A Room Temperature, Low-Stress Bonding Process to Reduce the Impact of Use Stress on a Sputtering Target Assembly

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Abstract

As semiconductor processing has moved to 300mm wafers, the size of deposition targets, including tungsten (W), tantalum (Ta), and molybdenum (Mo) has grown, and process complexity has increased as well. This added size and complexity contributes to the stress on a target assembly during the physical vapor deposition (PVD) process, and the target assembly's ability to withstand this stress has a large effect on the resulting deposition rates, yields, and film properties. One of the major sources of stress is the coefficient of thermal expansion (CTE) mismatch between metal targets in semiconductor processes, such as tungsten (CTE of 4.5*10-6/°C), tantalum (6.5*10-6/°C), and molybdenum (5.1*10-6/°C) compared with their backing plates, which are typically made of aluminum (23*10-6/°C), brass (21.2*10-6/°C), or copper-chrome (17.6*10-6/°C). Standard soldering and solid state joining processes have difficulty controlling stress produced by the CTE-mismatch. We will demonstrate how the NanoBond® process can be used to control stresses during the bonding and deposition processes. Modeling will be conducted to compare standard bonding processes to the NanoBond® process, accounting for CTE mismatches.

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Introduction

Refractory metals, such as tungsten and tantalum, are common metallizations deposited during semiconductor fabrication for microelectronic applications. Physical vapor deposition (PVD) is the preferred method of applying W, Mo, and Ta films. Planar sputtering targets of W, Mo, and Ta have experienced increasing size, commensurate with the increase in wafer diameter onto which the refractory metal is to be deposited. Specifically, as wafer diameters have increased to 200 and 300mm, particularly to enhance productivity, larger planar targets have been required.

Large planar targets must be generally affixed to large backing plates. The latter are generally needed for the purpose of providing structural support, facilitating cooling of the target material during deposition, controlling deposition properties, as well as reducing cost. The strength and uniformity of the bond between the target material and backing plate are critical, as well as the flatness of the resulting assembly. Over larger surface areas, the stresses induced into the assembly can be significant, especially when relying on conventional bonding processes. These stresses arise in large part due to the disparity between the coefficients of thermal expansion (CTE) of the target material compared to the backing plate material, as evident in Table 1.

Form No. 98663 R0

Table 1. CTE of typical target and backing plate materials.

Material	Linear α Coefficient of Thermal Expansion (CTE) at 20°C
Tungsten (W)	4.5µm/m-°C
Tantalum (Ta)	6.5µm/m-°C
Molybdenum (Mo)	4.8–5.1µm/m-°C
Aluminum	23µm/m-°C
Copper-Chrome	17.6µm/m-°C
Naval Brass	21.2µm/m-°C

Using conventional soldering processes to create the target-to-backing plate bond, the target assembly is heated to temperatures in excess of 160°C, expanding both the target and backing plate. As detailed by Duckham [1], when the solder re-solidifies and the assembly cools, excessive contraction of the metallic backing plate occurs in comparison to the low-CTE target material, resulting in a severely stressed bond. Over the large surface area of a 15"–18" diameter planar target, these stresses are apparent as fractures in the intermetallic layer forms between the bonding material (solder) and the target or backing plate metallization, warping of the assembly, and in extreme cases, causing delamination of the target from its backing plate.

Additionally, the conventional solder selected for this process is indium. Although bulk indium is very forgiving between mating surfaces of varying CTEs, indium has low strength and a low-melting temperature (as noted in Table 2). During sputter deposition, the indium bond is prone to melting, especially when operating at high deposition power densities. In these situations, indium bonds may weaken and ultimately fail to support the weight of large, heavy targets.

Table 2. Solder material properties comparison.

Material Properties	Indium Solder	SAC305 Solder
Melting Temperature (°C (°F))	157 (314)	217–220 (423–428)
Tensile Strength (psi)	273	7,200
Thermal Conductivity (W/mK)	86	58.7

An alternative bonding process is discussed in this paper based on using reactive multilayer foils, herein referred to as NanoFoil®, to perform room-temperature soldering. This process substantially relieves the stresses associated with the conventional hot-plate soldering because heat is deposited locally at the interface. Since the target and backing plate are not heated appreciably during the bonding process, it effectively reduces residual stresses. This is demonstrated using coordinate measurement mapping.

