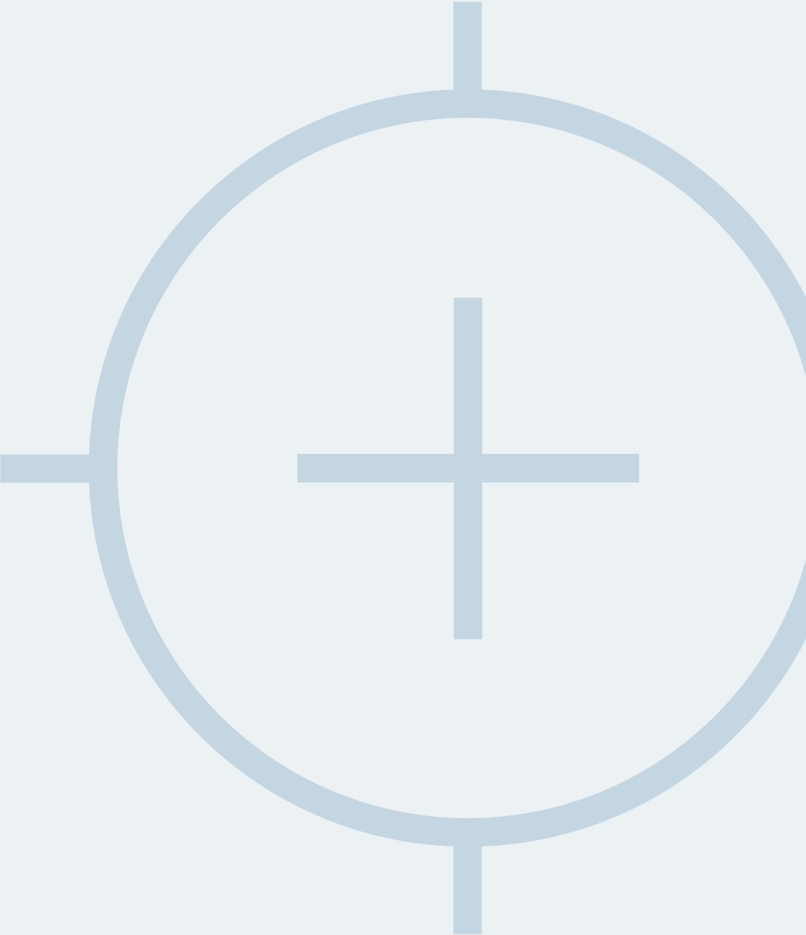
WAFER LEVEL PACKAGING USING HIGH FORCE BONDING OF ALGE

Margarete Zoberbier
SUSS MicroTec Lithography GmbH | Germany

Martin Heller
Kionix, Inc. | USA



Published in the SUSS report 2016

E-mail: info@suss.com

WAFER-LEVEL PACKAGING USING HIGH FORCE BONDING OF AlGe

Margarete Zoberbier SUSS MicroTec Lithography GmbH, Schleissheimer Str. 90, 85748 Garching, Germany
Martin Heller Kionix, Inc., Ithaca, New York 14850, USA

ALUMINUM-GERMANIUM EUTECTIC WAFER BONDING

Aluminum-Germanium (AlGe) eutectic wafer bonding is the most widely used wafer-level packaging process for MEMS gyroscopes in high volume production today. The history behind its usage for wafer bonding dates back over 20 years. A patent describing the usage of an Aluminum-Germanium layer stack to bond two wafers together, no mention of MEMS though, was first filed in 1991 by G. Schuster, et. al. [1]. The first MEMS specific publication was by P. M. Zavracky in 1995 and the first mention of using an AlGe eutectic wafer bond process to electrically connect a MEMS inertial sensor wafer to an ASIC wafer can be found in a German patent application from 1995 by G. Flach et. al. [2-3]. One of the main advantages of AlGe compared to other eutectic wafer bond processes like Gold-Silicon (AuSi) is its compatibility with a standard in-house CMOS ASIC wafer fab or outside foundries like TSMC, Globalfoundries, X-Fab. No overly burdensome countermeasures and procedures to limit process line cross contamination need to be implemented. The eutectic point for AlGe has a melt temperature in the vicinity of 690 K with an AlGe weight percent ratio of 48.4/51.6 according to literature [4]. This is about 60 K higher than the temperature of the AuSi eutectic point but not too high for having an ASIC compatible wafer bond process [5-7].

