Low Temperature, Fast Sintering of Micro-Scale Silver Paste for Die Attach for 300°C Applications

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Abstract

With an increasing demand for SiC and GaN high power devices that operate at high temperature, traditional solder materials are reaching their limitations in performance. In addition, there is a strong desire to eliminate high lead containing solders in Si power device packaging for use over conventional temperature range. Low temperature Ag sintering technology is a promising method for high performance lead-free die attachment. In a previous study, a pressureless sintering process and suitable metallization were demonstrated to provide high reliability die attach by using micro-size Ag sintering. The resulting die attach layer had approximately 30% porosity.

In this work, a low temperature pressure-assisted fast sintering process was examined. The porosity was decreased from 30% to 15% with application of a low pressure (7.6MPa) during a one minute sintering process. The shear strength for a 3 mm x 3 mm die was 70 MPa and the 8 mm x 8 mm die could not be sheared off due to a 100 kg shear module force limit. Both the Ag and Au metallization (die and substrate) were studied. Furthermore, a new substrate metallization combination was found that allows the use of Au thick film metallized substrates. High temperature (300 °C) storage tests for up to 2000 hours aging were conducted and results are presented.

Keywords: High temperature operation, die attach, sintered Ag, reliability

Introduction

Silver sintering technology for die attach was pioneered in European for power device die attach and has been considered as a promising replacement for high lead solder for high temperature and high power applications [1, 2].

G. Q. Lu has reported extensively on Ag nano-paste as a die attach material. For small die (1.71 mm x 1.38 mm and 2.26 mm x 2.26 mm), a pressureless sintering process yielded high shear strength up to 38 MPa [3] and could support high temperature operation of SiC power devices [4]. Ag substrate metallization provided better adhesion (40 MPa) than Au substrate metallization (20 MPa) [5]. For large die (6 mm x 6 mm [6] and 10 mm x10 mm die [7, 8]), pressure during the sintering process was still needed. To reach a shear strength >30MPa and good electrical performance, 3 MPa of lamination pressure was needed during sintering [6].

Pressureless sintering for large die has been presented in our previous work [9]. But the porosity was approximately 30%, which is expected to reduce the thermal conductivity and mechanical strength.

In order to decrease the porosity of the sintered Ag layer, application of pressure might be the only method. Lei, et al. [10] used four drying steps at 50, 75, 100 and 125 °C for 50 minutes, followed by 20 minutes of 275 °C sintering for attaching large-area die. With 5 MPa pressure, a relative low pore density of about 20% and shear strength of 31.6 MPa were achieved. Xiao, et al. [8] simplified the process to a 5 minutes 180 °C pre-dry under 3 MPa for one sintered Ag layer and pressureless sintering for another fresh thin layer for 30 minutes. A die-shear strength greater than 30 MPa with nearly perfect, crack- and void-free bond-line was obtained. Zheng et al. also used a double print method [11, 12] that dried a 1st layer of Ag sintering paste in N_2 at 180 °C for 5 minutes and sintered a 2nd 10 um layer at 275°C for 3 minutes with 5 MPa applied. The pore density was 23.48%. Applying sintering pressure above 3 MPa was sufficient for die shear strengths in excess of 40 MPa. Nitrogen during sintering was confirmed to lower the sintering pressure from 20 MPa to 10 MPa while achieving 20 MPa shear strength [13]. The process included a 130°C, 5 minutes pre-dry and a 300°C, 10 minute sintering. Recently, Li et al. experimented with a combination of pre-dry time from 10 to 45 minutes and sintering time from 1 minute to 8 minutes with pressure from 1 MPa to 15 MPa. The shear strength varied in wide range from 10 MPa to 100 MPa. The porosity was about 24 % [14]. All the publication mentioned above used a hot press to apply pressure during sintering and used a silicone rubber to protect the die.

In this work, a 150°C, one-minute pre-dry and a 300°C one-minute sintering process was developed. The reduction in the sintering time allowed the use of a flip chip thermocompression bonder for automated die attach.

