead attachments on these micro systems. Packaging of MEMS needs environmental protection, mechanical support and thermal management [4-6]. The mechanical support provides rigidity, stress release and protection from the environment. Thermal management is needed to support adequate thermal transport to sustain operation for the product lifetime. Packaging of MEMS is considerably more complex as they serve to protect from the environment, while, somewhat in contradiction, enabling interaction with that environment in order to measure or affect the desired physical or chemical parameters. The materials used for package should be selected to withstand not only handling during assembly and testing, but also throughout the operational environment of the product. Its robustness must be proven in terms of mechanical and thermal shocks, vibrations and resistance to chemical and other conventional life cycling tests especially needed for stringent environment applications. MEMS packaging involves three major tasks: assembly, packaging and testing. It costs about 50% to 90% of the total cost of the MEMS product [7].

2. RELATED WORK

The demand for miniaturization with increased number of inputs and outputs is challenging the performance of existing interconnection techniques. The soft soldering fabricates the joints at 160°C which is higher to the service temperature of soldered joint [8]. Alignment problems during the ball bonding step and system halt during process are the most occurring problems in the wire bonding techniques [9]. Parallel gap welding is high power consuming, and this requirement increases the process cost. Burning of joint pad under the weld head and heat flow in the device are the other disadvantages of parallel gap welding [10]. Isothermal solidification based interconnection technique offers solution to these challenges. Intermetallic phases (IP) are formed during the isothermal solidification process and thermodynamic conditions for the IP formation result in higher mechanical and thermal stability of these joints than the interlayer metal itself [11]. Following are the characteristic advantages of this joining technique [12-16];

- Controlled growth of the intermetallic phases.
- Homogenized joints, free from pinholes and micro-cracks.
- Low joint-fabrication temperature.

- Non use of toxic gases and metals.

Under the above said properties the isothermal solidification based interconnection technique has gained an important role in the Pb-free electronic assembly in recent times. This technique offers the possibility to fabricate joints of the same geometry that of the bond pads on device with zero 'free area to contact surface area ratio' [17]. Studies have revealed that larger the value of this ratio, lower is the joint strength. In case of the conventional joining techniques the bond geometries are constant and non-altering. The soldered joints are diffused circle shaped in case of soft soldering and wire bonding of leads. The parallel gap welded joints are flattered-linear shaped. The influence of the pad geometry has a great effect on the reliability of the solder joint.

3. EXPERIMENT

Square frame widths are screen printed on ceramic substrate with DuPont thick film Au paste and Au-In-Cu and Au-Sn-Ni interconnects are fabricated for different process temperature, pressure, thickness and reaction time. Isothermal solidification reaction progress, analyzed with help of optical and scanning electron microscopy (SEM), is reported in the paper. Effects of thermal shock and vibration on the package are examined during this course of work.

The corrosion resistivity is determined and analyzed by dipping the samples in solutions of different pH values. The shelf life test is conducted to predict the long time workability of the packaging. The effect of inner and outer dimensions of square frames on the mechanical strengths is summarized in this paper.

The thick film printed, dried and fired patterns of square frame widths developed for this course of study are shown in Fig 1;

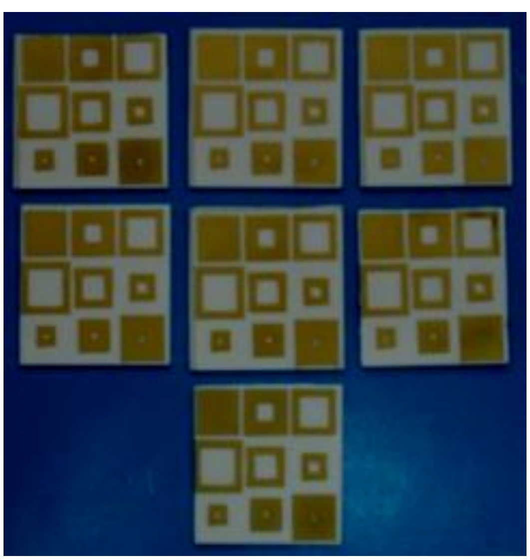

Fig. 1 The thick film Au square frame widths

Table 1 Details of the frame width geometries

Area (mm2)	Peripheral (mm)	X-Y Dimensions (mm)	
		Inner	Outer
Row 1; Square frames of constant outer dimensions			
49	28	0	7
40	40	3	7
24	48	5	7
Row 2; Square frames of constant peripheral line width (= 1mm)			
28	56	6	8
20	40	4	6
12	24	2	4
Row 3; Square frames of constant inner dimensions			
8	16	1	3
24	24	1	5
48	32	1	7

The dimensions of the Au square frames are reported in table 1.The samples are cut into separate units by using a diamond cutter. These cut pieces are then cleaned ultrasonically for 60 minutes in acetone. The interconnections are developed on these thick film metallization using the isothermal solidification based packaging technique.