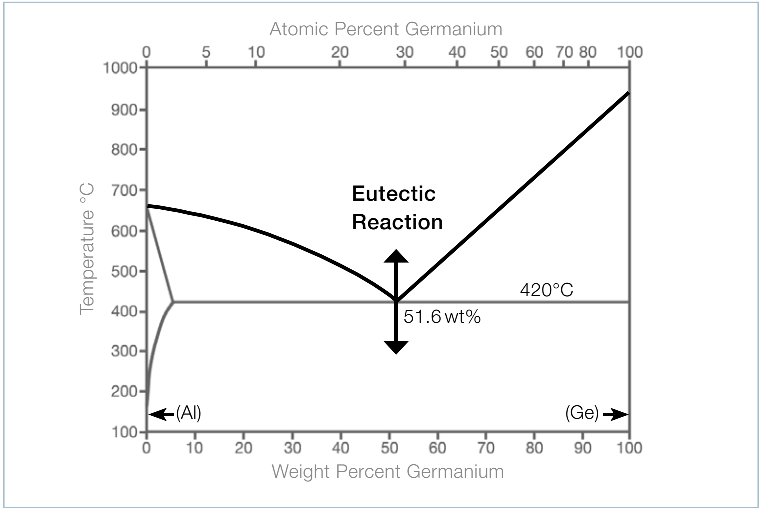


Figure 1 *Aluminum-germanium phase diagram showing simple eutectic reaction at 51.6 wt% Ge and at 420° C*

A eutectic alloy is sometimes called a "solder" however, this is not necessarily the correct metallurgical term. A eutectic alloy is a two component alloy that undergoes a direct solid to liquid phase temperature at a specific composition and temperature.

The composition and temperature define the reaction and are unique to only a few materials systems. Table 1 shows the alloys most often used for wafer-level bonding. The choices are alloys of gold, aluminum or copper since these materials are already used in semiconductor fabrication labs and in most cases have established processing and deposition methods.

Eutectic Alloy	Eutectic Composition	Eutectic Temp
Al-Ge	49/51 wt%	419° C
Au-Ge	28/72 wt%	361° C
Au-In	0.6/99.4 wt%	156° C
Au-Si	97.1/2.9 wt%	363° C
Au-Sn	80./20 wt%	280° C
Cu-Sn	5/95 wt%	231° C

Table 1 *Eutectic alloy commonly used in MEMS wafer-level packaging*

Figure 1 is the AlGe phase diagram.[7] This is a simple eutectic phase diagram with no intermetallic phase formation. The aluminum has a melting point of 660° C and germanium melts at 938° C. The eutectic reaction is at 51.6 wt % Ge and has a solid to liquid transition (eutectic point) at 420° C. In most eutectic bonding applications the rule of thumb is to remain at 7-15° C above the eutectic temperature.

Going to higher temperatures will increase the fluidity of the alloy and can lead to excess flow into unwanted regions in the die. However, if the temperature is not uniform the viscosity of the melt will vary. Some areas on the wafer may be solid and others liquid and the wafers will crack under the applied force as bending moments develop in regions with varying compliance.

METAL DEPOSITION

Ge can be deposited as an alloy layer on both sides of the interface then the wafers are simply aligned, brought into a contact and pressed together. After contact is established the wafers are heated to the eutectic temperature, melted and re-solidified. Alloys can be deposited by sputtering of alloy targets or electroplated in some but not necessarily all cases. The advantage of the direct melting of alloy layers is speed because the diffusion step can be avoided. Alternatively the aluminum can be deposited on one wafer and the germanium on the other substrate. Then the wafers are pressed together and heated (below 420° C) until the interface mixes. Note that limited solid solubility means that the diffusion is only a few percent and grain boundary reactions will play a major role in the success or failure of the bonds when completed with this strategy. After mixing the material the wafers are reflowed and cooled.

After eutectic bonds are cooled there is a possibility that microvoids form in the eutectic microstructure. These voids may be due to the Kirkendall effect which occurs when one element diffuses more quickly than the other and the lattice sites left behind are empty. Or rather then are filled with vacancies. If a substantial vacancy concentration exists then the vacancies can cluster and lead to microvoiding. In most cases this can be overcome by adjusting the cooling rates and the amount of hyper eutectic heating.(7)