NanoBond® Background

The NanoBond® process, which uses NanoFoil® as a localized heat source for the purpose of room-temperature soldering or brazing, has been previously described [2, 3, 4]. NanoFoil® is a multilayered, reactive foil comprised of alternating layers of nickel and aluminum. The source of heat derives from the exothermic reaction between the elemental layers of nickel and aluminum to form 50Al/50Ni, providing a maximum temperature of 1,500°C.

When the NanoFoil® is used to create a solder bond between surfaces pre-wet with solder, the heat generated by the exothermic formation reaction is rapidly dissipated through the adjoining solder layers, resulting in a very short reflow cycle. However, the heat released is not large enough to significantly heat the target and backing plate components.

The 96.5Sn/3.0Ag/0.5Cu (SAC305) solder was selected for use with NanoFoil® due to its high thermal conductivity, strength, ductility, high rate of reactivity, and higher melting temperature. Previous tests have relied on other solders for target bonding as well [1, 2].

Experimental Target Bonding Processes

Two separate processes were used for bonding an aluminum backing plate to a molybdenum target. A conventional hot-plate soldering process using pure indium was used and compared to a NanoFoil® bond (NanoBond®) using SAC305 solder.

Both the conventional hot-plate soldering process and the NanoBond® process began by preparing the bonding materials, including a pre-wet with solder, using the following procedure:

1. Targets and backing plates were bead blasted to prepare their surfaces.
2. Targets and backing plates were cleaned with high pressure nitrogen followed by an isopropyl alcohol rinse, and dried with nitrogen.
3. For the indium hot-plate soldering process only, the bonding surface of the target was metallized with a three-layer sputtered film.
4. Bonding surfaces of the targets and backing plates were masked with heat-resistant tape to expose only the areas for application of pre-wet solder.
5. Targets and backing plates were pre-wet with the selected solder alloy to a pre-determined thickness.

The conventional hot-plate soldering process utilized pure indium as the solder material. Pre-wetting requires a thermal ramp of the target and backing plate beyond the melting temperature of the solder selected (see Table 2). Pre-wetting for the NanoBond® process utilized SAC305 solder, which dictated a different thermal ramp.

The conventional hot-plate soldering process proceeded as follows:

1. The pre-wet surfaces were sandwiched together and the entire assembly was heated again to melt the indium solders together (157°C).
2. Weights were placed on the still-hot assembly.
3. The position of the target and backing plate alignment was verified while the solder was still molten.
4. The target assembly was covered with foil to insulate and the hot plate was turned off to allow assembly cooling.

The NanoBond® process proceeded as follows:

1. The pre-wet surfaces were machined to a uniform thickness of 0.010" and a flatness specification of 0.001" per 1.0" (0.025mm per 25.4mm).
2. The pre-soldered components were aligned relative to one another with the NanoFoil® sandwiched between them in close contact to the flat solder material.
3. The assembly was pressed together under a load of 3MPa, taking care to ensure pressure uniformity throughout the bond.
4. The NanoFoil® was then activated to initiate the exothermic reaction necessary to create the bond. The NanoFoil® was activated through multiple electrical pulses applied simultaneously.

Both processes for bonding a target to the backing plate require solder pre-wetting, which induces varying amounts of stress into the target and backing plate materials. During this pre-wetting step, the target and backing plate are soldered open-faced, allowing the solder to expand and contract through thermal excursions along with the substrate metallization. The hot-plate process requires a second reflow to bond the pre-wet target and backing plate together. Experimental results demonstrate that this bonding step contributed the highest stress on the assembly, as the solder is constrained by the CTE mismatched target and backing plate (see Table 1).

Experimental

The stress resulting from the bonding processes was measured by form inspection using a Zeiss Contura G2 RDS 700 Coordinate Measuring Machine (CMM). This equipment has a measuring range of 28" x 28" x 23", which provided double the surface coverage of the planar targets used, approximately 12" x 4" x 0.5". Before bonding, each planar surface of the targets and backing plates were measured using a 0.5" grid pattern. Approximately 207 depth readings were taken per surface to create a surface map. A total of 12 surfaces were mapped, 8 before bonding and 4 after bonding. The inside bonded surfaces were not measured post-bonding. Pages 4 and 5 show the surface maps of all outside surfaces, comparing the surfaces before bonding to after bonding using each bonding technique.

Results and Discussion

The stress due to thermal cycling during the bonding process of a Mo target bonded to an Al backing plate was physically evident in the warping of the assembly after bonding. Targets bonded using the indium solder process were found to have significantly greater warpage than those bonded with higher temperature SAC305 solder and NanoFoil®.

