Assessment of a Au-Sn transient liquid die attach for harsh environments electronics

by

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(Abstract)

The constant development of new technologies in the area of power electronics requires new interconnection materials capable of resisting high temperature environments for wide-bandgap semiconductors such as SiC. Die attach interconnections must be capable of resisting high operating temperatures while providing mechanical support, electrical connection, and a path for thermal management. These needs are addressed by the creation of joints via the process of inter diffusion of two metals with different melting points, called solid liquid inter-diffusion. Applying this process, to a gold-tin bond, we have demonstrated the formation of a joint at a temperature ranging from 315 to 340°C, resulting in a sound attach with a higher melting point.

The bond was evaluated in four different combinations of varying bonding conditions as a function of time and temperatures of exposure. Lap shear testing, differential scanning calorimetry analysis, and compositional analysis using EDS and SEM images were used to characterize bonding characteristics.

Evaluación de soldadura Au-Sn para soldaduras de empaque electrónico expuestas a ambientes hostiles

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(Resumen)

El desarrollo constante de nuevas tecnologías en el área de la electrónica de potencia requiere nuevos materiales de interconexión capaces de resistir entornos de alta temperatura para semiconductores de banda ancha como SiC. Las interconexiones deben ser capaces de resistir altas temperaturas de operación mientras proporcionan soporte mecánico, conexión eléctrica y una ruta para la gestión térmica. El cumplimiento de estas necesidades se abordan mediante la creación de uniones a través del proceso de inter-difusión de dos metales con diferentes puntos de fusión, llamada interdifusión líquido-sólido. Aplicando este proceso, a un enlace oro-estaño, hemos demostrado la formación de una unión a una temperatura que oscila entre 315 y 340°C, lo que da como resultado un sonido fijado con un punto de fusión más alto.

El enlace se evaluó en cuatro combinaciones diferentes de condiciones de enlace variables en función del tiempo y las temperaturas de exposición. Se usaron pruebas de cizallamiento por vueltas, análisis de calorimetría diferencial de barrido y análisis de composición usando imágenes EDS y SEM para caracterizar las características de unión.

To God and all my family for being a support during the journey.

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Chapter 1 Introduction

1.1 Motivation

There is an increasing demand for solder interconnections capable to operate above the traditional 125°C temperature limit. Aerospace, automotive, deep well drilling telemetry, and renewable energy sources are some of the many industries that had been demanding new technologies to embrace their functionalities in harsh environments. Power electronic modules systems (PEM's) drive the handling generation, transmission and distribution of energy. PEM's are also exposed to extreme thermal stresses from the outside of the electronic packaging [1]. Downhole in oil or gas during inspection and reparation, on photovoltaic panels, controlling and monitoring engines, etc., PEM's temperatures are influenced from outside the system. Beside to single modules, PEM's is a combination of multiple semiconductors.

Silicon carbide (SiC) is a semiconductor with advantages for power electronics, which is superior to Si and GaAs devices. SiC has over 170 polytypes where 6H and 4H are the most commonly used. This semiconductor is characterize by its wide band gap capabilities that has demonstrated to operate reliably at temperatures up to 500°C [2], [3]. It also own high breakdown field strength, that conduct to thinner and highly doped devices, faster switching speed for lower switching losses, low coefficient of thermal expansion and high thermal conductivity [1], [3], [4]. SiC suggests a dimension reduction in transmitter design, decreasing the production cost drastically with four times the power per package of silicon technology [5]. Therefore to the advantages mentioned before, SiC semiconductor had become a focus of interest to development technologies capable to operate at severe environment. However, this technology has been limited by their interconnection and packaging technology that cannot support the exposure to high temperatures.

The interconnections traditionally used in electronic packaging are lead-containing alloys such as Pb10Sn, Pb5Sn, and Pb1.5Ag1Sn. The melting point for those lead-containing alloys ranges between 260°C to 315°C, making these interconnections highly demanded due to their idyllic low temperature processing assets [6]. Lead (Pb) was used in many applications: plumbing, white paints, batteries and, electronics. Lead-rich bonds are stable in harsh environments, and good performance in mechanical resistance because of the lack of brittle intermetallic compounds have. Lead-alloys are characterized by its stable microstructure and no change during aging. Lead is a high density material with high soldering capacities, low temperature packaging process, and more important low cost and relative inert to oxidation [6]–[8]. However in 2002 an European legislation of the Restriction of Hazardous Substances

(RoHS) in electrical and electronic equipment banned the use of lead. Studies found lead is a neurotoxin that was affecting the heath in kids and adults. After this legislation, there is a necessity of developing lead-free interconnections technology.

An interconnection is the physical link that connects the die or chip into a substrate. Currently, the bonds used for high temperatures applications are Au-Sn, Au-Ge, Pb-Sn, and many others [9]–[11]. However, at high temperatures they fail due to multiple reasons. One of the persistent issues is the detachment caused by the differences in the coefficient of thermal expansion (CTE). The CTE is defined by the fraction of size changed in the material as response to temperature change. A bond supporting CTE mismatched materials will fail by shear if the temperature using at the application is large. Therefore, technologies have been using additional components, such as heatsinks, to route the heat and decrease the temperature of the systems. But the addition of components increases weight and volume to the system, making it more complex. Other failures are related by the lack of mechanical strength of the joint.

As noted, interconnections have become a critical area of research because of their complexity. Aligned with this, industries are aiming at novel packaging technologies with new processes that can support the development of such electronic systems. As result, the continuation of studies in the fabrication of bonds capable to resisting harsh environmental temperatures will reveal many others new challenges to be consider in order to continue its development.

1.2 Challenges

The process to create sound attach's has many aspects that need to be taken in to consideration during the fabrication to satisfy the challenges of their development. The bond needs to guarantee a full connection between the die and substrate, primarily, mechanical, electrical and thermal. The fabrication process needs to intend the elimination of voids inside the bond. The presence of voids inside a bond produces a weak interconnection between the two entities decreasing the contact area, increasing the thermal resistance, and most of the cases voids become a crack initiation sites.

It is desirable to maintain the actual industrial bonding processing temperature and low pressure packaging method. The actual processing temperatures are between 270°C to 350°C for Pb-rish, Au-Sn, Au-Si materials. In order to produce a bond maintaining the actual processes and simultaneously providing resistance to harsh environments is well required an innovative process technology. This technology must fabricate a joint that provoke a phase transformation during the assembly that results in a material with a high melting point and it is capable to work at higher temperatures. This demand is addressed by a transient liquid phase method. This method supports a low temperature, low pressure process that by diffusion of the materials in contact, the bond is transformed to a high melting point material. This topic will be explained on section 2.2 of this thesis.