Test Vehicle

Substrate Metallization: 5.08 cm x 5.08 cm x 0.64mm thick, 96% alumina (Al_2O_3) substrates purchased from Coorstek were used for this experiment. The substrates were metallized with three different thick film conductors. For Au or Ag metallized substrates, one layer of Au or Ag conductor thick film paste was printed onto the substrates and dried at 150 °C for 10 minutes, then fired at a peak temperature of 850 °C for 10 minutes. The third group of substrates was first metallized with a layer of Au thick film using the same procedure. The use of Au thick film for the die attach pad and interconnect routing eliminates the risk of Ag migration at high temperature and is compatible with Au wire bonding. However, to provide a "Ag" surface layer for the sintered Ag die attach, a layer of thick film Ag was printed on the previously printed and fired Au die attach pad. The Ag was dried and fired, creating a Ag top surface on the die attach pad. Die attach pads were fabricated for both 3 mm x 3 mm die and 8 mm x 8 mm die.

Die Metallization: Si wafers and SiC wafers were metallized on the backside by e-beam evaporation. For Au metallized die, Ti (50 nm), Ni (200 nm), and Au (200 nm) were sequentially deposited. Ag metallized die was fabricated by sequential deposition of Ti (50 nm), Ni (200 nm), and Ag (300 nm). The Si wafers were diced into 8 mm x 8 mm test dies and SiC wafers were diced into 3mm x 3mm test dies.

Assembly and Characterization Processes

Ag Paste Deposition: The die attach material was Ag sintering paste containing micrometer-size Ag particles. A 50μm thick laser cut stencil was used to print the silver sintering paste on the metallized substrate with a metal squeegee on an MPM semiautomatic printer.

Fast Pressure-Assisted Sintering Process: The fast pressure sintering process included three stages: pre-dry, die placement and sintering. The sintering process included a temperature ramp to a desired temperature, dwell time at the desired temperature and cool down. After the Ag sintering paste was printed, the substrates with fresh patterns were placed into oven to carry out the pre-dry process at 150 °C for one minute. The placement and sintering steps were accomplished with an FC150 die/flip chip bonder. The temperature was ramped at the maximum rate and a force was gradually applied to the die to reach the desired value in 100 seconds (Figure 1). When the temperature reached 300 °C, 60 seconds of dwell time was initiated. After 160 seconds from cycle initiation, the cooling process was activated and the force was gradually reduced as shown in Figure 1.

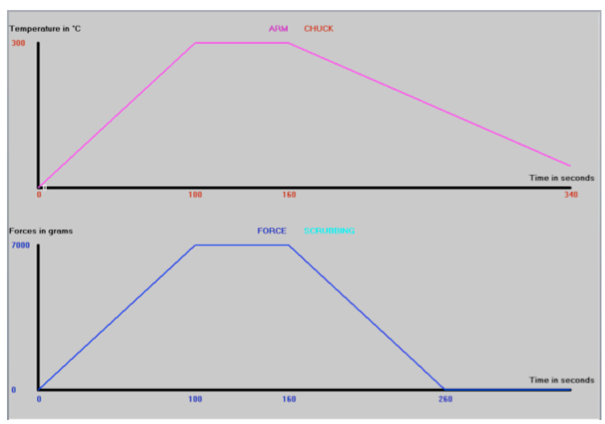


Figure 1. Temperature and force profile of pressure assisted fast sintering, exhibiting a 3°C/s ramp rate and sintering/force application dwell time of 60 seconds.

Characterization Process: In order to evaluate the different metallization material, as-sintered samples were analyzed by shear testing and sample cross sectioning imaging using scanning electron microscopy (SEM). In addition, sintered samples were aged at 300 °C for 1 hour, then analyzed by shear testing and cross sectioning.

