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# Failure Analysis On Power MOSFETs With Copper Wire Bonds

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Copper wire bonds are being used increasingly in microelectronic components as a less expensive alternative to bonds made of gold. So far, the evidence indicates that copper is a viable alternative, but proving its reliability will require new failure analysis (FA) techniques that are specific to the copper wire-bonding process.

In this article, we talk about some new FA techniques and procedures that have been developed specifically for components using copper-wire technology. We explain why copper wires need to be treated differently from gold and use case studies from power MOSFET devices to show a step-by-step example of an FA process designed to preserve all the evidence needed to perform an effective analysis on failed devices.

## Problems Of Decapsulation

A major issue is the method used to open up the part to see what caused the failure. The traditional wet chemical/jet etch decapsulation method does not work in copper-wire bonded products because the fumes from nitric acid have the effect of quickly etching copper wires. Figs. 1 and 2 show an example of copper wires that were corroded following use of the traditional decapsulation method developed for gold wire-bonded parts.

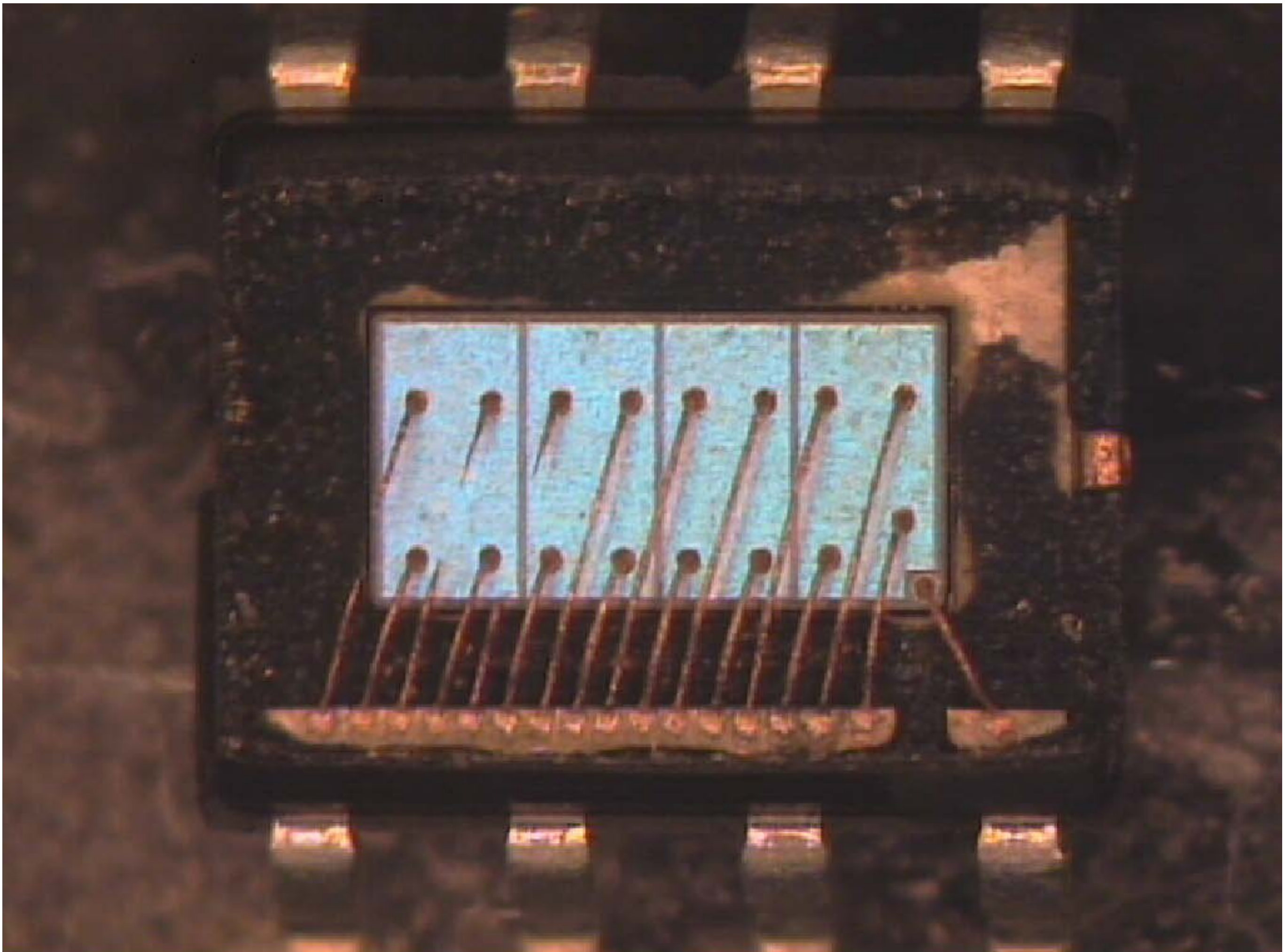

*Fig. 1. Traditional wet chemical decapsulation of copper-wire part.*

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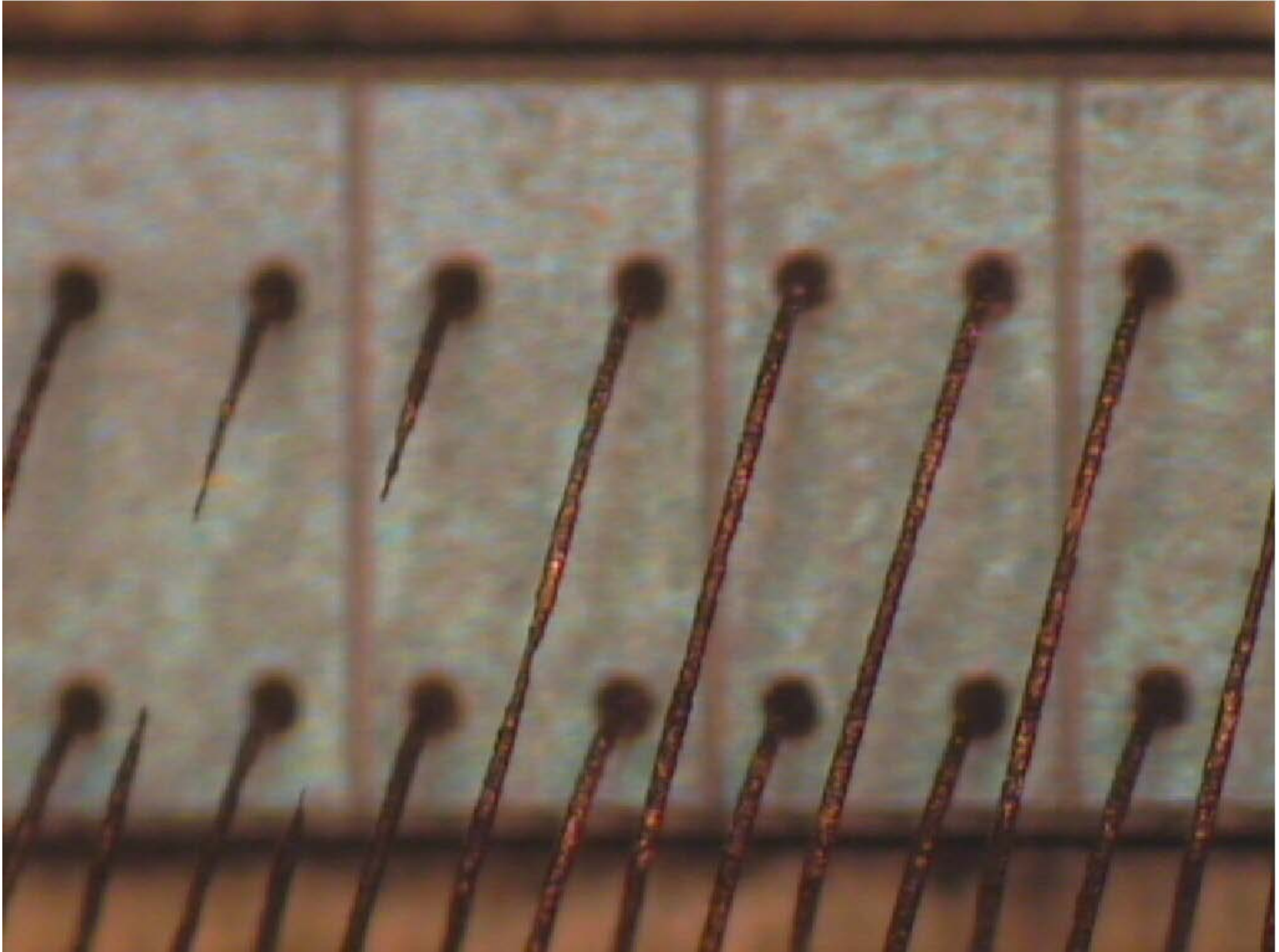

*Fig. 2. Enlarged image of the damaged copper wires shown in Fig. 1.*

Damage done to the wires by etching can complicate any subsequent analysis, so a corrosion-free decapsulation method is needed. One approach we tried was using laser decapsulation to partially remove the molding compound, followed by an optimized wet chemical etching/jet etch to expose the die surface. This minimizes the damage to copper wires and bonds.

A device decapsulated using this method is shown in Fig. 3. The integrity of the copper wires and bonds is clearly preserved, but even a minimal application of wet chemicals might wash away foreign substances that could turn out to be the root cause of the device failure.

