Use of Harsh Wafer Probing to Evaluate Various Bond Pad Structures

Stevan Hunter[1,3]

Jose Martinez[2], Cesar Salas[2], Marco Salas[2], Steven Sheffield[2], Jason Schofield[2], Kyle Wilkins[2]

Bryce Rasmussen[3], Troy Ruud[3], Vail McBride[3]

[1]**Idaho State University;** [2]**Brigham Young University Idaho**; [3]**ON Semiconductor**, Pocatello, ID, USA

contact: stevan.hunter@onsemi.com

Abstract

(This is part 2, continued from "Use of harsh Wafer Probing to Evaluate Traditional Bond Pad Structures"). Goals for circuit under pad (CUP) in aluminum – silicon dioxide (Al – SiO_2) based IC pad structures include the design of metal interconnects in all layers beneath the pad Al, and the ability to withstand harsh probing and wirebonding stress without SiO_2 cracking, without deforming or bending the interconnects. CUP pad designs having thin pad Al and Cu wirebond represent significant challenges. Previous work showed that the traditional pad designs are not at all robust to cracking, so major improvement in pad structure design is sought. This study uses harsh wafer probing to compare cracking tendencies for various pad structures having slots or holes in the metal sub-layers directly beneath the pad window. The presence of a full sheet of metal in a pad sub-layer will dominate the top SiO_2 cracking performance in the pad. A dramatic improvement in robustness to cracking is seen as the metal-top-minus-one (MT(-1)) layer reduces in pattern density. Interaction between cracks and metal pattern is analyzed, and further details regarding the mechanisms of cracking are discussed. Deformation in metal sub-layer features can be prevented or minimized, thus preventing bending of the top SiO_2, preventing cracks, increasing the capability for high reliability CUP pads. Robustness to cracking also increases the probing process margin. CUP pad objectives can be achieved even with harsh probing by following pad sub-layer interconnect layout guidelines within the pad window based on these experimental results.

Key words: wafer probe, bond pad, cracking, cratering test, circuit under pad, bond over active circuitry, pad ripple effect

Introduction

Part 1 of this series "*Use of Harsh Wafer Probing to Evaluate Traditional Bond Pad Structures*" reported on the use of harsh wafer probing to study the reliability of traditional bond pads having Aluminum (Al) alloy metallization and silicon dioxide SiO_2 dielectric, with full sheets of metal in each level connected electrically by tungsten (W) vias [1]. The top SiO_2 dielectric was found to crack easily from probing with cantilever probe tips for high overdrive and shorter tip length. Multiple probe touchdowns becomes an important factor in cracking for these harsh conditions. Top vias enhance the top SiO_2 cracks, which tend to propagate from via to via, and promote "lifting barrier" issues. Cracking from harsh probing can be reduced by increasing the pad Al thickness.

This paper continues the use of harsh probing with the same cantilever probe tips to aid in evaluating bond pad reliability, especially in terms of cracking, for pads with reduced density in metal layers directly below the pad window. Two issues tend to drive this experimentation: 1.) the need to develop mechanically stronger pads for best resilience to probing and other stresses, and 2.) the desire to route circuitry through the pad window region in any and all layers beneath the pad metal, permitting die size reduction and lowering of product cost. Cracks are a mechanical reliability concern in traditional bond pads, which some may consider as more of a nuisance in commercial grade products, not typically resulting in electrical failures. But prevention of cracks is important in high reliability products, and critical in circuit under pad (CUP) designs, since a crack can become an electrical leakage path between different voltage nodes.

The traditional pad structure is illustrated in concept in figure 1. We denote the top metal level as "MT", with "MT(-1)" indicating one metal level below, and so on.

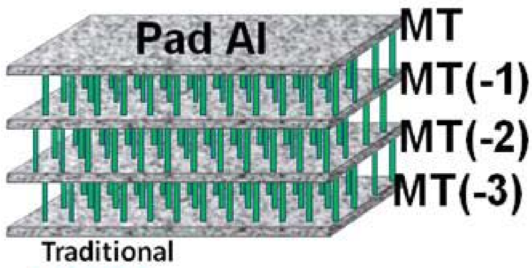

Figure 1. Illustration in concept of a traditional bond pad structure, 4 levels of Al-based metallization in this example. W vias electrically connect the full sheets of metal through SiO_2 dielectric that encases everything except the Pad Al surface at the top.