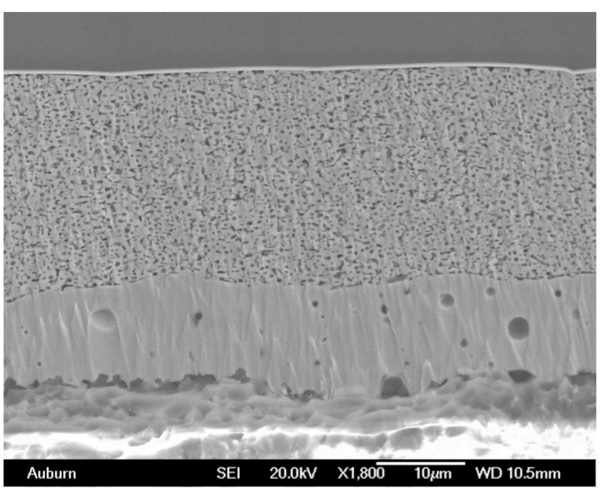
Die Shear Testing: A Dage 2400PC shear tester with a 100 kg die shear module was used for die shear testing. In some cases the die could not be sheared with the 100 kg applied force. For a 8mm x 8mm die, this corresponds to a maximum shear test limit of 15.3 MPa.

SEM Analysis: SEM cross sectional analysis was used to examine the microstructure of sintered Ag layers. Samples were diced into two pieces along the center of the die. For samples known to have low shear strength, the die was encapsulated with epoxy prior to dicing to maintain the integrity of the die attach films. Clean cross section structures were then prepared for SEM examination utilizing a Gatan ion milling machine with an Ion Tech 22cm Linear Ion Gun.

Process Development Results and Discussion

1. Au Die Metallization, Ag Substrate Metallization

8 mm x 8 mm Si dies with Ti/Ni/Au metallization were pressure sintered using 7.6 MPa on Ag thick film metallized substrates. None of the samples could be sheared when the maximum force of 100 kg was applied (shear strength > 15.3 MPa). As can be seen in the cross-sectional image shown in Figure 2(a), the as-built sample exhibited a die attach layer with a very dense microstructure. After 1 hour of aging at 300 °C, the small pores merged to form a larger porous structure as shown in Figure 2(b). A dense Ag layer approximately 1 μm thick formed on the die side. The pore size was smaller on the die side than on the substrate side, the porous structure was not homogenous from die to substrate.



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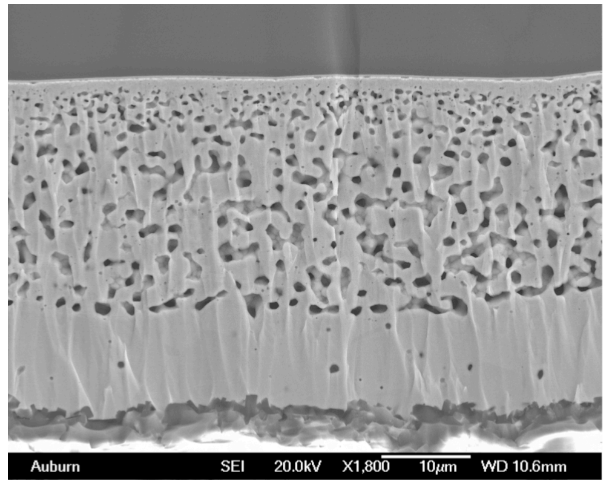


(b)

Figure 2. (a) Cross-sectional SEM image of die attach layer for an 8mm x 8mm Au metallized die with Ag thick film substrate that was sintered at 300 °C with 7.6 MPa pressure for one minute. (b) Cross-sectional SEM image of sample that was aged at 300 °C for 1 hour.

2. Ag Die Metallization, Ag Substrate Metallization

The 8 mm x 8 mm Ag metallized die assembled with the one-minute pressure-assisted (7.6 MPa) sintering process could not be sheared. Figure 3 shows the cross-sectional microstructure of pressure sintered as-built sample. A homogenous sintered Ag die bond with a porosity of approximately 15% was observed.