The melting points of the materials and the coefficient of thermal expansion are some of the properties interrelated to the bonding process. There is a significant influence of the temperature and holding time during bonding that affect the resulting structure. To calculate the time and temperature needed to produce the joint, kinetic models are used. However there are materials systems prove to the formation of intermetallic between the bonding materials and the matrix. The formation of intermetallic compounds inside or in the interfaces of the joint can compromise the bond reducing its mechanical strength.

1.3 Approach

The focus of this research is to characterize, mechanically and microstructurally, a 90wt.% Au/10wt.% Sn die attach formed by a Solid-Liquid Inter Diffusion mechanism. The interconnection presented is a two parts assembly with a 16 μ m total bond line thicknesses; i.e. 4 μ m Au/8 μ m Au20Sn deposition in one side and 4 μ m Au deposition in the other. The materials (Au and Au20Sn) were deposited using a novel technique of jet vapor deposition (described in section 2.3.1) and the bond was formed using a solid liquid inter-diffusion bonding process described in section 2.2. The merge of the deposition technique and the transient liquid phase method, combined with the gold-tin materials makes possible a low temperature, low pressure process generating a high melting point bonding.

The bonds were fabricated using four different bonding conditions varying temperature and exposure time. These combinations were analyzed in how time/temperature variables affect the performance of the bond. The bonds were evaluated using a differential scanning calorimetry (DSC) to confirm the completion of the diffusion during the bonding process. Then, a microstructural analysis was made to observe the effects of processing parameters in the formation of interconnection and intermetallic compounds. Furthermore, the bonds were submitted to an aging thermal process and the microstructure was also examined to discern the transformation of the microstructure based on the aging time. Subsequently, bonds were die shear tested at room temperature and at high temperatures. To perform the test at high temperatures testbed was designed and conducted (see chapter 4).

1.4 **Thesis Outline**

This chapter is a general explanation of the challenges in the fabrication of a bond capable to work at harsh environments and our motivation for this research. In the next chapter we detailed description of the bonding fabrication technique and a literature review that supports this work. The analysis of the microstructural stability of gold-tin as aging evolution can be found in Chapter 3. The description of the mechanism used to test the bond, controlling the environment, is detailed in Chapter 4. Finally, in Chapter 5 the mechanical strength of the bond is analyzed when exposed to temperatures.

2.1 **Die Attachments**

Electronic systems are fabricated following a hierarchy of microelectronics packaging. These microsystems use components that require mechanical and electrical connections to surrounding constituents. A complete electronic package may be divided by levels, where Level 1 includes, among others, the interconnection of the chip to the substrate. This interconnection requires a technology to provide electrical paths, mechanical support, and a thermal solution. The chip, also called die, is a semiconductor material on which a functional circuit is fabricated. The substrate is the support structure medium which may contain electrical routes and thermal channels for reliable operation of the system. Figure 1 is a schematically presentation of the die attachment.



Figure 1: Die attachment for electronic packaging

There are two broad categories for die attachments: adhesive and metallic interconnection. Adhesive die attachments are used in low power, small signal electronics such as consumer products. The most common used are epoxies and silver filled glass, as bonding agents. These adhesives attachments demonstrate satisfactory adhesion and temperature tolerance to work up to ~300°C but are poor thermal conductors [12]. A brief description of the adhesive process is as follows: the adhesive material is dispensed into the substrate, the die is picked and placed on top of the adhesive, followed by ultra violet or heat curing of the adhesive. One of the issues faced is the lack of control applying a thin layer of adhesive for low profile packaging. Another issue is the remnants of air gaps inside the pre-prepared mixture. This air gaps or voids are transferred to the product causing connection failures.

A similar process for a metallic attachment is the printed circuit board (PCB) where a paste of metallic powders is mixed in a flux medium. The process starts printing the pattern in the substrate, and then the components are picked and placed followed with the curing process. On the curing process the

paste is heated, the flux is a chemical cleaning agent that evaporates during the process while the metallic powder melts leaving a solder joint. One of the problems of the PCB process is to find the amount of paste to add. An excess of paste added into the substrate could cause a malfunction as a short circuit. This is because the paste can spread out and make contact with other components or connections. Whereas a too thin paste is printed, it may cause die lifting, cracking or leave loose components that were not attached to the circuit board because of the lack of material to interact. Same thing with an inadequate paste consistency in viscosity, a too thick consistency may lead to a poor adhesion of the components; on the other hand a light viscosity can produce weak connections that may fail in the future. Studies reveal than even after finding the paste consistency, when powder is used to create a joint, voids remain inside the bond. These voids produce a weak bond reducing the area of contact, and decrease the thermal flow, among other consequences. C. Ehrhard et. al, in order to address this problem, they developed a way to fill the voids adding solder next to the chip/component. This way the extra solder melts and fill the gaps left in the joint during the reflow step [13]. One of the disadvantages of this technique is the extra steps of positioning, pre-activation and cleaning to produce the bond. In addition, the final bond is very thick due to the copper powder used of 8-45µm diameter.

Metallic attachments are known to outperform adhesives in mechanical strength, thermal dissipation and stability. However the bond we are trying to produce needs to perform well at harsh environments and this requires high thermal conductivity. There are various techniques for metallic attachments for high temperature interconnection. Some of these techniques are: sintering of nanoparticles, liquid-based solder joints, and solid liquid inter-diffusion. However, metallic attachments are considered expensive connections and tend to be difficult to handle during the manufacturing process.

2.2 Solid-Liquid Inter Diffusion (SLID)

Automotive, aerospace, and deep well drilling are characterized by the high temperatures that are encountered by the electronics serving at harsh high operating conditions [14]. The growth of these technologies raises technological challenges in the pursuit of a reliable bonding that could provide acceptable mechanical strength as well as electrical and thermal conductivity. This research is oriented to SLID technique, which could be an enabler for the realization of next generation SiC electronics for harsh environments.

SLID or transient liquid phase (TLP) is a widely studied technique [15]–[17]. An advantage for this method is being fluxless; voids will not form, thus reducing the reliability problem associated with voids at the interlayers. Additionally, it produces strong interface-free joints with no remnant of bonding agents. SLID produces joints with microstructural and hence mechanical properties, similar to the base

material and does not require the high pressure needed in typical solid state diffusion bonding processes. It is a low temperature and low pressure process.