Experimental Pad Designs

Table 1 shows the bond pad structural factors that were varied within the pad window region. Various test pads were designed, then fabricated on wafers of four different CMOS technologies, from 0.6um to 0.18um gate length, with the bond pads all having similar Al-based metallization encased in SiO_2 dielectric below the pad window.

factor	levels					
Pad Al	.55um	.8um	1.0um	1.5um	3.0um	
Top Vias	(Dense)	sparse	none			
MT(-1)	sheet	dummy fill	wide slots	large holes	small holes	no metal
MT(-2)	sheet	dummy fill	wide slots	large holes	small holes	no metal
MT(-3)	sheet		wide slots			no metal

Table 1. Bond pad structure variations for harsh probing experiments

Most data was collected from the wafers with thinner top metal (thin pad Al), knowing of the higher tendency for cracking. Also, most experimental structures avoided the use of top vias within the pad window to permit better analysis of the effects of underlying metal patterns. Illustrations and photos of example pad structures are shown later in the analysis section.

As in the probing of the traditional pads already reported [1], the majority of experiments were with two coincident touchdowns, representing a condition that might be common in production, or 6 coincident touchdowns as an extreme condition to promote cracking. The wafer chuck "overdrive" or overtravel was varied between 2mils, typical of a production condition for well planarized probe tips and tooling at room temperature, and 4mils as a potential upper limit that may occur in production. A cantilever probe card was used, which has a relatively high force of 2g per mil of overdrive. Cantilever tips of 0.8mil diameter are bent at approximately 105deg and are in two layers: shorter tips at 17.5mils and long tips at 28.5mils, on tungsten-rhenium (WRh) needles of 7mils shank diameter.

Analysis

No significant difference was observed in the appearance of the probe marks between traditional and experimental pads which were probed identically on the same wafer. Please refer to the previous paper for the basic findings on probe marks [1].

MT(-1) Pattern Density: No cracks were observed for the experimental pad structures except in the harshest probe conditions of 6 coincident probe touchdowns at 4mils of overdrive. Only the traditional pad designs cracked easily. This is the first and primary result: any reduction in metal sub-layer pattern density reduces the tendency for pad cracking. This is immediately encouraging in regards to the placement of CUP circuitry through the pad window.

Figure 2 shows a trend of reduced pad cracking tendency when the metal pattern density in the MT(-1) layer is reduced.

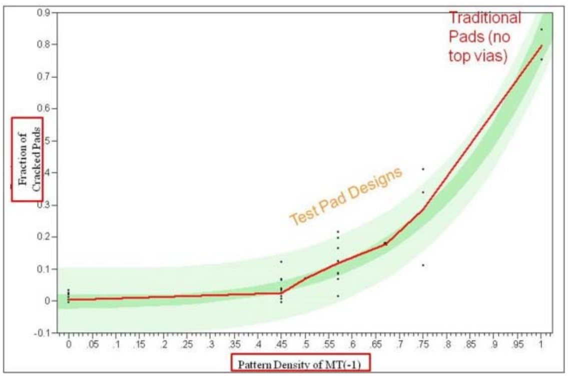

Figure 2. Fraction of pads that cracked vs MT(-1) pattern density in the pad window

This plot combines data from over 26,000 pads and numerous test pad designs in a single CMOS technology with 0.8um pad Al thickness, after harsh probing of 6 touchdowns at 4mils overdrive. None of the structures have top vias in the pad window. The Y-axis is the fraction of pads found to have cracks, with 1 being 100% of the pads inspected were found to have cracks. The X-axis is the metallization pattern density of the MT(-1) layer within the pad window, from 0 (no metal at all in MT(-1)) to 1 (full sheet of metal with no spaces in it).

Starting with full sheet MT(-1) in the traditional bond pad, the pattern density was reduced in the various designs by placing arrays of holes or long slots in uniform patterns through the pad window region. This dramatic trend in figure 2 shows that pad cracks from harsh probing can be prevented by designing CUP circuitry in the MT(-1) layer to have low pattern density. The particulars of the metal width and space features have a secondary effect, but the main effect of MT(-1) pattern density is very strong. Similar trends are observed in all of the technologies in our experimentation.

Cracking Results for Specific Pad Structures: Traditional pads performed the worst in terms of cracking out of all harshly probed experimental pad designs. In these experiments, essentially 100% of the traditional pads with top vias cracked under harsh probing of 6 probe touchdowns at 4mils overdrive. Removal of the top vias reduced the fraction of pads cracked to about 80% under harsh probing conditions. Figure 3 illustrates these traditional pad structures.

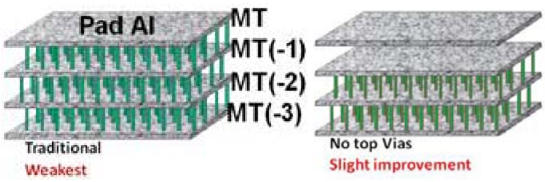

Figure 3. Illustration of a 4-level metal traditional style bond pads; (left) with top vias, (right) without top vias.