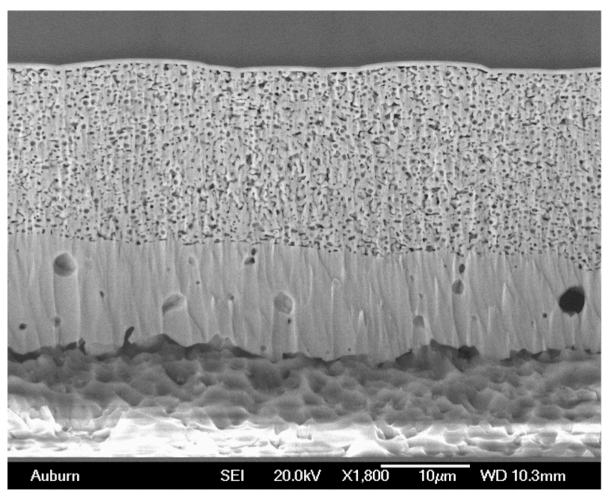
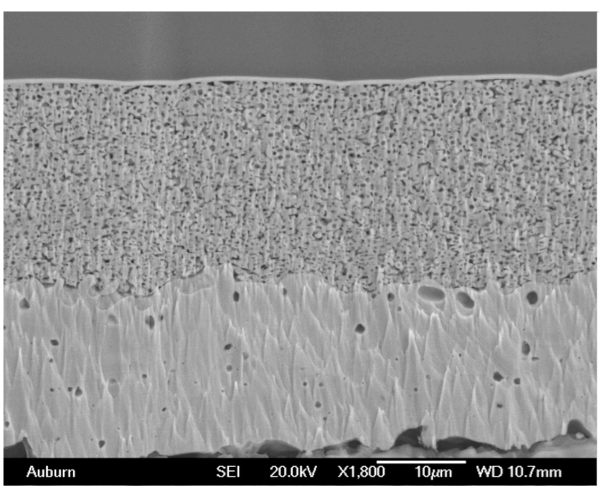


Figure 3 Cross-sectional SEM image of die attach layer of as-built sample that was 8 mm x 8 mm Ag metallized die with Ag thick film substrate sintered at 300 °C with 7.6 MPa for one minute.

3. Ag Die Metallization, Au + Ag Substrate Metallization

Due to Ag migration concerns, thick film Au metallized substrates are more commonly used in high temperature electronics packaging. Au thick film for the die attach pads and interconnect routing eliminates the risk of Ag migration at high temperature and is compatible with Au wire bonding. It has been shown that sintered micro-scale Ag has a reliability issue with 300°C storage when assembled on Au substrates with pressureless sintering [9]. To provide a “Ag” surface layer for the sintered Ag die attach, a layer of thick film Ag was printed on the previously printed and fired Au die attach pad. The Ag was dried and fired, creating an Ag top surface on the die attach pad. The Au thick film pattern was 16 mm x 16 mm; the Ag thick film pattern was 8 mm x 8 mm. After 850 °C firing for 10 minutes, the 8 mm x 8 mm die pattern of Au + Ag thick film showed signs of interdiffusion.

The die could not be sheared after the 1-minute pressure-assisted sintering. Neither did it shear after 1 hour aging at 300 °C. For the thick film cross section shown in Figure 4, the Au and Ag diffused into each other and formed a Au-Ag solid solution on the ceramic substrate side. The sintered Ag layer had a homogeneous porous structure. It is clear that the Ag grains in the die attach layer grew larger during the 1 hour aging at 300 °C. The pore size increases, while the number decreases with aging. No depletion region or continuous, non-porous Ag layer was observed.



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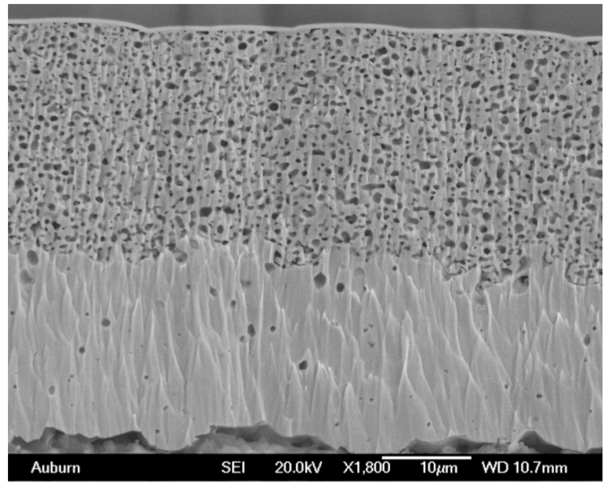


