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Mechanical properties of Ag-Ni seal rings for micro-systems

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Fabrication of mechanically stable interconnections on chip and micro-systems, applicable in hazardous environment, is the main objective of the device packaging techniques. Isothermal solidification based interconnection technique offers possibility of obtaining high mechanical stability of bonding. Seal rings, commonly fabricated at input opening of sensors, are developed using Sn interlayer metal. Effects of temperature, reaction time, pressure, thickness and geometry on the ultimate tensile strength (UTS), ultimate shear strength (USS) and ultimate torsional strength values are analyzed and reported.

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1. Introduction

Device packaging has been encountering new challenges in the existing and developing microelectronic engineering applications. In Micro Electro Mechanical Systems (MEMS) and sensors, packaging of the devices are equally important to the development practices [1-2]. The package serves the purpose of heat dissipation and mechanical support along with the electrical conduction through the inputs and outputs leads. Without reliable packaging and interconnects the device would fail. Reliability issue of the package proves more significant when the device is produced for applications in hazardous and stringent environments with higher accuracy requirements. The isothermal solidification [3-5] based interconnection technique is finding wide applications in the packaging of electronic devices and area sealing of the attachments in micro-systems [5]. This has the below summarized proven advantages [3- 4, 6- 7];

- Service temperatures of the joints are very high.
- Bonds are fabricated due to intermetallic phase formation, which are homogenized and micro-crack free.
- Interconnects are formed at low temperatures.
- This is low power consuming, economic technique.
- This is a Pb-free joining technique and therefore it is environment friendly.
- Possibility to fabricate joints according to the bond pad geometry with zero 'free area to contact surface area ratio'.

This technique is best suited for the chip level packaging of micro-systems due to its above mentioned properties.

Circular apertures, closely bonded with sensing unit, are commonly fabricated in sensors at input openings. The MEMS devices for fluidic and hydrodynamic measurements involve tube attachments. The purpose behind the fabrication of such designs is to avoid direct contact of measuring environment with the whole device, which in turn affects its proper functioning, and to obtain a measuring parameter at the particular sensing and measuring unit. Circle, being most symmetric geometry, offers the possibility of symmetric flow of the measurable physical quantity towards input from the environment; resulting higher accuracy in measurements and the sensing. Ring shaped joints are fabricated during the development of these micro-systems by employing soldering, brazing, welding and die-bonding techniques. These existing techniques have low thermal stability and show failure at higher temperatures, out gassing of toxicants, use of glues and Pb-containing integrands make these environment hazards [8-9]. Many researchers have studied the isothermal solidification based interconnections for square contact pads with a variety of metal combinations under different parameters. Present work is an extension of this to the circular and ring bond pad geometries. The mechanical properties of Ag-Sn-Ni seal rings are reported and analyzed in this paper. The selection of metals is based on the wider application of Ag and Ni in electronics and by studying the binary phase diagrams. Ag-Sn and Ni-Sn phase diagrams [10-12] are of interest for fabricating high temperature stable Ag-Ni joints at low temperatures. The intermetallic composition $AgSn_3$ is stable up to 480°C and Ni form intermetallic phases (IP) with Sn metal [Table 1].

Table. 1. Ni-Sn intermetallic phases and their melting temperature.

IP formed	Melting temperature °C
Ni_3Sn_4	796
α Ni_3Sn_2	483
β Ni_3Sn_2	1267
α Ni_3Sn	870
β Ni_3Sn	1167

The effects of reaction time, interlayer thickness, temperature and pressure on the ultimate tensile strength (UTS) and ultimate shear strength (USS) are depicted in the paper. The rigidity against torsion for three specimen geometries is reported and analyzed.

2. Experimental details

High purity (99.999%) Sn has been used as interlayer metal. The Sn melts at 232°C and intermetallic phase formation is achieved above this temperature. These IP are stable in a wide temperature range up to 480°C. Seal ring patterns are printed with DuPont Ag thick film paste no. 6141 on ceramic substrates using DEK printer. A steel mesh of 300 counts is used for screen preparation to produce fine grain size. After 25 minutes drying process at 125°C these printed units are fired up to 800°C in a Muffle furnace. The temperature profile of the furnace is given in Table 2.