Major improvement in crack prevention is possible by leaving out the MT(-1) in the pad window, with even further improvement by leaving out both MT(-1) and MT(-2), as illustrated in figure 4.

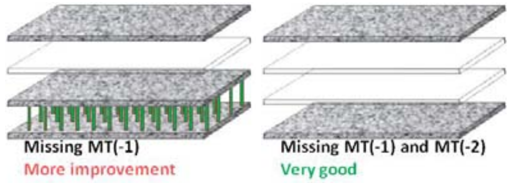

Figure 4. Illustration of bond pad structures having: (left) MT(-1) absent in the pad window, and (right) both MT(-1) and MT(-2) absent.

The SiO_2 thickness below the pad window becomes more than 2 times the original thickness when MT(-1) is removed from the pad window. Harsh probing stress doesn't cause as much bending of the thicker SiO_2 so its tensile stress is not as high, and most cracks are prevented. Having no CUP interconnects in MT(-1) defeats some of the purpose of an improved pad structure, but the prevention of cracks may be a worthwhile tradeoff. This design is certainly attractive for robust pads that don't require CUP circuitry in MT(-1).

Removal of the MT(-2) as well as MT(-1) in the pad window reduces the cracking tendency even further. The pad structure is even stiffer, having a much thicker SiO_2 block below the pad window that is much more difficult to bend in probing. This design is less interesting from a CUP point of view, and such a thick SiO2 becomes unattractive because of its ability to couple the probe stress into deeper structures or laterally outside the pad window.

Figure 5 shows two pad designs that actually behave similarly in harsh probing to the "MT(-1) absent" structure of figure 4, as long as the MT(-1) pattern density is low.

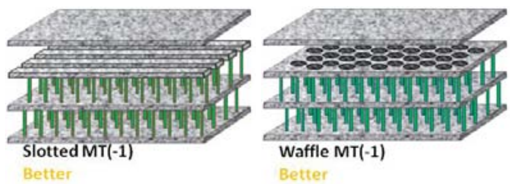

Figure 5. Illustrations of bond pad structures having: (left) slots in MT(-1), (right) array of holes in MT(-1).

Most of the cracking observed is actually due to the full metal sheet in MT(-2), not the patterned MT(-1) layer. The structure on the right has the MT(-1) pattern nicknamed "waffle" due to its appearance. Photos of some of the MT(-1) designs as seen in the cratering test follow. Figure 6 shows two of the slotted MT(-1) designs.

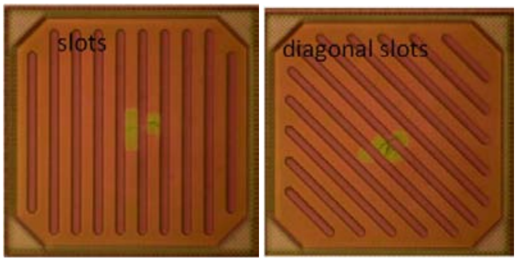

Figure 6. Examples of slot patterns in MT(-1) as seen in the cratering test. Note the cracks from probing and evidence of etching in the sheet MT(-1). (Left) slots parallel to the probe scrub direction, (right) diagonal slots.

Figures 7 and 8 show MT(-1) pattern examples having uniform arrays of holes. Both the pattern density and the width of metal between holes are important in preventing cracks.

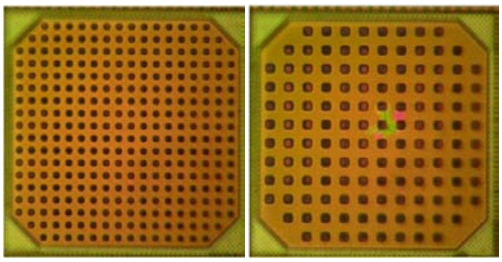

Figure 7. Designs with arrays of holes in MT(-1) as seen in the cratering test. Both patterns reduced cracks from harsh probing as compared to traditional pads.

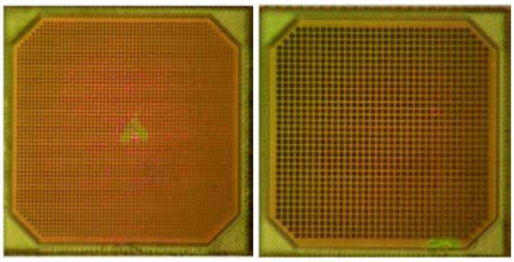

Figure 8. Designs with arrays of smaller holes in MT(-1) as seen in the cratering test. Both test patterns have the same metal width between holes, but the pattern on the right prevented cracks best in harsh probing, having wider holes and less overall metal density.

Figure 9 shows photos of two MT(-1) designs, with different patterns seen below in MT(-2).