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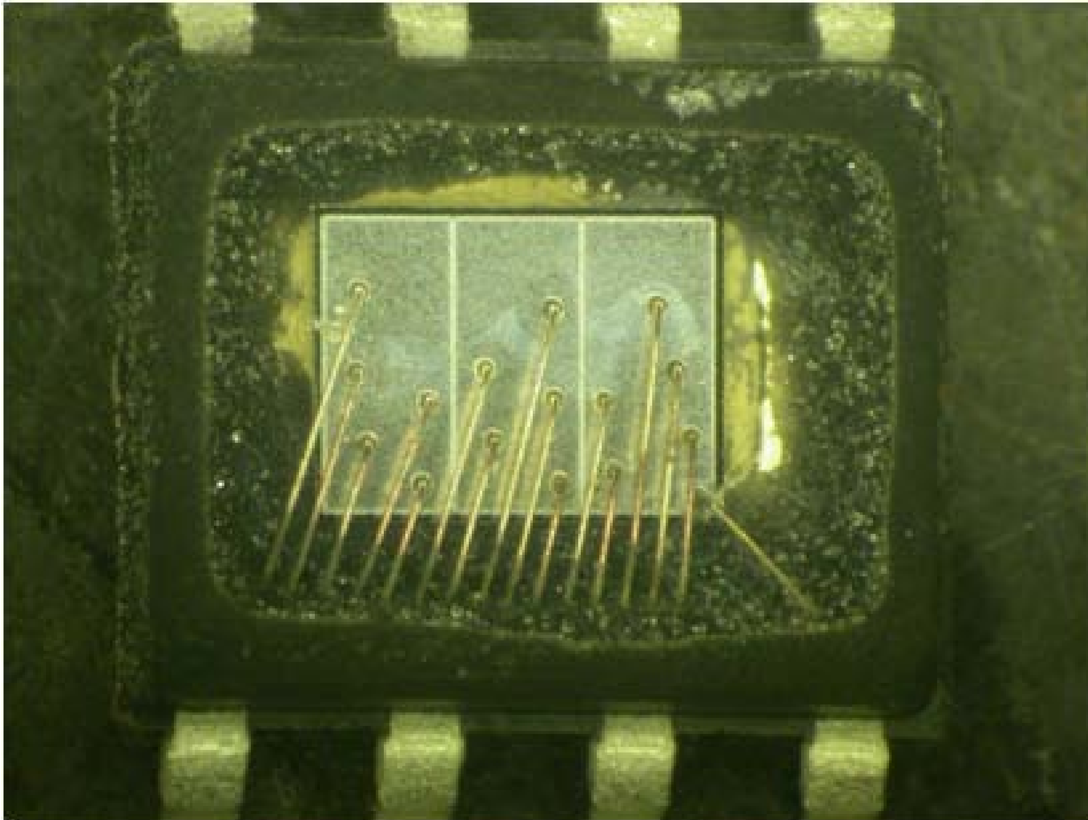

*Fig. 3. Laser/chemical decapsulation of copper-wire part.*

Eventually we found that the best method to facilitate examination of lifted wire bonds, die attach overflow, die surface contamination, and so forth, is a combination of laser decapsulation and plasma dry etching. Fig. 4 shows an example of a laser/plasma decapsulated part where the surface of the die, wires, and bonds is well preserved for further analysis.