During the pre-wetting phase, the NanoBond® process required a hotter reflow temperature in order to melt the SAC305 solder alloy. After the target was NanoBonded to the backing plate, however, the indium bond had substantially larger warpage. This demonstrates that the majority of stress incurred by the assembly was during the second reflow phase, as the assembly cooled in a CTE-constrained fashion. The advantage of using the NanoBond® process for bonding targets is evident through the flatness of these resulting target assemblies after bonding.

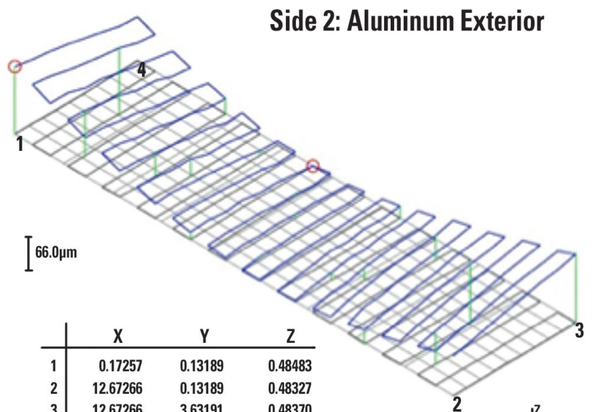
Indium Bonding

Coordinate surface maps of the Al and Mo outer surfaces before bonding (sides 2 and 8 respectively) and after bonding (sides 11 and 12) reveal significant warpage of the target and backing plate, with the Mo target deflecting in a concave orientation toward the constrained solder bond. Coordinate mapping reveals flatness measurements within 159µ on the Al surface and 85µ on the Mo surface prior to bonding. After target bonding of the Mo to the Al backing plate using the indium hot-plate bonding process, the same surfaces deflected to a flatness of 431µ on the Al side and 285µ on the Mo surface.

NanoFoil® Bonding

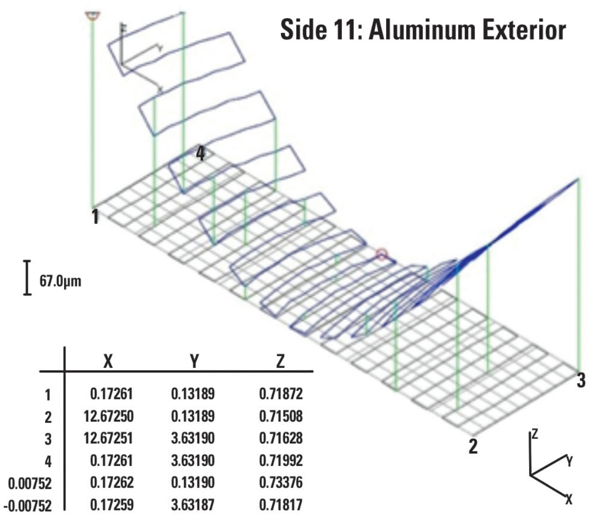
Coordinate surface mapping (page 5) of the Al and Mo outer surfaces before bonding (sides 3 and 6 respectively) and after bonding (sides 9 and 10) reveal only a minor degree of warpage of the target and backing plate. Coordinate mapping reveals flatness measurements within 121µ on the Al surface and 244µ on the Mo surface prior to bonding. After target bonding of the Mo to the Al backing plate using the indium hot-plate bonding process, the same surfaces deflected to a flatness of 142µ on the Al side and 98µ on the Moly surface. This last result indicates that the outer Mo surface became flatter following NanoFoil® bonding.

Side 2: Aluminum Exterior



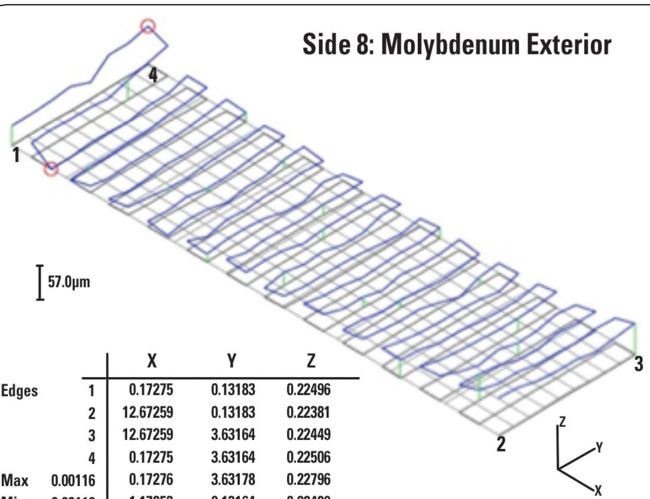
		X	Y	Z
Edges	1	0.17257	0.13189	0.48483
	2	12.67266	0.13189	0.48327
	3	12.67266	3.63191	0.48370
	4	0.17257	3.63191	0.48527
Max	0.00026	0.17266	0.13192	0.49015
Min	-0.00266	5.17252	3.63191	0.48464

