

Nickel Palladium-Based Pads for Higher Reliability in Au Wire Process

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Abstract

The necessity of high reliability in wire bonding processes is a well known factor, especially in Ultra Fine Pitch (UFP). High Temperature Storage (HTS) tests have become a crucial part in success criteria among others aspects in process qualification. The common Aluminum (Al) pad top stratum enables the gold to diffuse into the pad. HTS tests accelerate the growth of the Inter-metallic (IM) Inter-metallic until a certain point which the Au bond severs from the pad, either by itself (lifted bond) or during wire pull test. The last is characterized by low pull values. An alternative method of creating compatible interconnects is to change the Al top surface of the pad to a noble metal after it has left the IC fabrication clean room. One such method is depositing a layer of Nickel and Palladium (NiPd) using a known wet chemistry process. Unlike Al based pads, NiPd based pad prevent the IM growth, substantially reducing HTS failure main root cause. In this paper the Interconnect between Au wire 25um 99.99% (4N), and NiPd pads has shown easy implementation in terms of bond ability (same process window as used for Au on Al pad) and extremely stability over time with zero failures up to 5000hrs of 175°C Storage, while reference Al pad shown high level of lifted ball failure.

Electro-less Nickel and Palladium plating of bond pads

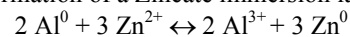
For this study the NiPd (Au) plating was applied to existing Al pads. However, modifications of the plating chemistry also allow the direct plating to the copper metal layers of a device. The main difference between the two processes is the pre-treatment of the surfaces before the electro-less nickel plating. The use of conventional Al pads in this study was a question of pad availability. The NiPd (Au) plating was done on Kulicke & Soffa conventional test wafers used to qualify wire bonding machines and capillaries.

Aluminium-Based Bond Pads

Because aluminum rapidly forms an oxide layer under environmental conditions, the surface needs to be protected with an alternative surface finish before nickel plating can proceed. Immersion zincation is the industry-standard choice to provide the required surface protection as well as the necessary roughness characteristics for the subsequent electro-less metal deposition.

Mechanism:

Formation of a Zincate immersion layer



To ensure complete and uniform zincation, the bond pads are first subjected to an acidic cleaning to remove any residual passivation, followed by an alkaline etch. Alkaline etching removes a thin pad surface layer and increases the microscopic pad roughness for improved mechanical and chemical reactivity for the subsequent zincation. The etching system is specifically formulated for homogeneous and linear aluminum surface removal. No wafer/pad design or galvanic potential selectivity has been found.

Even and controlled surface removal in the etching process ensures a maximum remaining pad thickness. Any unnecessary surface removal would reduce the bond pad thickness and could potentially cause reliability drawbacks, like pad deformation or damage of underlying structures.

Industry-known zincation processes are based on alkaline conditions, complexed with cyanide. The required double processing improves the pad surface uniformity of the zincation layer and generates fine, dense crystals. Latest environmental

regulations restrict the use of hazardous components within the electronic industry (ROHS, WEEE), and along with customer-specific requirements are driving the zincation process towards cyanide-free, fine-grain layer formation and single step application. The acidic zincation process used for the devices in this study was developed in order to reduce the number of process steps and simplify handling. Additionally the acidic process conditions minimize the attack of the polyimide passivation layer relative to the alkaline process conditions.