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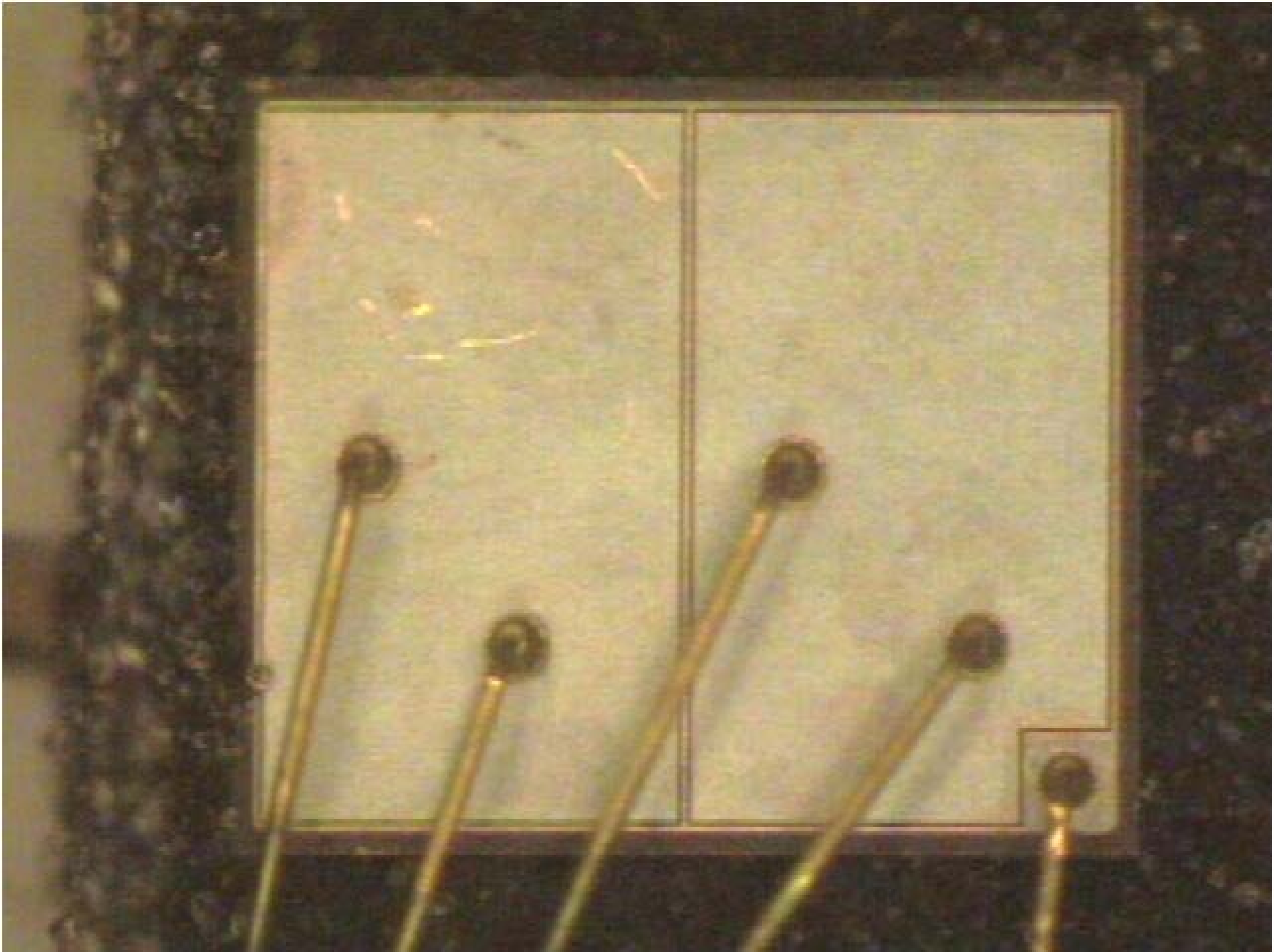

*Fig. 4. Laser/plasma dry decapsulation of copper-wire part.*

### *Copper Wire Bonds And Residual Aluminum From Metallization*

Copper wire bonds also need to be studied to determine the thickness of the leftover die metallization after the wire-bonding process. The minimum thickness of the aluminum layer remaining under the copper wire bonds is a critical factor for the long-term reliability of copper wire-bonded products. A focused ion beam (FIB) has been an essential FA tool for characterizing this aspect of the copper bonding process.

We developed a combination of parallel polishing and FIB cross-section analysis to create an FA process that could be done without using wet chemicals. Fig. 5 shows the parallel polishing off of the molding compound to expose the bare die surface. A thin layer of molding compound still covers the lower right half of the die because of a subtle die tilt in the original device.

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*Fig. 5. Parallel polishing off of molding compound. A minute tilt in die relative to the supporting lead-frame caused the upper-left corner of the die to be polished slightly more.*

Figs. 6 and 7 show photos of FIB cross-sectioning through a copper wire bond, indicating the minimum remaining aluminum thickness to be 0.125 µm. This is the kind of bond that needs to be avoided, but it could easily happen without a good analysis technique.