(b)

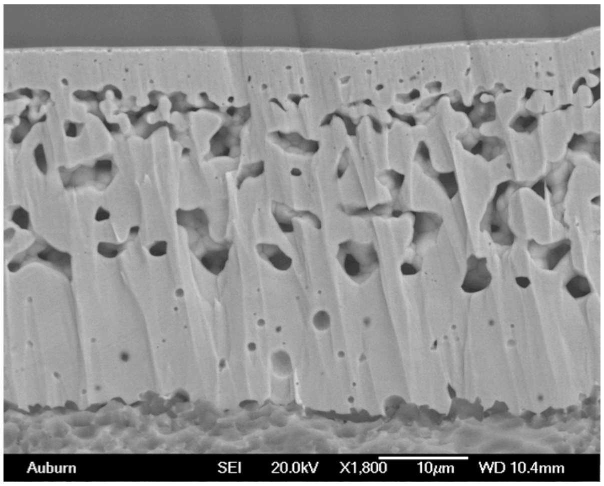
Figure 4. (a) Cross-sectional SEM image of die attach layer of as-built sample that was 8 mm x 8 mm Ag metallized die with Au + Ag thick film substrate sintered at 300 °C with 7.6 MPa for one minute. (b) Cross-sectional SEM image of sample aged at 300 °C for 1 hour.

Long Term Aging Study

In order to explore the high temperature reliability of the sintered micro-scale Ag die attach, a long-term reliability test was conducted at 300 °C. All sample groups were assembled using a 300 °C, one-minute pressure-assisted (7.6 MPa) sintering process.

1. Au Die Metallization, Ag Substrate Metallization

For Au metallized die with Ag thick film substrates, after 24 hours, the pore size increased and a non-porous layer of sintered Ag (~6 um) formed at the Au metallized die side of the attach layer as shown in Figure 5(a). This phenomenon was also observed in pressureless assembled samples [14]. However, compared to the pressureless assemblies, there was no depletion region observed with pressure-assisted assembly and the continuous, non-porous Ag layer was much thicker on the die side after 24 hours aging. The die could not be sheared until 500 hours, when the shear strength dropped to 12.8 MPa. In the cross section of the 500 hours aged sample (Figure 5(b)), a very thick, dense layer of Ag had formed on the die side of the sintered Ag layer and a depletion region was left behind near the substrate side. The lower shear strength was a result of this depletion layer.



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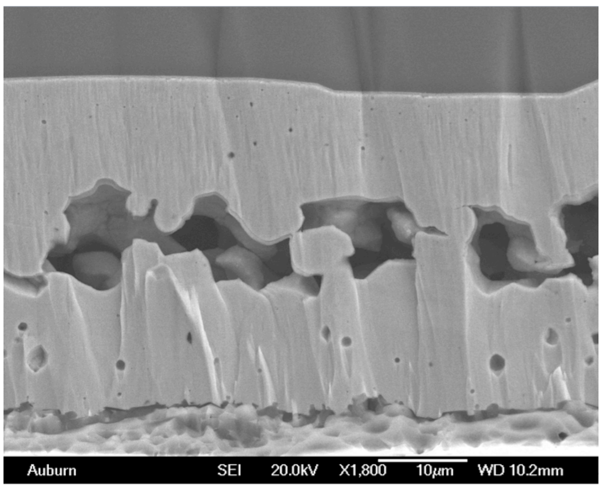


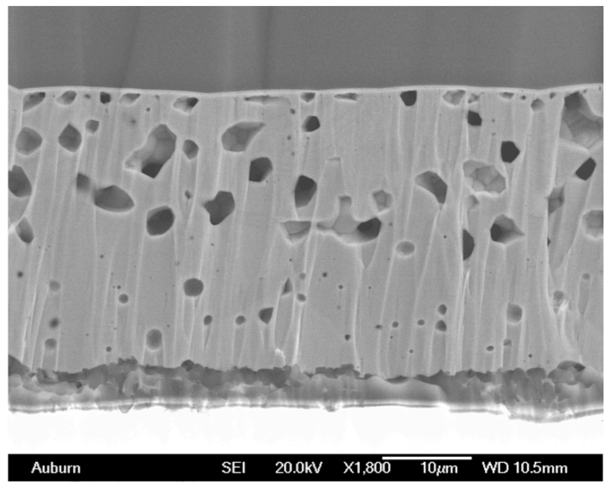
(b)