Selection of the substrate metals Cu and Ni along with interlayer metals In and Sn is based upon their wider applications in electronics and circuitry. Another basis is the binary phase diagrams analysis that reveals the possibility of thermo-mechanically stable IP formation for these metal combinations.

The interconnections are fabricated under different process parameter settings in a specially designed load press device. These interconnects developed are gone through joint strength tests. The maximum temperature up to which the interconnection remains stable defines the thermal stability of the interconnection. The sustainability of interconnection in different environments is examined in an environmental lab.

4. RESULTS AND DISCUSSIONS

Thermal stability measurements

The stability of the isothermal solidification based interconnections at the elevated temperatures is fully a matter of intermetallic phases developed during the fabrication process. These intermetallic phases developed between the joining surfaces show thermal stabilities that of the base metals. Thermal stability tests have been performed for interconnections fabricated for the following compositions;

- ✓ Au-In-Cu
- ✓ Au-Sn-Ni

To measure the maximum temperature stability of the interconnection a set of 10 square shaped samples has been tested. The un-bonding temperatures of each sample set fabricated of different metals have been measured and reported in Tables 2-3. The set of samples tested for each metal combination has been fabricated under constant process parameters. The process temperatures are different for the variety of joining metals; these are also reported with the tables. The samples are fabricated under 0.6 MPa pressure and 30 min reaction time, the thicknesses of low melting metals are also kept constant and which is 10 µm in this development practice.

The un-bonding temperature of each sample has been measured and reported in continued intervals. Different temperature intervals have been used for variety of sample sets to save the space in the tables drawn.

Table 2 Un-bonding temperatures of Au-In-Cu interconnections fabricated at 200 ^{O}C

Temperature interval (^{O}C)	Number of specimen un-bonded per interval
< 550	Nil
551 – 560	1
561 – 570	Nil
571 – 580	1
581 – 590	2
591 – 600	6

Tables 2-3 show the high temperature stability of the isothermal solidification based bonding. These are the temperature ranges most occurred in the high temperature environments. The anomalous low temperature raptures are found in all the combinations under test. L. Bernstein [18] reported similar trends for the Ag-In, Au-In and Cu-In binary systems and correlated these raptures with the incomplete transformation to high temperature phases in the interface. The interconnections fabricated on Au metallization with Sn interlayer are stable up to 500 ºC temperature. The Au-In-Cu interconnections are useful in packaging of devices for workability up to 600 ºC.

Comparing the measured thermal stabilities with the fabrication temperatures, the un-bonding temperatures are found vary high than that of the fabrication temperature. Therefore the application of isothermal solidification based interconnection technique is safe for chip level packaging and extension on an electronic assembly.

Table 3 Un-bonding temperatures of Au-Sn-Ni interconnections fabricated at 280 ^{O}C

Temperature interval (^{O}C)	Number of specimen un-bonded per interval
< 450	Nil
451 – 460	2
461 – 470	Nil
471 – 480	Nil
481 – 490	1
491 – 500	7

The mechanical strengths

The interconnection in electronic devices serves both the electrical supply and mechanical support to the attached components. The mechanical behavior of an interconnection determines its practical importance [19-25]. The mechanical properties of the fabricated specimens are characterized by the measured response to externally imposed strains and stresses. A large number of studies have been focused on the mechanical behavior of conventionally soldered joints to develop new solder alloy materials. P. K. Khanna et al. [26] investigated the tensile strength of isothermal solidification based bonding in Ni-Sn-Ni system. S. Sommadossi et al. [27] analyzed the behavior of interconnections on Cu substrates using In-48Sn interlayer alloy. These studies are focused on the phase formation during the bonding. Square shaped interconnections are fabricated by these researchers. The geometry of the interconnection fabricated is an important factor in the packaging of microelectronic devices and this also governs mechanical behavior of the interconnection. The tensile strengths of interconnections fabricated in total nine square frames of different dimensions have been analyzed and reported in this section.