CONVENTIONAL SURFACE PREPARATION

The goal of seal surface preparation before bond is to minimize the amount of surface oxides and other contaminants negatively impacting the wafer bond result as well as the process stability. Depending on the exact seal metal layer stack configuration, one has to prepare either Aluminum, Germanium or both types of surfaces. Germanium forms mainly Germanium-dioxide ($GeO2$) with a suboxide layer ($GeOx$, $x<2$) [8]. The $GeO2$ is water soluble, whereas the suboxide is not (8). A dip in HF with a sufficiently long DI water rinse afterwards enables also the removal of the suboxide layer [8]. The wafers should be stored under Nitrogen in the bond wait queue to prolong the time until the native oxide reforms.It has been reported that using a HBr based etchant and Nitrogen storage reformation of the native oxide layer on Germanium can be inhibited up to 24 hours (8). Aluminum forms a hard native oxide layer up to several nanometers thick. One documented solution is using a Hydrogen containing gas mixture and try to reduce the oxide in-situ during the wafer bond process. The efficiency of the process in the available temperature range is undocumented though [5]. Another possibility to deal with the native oxide layer on Aluminum is by using brute bond force to break thru the passivation layer. Published bond recipes for AlGe therefore usually mention bond forces in the 40-60 kN range, the exact amount of seal area per wafer and therefore the actual pressure on the seal area is rarely documented though [7-8]. A further process option to remove the native Alumina layer is using a reduced pressure Argon plasma before bonding to remove the oxide using an ion milling/Argon sputtering process.

Figure 2 *SUSS MicroTec XB8 semi-automated permanent bonder*

HIGH FORCE BONDING

Based on the assumption that high force should be able to break through and enable normal AlGe eutectic seal formation, a DOE based on process of record recipe was set-up to test the hypothesis on eutectic bond short loop wafers. Wafer bonding was accomplished using a SUSS MicroTec XB8 high force bonder with improved bond force uniformity compared to the previous generation and a maximum bond force of 100 kN. Another change from the previous tool generation is the dual zone heating configuration enabling better control of the temperature distribution within the bond chuck.

Bond	Bond force	Bond result
B01	20 kN	OK
B02	100 kN	OK

Table 2 *High force bond*

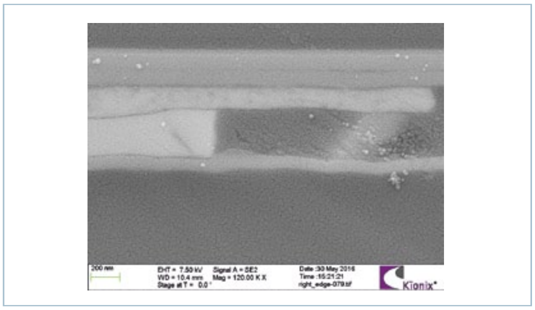


Figure 3 *Close up of AlGe eutectic mixture*

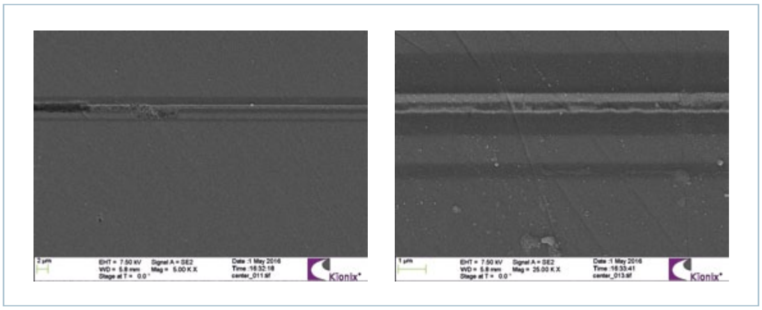


Figure 4 *XB8 bonded AlGe structures, 274 nm thickness of eutectic layer @ 100 kN*

Capshear / kgf	Sample 1 XB8	Sample 2 XB8	Reference @ 20 kN
Average	5,34	5,09	4,03
Min	4,77	4,27	2,84
Max	5,99	5,83	5,13
stdev	0,35	0,37	0,69

Table 3 *Capshear testing, comparison XB8 and reference bonded AlGe structures*

RESULTS

The wafers were successfully bonded in a void free fashion. Figure 3 and 4 show cross section pictures of the bonded wafers. Where 20 kN were applied as a reference bond which shows a thickness of the eutectic layer of 563 nm. Using the 100 kN bonding force in the recipe a thickness layer of 274 nm could be achieved. Metal squishing into scribe line could not been observed. Also the SAM with 5 µm resolution shows no voids or microvoids. The post bond wafer bow is in the range of only 100 to 150 µm, which is a very good result as all bonded wafer pairs tend to result in a higher wafer bow due to the different cooling effects in the bonder. Shear strength is slightly better compared to 20 kN (table 3) and SEM cross-sections show very good contact on all chips across the wafer with 100 kN recipe.

