A NEW ACTIVE SOLDER FOR JOINING ELECTRONIC COMPONENTS

Ronald W. Smith*, P. Vianco**, C. Hernandez**, E. Lugscheider***
I. Rass****, and F. Hillen****

ABSTRACT

Electronic components and micro-sensors utilize ceramic substrates, copper and aluminum interconnect and silicon. The joining of these combinations require pre-metallization such that solders with fluxes can wet such combinations of metals and ceramics. The paper will present a new solder alloy that can bond metals, ceramics and composites. The alloy directly wets and bonds in air without the use flux or premetallized layers. The paper will present typical processing steps and joint microstructures in copper, aluminum, aluminum oxide, aluminum nitride, and silicon joints.

INTRODUCTION

The joining of electronic components with solders places specific requirements on solder alloys for their respective use. Solders are used in a wide range of electronic component joining where alloy and process vary depending on their joint properties and process characteristics. Solders are used for i) die (chip) attachments, ii) interconnects / chip scale, iii) interconnects / printed circuit board level, iv) substrates / package attachment and v) package sealing. Figure 1 and 2 illustrates some of these applications.

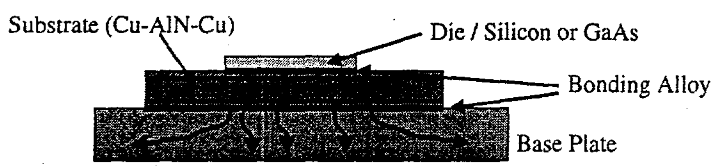

Figure 1. Heat spreaders substrates for electronics.

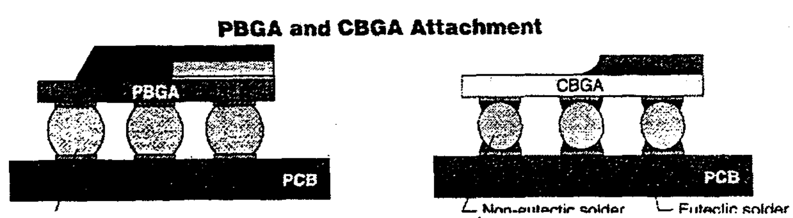

Figure 2. Solder connections in ball grid arrays (BGA's)

The solders that historically have been used are Pb/Sn, Sn/Ag, Au/Sn, In/Sn and Au/Ge. Their specific compositions will depend on their use and the combinations of materials being joined, as well as their required joining temperatures. The processes employed to join these various components are selected to be compatible with the materials, the stage of the assembly of the packages, their manufacturing compatibility and their cost. This paper presents a new family of active solders for bonding a range of dissimilar materials that are increasing in use in electronic packages[1,2,3].

*Materials Resources International, North Wales, PA, USA
** Sandia National Laboratory, Albuquerque, NM USA
***Technical University of Aachen, Aachen Germany
*** *Euromat, Hückelhoven, Germany

DISCLAIMER

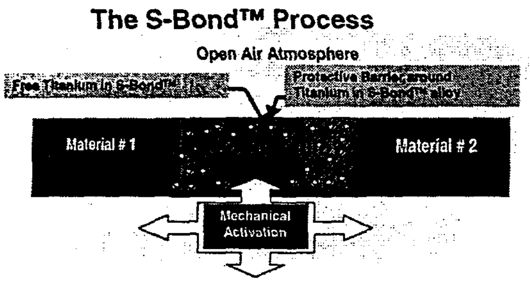

Figure 3. Illustration of active solder process

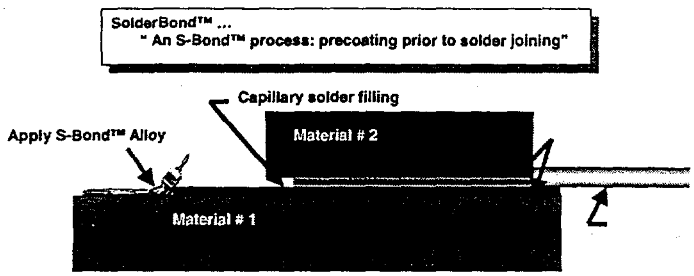

Figure 4. Illustration of active solder metallization.