The SLID process relies in the diffusion of two materials with different melting points using a low temperature processing without the bulk (mass) motion requirement. SLID is a moving boundary process involving two phases with four stages: dissolution of the interlayer, homogenization of the liquid, isothermal solidification, and homogenization of the bond region; as presented in Figure 2 (a) "A" is the material with a high melting point, and "B" is the lower melting point material, the assembly is heated until the "B" material melts; (b) is the liquid homogenization, where the moving boundary occurs; an erosion stage where the liquid interlayer thickens as the "A" material dissolves into the "B" until saturation occurs at the processing temperature; (c) the isothermal solidification takes place with the consumption of the low melting point material as new "A"-rich alloy is formed with a new, higher melting temperature; (d) homogenization of the joint is the last step [18].



Figure 2: Solid-liquid inter diffusion schematic process

Kinetic models are used to estimate bonding conditions for completing the SLID process. Nernst-Shchukarev and Berthoud equations can be used for the analysis of this process. This equation is used to calculate the dissolution rate into a molten metal for the homogenization stage. This model combines processing parameters (time and temperature) with the specimen's geometrical and compositional characteristics (volume of material to diffusion and surface area). The equation presented below assumes initial conditions of C = 0 at t = 0:

$$C = C_S \left[1 - \exp\left(-k\frac{At}{V}\right) \right]$$

C is the instantaneous concentration of the dissolved material in the molten solder, C_S the concentration limit of dissolved metal, t is time, *k* is the dissolution rate constant, *A* the wetted surface area, and *V* the volume of the melt [19].

As mentioned, the isothermal solidification is the rate governing step of the process [18], [20] where temperature and time become critical bonding parameters to guarantee a complete diffusion in the joint. R. Rodriguez et al. developed a kinetic model to study an assembly of 15.1µmAu/13.9µmAu20Sn

deposition thicknesses. The samples were subjected to the SLID process using three different temperatures and five different holding times as bonding parameters. The kinetic study was conducted calculating the rate of change of Au concentration and DSC analysis. This study found the bonding conditions to complete the SLID process for 15.1µmAu/13.9µmAu20Sn. Exposure temperature of 340°C for a ten minutes holding time was identified as the ideal bonding parameters for the completion of the SLID process on the specific gold tin assembly [17].

Beside the bonding process, the technique used to apply the material affects the product of the bond. As an example, the staking of foils, to produce this bond thin foils from different materials are alternately packed. This technique increases the diffusion area and reduces the bonding process time. However this technique faces the difficulties in the process of assembly when the operator needs to carefully align each layer one above the other. Therefore many of the difficulties observed in die attachments are related by the way materials are placed.

2.3 **Depositions Techniques**

In order to produce a solder joint by diffusion bonding a thin film or atomic layer of material is needed. Broadly, there are two deposition techniques: chemical and physical vapor deposition. An undoubtedly idealization of a deposition is to have a consist thickness of the material deposited everywhere along the surface.

Chemical deposition techniques are when a solid layer is leaved by a chemical reaction from a fluid (liquid or vapor) in to a solid surface. Using this technique the thin films tend to be conformal rather than directional. This means, arbitrarily the morphology of the interface, the deposition will be the same along the surface. This idealization is not real and had been found that the thicknesses can vary by the element morphology of the surface and the edges of the deposition. Therefore, as thinner the deposition less thickness variation will be found. Electroplated is an example of this technique where the material is submerged in a chemical solution with the corresponding ions of the metal coating. A potential difference is applied between the anode and the cathode causing an oxidation in the anode. The material to coat is negatively charged making the positive metallic particles be attracted to the surface and adhere as a coating.

Physical deposition can be mechanical, electromechanical or thermomechanical. A thin films using physical deposition are commonly directional rather than conformal deposition. An option for thin layer deposition using physical vapor deposition (PVD) is sputtering. This technique requires a high vacuumed state with argon (Ar) gas injection. By an external radio frequency excitation the Ar gas turned to positive Ar plasma where it consists of Ar atoms, +Ar ions and free electrons. Ar ions collide with a uniform magnetic field, the molecules are released and adhere to the substrate/matrix to make the coat.

Moreover, in electroplating and sputtering, the amount of deposition depends of the charge applied and the time of exposition, deposit a thin layer takes a long time to produce. As mentioned before none of these techniques has a uniform deposition along the material. This is because the atoms drop randomly from the matrix to the material and can cause a coarse finish. Using these techniques it is difficult to deposit a thin and uniform layer when in die attachments the thickness and flat surface is so important. Sometimes different techniques are combined with each other as presented in A.A. Bajwa et. al research, where they use Ag foils and electroplate Sn and In to produce Sn-Ag-Sn and In-Ag-In multilayer materials to produce an interconnection bonding [21].

2.3.1 Jet Vapor Deposition

Compared with the previous techniques jet vapor deposition (JVD) is a very promising method developed by Jet Process Corporation (JPC) for commercial production of solder coating [22].

The singularity of the JVD is the low temperature (less than 85° C) and low vacuum process (~1 torr). Another advantage of the JVD is the high rate of deposition, which means it is a fast process, where a 4 inch Si wafer with 5 microns of AuSn deposition the process could take about 10 minutes long. JVD technique provide a precision thin film from 1 to 20 microns for solders deposition with a tolerance control of ±2,500 Å. and uniform layer across 8 in wafer, making



Figure 3: Jet Vapor Deposition Schematic; JVD Technology (2018), http://www.jetprocess.com

possible multilayered depositions with the desire thicknesses. Also, it is economical and environmentally clean process because of the pure metals used and the high efficiency of the process that minimize wastes.

The JVD method uses a sonic fast flow jet of high purity inert gasses (argon, helium) in a nozzle shape. The flow rate, the orifice size and the pump speed of the systems are significant for a flow film deposition. Meanwhile, a fine wire ribbon is melted with a hot tungsten coil located in the upstream of the nozzle exit, after it is vaporized, individual atom alloys are swept downstream with the jet and deposited on the substrate. The low vacuum transports the atoms trough the nozzle to the substrate at an accurate control of the film thickness. A schematic of the JVD process can be observed in Figure 3. The wire can be Cu, Ag, Au, In and Sn related materials alloys (AuSn, InSn, SnAg, SnAgCu). Other than films, JVD is

also used to produce solder bumps as small as 4 microns. The larger area to deposit is eight inches diameter and capable to produce multilayered deposition.

2.4 Au-Sn System

Au-Sn solder alloys are a great interest for high temperatures die attachments. A combination of Au-Sn using SLID have been studied [10], [11], [23]–[26]. For SLID process using the Au-Sn system, Au is the high melting point material and the eutectic gold-tin (80wt.%Au/20wt.%Sn) is the low melting point material. As presented in Figure 4, eutectic gold-tin melts at 280°C and pure gold melts at 1064°C. As SLID being a process of diffusion between a solid and a liquid material, the processing temperature could be anywhere in between both melting temperatures (280°C < T < 1064°C). Therefore, the combination of gold and eutectic gold-tin, allows processing the bond at lower temperatures.



