LEAD FREE MICROELECTRONICS PACKAGING FOR BIOMEDICAL APPLICATIONS

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Global environmental concerns and pending legislation have driven the action towards Pb free electronics. Biomedical investigations and reports reveal the increasing toxic levels caused by human lead exposure. Wider applications of electronics and on chip micro systems in clinical laboratories and hospitals demand intense activities to develop Pb free solders and packaging techniques for microelectronic devices. Isothermal solidification based interconnection technique include Pb free process to fabricate high stable bonding. Au –Cu interconnects are fabricated and tested in different environments. Reaction progress, analyzed with help of optical and scanning electron microscopy (SEM), is reported in the paper.

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1. Introduction

The electronics is proving valuable assessor to biomedical engineering. Use of microelectronic devices and chip level micro-systems is finding wider applications in diagnosis, curing and monitoring of health parameters of patients in hospitals and clinical laboratories. After successful implementations of e-tongue, e-nose and biomedical micro sensor systems; the development of lab-on-chip is the next target for microelectronics. Miniaturization is corollary objective in this practice to explore the possibility of implantation of the device in human bodies. Reliable and hazards free packaging of the device is equally important to the development practice. In microelectronics packaging various bonding methods and mediums are used to make the interconnection to the substrate and to bond the package to the circuit board. The Pb containing solders, epoxies and flux are not applicable in these devices due to below summarized ill effects of Pb on human skills and physiological systems;

- Behaviour-Attention problems, distractibility and restlessness [1-4].
- Blood and circulation system -Anaemia [2, 4-6].
- Cognitive development-Intelligence Quotient (I.Q.) levels decrease [2, 4-9].
- Digestive system-Impaired Vitamin D metabolism; which affects bone remodelling, mineral absorption and calcium uptake [2, 4, 6, 8].
- Foetal-Miscarriage, still birth and neonatal death [2, 8, 10-12].
- Growth & development-Impaired pituitary-thyroid endocrine system [2-3].
- Hearing-Hearing impairment; auditory sensitivity decreased [2, 13].
- Movement and muscular-Visual-motor skills deficits causing problems in hand-eye coordination [2].
- Nervous system-Encephalopathy and other brain diseases [2, 6].
- Peripheral nervous system-Dizziness [4-5].
- Renal (kidneys) - Acute Nephropathy and other renal diseases [2-4, 6, 14].
- Sight-Retinal degeneration [2].

Beyond these worse effects Pb increases risk of early death from cancer [15], this not only affects human being but also to the animals and the whole environment. The improperly disposed off old electronic devices produces lead oxides which contaminate the ground water [16]. Keeping view on these facts and the environmental legislations and green standards in USA, Japan and European Union [17-18] the traditional packaging materials are found unsuitable for the lead free joining process. New materials and packaging techniques with optimized characteristics and process parameters are the pre requisites for this Pb free era.

Isothermal solidification [19-21] based bonding is an environment friendly and Pb free technique to produce high adhesion with an acceptable process temperature. The high process temperature increases the fabrication cost due to greater rate of power consumption. Under this fact the isothermal solidification based interconnection technique is cost effective. Good thermal and electrical conductivity of the bond produced and no use of toxicant gases and glues are the other advantages of this joining technique. Au-Cu interconnections are fabricated with Indium interlayer. The optical microscopy based results for intermetallic growth is reported in this paper. The reaction progress crystallography is analyzed with the help of SEM images. The specimens fabricated are tested against thermal shock, humidity and pH in an environment lab.

2. Experimental details

The selection of metals is based on the wider application of Au and Cu in electronics and by studying the binary phase diagrams [22]. Au-In and Cu-In phase diagrams are of interest for fabricating high temperature stable Au-Cu joints at low temperatures. Au and Cu form intermetallic phases with In metal [Tables 1-2]. High purity (99.999%) In has been used as interlayer metal. The In melts at 429 K and intermetallic phase formation is achieved. These are stable in a wide temperature range up to 975 K. Square shaped patterns of 5×5 mm^2 dimensions are printed with DuPont Au thick film paste no. 4119 on ceramic substrates using DEK printer. After a 20 minutes drying process these printed units are fired up to 1100 K temperature in a Muffle furnace. The post firing thickness measured with Light Section Microscope has been obtained in the range of 17-19μm.