Figures 3 and 4 (to the left) illustrate the essential processes by which the, fluxless, active solders can be processed to join various components. To overcome the low capilarity of these active solders, preplacement is required. The technique schematic in Figure 3 demonstrates that the preplaced alloy, when molten is "activated" by disturbing the molten pool/layers to break the thin tin oxides that form on the Sn-Ag-Ti alloy as it melts. Techniques that have been shown to work include brushing, vibrapeen spreading, spraying and via preplacement and ultrasonic action focused on the joint as in the ultrasonic equipment that is used in plastic welding.

Further techniques that may be used for electronic applications include using the active solder layers as a wetting layer, as is illustrated in Figure 4. In this process example, the active solder alloys is spread onto surfaces such as aluminum oxide, aluminum nitride and silicon, as well as aluminum, copper and titanium to enable wetting. After the surfaces to be bonded are wetted, they are placed together and mechanically disturbed followed immediately, while the active alloy is still molten (or is remelted) with application of a conventional solder, without the application of flux.

These process techniques combined with the active bonding nature of the reported Sn-Ag-Ti (plus various lanthanides) alloy, promise to enable its application for joining combinations of dissimilar materials in a range of electronics, as cited above. The work reported here is part of an ongoing investigation by the authors to determine the suitability of such active solders in electronic fabrications.

EXPERIMENTS

The objective of the planned work was to assess and measure the interaction and bonding of the low temperature, active Sn-Ag-Ti type solders against materials that would be experienced in electronics. To accomplish this a series of bond (solder joined) lap specimens were made. In this work, 1.2mm x 1.2mm x 0.5mm coupons of aluminum, copper, aluminum oxide, aluminum nitride and silicon were cut and polished. The pairs of these materials were left as polished and then degreased prior to heating to the joining. The joining consisted of heating the surfaces to 250°C +/- 10°C, melting a small amount (~ 0.2gm) of the solder alloy onto the surfaces followed by spreading the alloy onto the surface of each of the pairs faying surfaces. After working the alloy with a spreader into the surfaces the active alloy wetted the surfaces. When both surfaces were molten, an additional layer (~0.05mm) of the active solder was placed on one half on the joint and then the two halves of the joint were placed together. After placing the surfaces together a gentle movement of the two joints halve relative to one another was completed and then a weight was placed on the sets being bonded and the heat source was removed and the parts were cooled. The weight was sufficient to generate ~ 0.07MPa pressure at the joint interface. The pressure was found to be needed to assure that the faying surfaces remained in close proximity during solidification.

The bonded couples were scheduled for a range of temperature exposures and times. These isothermal treatments were designed to measure the interaction and level of the active solder's bonding as a function of time and temperature. These interactions would be able to determine the types of bonding with the various base metals and to determine the stability of the solder bonds in both solid state and near liquid state aging cycles. In this paper, the as-bonded and the high temperature (near solidus temperature, 205°C) aging experiments after 10 days exposure have been evaluated. Other temperatures from 25 – 205°C and from 10 hours to 100 days are currently under evaluation. The microstructures of these specimens are presented and discussed below.

RESULTS

Figures 5-9 below show the structure of the active solder bonded joint adjacent to the solder interface. The solder is seen to be multi-phase with the Sn-Ag eutectic phases and a range of Sn-Ti intermetallics that are created in the solder alloy when it originally produced. These intermetallics are not broken up in the processing of the solder and upon remelting these phases remain solid and become distributed in the joint.