Studies have discussed that the δ -phase is one of the most brittle phases with a tendency to crack [16]. Also, the δ -phase may be susceptible to transform into eutectic or near-eutectic structures with time which result in the formation of a low melting point material that will not tolerate high temperature operations [10]. It is for this reason that the bond needs to consists of the ζ -phase or ζ '-phase which have melting points up to 519°C [27], [28], with no transformation to low melting point phases [16], [10]. To achieve this type of joint, Tollefsen et al. designed a bond for high temperature (HT) applications using a

configuration of 10μ Mau/7.5 μ mAu-Sn/10 μ mAu. With these thicknesses and sequence they assure that the 7 μ mAu in each side reacts in the diffusion process and the remaining 3 μ mAu becomes an ideal layer to minimize the coefficient of thermal expansion induced stresses [25]. Another publication from these same researchers demonstrated that samples without the surplus Au showed a decrease in bond strength. This is caused by a brittle Au-Ni-Sn intermetallic compound (IMC) formation during thermal cycles which yield a pure gold layer in the center of the original bond [23]. Furthermore, samples were exposed to an aging experiment at 400°C from 100 to 2000 hours. For the first hundred hours, aging samples maintained stable die shear strength above 90MPa. For another set of samples, after two thousand hours of aging, die shear strength decreased <90MPa [1]. R. Rodriguez et al. obtained 40MPa average for 0 to 500 aging hours at 250°C [24]. Their samples were 15.1 μ m Au and 13.9 μ m Au20Sn thick. Another observation from this work was the formation of dendritic (Ni, Au)₂Sn₃ IMC's in the Cu/ENIG/AuSn layer, which was not observed at the Cu/ENIG/Au interface [17]. Figure 5 depicts the detail of the IMC dendrites presented in the investigation. R. W. Johnson et. al. reported a Kirkendall effect in gold-tin joints with voids increasing as aging progressed [1]. A difference in diffusion rates is what causes this phenomenon.



Figure 5: Dendritic IMC formation in Au/AuSn joint; R. Rodriguez et al. (2013)

3.1 Introduction

An Au-Sn bond interconnection was fabricated using SLID process and heat treated at 250°C from 1000 to 4000 hrs. The microstructure characterization of the bond was used to evaluate the intermetallic morphology formed, and to compare the depth of diffusion homogenization during the SLID process. Furthermore, the as-built samples were compared with aged samples in an attempt to evaluate the intermetallic growth.

3.2 **Sample Fabrication**

In order to create gold rich joints, using the SLID method, a 0.5mm thick SiC semiconductor was attached to simulate a functional sample. The assembly consists of two pre-assemblies; Figure 6 depicts a schematic of the final assembly prior to bonding. The die pre-assembly contains a 4x4mm², SiC diode from CREE with a backside 0.1µm titanium metallization and 4µm layer of gold, both deposited by an evaporation process. The substrate is an AlN direct bonded copper (DBC) where the remaining constituents of the attach system were deposited for the SLID process. The material deposition sequence for the substrate is as follows: 5µm electroless nickel immersion gold (ENIG), 4µm of Au, 8µm of eutectic Au20Sn and a ~400Å of gold flash. In this sequence the gold flash protect Au-Sn from oxidation and the ENIG layer works as a diffusion barrier between the copper substrate and the deposited material, in particular the reaction with Sn. Although ENIG is not in direct contact with the Au-Sn deposition, after the diffusion homogenization of Au/Au20Sn, Sn is dispersed through the bond. The Au and Au20Sn layers were deposited by Jet Vapor Deposition (JVD) system at the US ARL (Adelphi, MD) joining both pre-assemblies, the final layered bonding arrangement is 4µmAu/ 8µmAu20Sn/ 4µmAu which would yield a final composition of 90wt.%Au/10wt.%Sn if equilibrium is reached during bonding.

The previously presented sequence was selected based on R. Rodriguez et al. research [24]. The bond constituents on their research are the same: Au and Au20Sn using JVD as deposition method. The novel approach in this current work is the sequencing and the thicknesses of the deposition. R. Rodriguez et al. work presented IMC dendritic formation on the bond due to the interaction of Cu/ENIG/Au-Sn. Therefore, a bond of 4µmAu /8µmAu20Sn /4µmAu sequence was fabricated to avoid, or reduce, the IMC formation. This proposed sequence has two facing contact areas for the liquid-solid interface, doubling the diffusion surface area. Also, this configuration permits thinner depositions (8µmAu and 8µmAu20Sn

total) minimizing the material cost, reducing the thermal resistance therefore faster cooling. Furthermore, as hypothesis, it may reduce the processing temperature and time for the SLID process. Refer to Figure 7 to compare R. Rodriguez and the current bond depositions for this work.



Figure 6: AlN DBC showing the deposition of Au and Au-Sn.



Figure 7: Deposition sequence comparisons

 a) R. Rodriguez et al. research deposition
 b) Novel approach presented in this work

3.3 Bonding Process

The two parts pre-assemblies, die and substrate, were placed face to face, clamped with a ~3.3psi pressure and bonded in vacuum reflow furnace. The assemblies were bonded using four different conditions of varying time and temperature with the intent to investigate the effects of the processing parameters in the die attachment interconnection. The time and temperature bonding conditions were selected using the kinetics model analysis presented by R. Rodriguez et al. [17]. This model suggests the ideal value for parameters such as time and temperature for the completion of the SLID process on 15.1 μ mAu/ 13.9 μ mAu20Sn samples, to reach a final composition of 90wt.%Au/10wt.%Sn. It is critical to note, that the samples on that research (refer to Figure 7) had thicker material depositions. Due to the deposition sequence (Au/Au20Sn) the SLID process was forced to diffuse through one face only. Contrary to the configuration presented here, the deposition sequence of 4 μ mAu /8 μ mAu20Sn /4 μ mAu, the SLID process has two facing areas therefore two diffusion directions which allow thinner depositions

of each material. Moreover, the similarities in composition, the differences in thicknesses and deposition sequence; suggests a lower temperature and a shorter processing time as bonding parameters for the proposed bond. If proven correctly this study may justify the SLID technology as competitive practical method for the interconnection of SiC microelectronics.