Side 11: Aluminum Exterior



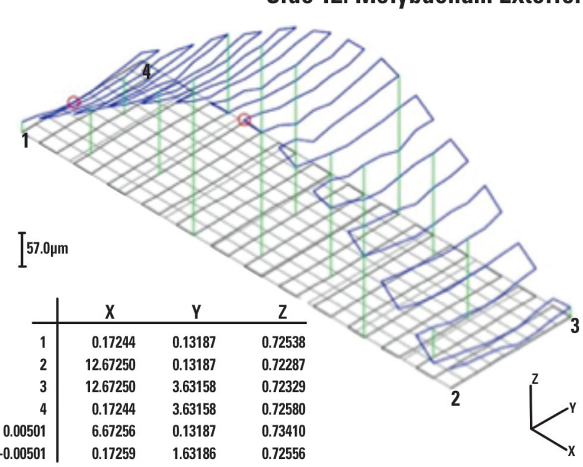
		X	Y	Z
Edges	1	0.17261	0.13189	0.71872
	2	12.67250	0.13189	0.71508
	3	12.67251	3.63190	0.71628
	4	0.17261	3.63190	0.71992
Max	0.00752	0.17262	0.13190	0.73376
Min	-0.00752	0.17259	3.63187	0.71817

Side 8: Molybdenum Exterior



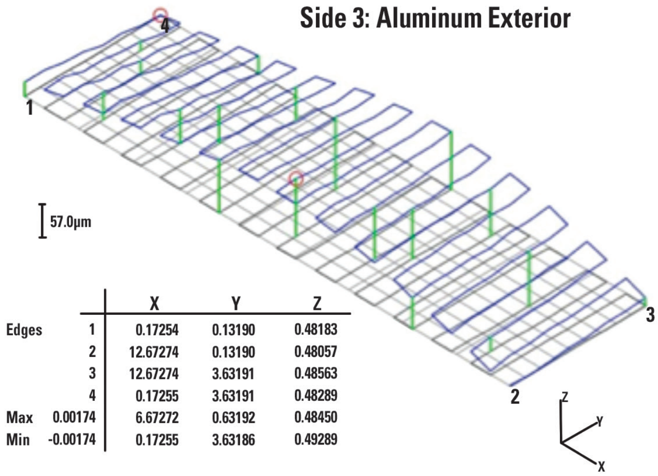
		X	Y	Z
Edges	1	0.17275	0.13183	0.22496
	2	12.67259	0.13183	0.22381
	3	12.67259	3.63164	0.22449
	4	0.17275	3.63164	0.22506
Max	0.00116	0.17276	3.63178	0.22796
Min	-0.00116	1.17253	0.13164	0.22489

Side 12: Molybdenum Exterior



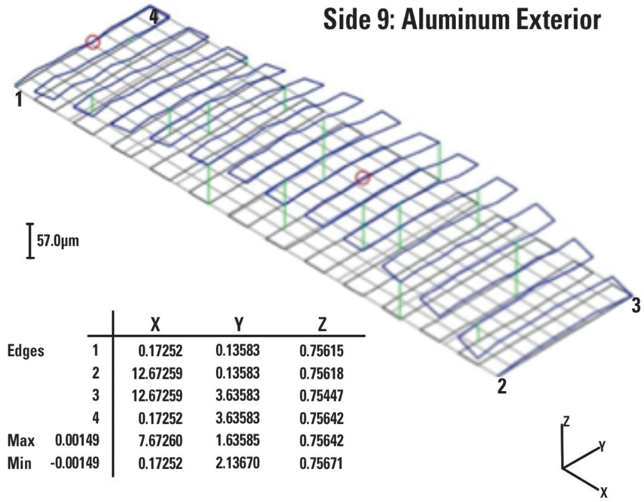
		X	Y	Z
Edges	1	0.17244	0.13187	0.72538
	2	12.67250	0.13187	0.72287
	3	12.67250	3.63158	0.72329
	4	0.17244	3.63158	0.72580
Max	0.00501	6.67256	0.13187	0.73410
Min	-0.00501	0.17259	1.63186	0.72556