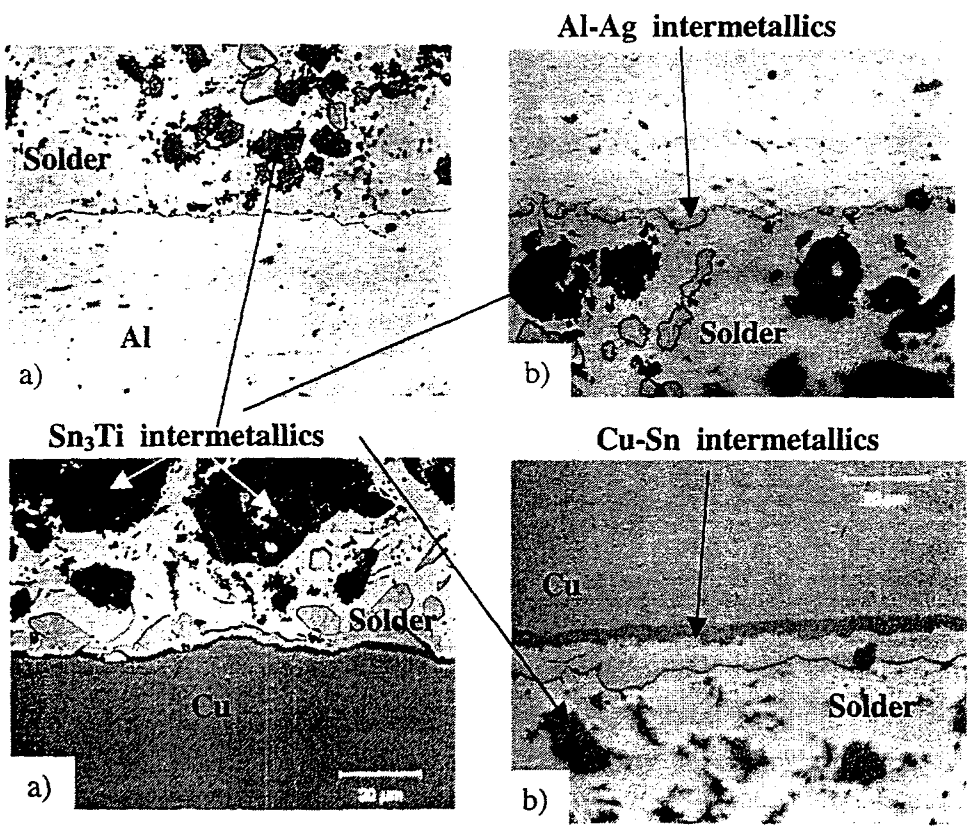

Figure 5. Al-Al joint showing the solder iterface:
a) as-bonded.
b) aged 10 days at 205°C.

Figure 6. Cu-Cu joint showing the solder iterface:
a) as-bonded.
b) aged at 205°C for 10 days.

These Sn-Ti intermetallics are likely a source of the Ti that is used for the active bonding that is believed to be responsible for the adhesion between the solder and the range of substrate materials to which the alloy bonds. As depicted in the joint interfaces presented here.

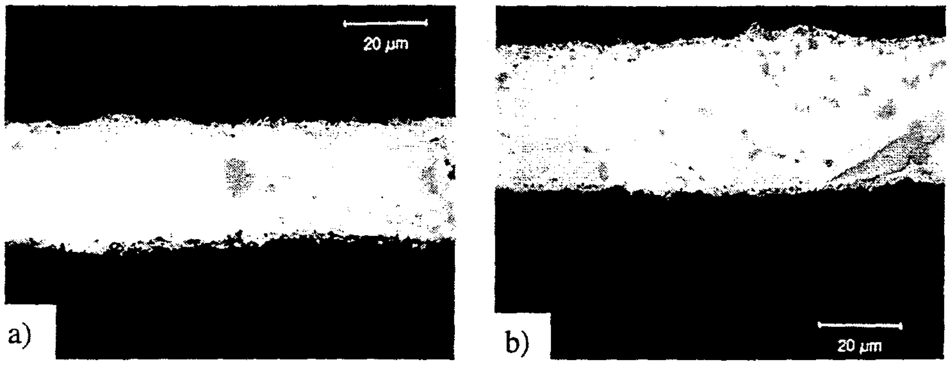

Figure 7. Al_2O_3 to Al_2O_3 joint showing the solder iterface:
a) as-bonded.
b) aged at 205°C for 10 days.