8				
Sample abbreviation	0	Ι	II	III
Temperature (°C)	315	315	340	340
Holding time (min)	5	10	1	5

Table 1: Bonding conditions and abbreviation

Applying the bonding parameters presented in Table 1, the samples were characterized by mechanical testing, morphological observations, thermal analysis, and thermal stability. With the bonding condition selected (O and III), a constant holding time of 5 min will be compared varying temperatures. Those conditions will present the effects of temperature in the bond. While the other configurations (O-I, II-III) compares the temperatures as function of time. These results will reveal the progress on completion of the SLID process. Evaluation and characterization of the joints was assessed via: metallographic analysis to inspect for IMC's growth and morphology, thermal analysis through differential scanning calorimetry to examine the melting point of the joint and the mechanical behavior at ambient and elevated temperature by shear testing.

3.4 Differential Scanning Calorimetry (DSC)

DSC is a thermoanalytical technique used to quantify the heat capacity of a material as function of changing temperature. Phase transitions or physical transformations are detected by the DSC as an endotherm or exothermal heat flow. With a known temperature ramp rate and a known mass, DSC calculates the difference in heat flow needed by the sample to maintain the same temperature as the reference. An endothermic example is when a sample experiences a solid to liquid transformation; the sample absorbs the energy through the transformation process and requires more heat flow to raise the sample temperature to match the reference. An exothermal is observed when a sample solidifies releasing energy and the sample need less heat flow.

In a bond constituted by gold and eutectic gold-tin the unknown is the completion of the SLID process. Eutectic gold-tin have a melting point of 280°C, if the processed bonds are thermally analyzed with DSC and an endothermic reaction is detected at 280°C, this proves the solid-to-liquid diffusion was not completed. Otherwise, if the sample does not present an endothermic reaction at 280°C this confirm there is no more eutectic gold-tin and the diffusion was completed. Note, a completion of the diffusion does not indicate full homogenization in the bond.

In the kinetics model presented by R. Rodriguez et al., DSC was used to quantify how much low temperature material remains to diffuse. The obtained results revealed endothermic peaks near the eutectic Au-Sn temperature, implying solid to liquid transformation in the joint [17]. That corresponds to an incomplete isothermal solidification process, therefore a lack of a full shift of the melting point during process. In the research presented here, DSC analyses were used to confirm that in fact there is no solid-to-liquid transformation for the proposed assembly, validating R. Rodriguez et al. model. Moreover, to confirm the melting point shift of the formed joint.

3.5 Aging

Aging is a treatment that speeds up a long-term physical transformation in a product. This method accelerates the effects by high level stresses to estimate the lifespan of a product. For bonding interconnections, aging is analyzed at elevate temperature exposures to accelerate the changes in the properties of the alloys.

The joints produced with the four bonding configurations were subjected to an aging process at 250°C for 1000, 2000, 3000 and 4000 hours. This timing selection is due to the results in other studies that present no properties variation during the first thousand hours [1]. With scanning electron microscopy (SEM) and an energy dispersive spectroscopy (EDS), the composition of the joint, the morphology and the thicknesses of the IMC were defined. It is expected that the thickness of IMC will increase as aging progresses as shown schematically Figure 8. Traditional metallographic techniques cold mounting, grinding and polishing were used to study the metallography of the samples.

4µm Au		
8μm	90wt%Au10wt%Sn	
80wt%Au20wt%Sn		
4µm Au	IMC	
5µm ENIG	ENIG	
a	b	

Figure 8: Formation of a stable Au-rich joint by SLID process. (a) As deposited layers. (b) After SLID process.

3.6 Results and Discussion

After fabricating the bonds using the four bonding parameters previously defined, samples were initially analyzed as-built. The samples were cross-sectioned and characterized using optical and scanning electron microscopy. Furthermore, the IMCs were quantified using Image-J software.

Representative SEM micrographs are shown in Figure 9, where the layers of the new Au-Sn composition and the Ni barrier are observed. A third layer identified in between, is an intermetallic compound formed by the reaction of tin and nickel. Research confirms the IMC formed by this constituents have a $(NiAu)_3Sn_2$ composition [9], [29], [30]. Although a $(NiAu)_3Sn_2$ is a high temperature resistant, the thick growth of this IMC is avoided in bonding interconnections due its brittle nature and its random needle-like structure that may degrade the reliability of the joint when it is submitted to stresses.

The IMC layer thicknesses found in the samples ranged in between 0.30 to $0.45\mu m$ for all four fabricated specimens. The IMCs exhibited a minor and uniform growth along the bond in compare to the dendritic IMCs observed in the R. Rodriguez et al., where the morphology was identified half way in the bond (~15µm) with random and 3D rod shape growths through the ENIG/Au20Sn side of the joint [7]. This dramatic difference is attributed to the deposition sequence, Au20Sn/Au/ENIG. In this sequence, the eutectic Au-Sn is not in direct contact with the ENIG, thus limiting the reaction between the Sn and the Ni. In order to tin react with nickel, the Au20Sn needs to diffuse through the gold layer to reach the nickel layer. With this in mind, the Au-Sn composition at the interface of the joint is rich in gold, which means, the atomic percent of tin in contact with nickel were reduced.



Figure 9: As-built layers outline micrograph

The quantitative chemical composition of the joints was assessed by energy dispersive spectroscopy (EDS). The EDS results presented in Figure 10, confirmed that Au/Au20Sn/Au deposited composition was transformed to 86.4at%Au/13.6at%Sn by the SLID process. This configuration

corresponds to ζ '- Au₅Sn phase which has a melting point up to 519°C, see Figure 11. The ζ '- Au₅Sn have a tendency to absorb nickel and this was confirmed with the IMC formed by Ni/Au/Au20Sn interface showing a (NiAu)₃Sn₂ composition [9]. Beside the IMC formed, the Ni barrier layer was still present after processing avoiding the reaction between tin and copper.



Figure 10: As-built EDS results



Figure 11: Au-Sn phase diagram

To prove the shift in the melting point, the four bonding configurations were analyzed using DSC. Results can be seen in Figure 12, where it demonstrates there is no solid to liquid transformation at 280°C where eutectic gold tin melts. These results not present any endothermic peak up to 550°C, evidencing a shift of melting point to be over 500°C for all four bonding conditions. Moreover, DSC confirms all four bonding conditions are enough to diffuse 8µm Au20Sn into gold.



Figure 12: As-built DSC results

Once samples were subjected to aging at 250°C, the DSC analysis was made for the samples exposed for 2000 and 4000 hours. Figure 13 depicts that none of the analyzed samples present a drastic change between bonding conditions. Samples processed at 315°C compared with samples processed at 340°C have no difference after aged. Additionally, there is no difference observed per aging time, samples exposed for 250°C for 2000hrs present the same pattern of the samples exposed for 4000hrs. Note, the differences in heat flow are related to the sample mass. These samples were cut from a complete assembly which includes the SiC die and the AIN substrate, therefore the calculation of mass of the micro-bond might not be accurate. The samples presented a uniform heat flow with no endothermic or exothermic peaks. Note, the shift recorder on the unit 315C_5min_4000hr do not represent a material transformation, this type of shifts happened when the specimen moves inside the DSC apparatus and the new contact area is smaller.