Overall, the process chemistry is optimized for chemical stability, wide operating window, and standardized process sequence to cover all aluminum pad alloys, constant and linear pad etching and uniform removal across the wafer

Copper-Based Bond Pads

Pre-treatment of copper pads also involves cleaning, etching and activation, but the details are different. The cleaning step improves the pad surface tension and increases the chemical activity for subsequent process steps. Cleaning is followed by a mild surface etch to remove any residual copper oxide. Any remaining oxide would weaken the adhesion and thus will negatively influence the bonding performance. Finally the activation process deposits a homogeneous and thin palladium layer on the surface. It acts as a catalyst to give the subsequent electro-less nickel deposition the required base for chemical reactivity

Electro-Less Metal Deposition

The first layer of the bond pad metal stack is applied by an electro-less nickel deposition process. Typical nickel layer thicknesses range from 1 μm to 3 μm . Any plating process can impart stresses on a surface. Being the thickest, the nickel layer has the largest potential to cause stress in the pads. The stress in the nickel layer is mainly influenced by the phosphorous co-deposit. Typical mid phosphorous nickel layers can range from 7% to 9.5 %P and generate tensile stress. Alternative electro-less nickel types with high P content between 10 and 11%P, generate compressive stress. The optimal combination of the individual bond pad metal layers enables an almost stress free bond pad metallization. Such stress management is especially important to reduce the bow of a thin wafer.

There are several purposes of the Nickel Palladium plating: One is to protect fragile structures under the pads from the stresses of wire bonding

process which can damage the pad under layers (these failure modes are common in active circuit devices and Low-K devices). Secondly, the complete metal stack is more resistant to metal diffusion during thermal process steps. Nickel Palladium plating provides greater protection from the Inter-metallic growth during reliability tests which may be characterized by 1st bond lift failures.

Palladium, with or without an additional very thin immersion gold layer, is a rather new finish as a bondable surface onto the nickel. It replaces the more traditional and much more costly thick, electrolytic gold finish. Acting as an additional protection barrier, the palladium significantly improves the bond pad stability, the corrosion resistance of nickel and the stress impact of the metallization stack. The excellent diffusion and corrosion barrier properties of palladium allow the nickel layer to be reduced from 5 μm to less than 3 μm , further minimizing stress in the pads.

Several studies have proven that the electro-less metal stack combinations of nickel/palladium and nickel/palladium/gold provide a bond pad metallization without the risk of generating Kirkendall voiding, which is the most significant reliability risk in Au-to-Al wire bonding. Due to the additional palladium layer, the Inter-metallic phases which are critical parts of the package reliability will no longer be an issue.

Experimental

NiPd and NiPd (Au) layers (Table 1) were plated onto 1 μm thick Al pads (Al-1%Si-0.5%Cu) of test wafers using the Atotech Xenolyte process described above. An identical test wafer without any Ni/Pd/Au was used as a reference. All devices were plasma cleaned before the wire bonding phase

Au Wire Bonding

The wire bonding process was established on a 50 μm bond pad pitch, using a K&S Maxum ball bonder series, 0.8mil Au wire (Heraeus, AW66 type, 99.99% (4N) gold alloy and K&S conventional capillary (capillary geometry: Hole=1.0mil; CD=1.3mil and Tip=2.8mil). The wire bonding process was established on PBGA test device at 170°C bond temperature. The Devices were bake tested at 175°C in air environment. Pull and shear tests were performed prior to bake test and at intervals up to 5000 hours.

Wire Bonding Results

As mentioned earlier, the aim of using NiPd (Au) plated pads with Au wire was to improve the reliability of Au wire applications without affecting the bondability. Eight different NiPd base pads vehicles (Table 1) were checked and compared.

Table 1: Sample description and summary bonding results

Sample #	Ni [μm]	Pd [μm]	Au [μm]	Ball Size [μm]	Ball Shear [gr]	Ball Sh/UA [gr/mil ²]	Wire Pull [gr]
Al-Ref	1 μm Al			39.0	11.6	6.3	5.6
A	3.0	0.3	0.03	39.8	17.1	8.9	5.5
B	3.0	0.3	0	39.3	16.9	9.0	5.5
C	3.0	0.1	0.03	39.6	16.7	8.7	5.5
D	1.0	0.1	0	39.5	16.2	8.5	5.4
E	1.0	0.1	0.03	39.9	17.0	8.8	5.5
F	1.0	0.3	0.03	40.2	17.2	8.8	5.6
G	3.0	0.1	0	39.7	15.9	8.3	5.6
H	1.0	0.3	0	40.1	15.7	8.0	5.5