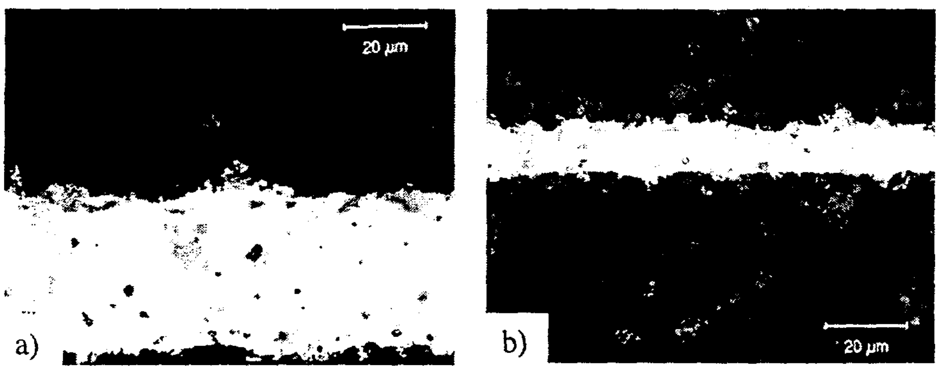

Figure 8. AlN-AlN joint showing the solder iterface:
a) as-bonded.
b) aged at 205°C for 10 days.

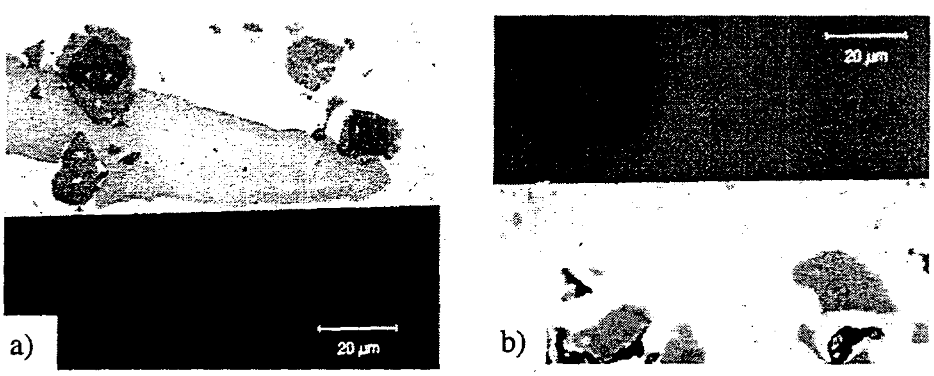

Figure 9. Si-Si joint showing the solder iterface:
a) as-bonded.
b) aged at 205°C for 10 days.

Figures 5 and 6 depicted the active solder bonded to metals aluminum and copper. One can see that the solder wets and bonds to both and is very stable in contact with the aluminum with a small, discontinuous Al-Ag phase forming while on the copper substrate a continuous Cu-Sn phase forms, as in conventional Sn based solders. There is one feature in the as-bonded Cu joint that shows some interphase fracture. This effect will be further studied in the other aging samples. After aging at 205°C for 10 hours there was no evidence of fracture. Figures 7-9 show the active alloy is capable of wetting and bonding to ceramics and silicon. Note in Figure 7 that there is no resolvable interactions that can be seen, but the solder is in intimate contact with the aluminum oxide surface. After 10 hours at 205°C, there may be some small barely resolvable interaction zone. Additional microscopy work will be required to better resolve if there are reactions. Figure 8 is another ceramic joint interface between the solder and aluminum nitride, an electrically insulative, thermally conductive ceramic. As in the aluminum oxide ceramic there is little resolvable interface interactions in the as-bonded joint, but after 10 hours at 205°C there is a change in the appearance in the AlN faying surface grains. Future electron microprobe analysis will be conducted to resolve what reactions may be occurring. These results on aluminum oxide and aluminum nitride show that the new active solder eliminates the need for pre-metallizing of faying surfaces that are normally used to solder to ceramics.