Table. 2. Temperature profile of the muffle furnace.

Time (minutes)	Temperature (°C)
0-10	0-200
10-40	200-500
40-130	500-800
130-140	800-800

During firing process the organic materials of thick film paste are evaporated at 350°C and above 600°C the binders (glass etc.) melt and produce hard stick bonding between the Ag- rich thick film layer and the ceramic substrate. The post firing thickness of samples has been measured with a Light Scanning Microscope. It is obtained in the range of 17-19μm. The samples of high quality printing with fine edges are selected through optical testing using 10X microscope. This whole process has been carried out in an ultra clean room to avoid any contamination of the materials. The Ag rings metalized on ceramic substrate are shown in Fig. 1.

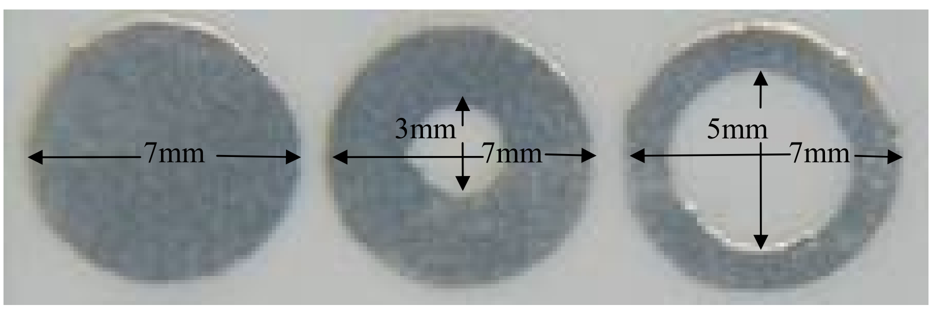

Fig. 1. Ag pad patterns (circular and ring) for the experiment.

High purity Ni (99.999%) has been used for the preparation of Ni-metal sheet of 17μm thickness by pressure rolling, grinding and buffing. This Ni-sheet of constant thickness is then cut as per the test pad geometries and dimensions to produce the Ni substrates for the bonding. At the last step the samples are polished using diamond paste to achieve a surface roughness less than 1μm. Similarly high purity Sn (99.999%) foils with prescribed dimensions and thickness are prepared. The thickness of 5μm is obtained by thermal evaporation of Sn on a Ni sheet in high vacuum. The printed ring patterns along with the Sn interlayer and Ni sheet are ultrasonically cleaned for 60 minutes. The Sn interlayer of specific thickness is then sandwiched between the thick-film-Ag pad and Ni-metal sheet with a ceramic substrate covering the top Ni layer. The assembly is heated rapidly up to temperatures above 232°C under variable mechanical pressure ranging 0.5-0.8MPa for specific reaction time to accomplish isothermal solidification reaction of Ag-Sn and Ni-Sn to form the high stable intermetallic phases. The temperature is controlled with temperature controller and has a continuous measurement by a calibrated Chromel-Alumel thermocouple. The set of samples prepared for different parameters are gone through tensile, shear and torsion strength measurements to obtain the UTS, USS and ultimate torsional strength. The effect of seal ring geometry on interconnect shear strength is analyzed for the three geometries of variable inner radius with 7mm constant outer diameter. Tests for harsh environment sustainability have been carried out in especially designed labs.

3. Results and discussion

3.1 Tensile strength measurements

The tensile strengths of samples fabricated under variable process parameters are presented in Figs. 2-4. Tensile strength depends up on the area of interconnect and therefore circular pads of 7mm outer diameter are used for these measurements. The effect of interlayer thickness on the bond strengths are summarized in Fig. 1. The variation in UTS for different thickness values is symmetric and ranging between 15-45MPa. Similar strengths are observed by other researchers [13-14]. Increasing the interlayer thickness the joint thickness increases which in turn results in higher tensile strengths.