Bondability

For the bondability check, the 1st bond was first optimized on the regular Al pads and then applied without modification to the NiPd (Au) pads. Examination of the bonding performance and metrology showed that there was no need to fine tune the parameters when switched from reference Al pad to NiPd (Au) pads. All eight cells of NiPd (Au) pads yielded higher ball strength by about ~2 gr/mil² (Figures 3, 4) compare to reference Al pad. All NiPd (Au) vehicles had larger gold remains coverage after ball shear compared to reference Al pad (Figure 5). 1st bond diameter and thickness were kept when bonding on all NiPd (Au) vehicles (Figure 1). In addition, no effect was found on wire pull values (Figure 2).

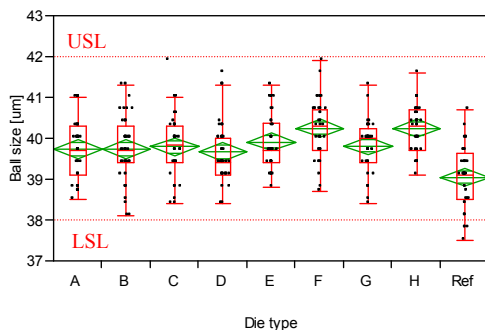


Figure 1: 1st bond diameter comparison: No major differences found between Reference Al pad and all NiPd vehicles (sample size=40 per cell)

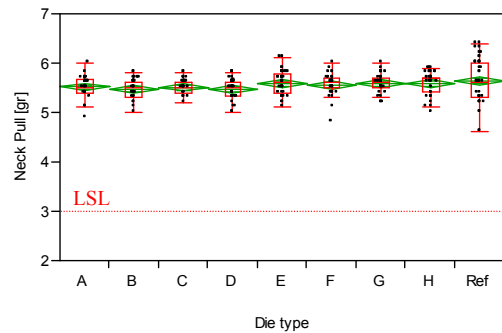


Figure 2: Wire pull (1st bond Neck pull) comparison: No differences found between Reference Al pad and all NiPd vehicles (sample size=40 per cell)

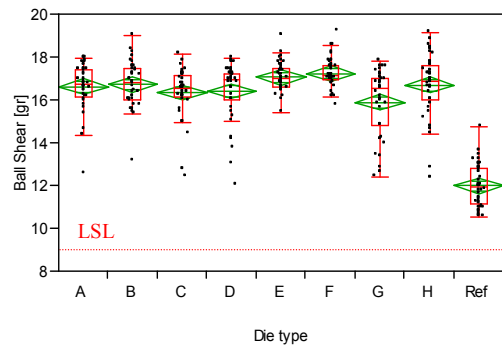


Figure 3: Ball Shear test comparison: Major differences found between Reference Al pad and all NiPd vehicles (sample size=40 per cell)

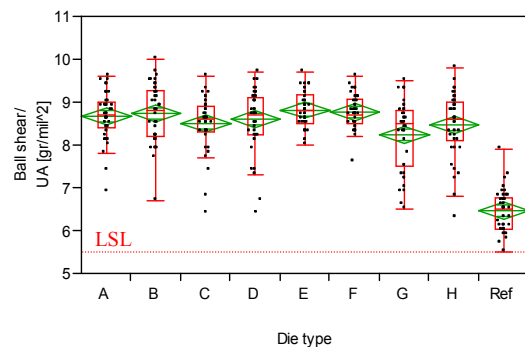


Figure 4: Higher ball shear with minor effect on ball size helps increasing the bond shear strength: Major differences found between Reference Al pad and all NiPd vehicles (sample size=40 per cell).

