

High Temperature, Pb-Free, Metallic Sputtering Target Bonding Using Reactive Multilayer Foil

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ABSTRACT

Sputtering targets used in physical vapor deposition (PVD) processes are bonded to compatible backing plates to promote cooling and to extend the life of the target material. There are several bonding methods used in the sputtering target manufacturing community: diffusion bonding; elastomer bonding; silver-filled epoxy bonding; and metallic bonding, typically using indium or tin-based alloys. The bonding method varies with the choice of target material, backing plate material, and intended bondline temperature during the deposition process. Metallic bonds provide excellent thermal and electrical conductivity, but are limited by the relatively low melting point of the solder material used - 157°C for indium or 217°C for tin-based alloys. This limits the power input, which in turn limits sputtering rates and final film properties. There is a desire for a higher temperature (> 300°C) metallic bonding process that can produce flat, stress-free target assemblies, enabling targets to run at higher temperatures for longer periods of time. This paper demonstrates a metallic bonding process using reactive multilayer foils and a high temperature alloy with melting temperatures as high as 380°C. This process is compared with typically-used traditional Sn-based solders, specifically comparing shear strengths, void analysis, and cross-sectional analysis.

INTRODUCTION

Sputter target bonding with reactive multilayer foil is a well-known, well-documented practice which has been commercially available since 2005. This industry-accepted bonding method offers higher strength than traditional indium bonding because it uses higher melting temperature solders. This allows end users a sputtering target assembly capable of performing at higher powers and higher deposition rates when compared to an indium-bonded target. Commercially accepted bonding practices using reactive multilayer foils typically use soft solders (Sn-based, lower temperature); however, there is a desire for a metallic bonding process using reactive multilayer foil coupled with higher temperature hard solders (Zn-based, higher temperature).

Compared to traditional indium bonding, SnAg solder used in reactive bonding reflows at 221°C, whereas indium reflows at 157°C. Although indium is a very compliant material, it has a low shear strength of 4 MPa compared to SnAg, which offers a higher shear strength of 28 MPa. Traditionally, SnAg solder is pre-applied to the backing plate and target material in separate operations [1]. The solder application process depends largely on the material type, but it is typically applied by heating the material on a hot plate above the melting temperature of the SnAg solder (221°C). The solder is then applied to the heated surface via mechanical agitation, flux/reflow, or via ultrasonic soldering methods.

As a heat source, reactive multilayer foils can reach temperatures exceeding 1500°C and are capable of reflowing any solder. This paper demonstrates bonding aluminum (Al) to molybdenum (Mo) using reactive multilayer foil and hard zinc-aluminum (ZnAl)-based solders. ZnAl-based solders offer melting temperatures in excess of 385°C and have shear strengths comparable to SnAg-based solders. The ZnAl solder was thermally sprayed onto the target and backing plate material. Different thickness reactive foils were compared, as well as the use of a proprietary adhesion promoter to help increase adhesion and shear strength. Thermal spray was employed for three reasons: (1) thermal spraying of zinc and aluminum for corrosion protection applications is a well-established technique [2]; (2) heating the aluminum to 400°C would be difficult on an open hot plate because aluminum conducts heat very rapidly; and (3) due to their lower melting temperatures, aluminum and aluminum alloys may be annealed or tempered as low as 325-350°C in a relatively short time. Overheating may result in altered properties such as stress relieving, sagging or warpage, altering hardness, tempering, surface condition, or melting the base metals in some cases. By employing thermal spray techniques, both the target and backing plate remain at room temperature during the entire bonding process [2].

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The following is a discussion of the experiments that were conducted, a table showing measured bond strength data of various assemblies used, and images depicting bond quality, along with a void analysis.

MATERIALS AND METHODS

All experiments used two separate lead-free zinc-aluminum alloys composed of 98 weight percent zinc and 2 weight percent aluminum (98Zn/2Al) or 85 weight percent zinc and 15 percent weight aluminum (85Zn/15Al). Both the 98Zn/2Al and 85Zn/15Al solders were selected due to their high melting temperatures, lead-free composition, high thermal and electrical conductivity, higher bulk shear strength, and commercial availability in solid solder wire form necessary for thermal spray. The experiments also included the use of a proprietary adhesion promoter which was applied onto the aluminum and molybdenum plates prior to thermally spraying the ZnAl solders. 40 μm -thick and 60 μm -thick reactive foils were used during the experiments. The ZnAl solders used in this experiment and their properties are listed in Table 1. All experiments included T6061 aluminum backing plates and molybdenum targets because of the large coefficients of thermal expansion differences between these two materials.