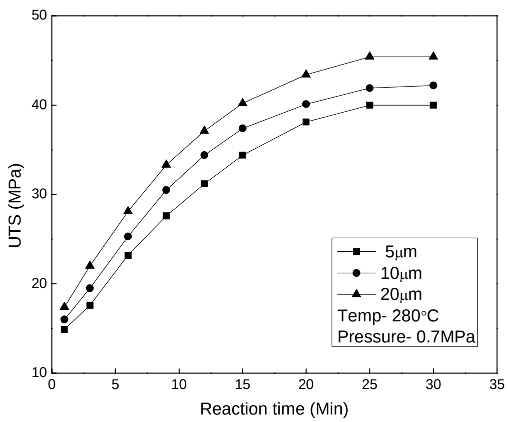

Fig. 2. Effect of interlayer thickness on UTS of interconnect.

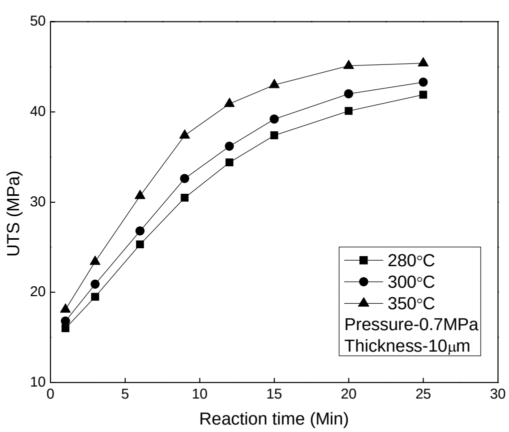

Fig. 3. Effect of process temperature on the UTS of interconnect.

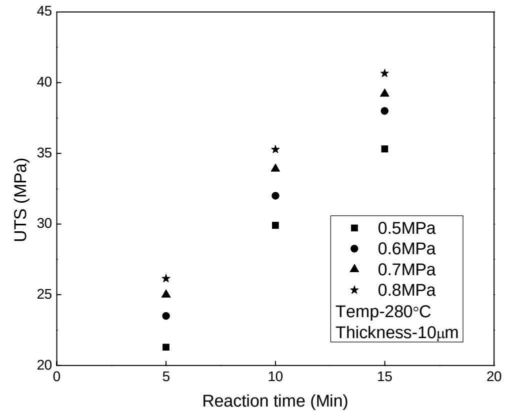

Fig. 4. Effect of pressure on the UTS of Ag-Sn interconnect.

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 3-25min 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. UTS values obtained for different pressures at constant temperature and reaction time give that increment in pressure results in higher bond strength [Fig. 3]. Pressure reduces the size of surface asperities which in turn increases the contact area between joining surfaces by reducing the number of voids at subsequent bonding stages.

3.2 Shear strength measurements

The ultimate shear strengths (USS) values are measured for specimens prepared for different process parameters. The trends observed for USS with temperature, pressure, thickness and reaction time are similar to those for UTS.

3.3 Torsional strength measurements

The torsional strength measured for prepared specimen joint reflects the effect of geometry on bond strengths, the rigidity of ring shaped interconnects is greater than the circular one [Table 3]. Increasing the inner diameter of ring seal the ultimate torsional strength become higher, this is in accordance with the principle of mechanics [15]. Another advantage of seal ring is the area saving which in turn save the material and contribute in cost effective packaging.

Table. 3. Effect of geometry on torsional strength of interconnect.

Geometry of interconnect	Inner diameter (mm)	Outer diameter (mm)	Area (mm^2)	% Area	% Torsional strength measured	% Ultimate torsional strength
Full circle	0.0	7.0	38.46	100	100	100
Ring	3.0	7.0	31.40	81.63	100	122
5.0	7.0	18.84	48.97	97	198	

3.4 Environment test results

Results for -20/+80°C thermal cycle testing, vibration resistance testing at room temperature (25°C) and combined environment (thermal cycle + vibration) testing show that the interconnects fabricated are good stable against the thermal shocks and vibration stresses.

4. Conclusions

The Ag-Ni seal rings are developed using isothermal solidification based interconnection technique. The UTS and USS values of the seal rings varies between 15-45MPa for different process parameters. The ultimate torsional strength measured for three specimen geometries show that ring seals are stronger than the full circular seal.

The stability of seal rings fabricated is tested in environmental lab and the results support the use of isothermal solidification based bonding technique for the devices applicable in hazardous environments.

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