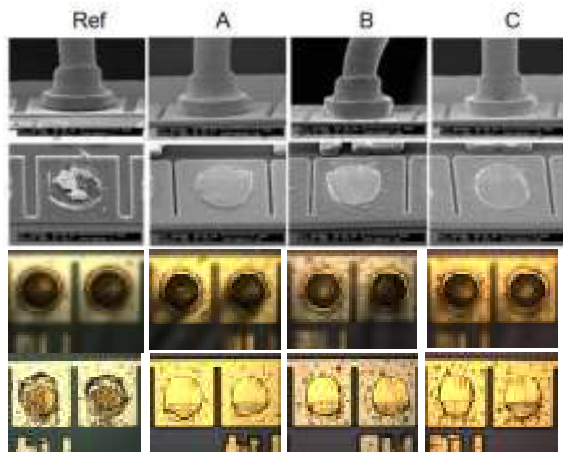


Figure 5: An example of 3 NiPd (Au) vehicles which had larger gold remains coverage after ball shear compare to reference Al pad

Reliability

All NiPd (Au) test devices passed the bake test up to 5000 hrs without any ball lift failures (the test was stopped at 5000 hrs). On Al pads, failures occurred at 2000hrs until the end of the test. 1st bond images after 3000hrs point showed massive Inter-metallic growth on the Al pad pads while none of the NiPd (Au) pad devices showed any growth of Inter-metallic at all.

On Al pads, the Inter-metallic growth increases the bonded ball area and, additionally, the Inter-metallic layer composition is harder than pure gold. These two factors combine to cause the shear strength of Au-on-Al to increase during a bake test. In contrast, there is no Inter-metallic growth on any of the eight types of NiPd (Au)-based pad (Figure 6). Hence the ball shear strength on NiPd (Au) pads does not increase during bake time. In fact, as in the case for copper wire, the shear values remained constant over the 5000 hrs bake test.

1st bond images after the 3000hrs check point showed massive Inter-metallic growth to Al pads while all NiPd base pad vehicles images shown no growth of IM at all. Al base pad bond strength increased with time compare to a stagnate change in shear values of the NiPd based pad from the first reliability check point till 4000hrs. At the 5000hrs check, ref Al base pads yielded lower shear strength. Moreover, Neck pull values decreased from ~6gr to 3.8gr due to many ball lift failures (58% of the reference Al pads bonds were lifted at 5000 hrs.)

The high ball shear strength received with Reference Al pad (figure 7) is a results of the Inter-metallic growth (as evident in the darker area around the ball edge in figure 9) compared to the situation with all NiPd cells. Reference Al pad Inter-metallic growth increases the bonded ball area. Additionally, the Inter-metallic layer composition is harder than pure Au. The higher Shear per unit area received with the Al pads is probably a combination of both factors. All 8 NiPd cells had the same appearance (no Inter-metallic growth evidence) and the same shear values till the end of the acceleration aging test (5000 hrs).

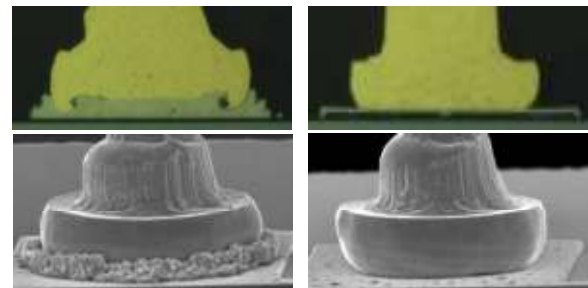


Figure 6: 1st bond images after 3000hrs aging: Inter-metallic growth increases with reference Al pad (left side), while no Inter-metallic growth is evident on the NiPd pad plating (right side)