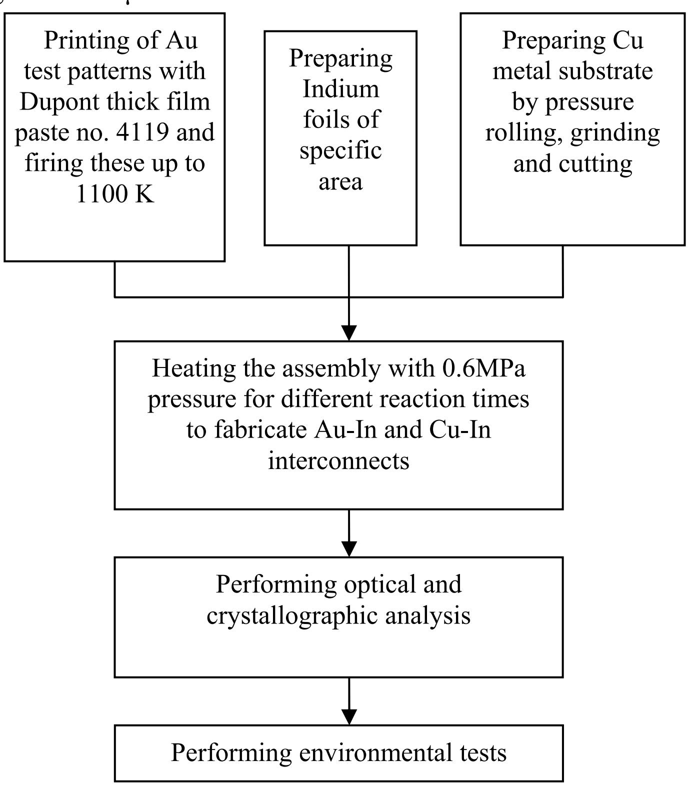

Fig. 1. Experiment flow chart showing the process sequences

High purity Cu (99.999%) has been used for preparing Cu-metal sheet of 20µm thickness by pressure rolling, grinding and buffing. This Cu-sheet of constant thickness is then cut into pieces to produce the Cu substrates for the bonding. Similarly high purity In (99.999%) foils of 10µm thickness are prepared. The In foil is sandwiched between the thick-film-Au pad and Cu-metal sheet with a ceramic substrate covering the top Cu layer. The assembly is heated up rapidly to 453 K temperature in the load press apparatus under 0.6MPa pressure for different reaction times. With the progress of Au-In and Cu-In isothermal solidification reactions the high stable intermetallic phases (IP) are formed. The temperature is regulated with temperature controller and has a continuous measurement by a calibrated thermocouple.