The tensile strengths of the specimen fabricated for variety of process parameter settings have been measured up to 60 M Pa. Tensile strength of the isothermal solidification based interconnection increases with the reaction growth and it's a function of area of actual joining. Thickness of the low melting interlayer governs the thickness of the intermetallic zone which in turn increases the tensile strength of the joint.

The variation in UTS for different thickness values is symmetric and is varies from 14 to 62 MPa. By increasing the interlayer thickness the interconnection zone thickness increases which in turn results in higher tensile strengths.

Temperature is the most important parameter in isothermal solidification process; change in it causes great variations in diffusion and creep reaction kinetics. The UTS data for joint specimens developed at different temperatures for 1 to 30 min reaction time reveals that isothermal solidification process become faster for higher temperatures.

Pressure is an important parameter of isothermal solidification based interconnection technique. Optimum pressure is required in order to obtain maximum joint strength.

Similar variations, with the process parameters, in UTS values have been observed in the other joining compositions. The Au-In-Cu interconnection shows the highest UTS of 62 MPa, specimen fabricated at 200 ºC temperature for 30 min reaction time with 20 µm thickness under 0.7 MPa pressure, among the three compositions under test.

The results of UTS measurements for different geometries establish that UTS of an interconnection depends upon the intermetallic phases and therefore it is not a function of the pad geometry.

The tensile strength of an interconnection is a measure of its working efficiency with portability. Tensile strength of a fabricated interconnection is highly significant in the present scenario where the consumers are demanding for smaller and lighter portable electronic devices T. B. Wang et al. [28] has highlighted the advantages of the Au-In isothermal solidification based die bonding technique.

The effects of interconnection parameters on the Au-Sn-Ni systems have been analyzed and obtained in high strength range. Minor and Morris [29] studied the microstructures and the intermetallic phase formation of Au-Sn-Ni metal combinations. These IP grown [Fig. 1] contribute in the strengths of the bonded joints.

The USS values are measured for specimens prepared for different process parameters. The variations in USS, observed for change in temperature, pressure, thickness and reaction time are similar to those measured for UTS. The measured USS values reveal the effect of inner and outer dimensions of the frame widths. For constant outer dimension, USS increases with increment in inner dimension. For constant inner dimension, USS increases with increment in outer dimension. For the frames of constant peripheral the USS significant depends up on the ratio of outer to inner dimension.

The surface growth during the interconnection process

Fig. 1 The Au-In-Cu interconnection developed for 30 min reaction time at 200 ºC under 0.7 MPa pressure with 10 µm Indium thickness

Figure 1 represents a good adhesion between the Au and Cu surfaces for hollow square bond pad geometry. After completion of the isothermal solidification reaction the Indium has been consumed completely and IP are formed. Some quantity of Indium out flow during the joining process, this is visible in stack form. S. Sommadossi et al. [30] investigated the Cu-In-Cu interconnections developed at 180 ºC under 0.5 MPa pressure and reported the probable intermetallic phases grown in the sample area under metallographic observations.

The continued and homogenized crystal growth contributes in the thermo-mechanical strengths. With increment in time the voids are minimized and intermetallic phases grow evenly all over the joining surfaces. The deformities including micro cracks and pores are eradicated with reaction progression and uniformly distributed IP form good and strengthened bonding.

The results of the environmental tests are summarized in Table 4;

Table 4 The environmental test results of Au-Sn-Ni interconnections

Test performed	Number of samples tested	Number of the test qualifying samples
Thermal shock	5	5
Vibration	5	5
pH dip	5	5
Shelf life	5	5

The environment test results show the efficient workability and long-time sustainability of isothermal solidification based packaging of MEMS in harsh and stringent environments.

5. CONCLUSION

The isothermal solidification based packaging of MEMS devices offers high thermo-mechanical stabilities. These values are best suited for subsurface monitoring of geothermal reservoirs. The selective area sealing fabricated with square frame widths are long time workable at elevated temperatures and under harsh environment conditions. Development of packaging for circular frame widths of miniaturized dimensions using isothermal solidification based technique is proposed for the future work.