Figure 13: Aged samples DSC results

The IMC layer for the aged samples was thick enough to be observed using optical microscopy. After 1000 aging hours the IMC layer's thicknesses were \sim 10 times thicker than the original samples. Table 2 summarizes the IMC thicknesses for the as built and after aged for all four processing condition.

Conditions	O – 315°C, 5min	I – 315°C, 10min	II – 340°C, 1min	III – 340°C, 5min
As built	0.377	0.448	0.318	0.452
1000hrs	N/A	3.76	N/A	3.34
2000hrs	3.77	3.10	N/A	5.18
3000hrs	3.76	5.10	3.30	6.40
4000hrs	6.30	5.00	6.40	4.89

Table 2: IMC thicknesses (µm) for as-built and aged samples.

Data suggests that in fact the deposition sequence, where Au-Sn is isolated by $4\mu m$ of Au from the Ni layer, served as a barrier for the formation of the dendritic Sn-Ni IMC's. However, as the aging progressed, results suggest an increment of Sn diffused in the Au layer as evidenced by the reaction of Sn and Ni and subsequent growth of IMCs thickness.

From inspection it can be inferred that the fabrication of the bond with higher temperatures and/or prolonged holding times provided favorable conditions for the completion or near completion of the isothermal solidification step and perhaps partial homogenization. This homogenization yielded a better dispersal of tin across the bond and therefore closer to the ENIG interface which leads to the reaction of the Sn-Ni. For those processed at lower temperatures or shorter holding times, the homogenization step within the SLID process may have not started, therefore the Sn atoms are still concentrated near the center of the bond, far from the nickel interfaces. This explains why the IMCs are thinner for these processing conditions. Moreover, can be consider that for those conditions the initial aging hours are in fact finalizing the homogenization step, whereas for the higher temperature/holding times conditions that the SLID process is closer to completion and thus the aging starts affecting the IMC growth earlier. At long aging times all samples are homogenized independent of initial bonding conditions which may explain why the IMC layers are very similar in thickness after 4000 hrs at 250°C. In addition, the research presented by Torleif et. al., notice a pure gold layer left in the original bond due to a continued diffusion between tin and nickel creating Ni3Sn2 and Ni3Sn4, samples were aged at 250°C for 6 month [23]. This phenomenon was not observed in this work, none of the samples after 4000hrs of aging present a layer of pure gold in the center of the bond.

Another observation is an apparent new layer within the Au-Sn that grew with aging time. This is observed in Figure 14, where Figure 14a is a 315°C-10min sample with 1000 aging hours and Figure 14b shows the same bonding condition with 2000 aging hours. This parting line was only observed in samples bonded at 315°C. It is believed that when using low temperatures, the erosion and solidification steps in

the SLID process occurs, but the homogenization was not completed, and the aging time is completing this last step as discussed before. Further EDS analysis will be necessary to confirm this hypothesis and to quantify the material composition on each layer.



Figure 14: A 315C-10min aged sample. (a) 1000 aging hours at 250°C, (b) 2000 aging hours at 250°C.

From the observations it was found that there is a repetitive pattern of gap between the SiC chip and the interconnect material that can be associated with the inherent roughness of the copper layer in the DBC substrate. The deposited layers conformed to the copper surface profile resulting in the gaps depicted in Figure 15.

Cracks were observed through the bulk of the attach material as shown in Figure 16 and never at the IMC layer. Figure 17 shows a sample aged for 3000 hours with a very thick IMC layer but no cracks. The cracking of samples after aging is believed to be due to thermal shock induced during the removal of specimens from the furnace. Despite the cause of the stress, the data that failure tends to occur through the bulk suggests that the IMC layer may not be a reliability problem for this type of joints.



Figure 15: Copper roughness affecting contact area.



Figure 16: Cohesive cracks through the bulk of the joint.



Figure 17: 340C-5min sample subjected to 3000 aging hours. A thick IMC layer and disturbed ENIG layer are evident.

3.7 Conclusion

A modified JVD layering sequence of the SLID Au-Au/Sn constituents was presented and evaluated in terms of the microstructural stability of the system. Having the eutectic Au-Sn material separated from the ENIG layer using Au as a barrier proved to be a solution for constraining the formation of dendritic Sn-Ni IMCs as well as for protecting the ENIG metallization. As-built samples showed a very minimal formation of an IMC layer with thicknesses well below one micron. To produce a bond of 4µmAu/ 8µmAu20Sn/ 4µmAu with SLID process, 315°C and 5min holding time is enough to diffuse the eutectic gold-tin and shift the melting point over 550°C. The aging experiment revealed that within 1000 hours at 250°C the IMC layer grew by an order of magnitude. Nevertheless, the IMC layer showed dendrites formation into the bulk attached. Homogenization of the Sn distribution during aging is believed to be the cause for the reaction of the Sn atoms with the Ni from the ENIG layer. Despite the growth of these IMCs during prolonged aging, no cracks were observed through the IMCs.

The new Au-rich die attachment was mechanically tested. With the purpose of investigating the bonding strength, via die shear test; it was necessary to transform a tensile equipment apparatus to mimic the test. A testbed was analyzed, designed, fabricated and tested. This chapter describes the testbed, the custom shear jig, and the controlling system.

4.1 Lap Shear to Die Shear Conversion Tool

Researchers have been analyzing the bonding strength by lap shear or fatigue testing at room temperature [9], [11], [21], [31]. Testing at room temperature cannot represent the bond strength when it is exposed to high temperatures. Therefore, investigators have been assessing the strength of the interconnections at high temperature environments. In this research a die shear test was perform to quantify the mechanical strength of the as-built bond, and to evaluate the effect on the mechanical strength when it is exposed to high temperatures.

First, to perform a die shear test using Mark10 tensile equipment, a fixture tool was custom made in order to mimic the test. The tool transforms a tensile testing apparatus into a die shear tester where the force acts in the interface between the substrate and the die. The fixture was designed with the objective to concentrate the forces direct in to the bond neglecting external stresses such as bending or torsion. To emulate a die shear test, the force was applied perpendicularly, with an uniform distribution force to the edge of the die following the MIL-STD-883E [32]. The shear test is performed as follows, the substrate with the bonded dies slides inside the tool pulled by the tensile machine, the die is presses upon the wedge of the tool with a speed rate of 10μ m/s while the force is recorded, see Figure 18. Then the shear strength is calculated by measuring the bond area.