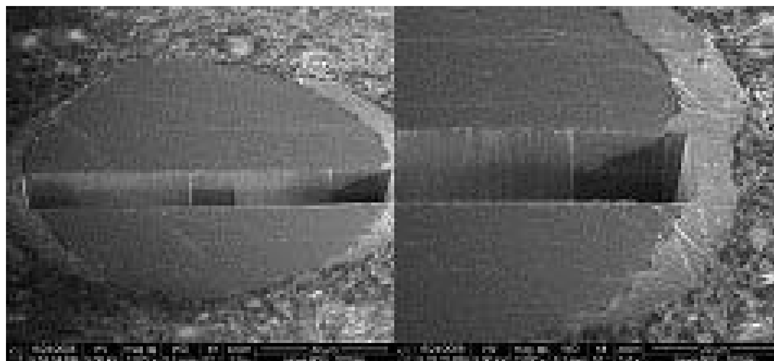

*Fig. 6. FIB cross-section through a copper wire bond.*

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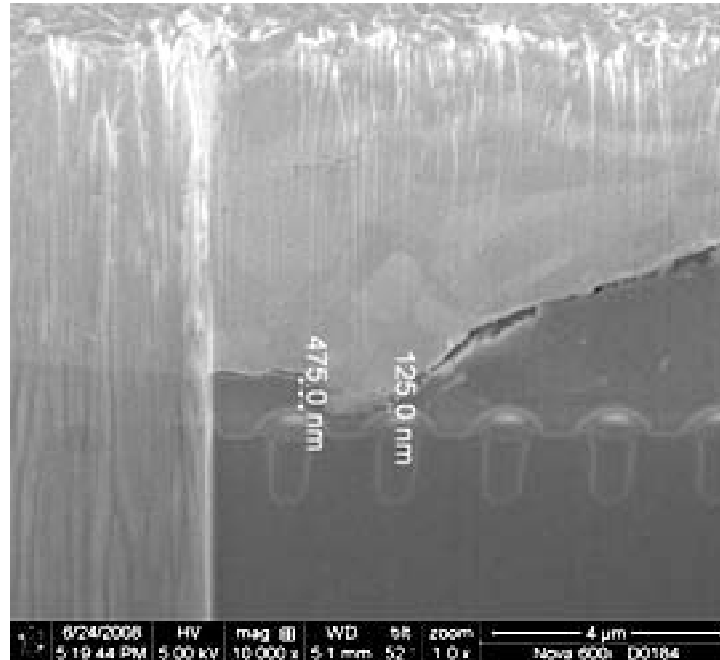


*Fig. 7. FIB cross-section through a copper wire bond—a close-up.*

A faster way to measure the thickness of the aluminum layer under the copper wire bonds is a chemical etching method that etches away only copper wires and bonds while preserving the aluminum layer underneath, enabling an FIB cross-section analysis. The advantage of this method is that it provides an overview of all the copper wire bonds across the whole die surface, allowing the appropriate wire bond to be selected for FIB cross-section analysis.

Fig. 8 shows an overview of die surface after wet chemical etch. Fig. 9 shows the FIB cross-sectioning through one of the wire-bonded areas. Note that the grain boundary of the aluminum top metallization and the push-out of aluminum at the perimeter by wire bonding can be clearly seen, indicating that the top metal surface had not been altered.

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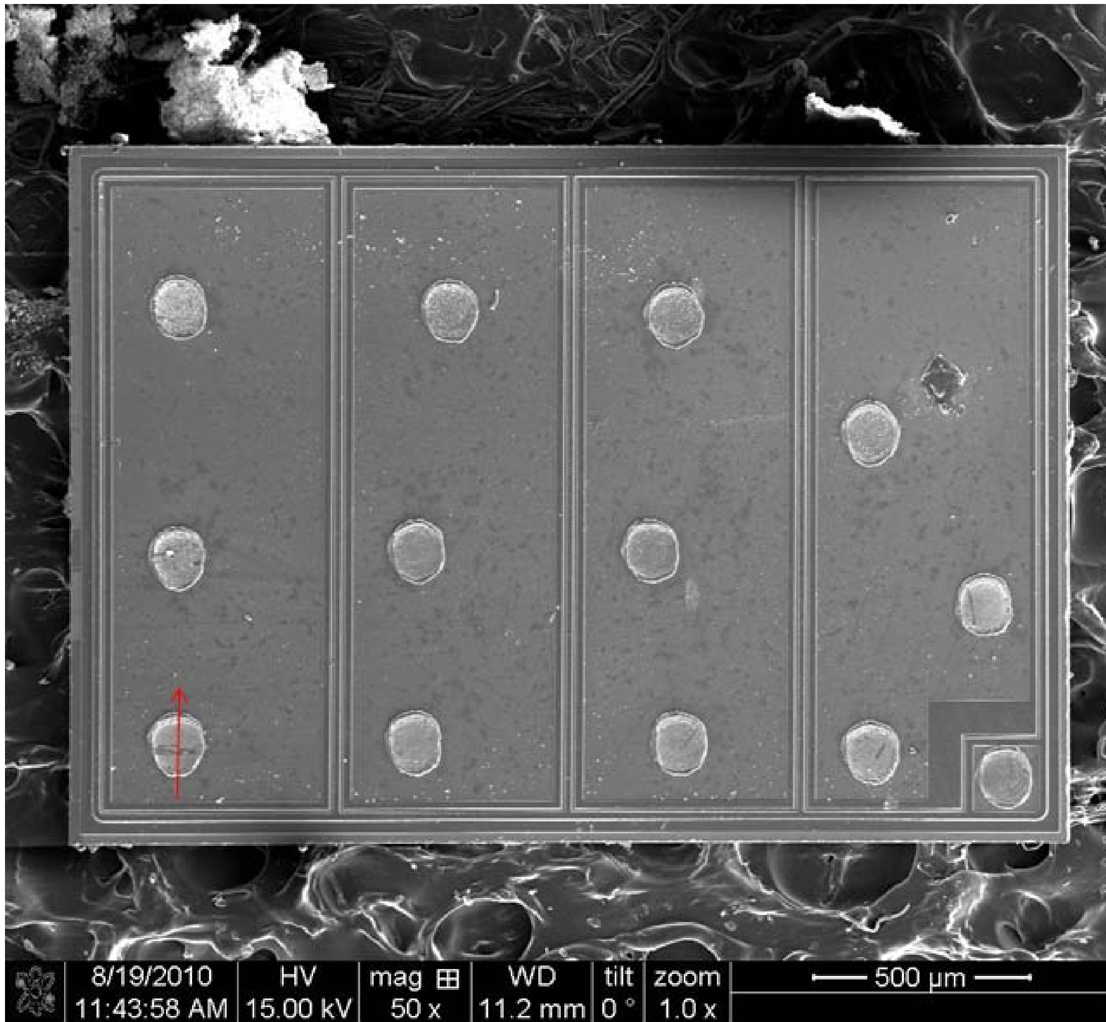