Figure 5. (a) Cross-sectional SEM image of die attach layer of sample that was 8mm x 8mm Au die with Ag substrate sintered at 300 °C with 7.6 MPa pressure for one minute and aged at 300 °C for 24 hours. (b) Cross-sectional SEM image of sample aged at 300 °C for 500 hours.

2. Ag Die Metallization, Ag Substrate Metallization

For the Ag metallized die and substrate combination, the die could not be sheared (the shear strength was higher than 15.3 MPa) after 2000 hours of aging at 300 °C. The microstructure of samples after 24 hour aging and 1500 hours of aging is shown in Figure. 6. The morphology of the porous structure remained stable after 24 hours.

Since the 8 mm x 8 mm dies could not be sheared, 3 mm x 3 mm die were assembled and aged at 300^{o}C. The shear strength data was stable and consistent, remaining at approximately 72 MPa during aging (Figure 7). The porous structure of the small die samples was similar to the larger die (8 mm x 8 mm) samples. The porosity of the sintered Ag area was calculated using Matlab code from cross section SEM images. Three 3 mm x 3 mm die samples were prepared and the mean porosity was calculated to be 17%, which was similar to the 8 mm x 8 mm die samples (15%). The tolerance of the porosity calculation is estimated to be $\pm 2\%$ because of the surface topology, definition of boundary and image quality of the SEM images. However, it does provide a relative comparison of densification among different sintered Ag die attachment. Other research groups have encountered the same porosity accuracy issue [7, 15].



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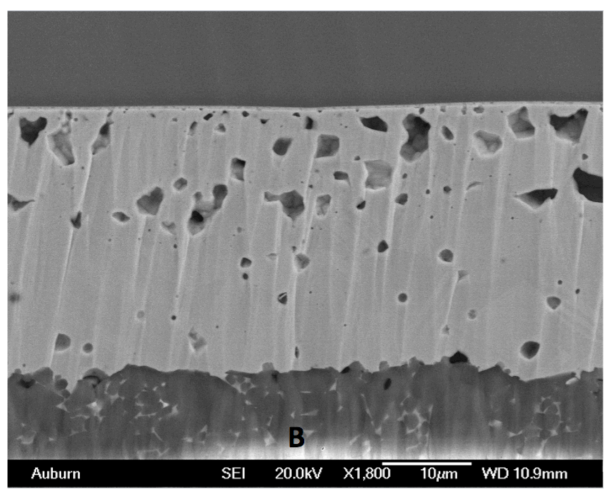

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Figure. 6. (a) Cross-sectional SEM image of die attach layer of sample that was 8mm x 8mm Ag die with Ag substrate sintered at 300 °C for one minute and aged at 300 °C for 24 hours. (b) Cross-sectional SEM image of sample aged at 300 °C for 1500 hours.