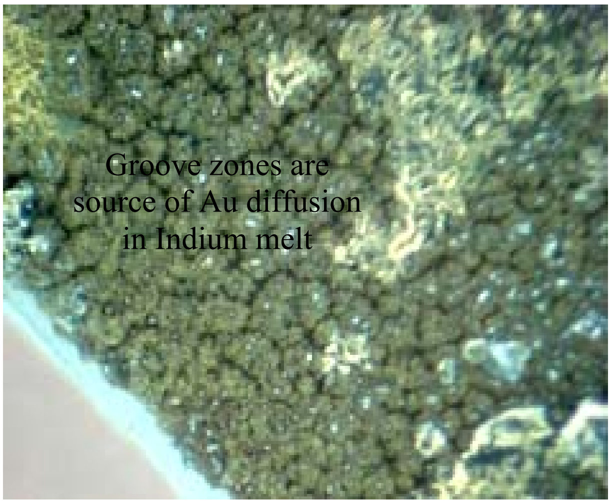

Fig. 2. Groove formations on Au substrate

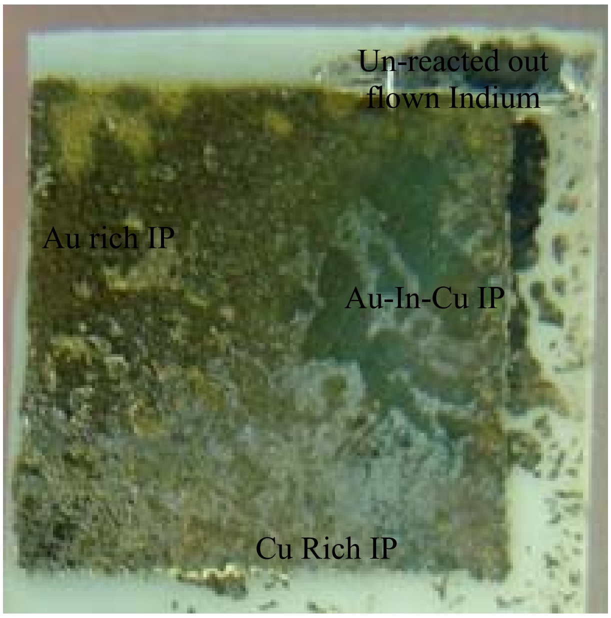

Fig. 3 Optical imaging of IP growth on Au substrate after 120 sec reaction process.

Fig. 4. Optical imaging of IP growth on Cu substrate after 120 sec reaction process

The interconnect specimen are gone through 60 minute ultrasonic cleaning in methanol before the optical and crystallographic imaging. The effect of changing environment on the mechanical and thermal properties is analyzed in this course of study. The fabricated samples are tested for 253 / 323 K thermal shock to predict the efficiency of joint in changing environments, during the biomedical investigations with automotive laboratory equipments. Keeping the biomedical applications on view, interconnect specimens are stored in different humidity conditions for 240, 1000 and 5000 hours. To check the sustainability in pH varying environment, joints fabricated are dipped in solutions of different pH ranging ± 0.5 points around the pH value of human blood. Summary of the experiment is given in the flow-chart [Figure 1];

3. Results and discussion

Peeled off surfaces of the Au-In-Cu interconnect after 120 sec of reaction at 353 K are shown in Figures 1-3. Grooves are formed in substrate surfaces and diffusion of grains in Indium melt take place to form stable IP [Figure 2]. The 40X Optical images show different regions of Cu rich and Au rich phases on substrate surfaces [Figures 3-4]. Partial quantity of Indium out flow in molten state and remain stacked around the reaction zone. This highlights the importance of accurate estimation of interlayer thickness to ensure complete consumption of the low melting metal. The surface asperities, uneven pressure and creation of different temperature zones at the interface are responsible for discontinued surface growth. The deformities including micro cracks and pores are eradicated with reaction progression and uniformly distributed IP form good and strengthened bonding. The Scanning Electron Microscopy presented in Figures 5-6 reveal that homogenized interconnect is obtained after 240 s of reaction.

Table 1. Au-In IP and their melting temperature

IP formed	Melting Temperature (K)
$AuIn_2$	>750
AuIn	>725
Au_5In_3	>700
Au_7In_3	>750
Au_3In	>750
Au_7In_2	>575