REFERENCES

[1] Fridleifsson I. B., Renewable and Sustainable Energy Reviews, Vol. 5, No. 3, 299 (2001).
[2] Schiermeier Q., Tollefson J., Scully T., Witze A. and Morton O., Nature, Vol. 454, 816 (2008).
[3] Gupta H. and Roy S., Geothermal Energy : An Alternative Resource for the 21st Century, Elsevier (2006).
[4] Herrel D. J., IEEE Micro., Vol. 13, No. 2, 10 (1993).
[5] Frear D. R., JOM, Vol. 51, No. 3, 22 (1999).
[6] Lau J., Lee C., Premachandran C. and Aibin Y., Advanced MEMS Packaging, 1st Edition, McGraw Hill, (2009).
[7] Deshpande A. W., MS Thesis, Study and characterization of plastic encapsulated packages for MEMS, Worcester Polytechnic Institute, Worcester (2005).
[8] Khanna P. K., G. Dalke and W. Gust, Z. Metallkd., Vol. 90, No. 9, 722 (1999).
[9] Zhong Z. W., Microelectronics Int., Vol. 25, No. 3, 19 (2008).
[10] Sharma R. P., Khanna P. K., Kumar D., Kumar S. and Pandey H. C., Proceedings of IEEE International Conference Microwave-08, 739 (2008).
[11] Sharma R. P., Khanna P. K. and Kumar D., Thin Solid Films, 519 (2010) 1192.
[12] Sharma R. P., Khanna P. K., Kumar D., Suri N. and Pandey H. C., Integrated Ferroelectrics, Vol. 120, 49 (2010).
[13] Khanna P. K., Bhatnagar S. K. and Gust W., Mat. Letters, Vol. 40, 170 (1990).
[14] Studnitzky T. and Schmid-fetzer R., J. Electron. Mater., Vol. 32, No. 2, 912 (2007).
[15] Sommadossi S. and Guillermet A. F., Intermetallics, Vol. 15, 912 (2007).
[16] Khanna P. K., Bhatnagar S. K., Dalke G., Brunner D. and Gust W., Mater. Sci. Engg. B, Vol. 33, L6 (1995).
[17] Plumbridge W. J., J. Electron. Mater., Vol. 37, No. 2, 218 (2008).
[18] Bernstein L., J. Electrochemical Society, Vol. 113, No. 12, 1282 (1966).
[19] Suganuma K., Current Openions in Solid Sate and Mater Sci., 55 (2000).
[20] Abetw M. and Selvaduray G., Mater. Sci. Engg., Vol. 27, 95 (2000).
[21] Glazer J., Int. Mater. Rev., Vol. 40, No. 2, 65 (1995).
[22] Frear D. R. and Vianco P. T., Metall. Mater. Trans. A, Vol. 25, 1509 (1994).
[23] Pang J. H. L. and Xiong B. S., IEEE Trans. Compo. Packag. Technol., Vol. 28, No. 4, 830 (2005).
[24] Andersson C., Tegehall P. E., Andersson D. R., Wetter G. and Liu J., IEEE Trans. Compo. Packag. Technol., Vol. 31, No. 2, 331 (2008).
[25] Tai L. J., Tsai I. and Wu E., IEEE Trans. Compo. Packag. Technol., Vol. 31, No. 2, 503 (2008).
[26] Khanna P. K., Bhatnagar S. K., Chang L. S. and Gust W., Z. Metallkd., Vol. 90, 470 (1999).
[27] Sommadossi S., Huici J., Khanna P. K., Gust W. and Mittemeijer E. J., Z. Metallkd., Vol. 93, 496 (2002).
[28] Wang T. B., Shen Z. Z., Ye R. Q., Xie X. M., Stubhan F. and Freytag J., J. Electron. Mater., Vol. 29, No. 4, 443 (2000).
[29] Minor A. M. and Morris J. W., Metallurgical and Mater. Trans. A, Vol. 31, No. 3, 798 (2000).
[30] Sommadossi S., Khanna P. K., Bhatnagar S. K., Litynska L., Zieba P., Gust W. and Mittemeijer E. J., EUROMAT-99, Vol. 4, 214 (2000).