Results summary:

- Median capshear strength shows a dependency on the applied bond force
- Larger bond force leads to an increased capshear strength
- Dependency between capshear strength and bond force is non-linear (Figure 5)

CONCLUSION

The AlGe high force bonding shows an increased capshear strength, which is caused by the increased bond force and resulting in thinner eutectic metal layers. The uniformity of the bonded structures over the wafer leads to a higher yield. The new heater design with its double side air cooling, with special thermal isolation and flange cooling, leads also to a better post bond bow of the bonded wafers. In summary one can say the new features lead to a high yield due to the homogeneity of the temperature and bonding force distribution in the XB8.

In general for device manufacturers the key motiviation to transition to metal based wafer-level bonding is the increased hermeticity which improves device functionality but more importantly enables the continued scaling of the device to smaller sizes. But it also needs a better temperature and bond force homogeneity in the bond equipment itself.
The economic and technological advantages of metal bonding in MEMS wafer-level packaging are clear and these methods will continue to increase in use as market became more consumer oriented and integration with other components increases.

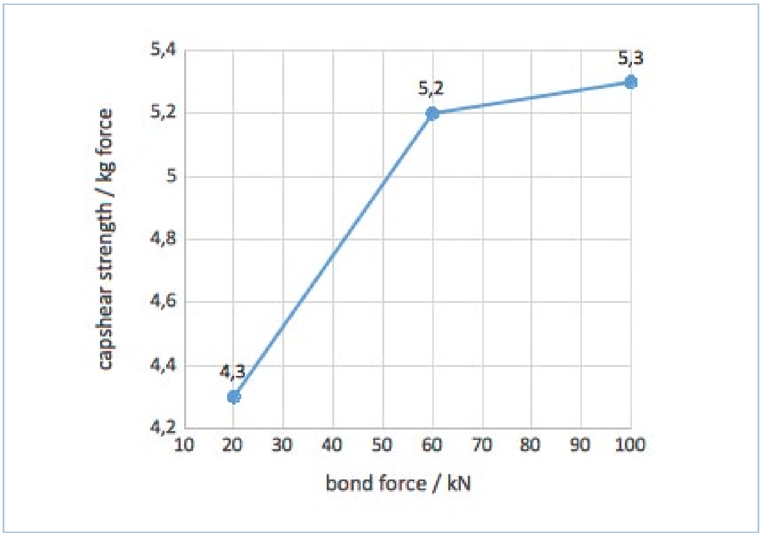


Figure 5 *Capshear strength as a function of bond force*

References

[1] *G. Schuster and K. Panitsch, "Process for the laminar joining of silicon semiconductor slices", US5693574 (1997)*

[2] *P. M. Zavracky and B. Vu, "Patterned eutectic bonding with AlGe thin films for MEMS, in Proc. Micromachining and Microfabrication Process Technology", p. 46-52, SPIE, Bellingham, WA (1995)*

[3] *G. Flach, U. Nothelfer, G. Schuster and H. Weber, "Micromechanical acceleration sensor", US5905203 (1999)*

[4] *H. Okamoto, Journal of Phase Equilibria and Diffusion, 19, 86 (1998)*

[5] *S. S. Nasiri and A. F. Flannery, "Method of fabrication of a AlGe bonding in a wafer packaging environment and a product produced therefrom", US7442570 (2008)*

[6] *S. Sood, S. Farrens, R. Pinker, J. Xie and W. Cataby, "ECS Transactions", 33, 93 (2010)*

[7] *S. Sood, "Advanced Metal-Eutectic Bonding for High Volume MEMS WLP", in IEEE MEMS Bay Area Meeting (2014)*

[8] *B. Onsia, T. Conard, S. De Gendt, M. Heyns, I. Hoflijk, P. Mertens, M. Meuris, G. Raskin, S. Sioncke and I. Teerlinck, "Solid State Phenom", 103, 27 (2005)*

Margarete Zoberbier started at SUSS MicroTec in 2001 as Application Engineer Bonder for the development and improvement of bonding processes. After being in charge for Business Development Bonder in Europe, Margarete moved to the Business Development Group of 3D integration in 2008. Since 2013 she is responsible for the Product Management for the permanent bonders. Margarete co-authored several papers in wafer bonding and related areas. She received a Master degree in Precision- and Microengineering field from Georg Simon Ohm University of Applied Sciences in Nuremberg, Germany.