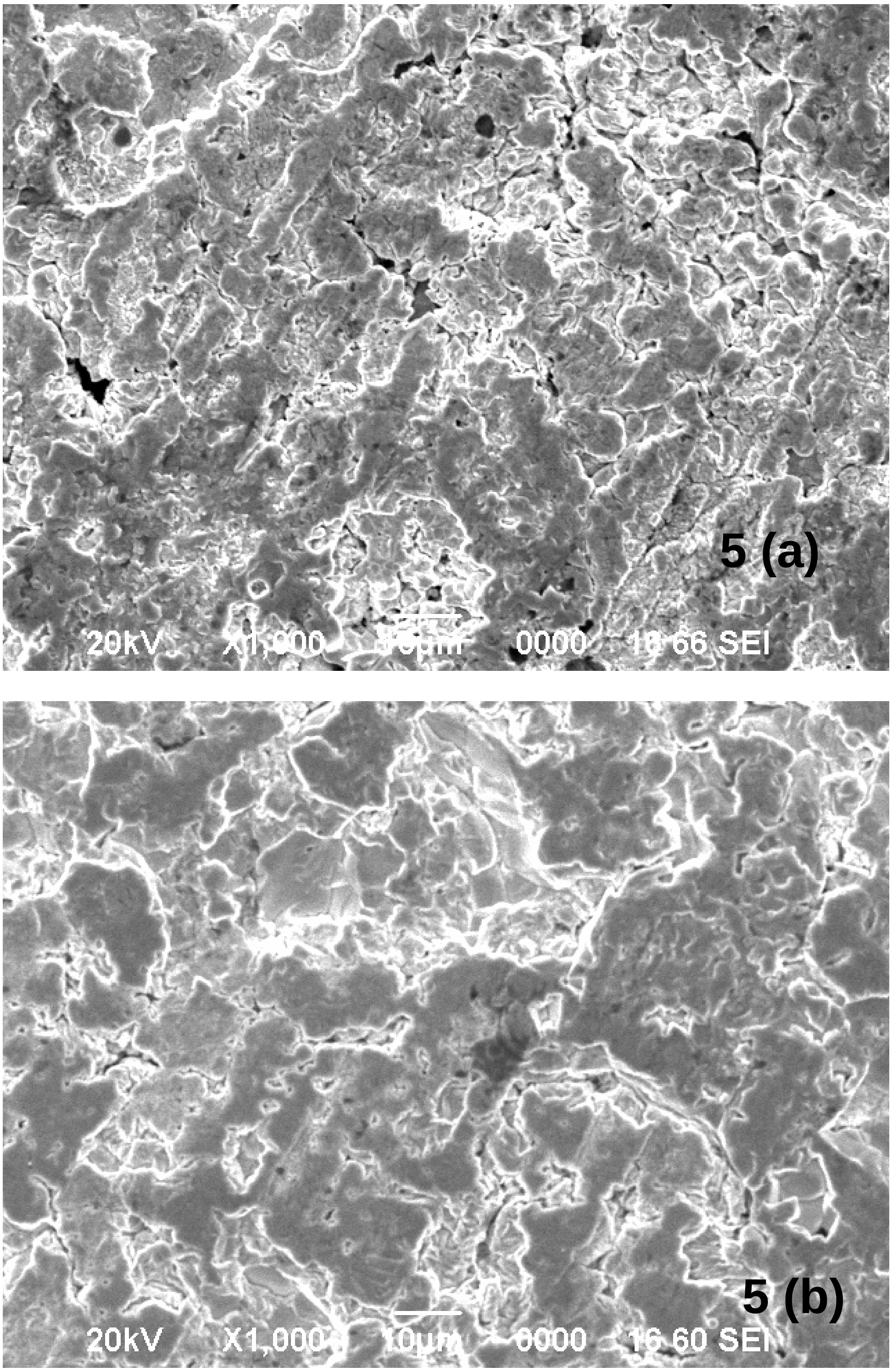

Fig. 5 SEM images of IP growths on Au substrate, (a) for 60 seconds reaction discontinuity in surface is observed (b) for 240 sec homogenized bonding is obtained.