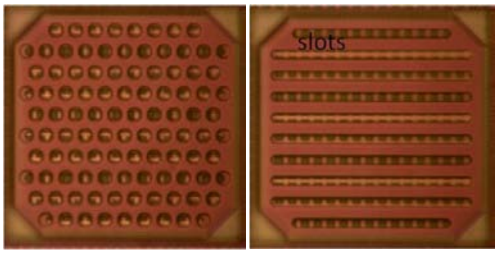

Figure 9. MT(-1) designs, with different patterns below in MT(-2); (left) MT(-1) array of large holes, (right) MT(-1) slotted metal.

These designs actually didn't prevent cracks as well as some others, having fairly wide MT(-1) between the holes or slots. Also, the slotted pattern on the right has its slots perpendicular to the probing direction, resulting in more cracks than the designs having slots parallel to the probing direction. Assuming that the bond pads are placed around the die edge, CUP routing through the pad regions is most likely to be parallel to the die edge. In these experiments, probe scrub is perpendicular to the die edge. Crack prevention for harsh probing must consider the probe scrub direction vs the circuitry routing direction, especially in MT(-1).

Reduced pattern density in MT(-1) won't prevent all cracks if MT(-2) is a full sheet beneath. Even the presence of a full sheet of metal in MT(-3) can cause some cracked pads. Once the full sheets in MT(-1), MT(-2), and MT(-3) are replaced with lower density metal patterns in the pad structure, cracking is greatly reduced or prevented.

We also see that patterned MT(-1) structures in the pad window can add to the cracking if the metal width between spaces, slots, or holes becomes wide enough. Harsh probe stress is then able to cause deformation of the Al, allowing the SiO_2 to bend sufficiently to crack.

Figure 10 shows photos of the ripple effect from harsh probing, as seen in the cratering test. Note that only the pad having slotted MT(-1) has no visible ripple, and no cracking in this case.

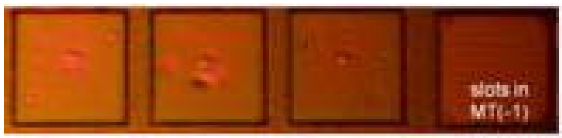

Figure 10. Pad photos to observe ripple effect in the cratering test; (left 3) ripple and cracks due to deformation of the full sheet MT(-1) in traditional

pads without top vias, (rightmost) no ripple or cracks for MT(-1) having slots.

These crack prevention results for lower metal density MT(-1) are very encouraging when considering the idea of circuitry under the pad. Individual MT(-1) lines routing through the pad, or wide MT(-1) busses having an array of holes when they are within the pad window, can actually help prevent cracking from harsh wafer probe! However, as mentioned, the presence of a full sheet in MT(-2) still contributes to pad cracking and must be avoided in a robust pad structure.

Moving on to other experimental structures, figure 11 shows structures with MT(-1) absent, and having only slotted metal or metal with arrays of holes in MT(-2) and MT(-3).

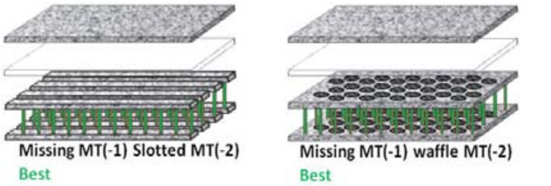

Figure 11. Illustration of bond pad structures having MT(-1) absent, and: (left) slotted MT(-2) and MT(-3), (right) array of holes in MT(-2) and MT(-3).

The pad structures of figure 11 are noted as having performed "best" in terms of "circuitry" beneath the pad being able to withstand harsh probing without any cracks or other detectable damage. These pad designs have the disadvantage of no MT(-1) circuitry under pad, but they are highly effective in crack prevention.

Another pad structure is shown in figure 12. It has all sub-layer metals absent in the pad window, with no cracks from harsh probing.

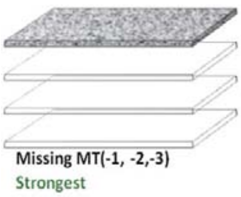

Figure 12. Illustration of a bond pad structure where all metal sub-layers are absent in the pad window.

The very thick SiO_2 and absence of any deformable layer beneath the pad window makes this structure strongest of all in preventing cracks. The probing stress is insufficient to bend this thick SiO_2 film. However, this structure is not interesting at all in terms of CUP, having no circuitry under the pad window. In addition, concerns about the SiO_2 transferring more probe stress directly to the underlying films and Si devices, makes this structure more undesirable.

Cracking Performance Summary for Some Specific MT(-1) patterns: Figure 13 compares cracking results for various MT(-1) patterns harshly probed in a single CMOS technology having 0.8µm pad Al thickness, revealing more detail about the nature of bond pad cracking.