The fixture was manufactured in an Al6061. This aluminum alloy is easy to machine, with a tensile strength up to 310MPa, corrosive resistant, light weight, and it is a low-cost material. Aluminum melts at 585°C, over that 5 times the temperatures used to perform the die shear tests. This temperature difference is substantial to neglect deformation that can be considered at noise in the data collection. Additionally, the tests were performed at a low rate, 10μ m/s (0.2 in/min), which reduces the ductile deformation that can cause high speed strain rates in the fixture.

The tool was designed to conduct three tests sequentially. Each specimen is made with a substrate strip and three bonded dies. Therefore, the fixture was made long enough to provide stability to the

elongated strips. The width of the fixture helps to control the temperature while the test is performing. The tool and the specimen are heated at the same time, the large mass of the fixture reduces a possible thermal shock to the sample. The wedge, where the test is conducted, was made thick with the intent to provide a rigid structure to transmit a uniform force through the interconnection. The wide end compensates the thickness and the offset of the sample under test, allowing clamping the specimen on one side of the tensile equipment and other end to the tool, being both clamps perfectly aligned.



Figure 18: Schematic of the die shear tool conversion

4.2 Sample for Die Shear Testing

The samples prepared for die shear testing required a new configuration to conduct the test. The samples were fabricated using Au-Sn following the SLID bonding method as explained in section 3.2. Copper strips of 0.4x4in with ENIG/4 μ mAu depositions were used as substrate and three 0.2in² dice of Cu/ENIG/4 μ m Au/8 μ m AuSn/Au-flash were placed along the strip as dies. Three dies were placed in the same strip to ensure all dice were bonded under the same temperature/time conditions and to re-produce the test.

For the shear test, the samples were bonded using the low temperature conditions of 315°C with 5 and 10min holding time. The bonding conditions at 340°C were neglected by the DSC results presented in section 3.6 where it confirms a full diffusion of the eutectic gold tin, and a shift for a higher melting point for all bonding conditions. Therefore, the bonding conditions used for this effort supports a low temperature, low cost manufacturing process. The samples were bonded at 315°C for 5 and 10min holding time with a heating ramp rate of 1.7°C/sec. Each dice had a dead weight of 61.6g, as presented in Figure 19, during the bonding process.

The first die of each strip was tested at room temperature and the others were tested at 100°C. The preselected temperatures were based of the previous research where they used different materials and deposition techniques (foils, sintering of powders, solder ball, electroplated) and where they observed a high strength resistance up to 100°C [15], [33], [34].



Figure 19: Die shear sample assembly

4.3 Heating System Setup

To test at high temperatures, a heat source needs to be included in the setup of tensile machine and the fixture tool. The challenge of the test was to control the temperature of the system. Therefore, the heating system integrates a circuit between the heat source and the temperature controller. The circuit provides a temperature control to ensure performing the test at the desired temperature. Two Omega Lux semi-cylindrical ceramic heaters were used as heating sources, both placed face-to-face to simulate a chamber. A ceramic cover was placed on top of the heaters to enclose the system and to reduce air flow through the center of the chamber produced by the air density. To power the heaters a variable transformer supports the voltage reduction from 120VAC to 60VAC. The temperature controller was a WATLOW 93that was used to increase the temperature of the specimen and maintain the temperature during the test. The sensor used to control was an Omega Kapton thermocouple "K" type located inside the chamber reading the ambient temperature and an extra thermocouple was used to monitor the specimen temperature.

A brief description of how the system works is as follows: the controller monitors the temperature of the system, if the temperature is below as programed the controller provided continuity to a subsystem, where a relay is placed to close the circuit to the heaters and turn them ON. The schematic of the circuit is presented in Figure 20.

Variable Autotransformer 120 VAC/ 60 VAC



Figure 20: System Connection Circuit Schematic

4.4 **Test Preparation**

A sample strip is positioned inside the fixture, making sure it slides inside the fixture without resistance. On the top grip of the Mark10 tensile apparatus, the fixture is secured; the end of the strip is fixed at the bottom grip. The ambient thermocouple is placed, and the thermocouple reading the sample temperature is pre-cured using OB-200 epoxy adhesive with a highly thermal conductivity made for thermocouples that resists temperatures up to 260°C. The semi-cylindrical heaters enclose the specimen as a chamber and turned ON so that the testing temperature is reached. The complete setup in presented in Figure 21. The ramp rate to heat the samples was 10°C/min with $\pm 2°$ C deviation. The system runs at 100°C, but can be used to temperatures over 300°C. After the system stabilizes and sample thermocouple reaches the temperature $\pm 2°$ C of tolerance, after 5 min soak time the test is run at a 0.10µm/s shear speed. Figure 21 present the setup of the test.



Figure 21: Die Shear Test Setup

5.1 Introduction

The mechanical strength of a bond is a fundamental property for electronic packaging. A weak interconnection can be cause by: voids left in the joint, inappropriate bonding conditions, mismatch in coefficient of thermal expansion or the formation of unwanted IMC, among other. After addressing all the challenges in the creation of a new interconnection, it is necessary to study the mechanical behavior at operational environments, specifically high temperatures exposure. For this reason, researchers are analyzing the effect of temperature in the bond. These experiments are commonly done by exposing the bond to temperatures for prolonged time to analyze the mechanical effect of aging, applying constant stresses to produce creep or reliability by thermal cycling fatigue. A research done by S Egelkraut et al. studied the strength evolution during thermal aging. The materials analyzed were gold-germanium and lead-tin aged at two different temperatures (200°C and 250°C) for 500 hrs and 1000 hrs. In the study they compared the impact between copper and nickel metallization. Where nickel metallization presents an accelerated decrease of the shear compared with the copper metallization. AuGe12 solder joint with copper surface remains almost constant over 1000 hrs at 200°C otherwise, the results for the ones exposed at 250°C slightly decrease at 500 hrs. In addition, PbSn5 presents a reduction in shear strength with the increasing aging time without differences between the aging temperatures [11]. Other similar investigation was made by X Wei et. al. for a AuSn20Ni composition. There assembly consists of an alternate stake of gold and tin foils that are cold rolled to create Au20Sn. The nickel is electroplated followed by the reflow to create the bond. After the bond is fabricated, the samples were aged at 150 and 200°C for 1000 hrs period. The results present a slightly shear strength reduction for the samples aged at 150°C in comparison to the samples aged at 200°C that the shear strength decreased drastically from 46 to 36MPa [9]. As can be seen these types of testing for electronic packaging are long lasting and costly. Also, the mechanical testing presented before are for samples that had been exposed to high temperature, cooled down followed by testing at room temperature. Therefore, there is a highly concern what would be the result of testing in a combined environment where temperature and load are applied.