*Fig. 8. Overview of die surface after removal of copper wire bonds.*

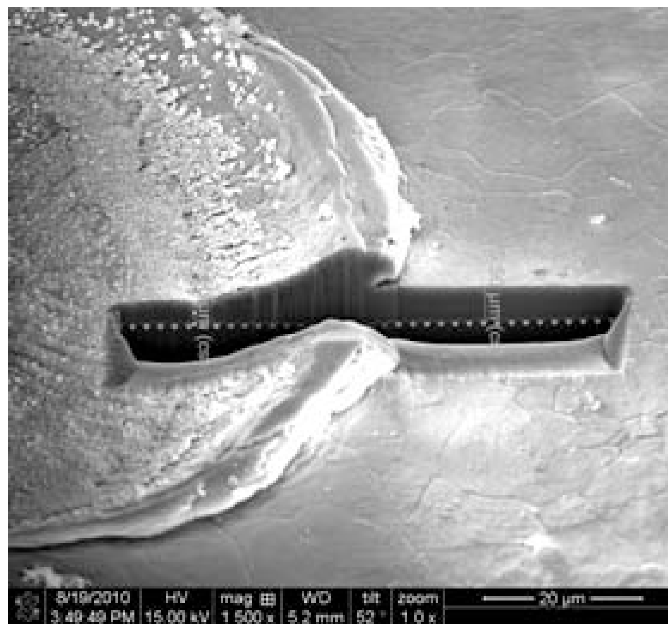


*Fig. 9. FIB Cross-section through the copper wire-bond area.*

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The traditional mechanical method of exposing a cross section of the wire bonds often results in "smearing" of the copper at the interface between copper bond and under-the-bond metal. Local FIB fine polishing after mechanical grinding can solve this problem. Figs. 10 and 11 show the images after mechanical/FIB fine polishing of the cross section.