Finally, Figure 9 shows that the active alloy enables the bonding to Si, without the use premetalizations. The figures show a clean interface and close alloy contact with the Si surface but with no resolvable interactions. Even after 205°C for 10 hours there is no interactions seen. However, as seen in Figure 9b above and Figure 10b below, there may be some "dewetting" or other failure of the alloy/Sn_3Ti or the alloy/Si interfaces. This phenomena may have been a temperature control issue (205°C is only ~ 10°C from the solidus) where some remelting of the solder alloy could have begun. This will be evaluated in the course of the continuing investigations.

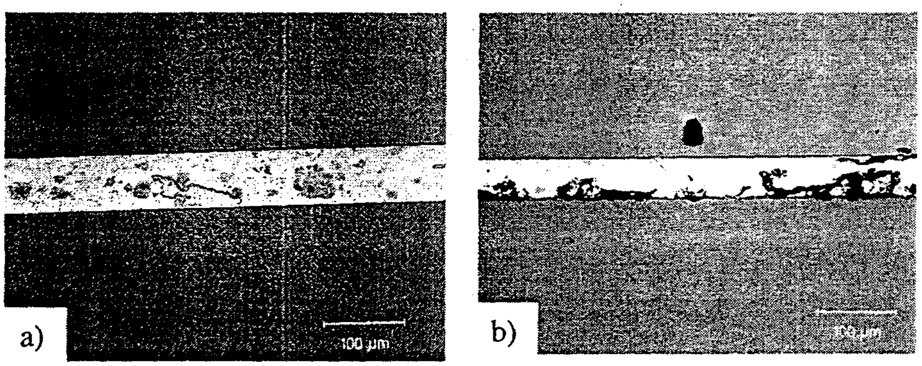

Figure 10. Si-Si joint showing the solder iterface:
a) as-bonded.
b) aged at 205°C for 10 days.
At lower mag. (200x)

Figures 11-13 below show another application example where aluminum metal matrix (Al-MMC's) are being used in electronic packages where high thermal conductivity and low CTE are required. The active alloy can be seen in these figures to be able to join such composites.

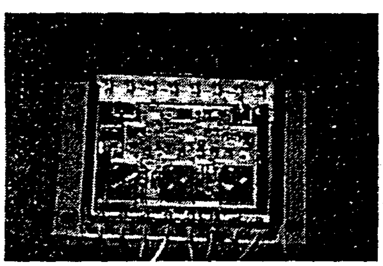

Figure 11. An Al-MMC electronic pakage.

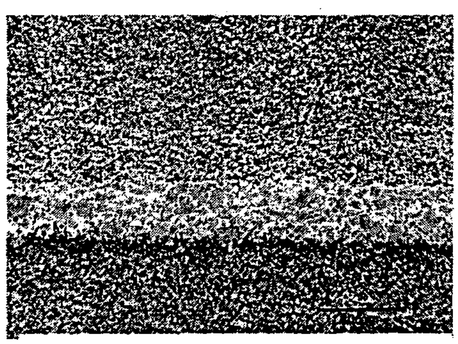

Figure 12. AlSiC joint joined with active solder.

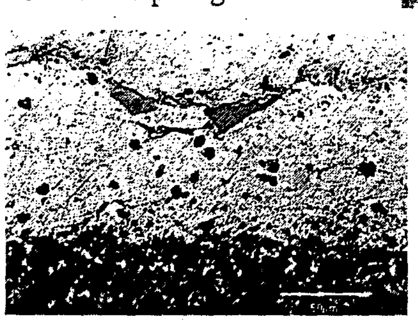

Figure 13. Al-SiC joined to Kovar® using active solder.

Figure 11 shows an electronic package that has a Kovar® (Fe-Ni/low CTE) alloy lid bonded to the Al-MMC body. Figures 12 and 13 illustrate how the active alloy has bonded to the aluminum matrices and wetted and adhered to the SiC phases seen in such Al-MMC composites. Note the good wetting and bonding of the active solder to the Al-SiC and the Kovar® materials.

