# Ag-Sintering as an Enabler for Thermally Demanding Electronic and Semiconductor Applications

*Silver sintering has become a reliable industrial bonding technology with superior thermal and electrical performance while meeting automotive grade quality standards.*

*By Marco Koelink, Advanced Packaging Center (APC), Business Development Manager and Commercial Manager and Michiel de Monchy, European Applications Manager Die Attach and Preforms, Alpha Assembly Solutions*

Silver (Ag) sintering or low-temperature diffusion bonding is receiving an increasing interest, mainly because of excellent electrical and thermal conductivities compared to other metals. In combination with some very interesting optical properties, the potential applications range from power electronics, to printable electronics and (optical) biosensing (Peng, 2015). The use of Ag-sintering is currently mainly driven by either the replacement of lead-containing bonding materials (environmental or sustainability considerations) or the application in power electronics, specifically in applications which are sensitive to energy efficiency due to limited power availability such as is the case for instance with electrical vehicles (EVs). Main consideration in transitioning from traditional bonding materials to Ag-sintering are cost and reliability (Scola, 2015). As early adopters of this technology are pioneering now the application of this technology on an industrial scale, more and more reliability data will becoming available. As the technology is maturing and the number of applications is growing, it is to be expected that also prices will eventually go down to become more comparable with more traditional bonding materials. This will open the market for more wide-spread applications. This paper discusses some of the background of Ag-sintering, as well as some of the industrialization and reliability aspects of this technology. The companies APC, Boschman Technologies and Alpha Assembly Solutions provide respectively development, equipment (industrialization) and material services in this field.

**Ag-sintering**

Many developments in solder technologies have over the last 10 years been driven by internation legislation to achieve lead-free solder materials and improve the reliability of the joints. Recently also the introduction of electric and hybrid automotive vehicles spurred the demand of efficient high-power electronics, mainly to improve the driving range (most important benchmark in competition with traditional vehicles). Several technologies have been introduced meanwhile to achieve high performance power modules with high reliability. Some examples of such technology include for instance gold base, high cost solders such as AuGe and AuSn, SnSb alloys, as well as silver sintering. The silver sintering technology has been pioneered by several solder material companies for several years (Siow, 2014). Using the proprietatary knowledge of APC and Boschman Technologies, specifially the dynamic insert technology, the technology has recently also successfully been industrialized.

The Silver sintering process is based on solid state diffusion, where Silver particles are fused together and to the metallization of dies and substrates. One of the major drivers for this process is the change in free energy within the silver sintering product. Smaller particles will have more free energy and need less external energy to initiate the fusion process. Argomax®, a product group developed by Alpha Assembly Solutions (see figure 1), contains agglomerates of particles of about 20 nm, thus allowing sintering parameters at temperatures comparable or lower to those of lead free solder reflow. This temperature together with the relatively low pressures of maximally 10 MPa allows for a wide range of products to be sintered. The unique sintering inhibiter of the Argomax® allows the material to be deliver in either paste or pre-dried film. This will again will increase the processing possibilities within industrialized processes.


*Figure 1: Alpha Assembly Solutions offers a range of sintering materials in different formats suited for different applications*

The fusion of the silver will only succeed if the interface materials are pure metallic. Also both the metallization of the dies and the substrates need to be relatively free of oxides. The easiest surface to bond to is Ag itself. If Ag cannot be used, noble materials such, as Au, Pd, or Pt are the next useable materials. The thicknesses of the metallization does not need to be more than 1 μm because the diffusion of the silver does not penetrate beyond 25 to 75 nm. When another specific Argomax® material is used, sintering to Copper in an ambient atmosphere can also be used. It is unfortunately not possible to bond to surfaces that have got dense oxide structures such as Nickel and Aluminum, nor can bare Si be used.

*Figure 2: Sinterstar Innovate-F-XL; Universal Sinter System using Film-Assist and Dynamic Insert Technology; Ag Sintering Temperature up to 320 °C; Real time controlled pressure (0.2-40 MPa); Large sintering area 350 x 270 mm; Protecting gas supply optional and Suitable for all kind of carriers, such as: - Lead frames – Substrates - Ceramics – Wafers*

Silver sintering meanhwile offers a new die attach technology with a void-free and strong bond with very high thermal and electrical conductivity (upt to 200-300 W/mK and 2-2.5 μΩcm). The Ag-sintering process is defined either by temperature and time or temperature, time and pressure. Whereas the process defined by temperature and time ("pressure-less") is relatively easily industrialized (via reflow ovens or comparable), the process defined by temperature, time and pressure requires accurate and independent control of all three variables. It is for the process that requires pressure that Boschman was able to develop and create both semi-automated (see figure 2) and full-automated equipment using their unique high precision dynamic insert pressure control in combination with sophisticated and precise temperature control. The systems provide automated control of the sinter process with programmable temperatures up to 320 ºC, pressures dynamically variable between at least 10-30 MPa and a maximum sinter area of 350 x 270 mm. Boschman offers specific tool solutions according customer wishes and application specific requirements. A roll to roll film protects the devices during the sintering operation and keeps the die clean. System can also run without film in case direct hard sintering is needed.