Table 1: Comparison of Zn/Al solders.

	98Zn/2Al	85Zn/15Al
Density (g/cc)	6.92	5.7
Liquidus ($^{\circ}\text{C}$)	385	460
Solidus ($^{\circ}\text{C}$)	377	382
CTE: $10^{-6}/^{\circ}\text{F}$	12–15	12–15
Thermal Conductivity (W/m $^{\circ}\text{K}$)	105–125	105–125

The molybdenum targets and aluminum backing plates were prepared by thermally spraying ZnAl solder either directly onto a grit blasted surface or over a proprietary promoter, which was pre-applied to the target and backing plate.

The Mo targets and Al backing plate materials were prepared using the following procedure:

1. An Al plate measuring 4" x 4" x .25" thick was prepared for solder application by thermal spray, first grit blasting one surface of the plate.
2. For samples with an adhesion promoter, the proprietary adhesion layer was applied directly onto the Al backing plate.
3. The grit blasted surface of the Al plate was then thermally sprayed with the ZnAl solders .030" thick.
4. For samples with an adhesion promoter, the ZnAl solder was thermally sprayed over the adhesion promoter .030" thick.
5. The same procedure was replicated on the molybdenum targets, also measuring 4" x 4" x .25" thick.

Once the solder is pre-applied to the separate components, it is important to ensure that the surface of the solder material is flat to a specification of .001" per 1.0" (0.025 mm per 25.4 mm) [1]. Flat solder surfaces ensure that the reactive foil, when sandwiched between layers of solder, makes contact with both solder layers and reflows, creating a metallic solder bond (Figures 1, 2, 3, and 4).

6. The pre-wet surfaces of both the Al backing plate and Mo target were machined flat to a uniform thickness of 0.010" and a flatness specification of .001" per 1".
7. Reactive foil either 40 μm - or 60 μm -thick was placed on the solder surface of the Al backing plate. The Mo target was then placed on top of the reactive foil (solder side down) such that the reactive foil was sandwiched between the solder layers.
8. The assembly was aligned and placed under a load of 3 MPa to ensure uniform pressure throughout the entire bond area.

Table 2: Average shear strengths of bonds formed using reactive multilayer foil for different Zn-based solders. SAC305 is included for comparison.

Solder	Reactive Multilayer Foil Thickness	Process	AVG Shear Strength (MPa)
98Zn/2Al	40 μm	Thermal Spray	14 MPa
98Zn/2Al	60 μm	Thermal Spray	16 MPa
85Zn/15Al	40 μm	Thermal Spray	10 MPa
85Zn/15Al	60 μm	Thermal Spray	15 MPa
SAC305	60 μm	Hot Plate	25-30 MPa
98Zn/2Al	40 μm	Thermal Spray with Bond Coat	21 MPa
98Zn/2Al	60 μm	Thermal Spray with Bond Coat	20 MPa
85Zn/15Al	40 μm	Thermal Spray with Bond Coat	21 MPa
85Zn/15Al	60 μm	Thermal Spray with Bond Coat	20 MPa

9. The reactive foil was then activated in a single location using a low voltage (2V, 10A) resistance soldering system.

The activation initiated an exothermic reaction in the reactive foil, which created localized heat at the adjoining solder layers, thus creating a metallic solder bond. The procedure was repeated using 85Zn/15Al. A total of 4 assemblies were prepared using 98Zn/2Al solder (2 with 40 μm reactive foil and 2 with 60 μm reactive foil). A total of 4 assemblies were prepared using 85Zn/15Al solder (2 with 40 μm reactive foil and 2 with 60 μm reactive foil).