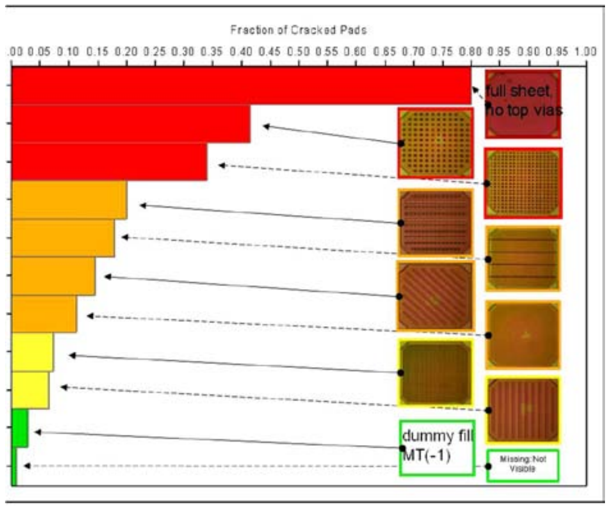

Figure 13. Chart showing the % of pads cracked for various MT(-1) patterns, worst for full sheet MT(-1) and best for MT(-1) absent from the pad window.

Again we see that replacing the MT(-1) full sheet (figure 13 top right, 80% cracked pads) with any uniform pattern that reduces the MT(-1) density will significantly reduce cracking. Next in the chart is an array of holes in MT(-1), 2 pad designs with different hole sizes, for overall 75% pattern density. The number of cracked pads reduces to half, with 35 and 40% cracking of top SiO_2 above these MT(-1) patterns. The MT(-1) pattern with smaller metal width performed better.

Next, at 20% of pads cracked, is a slotting pattern with 57% MT(-1) density in the pad window. Slots in the metal create 4µm wide metal busses with 3µm spaces between. These slots run perpendicular to the probe scrub direction. We see that simply running metal lines MT(-1) as in a CUP design, instead of a full sheet reduces the cracking tendency by a factor of 4!

Next, at 17% cracked pads, the MT(-1) pattern is a series of wide metal busses having arrays of small holes running through the pad window perpendicular to the probe scrub direction. Pattern density in each bus is 75%. Not all of the cracks occur in the bus regions, but some cracks initiate at the boundary between the bus metal and the space between busses as the probe harshly scrubs across from one bus to another.

Referring still to figure 13, the diagonal slots pattern with 57% MT(-1) pattern density had about 14% cracked pads. This is not likely as a CUP design, but highlights an advantage in rotating the pattern at 45º from the probe scrub angle.

At 11% pad cracking, the MT(-1) sheet is filled with an array of small holes, for 75% pattern density.

The next pattern with an array of holes in the MT(-1) sheet has only 50% pattern density, resulting in only 7% cracked pads. Cracking has now reduced by more than a factor of 10 as compared to harshly probed traditional pads without top vias!

The next slotted metal pattern with 6% cracked pads creates 4µm wide MT(-1) busses and 3µm spaces running parallel to the harsh probe scrub direction. Cracks tend to initiate only above the center of a metal bus, not over the space.

The dummy metal fill MT(-1) pattern of about 45% pattern density had less than 3% of pads cracked. This illustrates that metal fill or other small pattern features can be present without necessarily causing more pads to crack, as long as the overall pattern density is low.

The "missing" MT(-1) pad designs were best in this set. Cracking was very rare, though it shows about 1% on the chart. Removal of the MT(-1) from within the pad window prevents CUP circuitry on that layer, but has reduced the cracking from harsh probing by over 2 orders of magnitude as compared to traditional pads.

Discussion on Pad Robustness to Cracking

Removal of the full sheets of metal in pad sub-layers is the largest single factor in crack prevention. Using only patterned metal in the pad sub-layers greatly increases a pad's robustness to cracking from harsh probing. The design of MT(-1) in the pad window is most important, including a low pattern density and a relatively small metal width between spaces or holes. A subtle improvement is observed in crack prevention when vias are present beneath the first patterned metal sub-layer. Top vias tend to enhance cracking in the top SiO_2, but vias in the lower levels help prevent cracks!

Reducing the metal density in the full sheet MT(-2) is important in reducing pad cracks. Even the full sheet in MT(-3) promotes cracking and it's density should be lowered slightly to ensure better robustness to cracking.

Reducing the pattern density of metal sub-layers is a viable method for CUP designs that can withstand harsh probing. In fact it's the design of the Al circuitry under the pad itself that prevents the cracking. The restriction against high density routing circuitry in MT(-1) seems a worthwhile tradeoff for high reliability CUP without any additional manufacturing cost.