Before going any further, during this investigation we noticed there is other aspect that can affect the bonding product, the manufacturing process. The samples fabricated for the shear test were a two parts assembly. All the materials were deposited on copper sheet, 0.08in thick, and subsequently cut to the desire dimensions. The substrate strips made by copper/ ENIG/4 μ mAu, and the die made by

Cu/ENIG/4µm Au/8µm AuSn/Au-flash. The first intent cutting the material was via shear; this method used a sharp blade to apply shear and make the cut. The downside of using this method was revealed in the ductile deformation of the sample. The expected dimensions area for the die was 0.2in², where it was reduced for more than a half after being cut. Moreover, the SLID process was affected. In order to produce a joint via diffusion bonding, the two parts need to be in complete/direct contact. Therefore, uneven or high porosity surfaces are not favorable for this process. As can be seen in Figure 22, the contact area was reduced caused by the deformed edges. Now the deformed areas are not in direct contact with the other surfaces. The material deposited in the deformed area will not be part of the diffusion, consequently the material is wasted and the final bonding composition can be affected.



Figure 22: Samples cut by shear
 a) Pre SLID process – edge deformation, contact area reduction
 b) Post SLID process – maximum defunded area

For this reason, a second cutting intent was using wire electrical discharge machining (EDM). The cut is made when a material is wetted with a dielectric liquid, two electrodes produce an electrical discharge through a wire while it is cutting the material. This method was very precise, the die area of $0.2in^2$ was achieved and no ductile deformations were produced. The difficulty found using this method was the sparkles produced by the electrical discharge reach melting temperatures up to 800°C and the low temperature cooling rate from the process [35]. These two singularities of the EDM process are not favorable for our specimen. The samples where heated unrestrainedly when comparing to the eutectic gold-tin deposited, it has a melting point of 280°C. Therefore, we consider there was a micro reaction produced during the EDM process that conducts a premature diffusion. Which means, the SLID process starts earlier in one of the parts of the pre-assembly bond. As result, when the samples where submitted to the SLID bonding process some parts where already pre-diffused with a AuSn composition different of Au20Sn and it were needing high temperatures for the process because it was already a gold-rich composition. The areas not affected by this phenomenon follow the SLID processing proposed. As result, the composition of the produced bond needs to be analyzed. Figure 23 presents a schematic of this even.



Figure 23: Sample cut by wire EDM Pre SLID process – premature diffusion, change in composition

b) Post SLID process – change in defunded area, different composition compared with proposed in this work

5.2 **Results and Discussion**

a)

After fabricating the bonds by SLID processing at 315°C varying the holding time for 5min and 10min, the effects of the cutting process investigated. There is no doubt the material cutting method has a direct impact in the produced bond. Figure 24, present two samples with the same bonding diffusion area that were diced with different methods. The sample cut by shear, clearly present a deformation in the "die" side. The Au20Sn that was in direct contact with the gold contribute in the diffusion process, the Au20Sn that was not in contact, melts during the heating process, sliding down to the "substrate" leaving undiffused clumps. In the other side, the samples diced by wire EDM the present an unorganized and random diffusion pattern. It also was observed that all the samples cut by wire EDM the die surface look opaque from the original. Therefore we conclude there was a premature reaction that was changing the composition and restringing the bonding process. Note, all the samples were sonicated and deep cleaned to eliminate solution residues and oils before the bonding process.



Figure 24: Cutting process and its effects

Subsequently, the die shear strength was compared to study the performance of the bond at 100°C. Due to the problems faced in the cutting step, each sample area was measured using ImageJ software to calculate the strength. As can be seen in the plot presented in Figure 25, rather than the bonding conditions the shear strength is higher than 100MPa. The samples bonded at 315°C-10min have an average strength of 147.2 MPa, higher than the samples bonded at 315°C-5min with an average strength of 111.2 MPa. This is because during the SLID processing the diffusion between eutectic gold tin

and gold was more progressive. This idea is established based to the data presented in section 3.3 - Table 2, where the IMC thickness for the sample produced at $315^{\circ}C$ -5min were thinner than the IMC measured for the $315^{\circ}C$ -10min sample. Accordingly to the EDS results, the IMC formed is $(Ni, Au)_2Sn_3$. In order to this IMC be formed, the tin need to diffuse through the gold before reaching the nickel interface. Therefore, the thicker the IMC, a progressive diffusion has been achieved. As a result it is expected to see a higher strength in the samples processed for longer periods.



Figure 25: Die shear results

5.3 Conclusion

This work proved it is possible to fabricate a high strength resistant bond with micro layers of Au/Au20Sn supported by SLID processing. It confirmed that a fabrication condition of 315° C for a period of 5min is enough to produce a bond with a die shear strength of 111.2 MPa when it is exposed to 100°C. In addition, bonds fabricated with longer duration, support a better diffusion resulting in a higher strength resistant bond. Therefore, samples bonded at 315° C – 10min have an average die shear strength of 147.2 MPa tested at 100°C. Beside the die shear strength, the method used to cut the samples affect the diffusion area, therefore the composition of the bond and consequently the mechanical strength.

Chapter 6 Summary and Conclusions

This investigation achieved an 86.4at%Au/13.6at%Sn interconnection from a layered bonding arrangement of $4\mu mAu/8\mu mAu20Sn/4\mu mAu$. The material depositions were with the novel JVD processing and fabricated via SLID method.

- A modified JVD layering sequence of the Au/Au-Sn SLID constituents was tested and evaluated in terms of its microstructural stability.
- SLID process demonstrated to be a suitable alternative for attaining a shifting melting point solution without the need of a high temperature processing as confirmed by DSC results.
- As built samples showed the formation of a thin IMC layer, thus confirming the effect of the Au layer acting as a diffusion barrier.
- The aging experiment confirmed an order of magnitude growth of the IMC layer.
- Shorter dwells and lower processing temperatures resulted in partial homogenization of the joints, which further progressed to stabilization during aging.
- Longer dwells and lower processing temperatures resulted in a superior diffusion with a high strength resistant bond.

The implement of standardized parameters of: deposition technique, material sequence, material thickness, temperature and time processing; will impact positively the packaging industry for harsh environment exposition. High power electronics, aerospace, automotive, among others will be capable to improve their systems capabilities with the execution of the innovative packaging process presented without changing the actual processes.

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