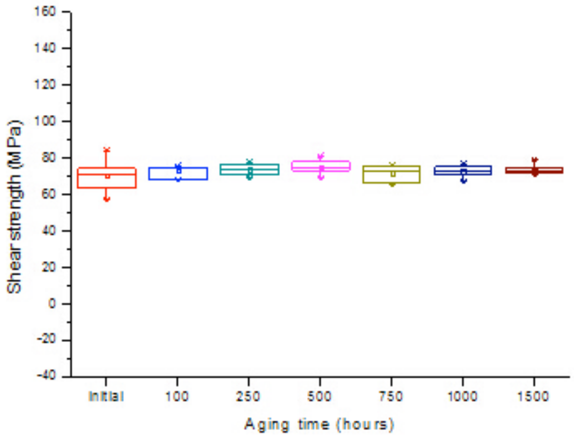
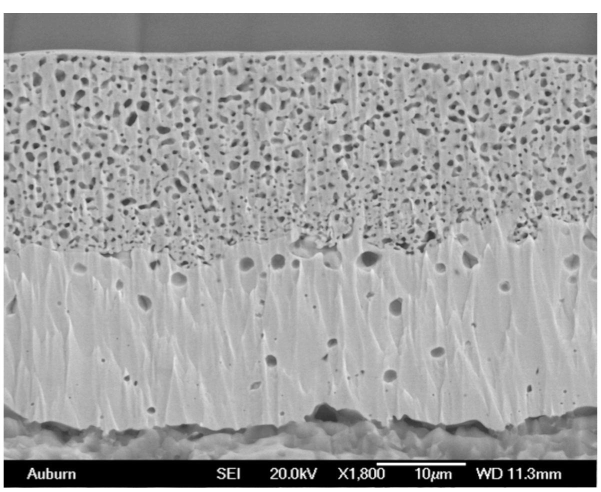


Figure 7. Shear strength of 3 mm x 3 mm Ag metallized die with Ag thick film substrate pressure-assisted (7.6 MPa) sintered at 300 °C for one minute and aging time from initial to 1500 hours.

3. Ag Die Metallization, Au + Ag Substrate Metallization

After 2000 hours of 300 °C aging, all the dies (8 mm x 8 mm) on the Au + Ag thick film substrates could not be sheared off from the substrates. Figure 8 (a) shows the cross section of a sample after 24 hours at 300^{o}C. The pore structure was very similar to the 1 hour aged sample (Figure 4). Figure 8 (b) is a SEM cross-section image after 2000 hours at 300^{o}C. The pore size increased and the structure was significantly different from the Ag thick film sample after 1500 hours (Figure 6(b)). No depletion region like observed after only 500 hours of aging with the Au thick film substrate (Figure 5 (b)) has formed. This is consistent with the inability to shear the die after 2000 hours at 300^{o}C.



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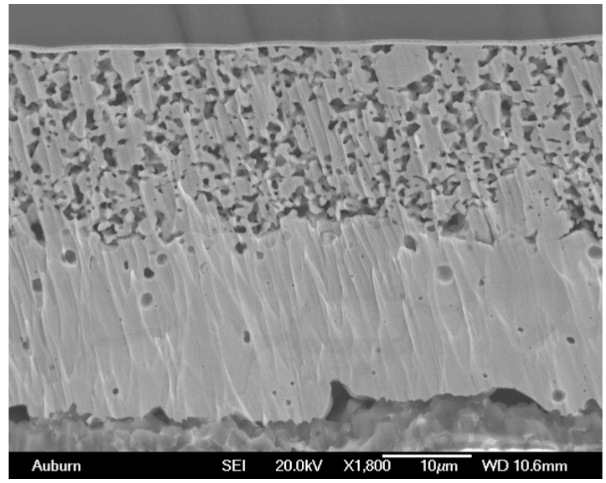

(b)

Figure 8. (a) Cross-sectional SEM image of die attach layer of 8mm x 8mm Ag metallized die with A Ag thick film substrate pressure-assisted (7.6 MPa) sintered at 300 °C for one minute and aged at 300 °C for 24 hours. (b) Aged for 2000 hours.

Conclusion

A pressure-assisted fast Ag sintering process has been demonstrated for large die (8 mm x 8 mm) and small die (3 mm x 3 mm). The void percentage was significantly decreased from 30% to 15% by using low pressure for one minute during sintering. Degradation of shear strength was observed with high temperature storage of Au metallized die on thick film Ag metallized substrates. For Ag metallized die and Ag thick film metallized substrate, high shear strengths (~70 MPa) were maintained after high temperature aging at 300 °C. To use sintered Ag on Au thick film metallized substrates, printing of a thick film Ag layer on top of the Au die attach pad has been explored. Pressure-assisted, fast sintering of micro-scale Ag die attach of Ag die metallization with Au + Ag thick film metallization is a viable assembly process for high temperature die attach.

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