Robust pads clearly provide more process margin in wafer probe in terms of cracking. But harsh probe marks are larger and deeper, so they may adversely affect wirebond even when not cracked.

The ripple effect seen from the cratering test can be a valuable tool in judging a pad's robustness to cracking. The more robust pads have no visible ripple, indicating no sub-layer Al deformation, hence little bending of the top SiO_2, so no cracks.

Probe Interaction with MT(-1) Pattern

Cracks from harsh probing were studied extensively in the cratering test to look for potential interactions of the probe tips with sub-layer metal patterns during harsh probing. We find that cracks from harsh probing relate very much to the pad sub-layer patterns, especially in MT(-1). The following examples, figures 14 – 20, illustrate actual crack locations and shapes in relation to the MT(-1) pattern, each from one harshly probed representative pad, with the probe scrub direction always "down the page". Some are enhanced photos from cratering test, while others show the actual crack shapes superimposed over an illustration of the MT(-1) pattern for better clarity. Gray color in the figures represents the MT(-1) metal, and brown represents spaces in the MT(-1) pattern.

In the previous study [1], it was shown that cracks over full metal sheet MT(-1) tend to match the probe tip heel shape of the cantilever probe tips. Figure 14 illustrates how an expected crack shape changes when interacting with a MT(-1) pattern with 4µm wide metal lines running perpendicular to the probe scrub direction.

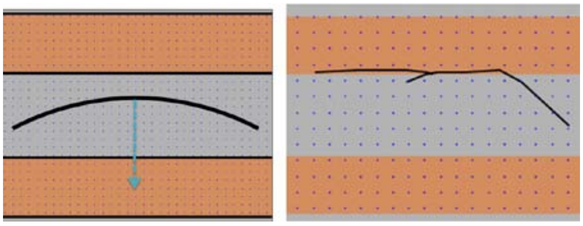

Figure 14. Top view illustrations of: (left) a typical crack shape expected from the probe tip over wide MT(-1) [gray color], (right) image of an actual crack initiating at the point where the MT(-1) line begins. Brown color represents the SiO_2. The cantilever probe scrub direction is downward. (Small dots on the illustrations are not vias, they are just grid points).

In addition to the cracks that form above the wide MT(-1) wide features, cracks over patterned MT(-1) with metal lines perpendicular to the probe scrub direction tend to initiate above a transition point between the space and the metal line. Crack propagation near a transition may also tend to follow the metal edge.

When the MT(-1) line pattern is parallel to the probe scrub direction, as in figure 15, we see that: 1.) the cracks tend to initiate only over the metal lines, and 2.) crack propagation changes direction when encountering the thicker SiO_2 in the slot regions.

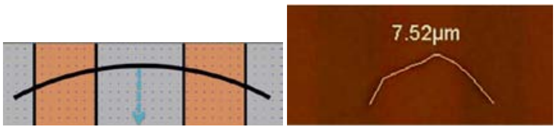

Figure 15. Top view illustrations of: (left) a probe tip "heel" shape (the expected crack shape), drawn on a "slots" MT(-1) structure where the downward probe scrub direction is in parallel with the slots, (right) image of an actual crack initiating above the metal line, but changing direction significantly due to the presence of thicker SiO_2 in the slots.

The crack of figure 15 (right) initiated above the metal, but the direction of propagation turns more toward following the edges of the metal line. Cracks don't initiate in the thick SiO_2 regions, only above MT(-1) or at the edge of MT(-1) features. Crack propagation is physically not favored in the thick SiO_2 of the spaces between MT(-1) features.

Figure 16 shows a crack over diagonal MT(-1) lines.

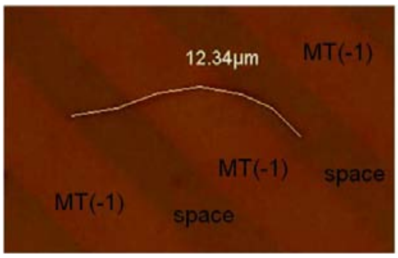

Figure 16. Photo of a crack (highlighted in white) above a MT(-1) pattern with diagonal metal lines of 4um width. Harsh probe scrub direction is down.

This crack initiated over the metal with the usual curvature, then changed direction of propagation as the crack encountered thicker SiO_2 on each side. On the right side, the crack tends to follow the edge of the metal line. On the left side, it turns more perpendicular to the probe scrub direction as it crosses the space.