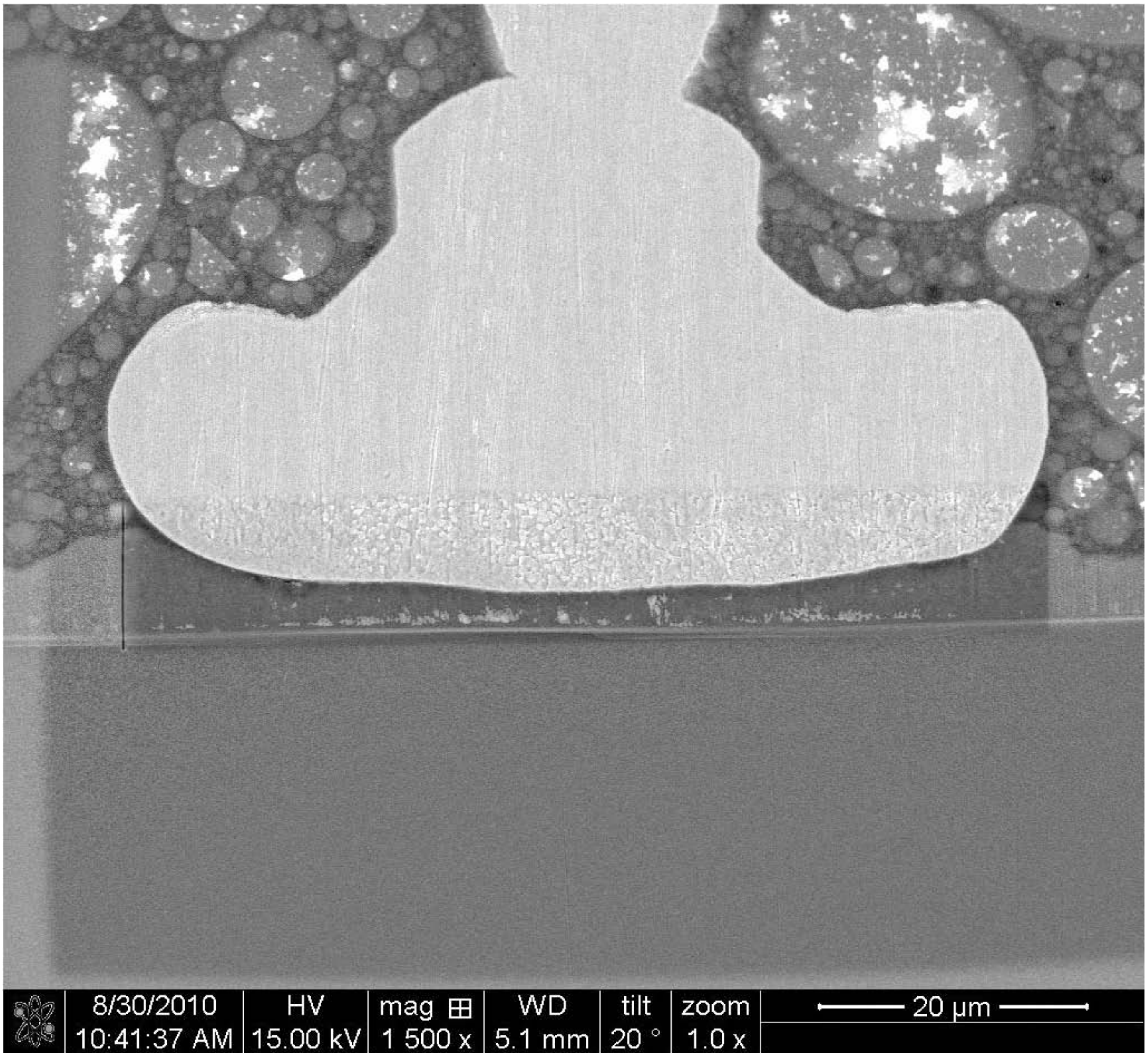


*Fig. 10. A copper bond cross section prepared by mechanical grinding, followed by FIB fine polishing.*

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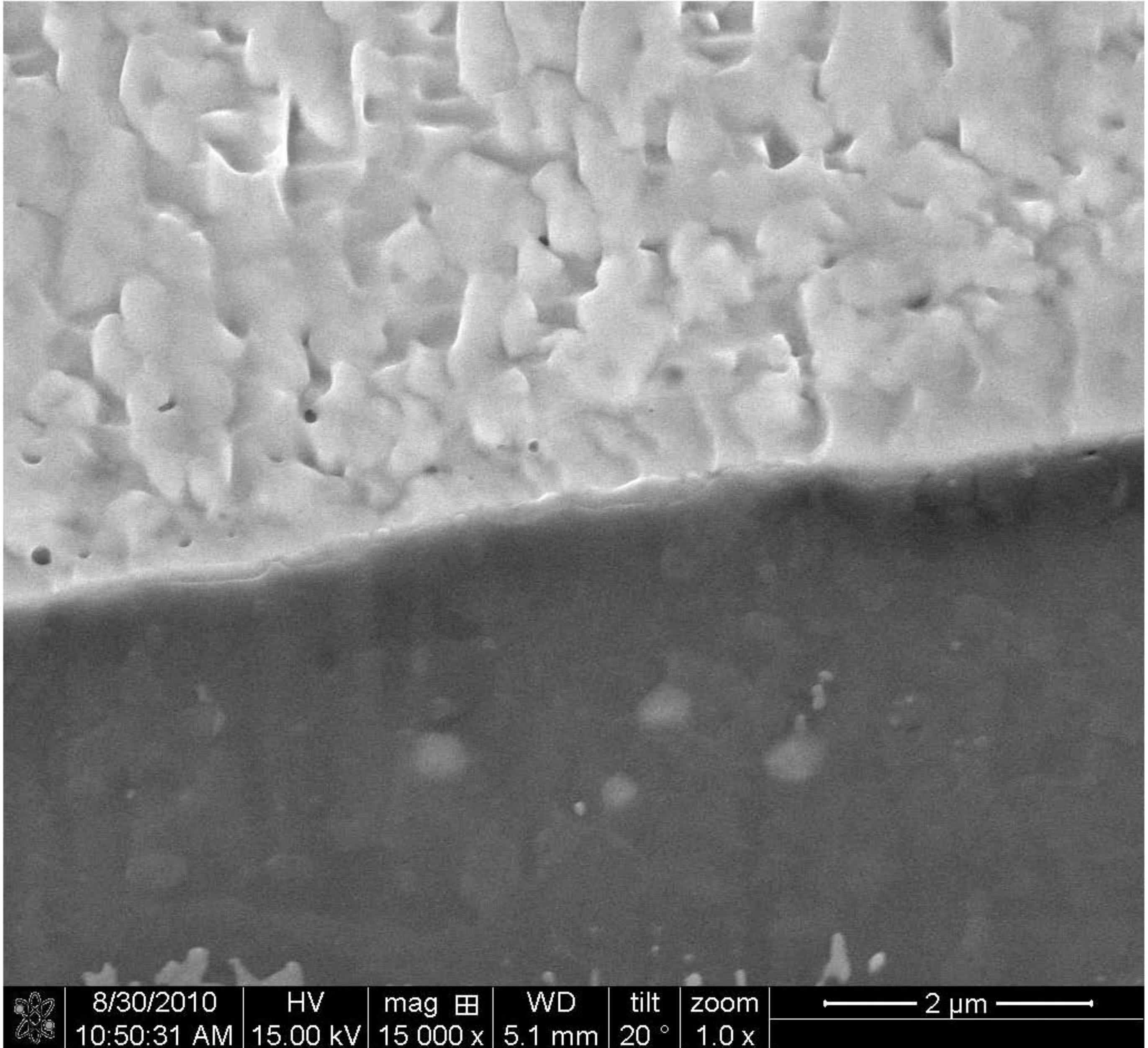


*Fig. 11. Enlarged picture of copper bond and aluminum interface shown in Fig. 10.*

**Case Study One**

The device, a MOSFET bonded with copper wires, failed with high on-resistance after 1000 cycles of condition C temperature cycling. The source wire bonds and wedge bonds needed to be carefully examined. First, we exposed the copper wedge bonds using only laser decapsulation, as these could be easily damaged by traditional wet-decapsulation methods.