BOND (SHEAR) STRENGTH

Table 2 shows the bond strengths of various assemblies outlined in this experiment, which were measured by using an Instron model # 5569 across three 1"-square samples of each material set. For comparison, SAC305 solder and 60 μm -thick reactive multilayer foil, which is commonly used in the sputter target bonding processes using reactive multilayer foils, are also included in Table 2. Al shear samples failed at the solder-to-Al and/or solder-to-Mo bondline, not at the reactive multilayer foil bondline. As expected, the bond strength of the solder is not the weak point; rather, the weak point is the thermal spray bondline. By comparison, the addition of the adhesion promoter increased shear strength by 5 Mpa.

BOND QUALITY

Bond quality was measured by using scanning acoustic microscopy (C-scan), which is able to detect bonding flaws at the bonding interfaces. Results showed bond quality that is similar to published reactive bonding methods using SnAg-based solders. Solder composition and reactive foil thickness showed no measureable differences in terms of void percentage among the samples tested. Figure 1 shows a typical C-scan from the experiments. The white dot in the bottom of the image indicates a void in the solder bond line and the dark regions indicate good bond quality between the target material and backing plate.

Cross sections were examined to determine the bond quality at the interfaces. Figures 2-7 are cross sections from the thermal spray interfaces as well as the solder and reactive foil interfaces. Results indicate good mechanical adhesion at the thermal spray interfaces, both with and without the adhesion layer. Due to the relative low boiling point of zinc (419.5°C), there was concern that the heat generated from the exothermic reaction of the reactive foil would cause voids at the direct interface of the reactive foil to the ZnAl solder. Cross sectional analysis indicates no voiding at these interfaces, as seen in Figure 6.

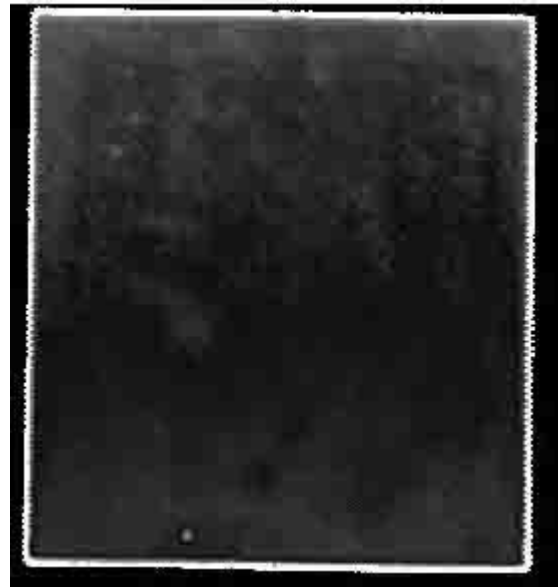


Figure 1: C-Scan of target assembly.

CONCLUSION

The use of reactive foils to bond sputtering target assemblies is a well-established technique with SnAg-based solders. By employing thermal spray techniques and using higher temperature solders, reactive bonding is a viable process to create high temperature sputtering target assemblies.

Next steps will include bonding different target and backing plate materials over a larger sample size and optimizing the thermal spray process to achieve higher shear strengths. In addition, other solder application methods will be considered and compared to thermal spray techniques. Lastly, sputtering experiments with ZnAl-based solder as a bonding material will be run to determine the benefits, if any, on film properties, process temperature, and sputtering rates and durations.

REFERENCES

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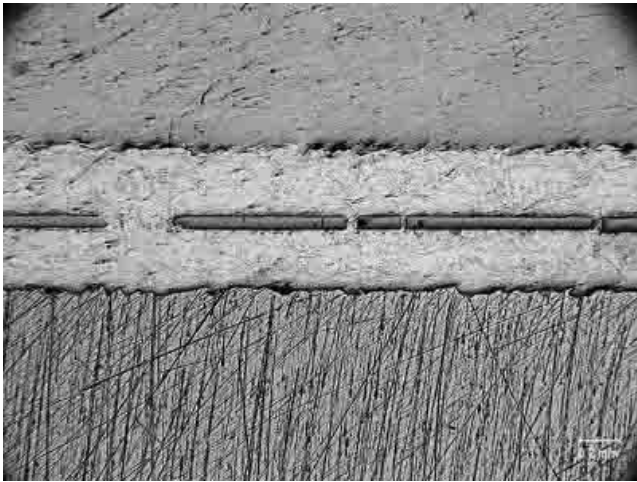


Figure 2: Cross section of 98Zn/2Al solder with 60 μm reactive foil.