Recall from figure 13 that metal lines parallel to the probe scrub prevented cracks significantly better than metal lines perpendicular to the scrub. Note that the modulus of SiO_2 film is more than 10% higher than that of the Al in the metallization, and the SiO_2 is stronger in compression, while the Al tends to deform plastically. We can explain that the probe's downward force during scrub bends the SiO_2 above MT(-1) films more than it compresses the thicker SiO_2 in the spaces. Downward probe force on a supported SiO_2 film (as in a MT(-1) "space") will simply cause some compression of the SiO_2, while downward force on thin SiO_2 over Al (as in a MT(-1) metal line location) will also deform the Al locally and bend the SiO_2. High tensile stress at the bottom of the SiO_2 film can initiate a crack during this bending.

Reduced cracking in a pad structure like figure 15 as compared to figure 14 can be explained by the probe tip being partially "supported" by the stiffer, non-deforming SiO_2 in the MT(-1) spaces during scrub, preventing significant bending of the SiO_2 above the MT(-1) line. Cracking in the case of MT(-1) lines perpendicular to the probe scrub, as in figure 14, can occur both when the entire tip "heel" is located directly above the MT(-1) line and also when the probe tip scrubs across a transition of space to metal or metal to space.

Moving on to other MT(-1) patterns, figure 17 shows an expected crack shape for MT(-1) having an array of holes, with the very different shapes of actual cracks for comparison.

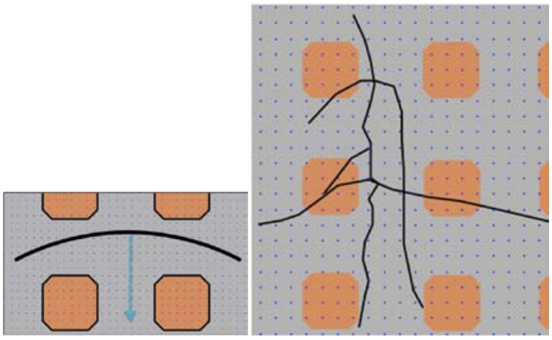

Figure 17. (left) probe heel tip shape drawn over a MT(-1) pattern with an array of holes, (right) actual crack shapes from one harshly probed pad, initiating over the MT(-1) and propagating in various directions due to interaction with the "holes".

Cracks initiate over the MT(-1), and the crack shapes change significantly as they propagate due to the presence of the thicker SiO_2 in the "holes". Multiple cracks are likely due to the repeated probing (6 touchdowns at 4mils overdrive in these experiments) Similar crack interactions are observed for various dimensions of hole arrays in MT(-1) as seen in figures 18 – 20.

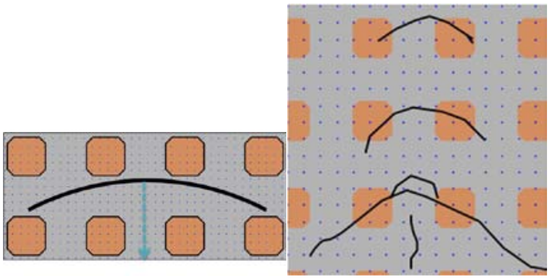

Figure 18. (left) probe tip heel shape, (right) cracks in a pad initiating over the MT(-1) and changing propagation direction due to interaction with the "holes".

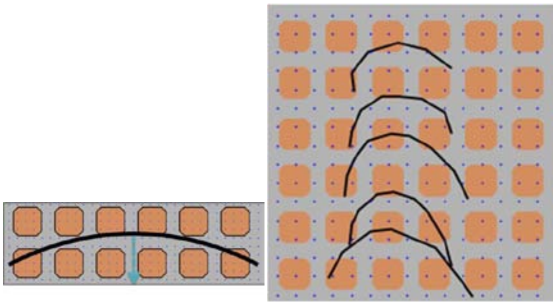

Figure 19. Similar to figure 18 with a denser array of holes.

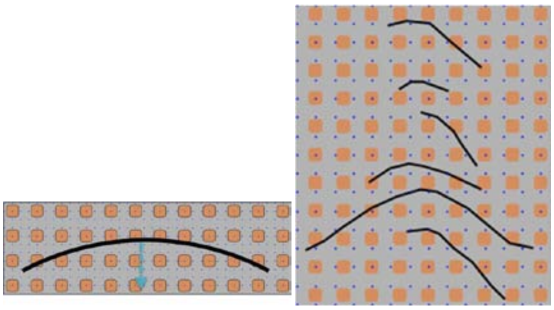

Figure 20. Similar to figures 18 and 19, with a smaller dense array of holes.

As we have seen in a number of examples, cracks in harsh probing tend to initiate over the MT(-1) regions or at transitions between MT(-1) and a slot or hole. Crack propagation does not necessarily replicate the probe tip "heel" shape as it does for full sheet MT(-1), but the propagation changes due to the presence of thick SiO_2 between MT(-1) features. For cases with the arrays of holes, referring again to figure 13, we can see that narrow metal designs with larger holes (as in the best performing MT(-1) holes array) is beneficial – again suggesting that the probe is being more uniformly "supported" by the thick SiO_2 regions in spaces, preventing SiO_2 bending above the narrow MT(-1) regions.