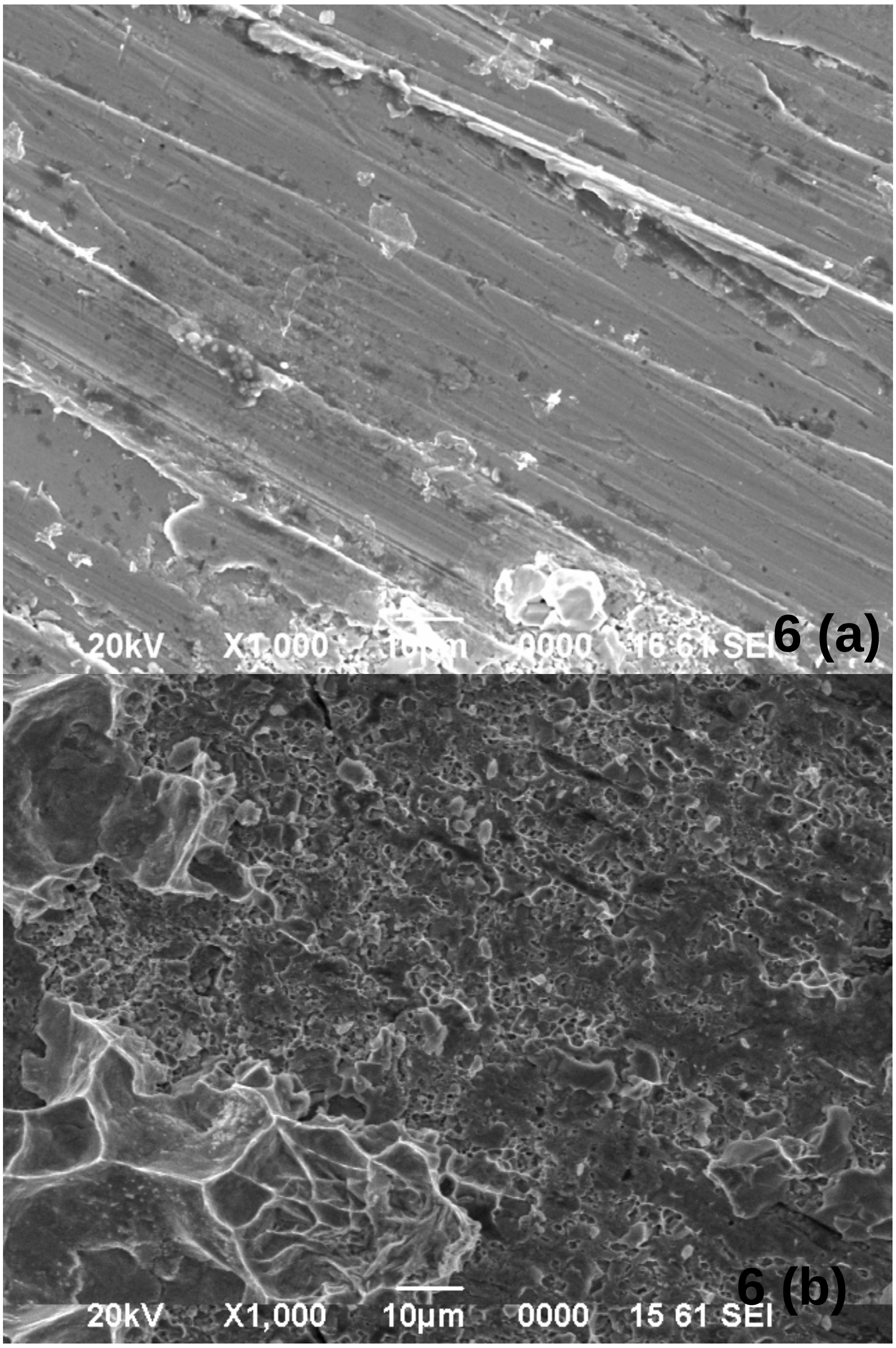

Fig. 6 SEM images of IP growths on Cu surface; (a) for 30 sec reaction time diffusion of Cu in Indium melt from grooves is visible (b) for 240 sec reaction time homogenized layer of Cu-In IP covers the surface

Table 2. Cu-In IP and their melting temperature

IP formed	Melting Temperature (K)
$Cu_{11}In_9$	>550
Cu_2In	>900
Cu_7In_3	>950
Cu_4In	>975

The isothermal solidification reaction leads to IP formation by solid-liquid inter diffusion. During thermal shock tests and storage at higher temperatures solid-solid diffusion take place and the joint strength increases. The intermetallic composition remain unaffected of humidity, the interconnection in turn show no change in strength and melting temperature during humidity test. The specimens fabricated show good resistance against corrosion due to the presence of high anti-corrosive Au in the Cu rich and Indium rich IP.