**Applications and Reliability**

Although silver sintering has attracted considerable attention, fundamental understanding of this technology is still limited. Recently several studies have been published aimed at gaining in-depth insights into the physics of material and processes related to silver sintering (e.g. Yan 2015, Peng 2015). Increased fundamental understanding leads to better understanding of reliability and failure mechanisms. Although with work is far from complete, sufficient information has become available to suggest that Ag-sintering offers basically good shear strength performance and thermo-mechanical reliability under various conditions (Khazaka, 2014, Yan, 2016, Henaff, 2016 and Greca, 2016). The pressurised version shows better performance and better process control compared to the pressure-less version (Khazaka, 2014).

Silver sintering can be applied in many high-power or high-power-density applications. This includes solid state lighting, high-power (semiconductor) lasers, solar application (e.g. concentrated photo voltaics), power electronics for wind turbine systems and more. Figure 3 shows an example of a power device. Design studies for LED packages have shown to yield excellent performance and extremely stable against further assembly processes and harsh operating conditions (Jordan et al, 2015, see also figure 4). But also applications that are sensitive to energy losses are utilizing silver sintering for instance in energy harvesting in thermoelectric devices (piezoelectric) or printed electronics.

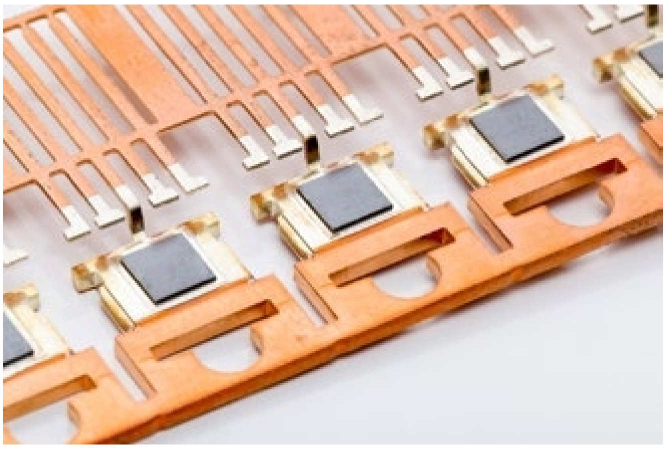

*Figure 3: an example of a lead frame based power device using silver sintering*

Specifically power applications however (IGBT's, RF-power, power MOSFET's, thyristors and more) benefit from this technology (Yu, 2016). In particular application areas that are primarily driven by (ultimate) perfomance justify the use of this technology over the (initial) cost adder that is associated with this. A prime example is the industry of electric and hybrid vehicles where efficient power electronics is a necessity to compete with traditional combustion engine vehicles to achieve sufficient driving range. Studies have shown that also automotive applications high performance can be combines with high reliability (Steger, 2012).


*Figure 4: Relative comparison of different die-attach technologies suitable for LED applications. Courtesy of Courtesy Gyan Dutt, ALPHA, LED A.R.T Conference, Nov 17-19 2015, Atlanta USA*

Another advantage of silver sintering is that, after processing, the melting temperature of the layer will be equal to the melting temperature of Silver (962°C). This entails that the maximum junction temperature Tj of a device can be significantly higher compared to conventional die attach materials. (Khazaka, 2014). Materials can as a rule of thumb only be reliably operated to 0.8 x the melting temperature in degrees C. (Knoer 2010). This means that a high lead solder can be operated up to 180°C, whereas a silver sintered bond can in theory be operated up to 760°C. In practice the silver bond has been tested up to 500°C. This facilitates the application of silver sintering in combination of wide band-gap semiconductor materials (SiC, GaN) which can operate at much higher temperatures compared to silicon-based materials.

Meanwhile other application areas are being investigated, ranging from surface mount applications, interconnect fabrication, substrate bonding, printable electronics and more (Natsuki, 2015). Siow et al (Siow, 2016) publised an overview on the development state of silver sintering as a function of patent applications, processes, materials and industries and companies that are commercializing this technology.