Also from figure 13, the dummy metal fill with 50% drawn MT(-1) pattern density did well in preventing cracks. Figure 21 is an example photo of cracking above the dummy fill pattern.

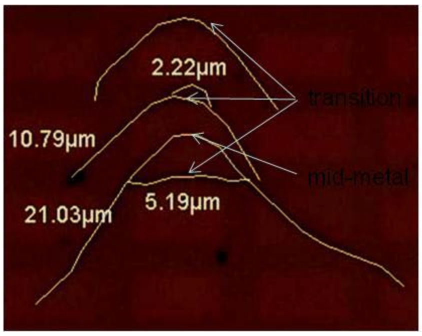

Figure 21. Cracks above MT(-1) dummy fill pattern. Cracks initiate only at the transition from space to metal, or in the center of the metal.

The dummy fill pattern has rectangles of MT(-1) surrounded by spaces, opposite to the metal sheets with holes in the previous figures. Harsh probing perpendicular to the long direction of the metal is able to cause cracking when the probe crosses from space to metal in 3 out of 4 cracks. Crack shape and propagation is influenced by the presence of spaces surrounding the MT(-1) features.

MT(-2) and MT(-3) layers: Cracks above wide features in MT(-2) sub-layers is essentially the same as if the MT(-2) was a full metal sheet. Lower pattern density is important, though the density doesn't need to be as low as in the MT(-1), because the thicker SiO_2 above MT(-2) doesn't bend nearly as much. Interaction with MT(-2) pattern edges is less pronounced than for the edges of MT(-1) patterns, but it has been observed in some of the harsh probing experiments. MT(-3) full plate can influence cracking similar to MT(-1) and MT(-2), but the even thicker SiO_2 above MT(-3) is so difficult to bend that cracking even in harsh probing is rare.

We note that in all of the above cratering test results for cracks that the only visible cracks are those which broke the top surface of the SiO_2, and the barrier layer above. Cracks initiating in the bottom of the top SiO_2 layer above MT(-1) must propagate to the top of the SiO_2 to be easily detected – which has occurred in these cases due to the repeated probing at high overdrive. But such cracks will not necessarily be visible without the harsh conditions. Cracks forming at transitions between space and MT(-1) features are expected to be easier to detect in a cratering test because the cracks initiate in the top of the top SiO_2. The SiO_2 bends downward as the probe tip moves from the thick SiO2 of the space over the top of the MT(-1) causing high tensile stress in the top of the top SiO_2 at the transition.

Harsh wirebonding has also been studied on many of the same experimental bond pad structures, as reported in another work from our group [2].

Conclusions

Harsh probing conditions have been applied experimentally to various bond pad structures having Al-based metallization layers and W vias in SiO_2 dielectric, following procedures as previously reported for traditional pad designs. Cracking of the top SiO_2 as detected in the cratering test after harsh probing is worst for "traditional" pad designs where full metal sheets are in the pad sub-layers. Removal of top vias helps to reduce cracking. Reducing the pattern density of (especially MT(-1)) in the metal sub-layers significantly reduces cracking, demonstrating that CUP circuitry may be routed through the pad window in all metal sub-layers while strengthening the pad against cracking from harsh probe conditions. The harsh probe scrub interacts with the MT(-1) pattern, with slots in parallel with the scrub direction being best for crack prevention. MT(2) pattern density is less important in harsh probing than the MT(-1) pattern density, but it plays a role in robust pad design. This data also implies that for CUP circuitry running parallel to the die edge, prevention of cracks can be improved by aligning the probe tip scrub to be parallel to the die edge.

Simple guidelines drawn from these results may be used to design CUP bond pads that successfully prevent cracking even when harshly probed. The basic principle in prevention of cracks during wafer probe is to prevent the top SiO_2 from bending significantly. Robust CUP pad structures can be manufactured in the existing process, facilitating die size shrink for lower cost products while potentially permitting wider process margin in wafer probe.

Acknowledgements

We acknowledge the excellent work of personnel of ON's Pocatello Materials Analysis Lab, Lynda Pierson, Troy Welch, and Jeff Ticknor. Thanks also to Lawrence Nestor for the harsh probing work.

References

1 Hunter, et al, "*Use of Harsh Wafer Probing to Evaluate Traditional Bond Pad Structures*", IEEE SWTW 2011, (submitted to IEEE CPMT)
2 Hunter, et al, "*Use of Harsh Wirebonding to Evaluate Various Bond Pad Structures*", IMAPS EMPC 2011