The figures above show additional use of the new active solders with composites. The figures below, Figures 14 and 15 show a promising application for the active solders for joining AlN to copper for use in electronic power modules that are used in switching and controlling high amperage current elements. A key characteristic for these type joints are the high thermal conductivity that requires metallic bonds between the Cu and the AlN ceramic substrates. Figure 14 shows a commercially available type substrates that provides Cu-pads to which Si-elements are bonded and interconnects are made.

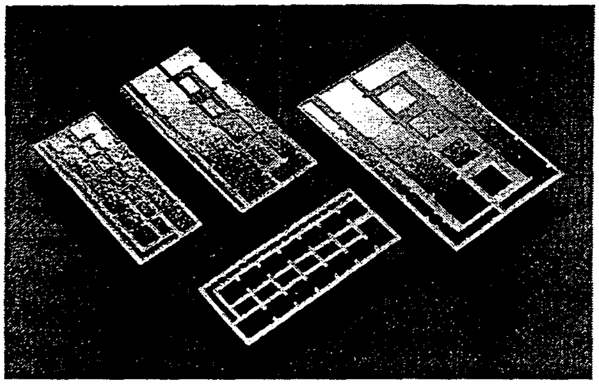

Figure 14. Photo of commercial AlN-Cu substrates used in power modules.

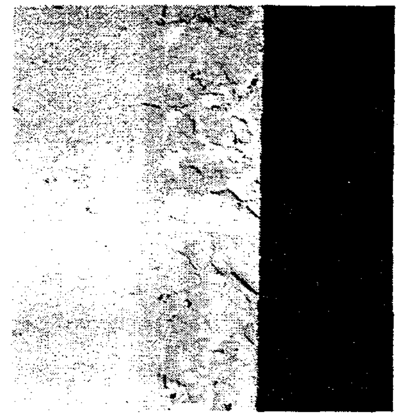

Figure 15. An example of a Cu-AlN joint with active solder joint.

The joint structures presented in this paper show that the new active solder, although not yet fully understood, has the capability to bond to metals, ceramics and composites. Thus, the active solder has the potential to be a versatile bonding process and alloy for many emerging electronic applications, especially those for which flux use is prohibited or require that dissimilar materials be joined.

Data on specimens, not part of this direct investigation, show that the active alloy shear strengths for aluminum bonded to aluminum are 45-60MPa while the strengths in aluminum oxide to aluminum nitride bonding dropped to ~ 20-30MPa. Other data show the properties of the alloy to have substantially the same thermal and electrical properties as Sn-Ag based solders. For example the active alloy had CTE of 19-21 ppm/°C while the thermal conductivity was 48-50 W/mK. Electrical resistivity was near that of Sn-Pb alloys.

CONCLUSIONS

The completed work shows that the active solder, Sn-Ag-Ti with lanthanides can wet and bond to a variety of materials such as copper, aluminum, silicon, aluminum oxide and aluminum nitrides that are expected to have a significant role in electronic devices. The metallographic investigations conclude that in all cases bonds have been established and that in aluminum and copper joints there are reactions on the interfaces that indicate good bonding can be achieved. For the ceramics, aluminum oxide and aluminum nitride it is evident there is adherence but with little of no resolvable interface reactions. The silicon bonding is similar to the ceramic bonding, but the interface is much smoother.

Upon aging at 205°C for 10 days, there are significant interface reactions with Cu base metals that have continued to age and grow. The aluminum interface us much more stable with the appearance of Al-Sn and Al-Ag phases. The ceramic bonds look very stable and there is some indication that reactions may be occurring, but additional testing and analysis will be required to measure this. Finally, for the silicon joined with the active alloy, there appeared to be dewetting but the Si interface remains substantially inert. The dewetting is being investigated as to its cause by too high an aging temperature where the joining alloy was above its solidus temperature.

In conclusion, the active solder presented here seems to have potential as a versatile bonding alloy that can join metals, ceramics and composites without flux and without pre-metallization. With these attributes, there appears to be wide spread application for such low temperature, active solders to make die attachments, substrate bonds, heat sink attachments and low CTE package assembly.

ACKNOWLEDGEMENTS

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