**Conclusions**

Silver sintering is emerging as a proven and reliable bonding technology for high-power or high-power-density applications providing superior electrical and thermal conductivity compared to traditional bonding technologies. The technology is particularly suited for high power electronics such as IGBT's, and MOSFET's, applications with wide band-gap materials (SiC and GaN) and application that require lead-free bonding materials or high performance (notably high power electronics for electric and hybrid automotive vehicles). The sintering technology is mostly categorized in pressure-less and pressurized applications. Companies like Alpha Assembly Solutions and Boschman provide industrial services and solutions for the industrialized use of materials, processes and production equipment for the pressurized applications that yield the best performane and reliabiliy.

**www.alphaassembly.com**

**www.apcenter.nl**

**References**


1. Siow, K.S., "Are Sintered Silver Joints Ready for Use as Interconnect Material in Microelectronic Packaging?", Journal of ELECTRONIC MATERIALS, Vol. 43, No. 4, 2014
2. Khazaka, R., Mendizabal, L. and Henry, D., "A review on nano-silver interconnection: parameters affecting the joint shear strength and its long term high temperature reliability ", Journal of Electronic Materials, Vol 43, No 7, July 2014, p 2459-2466.
3. Natsuki, J., Natsuki, T, Hashimoto, Y. , "A Review of Silver Nanoparticles: Synthesis Methods Properties and Applications", International Journal of Materials Science and Applications, Vol 4(5): p325-332, 2015
4. Jordan, R.C., Weber, C., Ehrhardt, C., Wilke, M., and Jaeschke, J., "Advanced packaging methods for highpower LED modules",Journal of Solid State Lighting, Vol 2, No 4, 2015
5. Le Henaff, F., Greca, G., Salerno, P., Mathieu, O., Reger, M., Khaselev, O., Bouregdha, M., Durham, J., Lifton, A., Harel, J.C., Laud, S., He, W., Sarkany, Z., Proulx, J. and Parry, J., "Reliability of Double Side Silver Sintered Devices with various Substrate Metallization", PCIM Europe 2016
6. Steger, J., "With Sinter-Technology: Forward to Higher Reliability of Power Modules for Automotive Applications". Power Electronics Europe, Issue 2 2012.
7. Knoerr, M., Schletz A; "Power Semiconductor Joining through Sintering of Silver Nanoparticles: Evaluation of Influence of Parameters Time, Temperature and Pressure on Density, Strength and Reliability" CIPS 2010
8. Yan, J., Zou, G., Liu, L., Zhang, D., Bai, H., Wu, A. and Zhou Y.N., "Sintering mechanisms and mechanical properties of joints bonded using silver nanoparticles for electronic packaging applications", Welding in the World, May 2015, Vol 59, Issue 3, pp 427-432.
9. Peng, P., Hu, A., Gerlich, A.P., Zou, G., Liu, L. and Zhou, Y.N., "Joining of Silver Nanomaterials at Low Temperatures: Processes, Properties, and Applications", ACS Appl. Mater. Interfaces 2015, Vol 7, pp 12597−12618
10. Yan, J., Zhang, D., Zou, G., Liu, L., Bai, H., Wu, A. and Zhou, Y.N., "Sintering Bonding Process with Ag Nanoparticle Paste and Joint Properties in High Temperature Environment" Journal of Nanomaterials, 2016, Vol 2016, pp 1-8
11. Siow, K.S. and Lin Y.T., "Identifying the Development State of Sintered Silver (Ag) as A Bonding Material in the Microelectronic Packaging via A Patent Landscape Study", Journal of Electronic Packaging, Vol 138, Issue 2, April 2016,
12. Greca, G., Le Henaff, F., Harel, J.C., Boschman, E. and He, W., "Double Side Sintered IGBT 650V/ 200A in a TO-247 Package for Extreme Performance and Reliability", 18th Electronics Packaging Technology Conference, Singapore, November 2016.
13. Yu, F. "Ag Sintering Die and Passive Components Attach for High Temperature Applications", dissertation Auburn University Alabama, USA 2016.
14. Scola, J., Tassart, X., Vilar, C., Jomard, F., Dumas, E., Veniaminova, Y.,Boullay, P. and Gascoin, S. "Microstructure and electrical resistance evolution during sintering of a Ag nanoparticle paste.", Journal of Physics D: Applied Physics, 2015, Volume 48, Number 14.



Advanced Packaging Center
Marco Koelink
Stenograaf 3
6921 EX Duiven
The Netherlands
Phone: +31 6 46846563
Fax: +31 26 3194999
E-mail: MarcoKoelink@apcenter.nl

Alpha Assembly Solutions
Michiel de Monchy
Energiestraat 21
1411 AR Naarden
The Netherlands
Mobile: +31 (0)622 415 413
Office: +31 (0) 35 69 55 429
Michiel.deMonchy@alphaassembly.com
www.alphaassembly.com