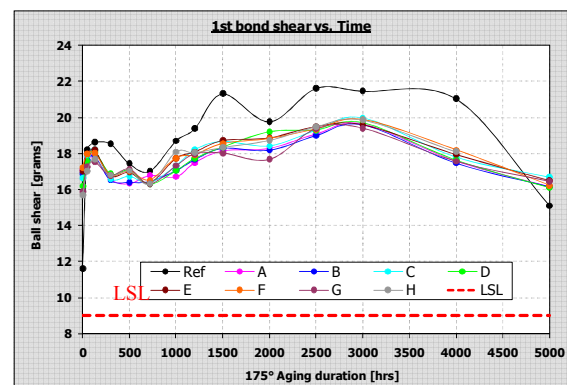


Figure 7: 1st bond ball shear. Higher shear values to reference Al pad due to Inter-metallic growth while all NiPd cells have shown similar shear values throughout all test duration

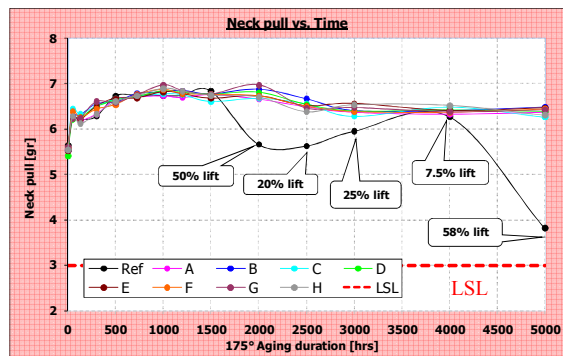


Figure 8: 1st bond neck pull comparison. Reference Al pad ball lifts vs. no ball lifts appeared in all NiPd cells and stable bond strength variances during the reliability duration

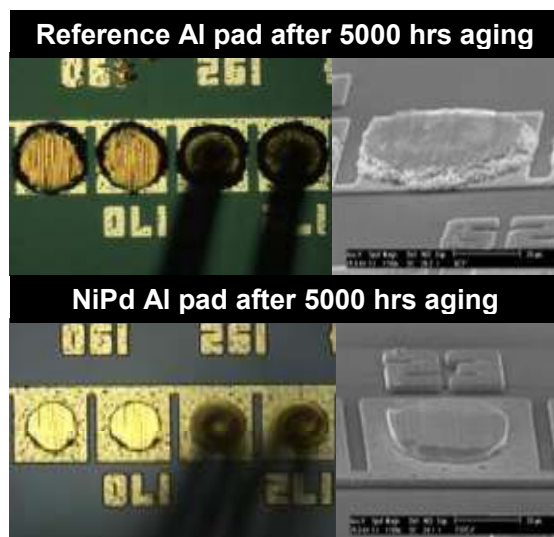


Figure 9: Reference Al pad Inter-metallic growth increases the bonded ball area (left side) compare to NiPd cells which had no Inter-metallic growth evidence and no bonded ball area incensement

Conclusions

NiPd and NiPdAu metal stacks on top of Al pads are demonstrated to be a highly robust pad metallization for Au wire bonding. Bonding performance and bake-test reliability are superior to that of bare Al pads. No voiding or other reliability issues are seen with 4N-gold wire in extended 175°C bake test. Bond windows are very large and in this case the parameters used for Al could be applied directly to the NiPd without major modifications in wire bonding process. This test can be a good base

line for extending the NiPd pad based tests to other platforms under other conditions.

NiPd base pads have no Pad Splashes compare to Al pad which may be more useful in applications where the distance between pads is narrow (BPO and BPP are close one to each other), or in applications where the bonding on the metallization layer is forbidden or risky.

NiPd base pads may yield larger ball size than Al base pad, but the ball size difference is not significant. The harder pad metallization of the NiPd pads will have clear advantages in sensitive devices such as low-k or active circuit beneath pads devices.

The uses of thicker NiPd metallization may be useful for sensitive die applications due to its higher resistance to bond forces applied to the pad while thinner NiPd metallization is more useful in applications when small bond pad pitch (BPP) and bond pad open (BPO) are used and 3 μm Ni thickness may be crucial.

The relation between thickness of the NiPd metallization and its resistance to pad damage will be tested in the nearer future.

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