Side 3: Aluminum Exterior



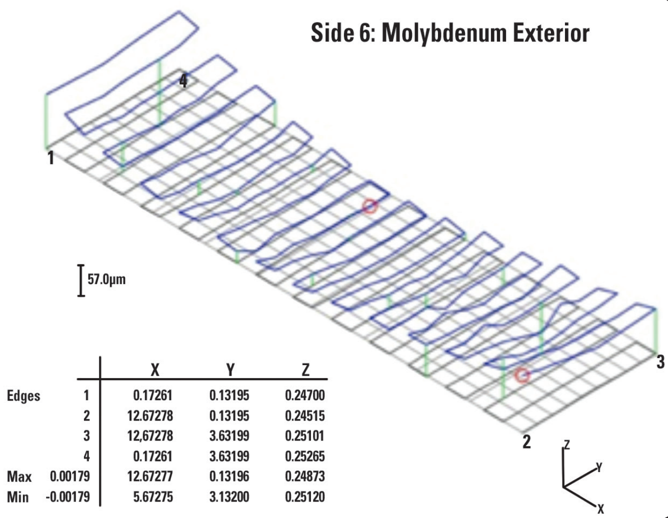
		X	Y	Z
Edges	1	0.17254	0.13190	0.48183
	2	12.67274	0.13190	0.48057
	3	12.67274	3.63191	0.48563
	4	0.17255	3.63191	0.48289
Max	0.00174	6.67272	0.63192	0.48450
Min	-0.00174	0.17255	3.63186	0.49289

Side 9: Aluminum Exterior



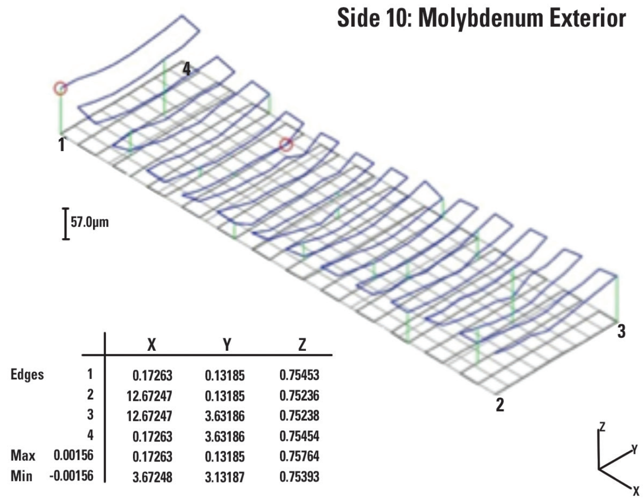
		X	Y	Z
Edges	1	0.17252	0.13583	0.75615
	2	12.67259	0.13583	0.75618
	3	12.67259	3.63583	0.75447
	4	0.17252	3.63583	0.75642
Max	0.00149	7.67260	1.63585	0.75642
Min	-0.00149	0.17252	2.13670	0.75671

Side 6: Molybdenum Exterior



		X	Y	Z
Edges	1	0.17261	0.13195	0.24700
	2	12.67278	0.13195	0.24515
	3	12,67278	3.63199	0.25101
	4	0.17261	3.63199	0.25265
Max	0.00179	12.67277	0.13196	0.24873
Min	-0.00179	5.67275	3.13200	0.25120

Side 10: Molybdenum Exterior



		X	Y	Z
Edges	1	0.17263	0.13185	0.75453
	2	12.67247	0.13185	0.75236
	3	12.67247	3.63186	0.75238
	4	0.17263	3.63186	0.75454
Max	0.00156	0.17263	0.13185	0.75764
Min	-0.00156	3.67248	3.13187	0.75393

Conclusions

A negative characteristic of sputtering targets bonded using conventional indium hot-plate soldering methods is warpage of the assembly. Bonds formed between molybdenum targets and aluminum backing plates using room-temperature NanoFoil® bonding processes resulted in planar targets that did not exhibit the characteristic warpage found in conventional indium hot-plate soldered assemblies. Coordinate surface maps of targets bonded using NanoBond® processes identified the surface flatness before and after bonding. The surface features altered only incrementally in comparison to similar assemblies bonded using hot-plate bonding methods. As such, the target assembles using the NanoBond® process are under less mechanical stress, and will provide more reliable, large-area sputtering at high power densities.

References

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