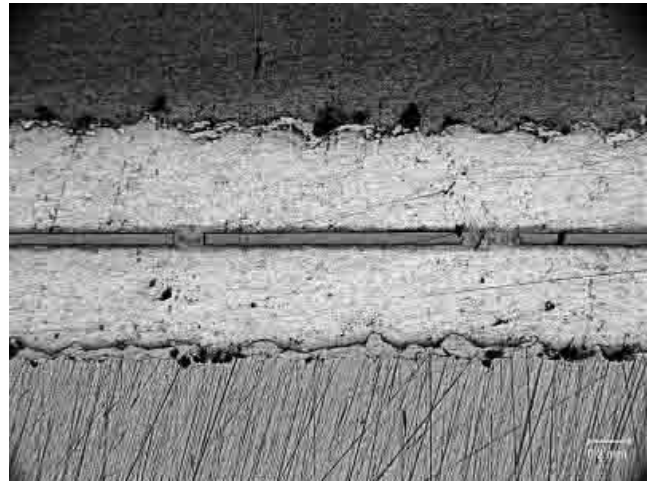


Figure 5: Cross section of 85Zn/15Al with adhesion layer; 60 μm reactive foil.

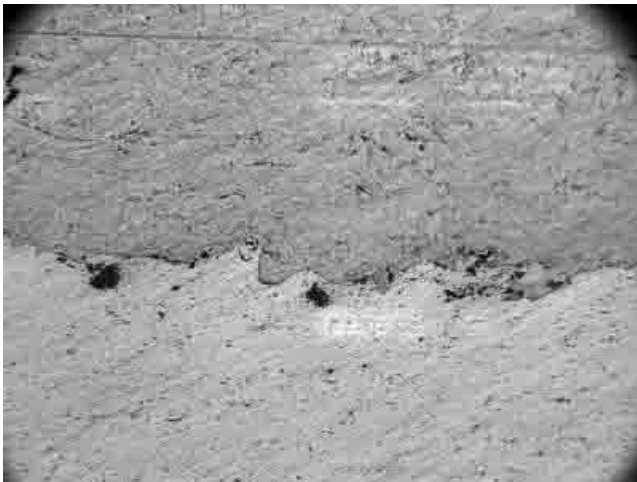


Figure 3: Cross section of 98Zn/2Al thermal spray interface.

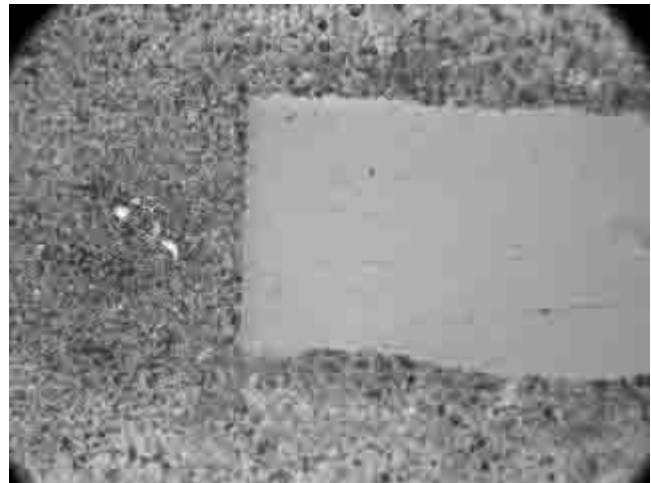


Figure 6: 85Zn/15Al cross section.

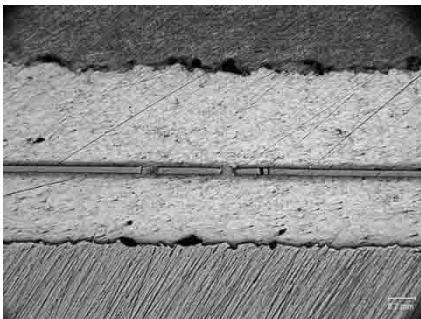


Figure 4: Cross section of 85Zn/15Al solder with 60 μm reactive foil.



Figure 7: 98Zn/2Al reactive foil.