4. Conclusions

[1] Pb is causing immense problems to human health. Development of Pb free electronics for biomedical applications is demanding utmost preference to avoid the risks of exposure to Pb in clinical laboratories and hospitals.

[2] Isothermal solidification based packaging technology offer the possibility to develop stable interconnections in a Pb free environment. This innovative technique is cost effective in fabricating joints of good adhesion quality.

[3] The environment test results performed for package specimens reveal that this technique is suitable for body implantable devices and automotive biomedical instrumentation.

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Refrences

[1] H. L. Needleman, J. A. Riess, M. Tobin, G. Biesecker, J. B. Greenhouse, JAMA, **275/5**, 363 (1996).
[2] H. L. Needleman, Human Lead Exposure, CRC Press (1992).
[3] N. Castellino, P. Castellino, Inorganic lead exposure, Ed N. Sannolo, Lewis Publishers (1995).
[4] M. F. Werbach, Foundations of nutritional medicine, Third Line press, Tarzana California (1997).
[5] M. A. Smith, L. D. Grant, A. Sors, Lead exposure and child development: an international assessment, Kleeven Academic Publishers (1989).
[6] S. E. Royce, Lead toxicity, US Dept of Health and Human Services, Agency for Toxic Substances and Disease Registry (1992).
[7] H. Zailina, R. Junidah, Y. Josephine, H. Jamal, Asia Pac. J. Public Health, **20/4**, 317 (2008).
[8] A. Fischbein, Occupational and environmental lead exposure. In Environmental and Occupational Medicine, 2nd Edn, Ed W.N. Rom. Little, Brown & Co. (1992).
[9] B. P. Lanphear, K. Dietrich, P. Auinger, C. Cox, (2000) Cognitive Deficits Associated with Blood Lead Concentrations <10 μg/dL in US Children and Adolescents, Public Health Reports, **115**, 521 (2000).
[10] C. Winder, Reproductive and chromosomal effects of occupational exposure to lead in the male. In Reproductive Toxicology Review, **7**, 221 (1989).
[12] R. Shukla, R. L. Bomschein, K. N. Dietrich, C. R. Buncher, O. G. Berger, P. B. Hammond, P. A. Succop, Pediatrics, **84/4**, 604 (1989).
[13] G. P. Wong, T. L. Ng, T. R. Martin, D. F. Farquharson, Obst. Gyne. Survey, **47/5**, 285 (1992).
[14] J. Schwartz, D. Otto, Blood lead, hearing thresholds, and neurobehavioral development in children and youth. In Archives of Environmental Health, **42/21**, 153 (1987).
[15] M. L. Adham, Env. Health Perspectives, **105/9**, 928 (1997).
[16] M. Lustberg, E. Silbergeld, Blood Lead Levels And Mortality, Arch Intern Med, **162/21**, 2443 (2002).

[17] L. Yang, J. B. Bernstein, K. Chung, Microelectronics Int, **18/3**, 20 (2001).
[18] R. Ciocci, M. Pecht, Microelectronics Int, **23/2**, 45 (2006).
[19] M. Kamal, E. S. Gouda, Materials and Manufacturing Processes, **21/8**, 736 (2006).
[20] P. K. Khanna, S. K. Bhatnagar, W. Gust, Material Letters, **40**, 170 (1999).
[21] P. K. Khanna, S. K. Bhatnagar, L. S. Chang, W. Gust, Z. Metallkd, **90/7**, 470 (1999).
[22] S. Sommadossi, J.Huici, P. K. Khanna, W. Gust, E. J. Mittemeijer, Z. Metallkd, **93**, 496 (2002).
[23] Desk Handbook: Phase Diagrams for Binary Alloys, ASM Int. (2000).