Figs. 12 and 13 show the exposed copper wedge bonds after laser decapsulation. SEM inspection revealed cracks on wedge bonds of the MOSFET, which could be the main cause of the anomalously high $R_{DS(ON)}$.

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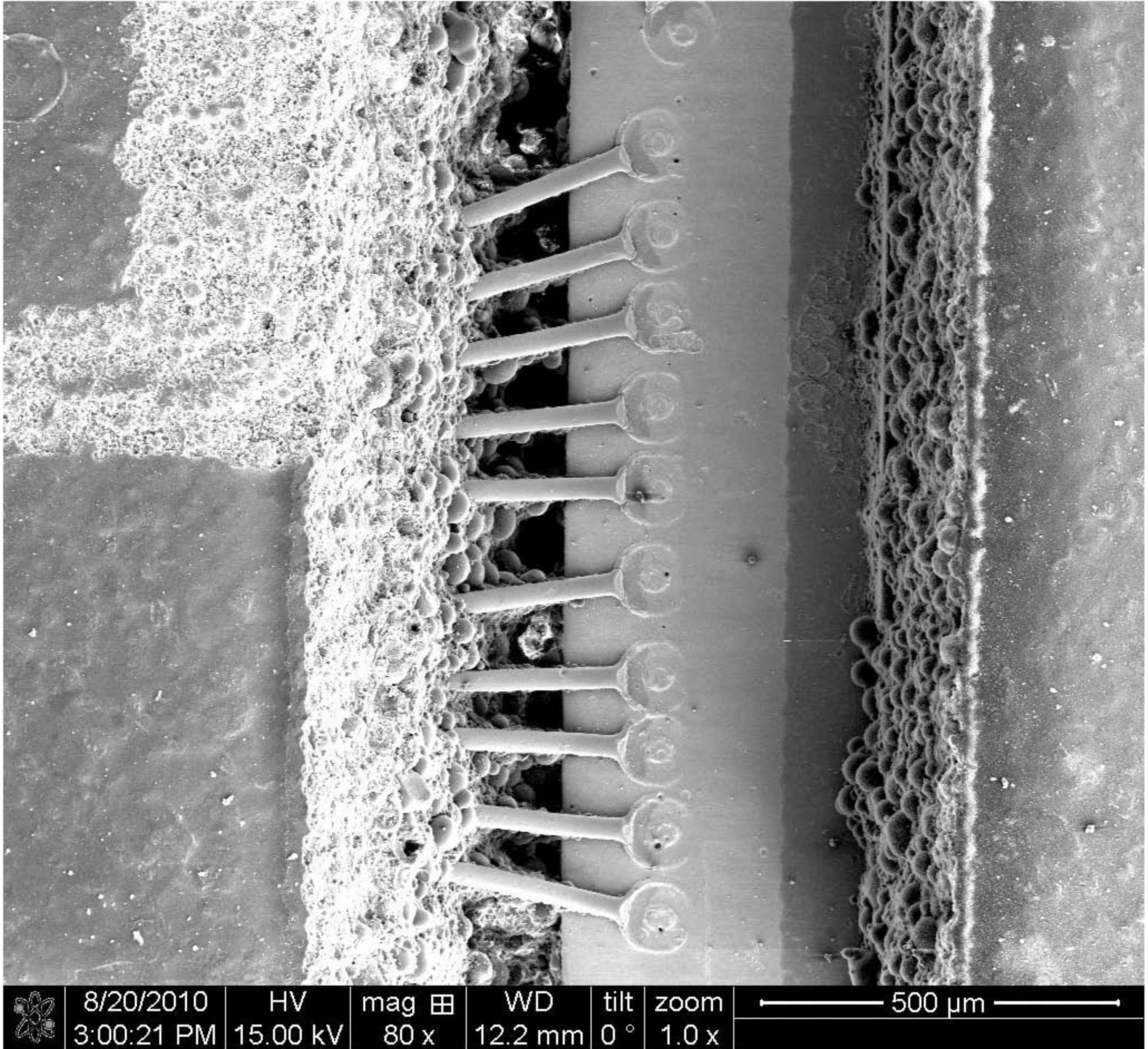


*Fig. 12. Laser decapsulation to expose the copper wedge bonds.*

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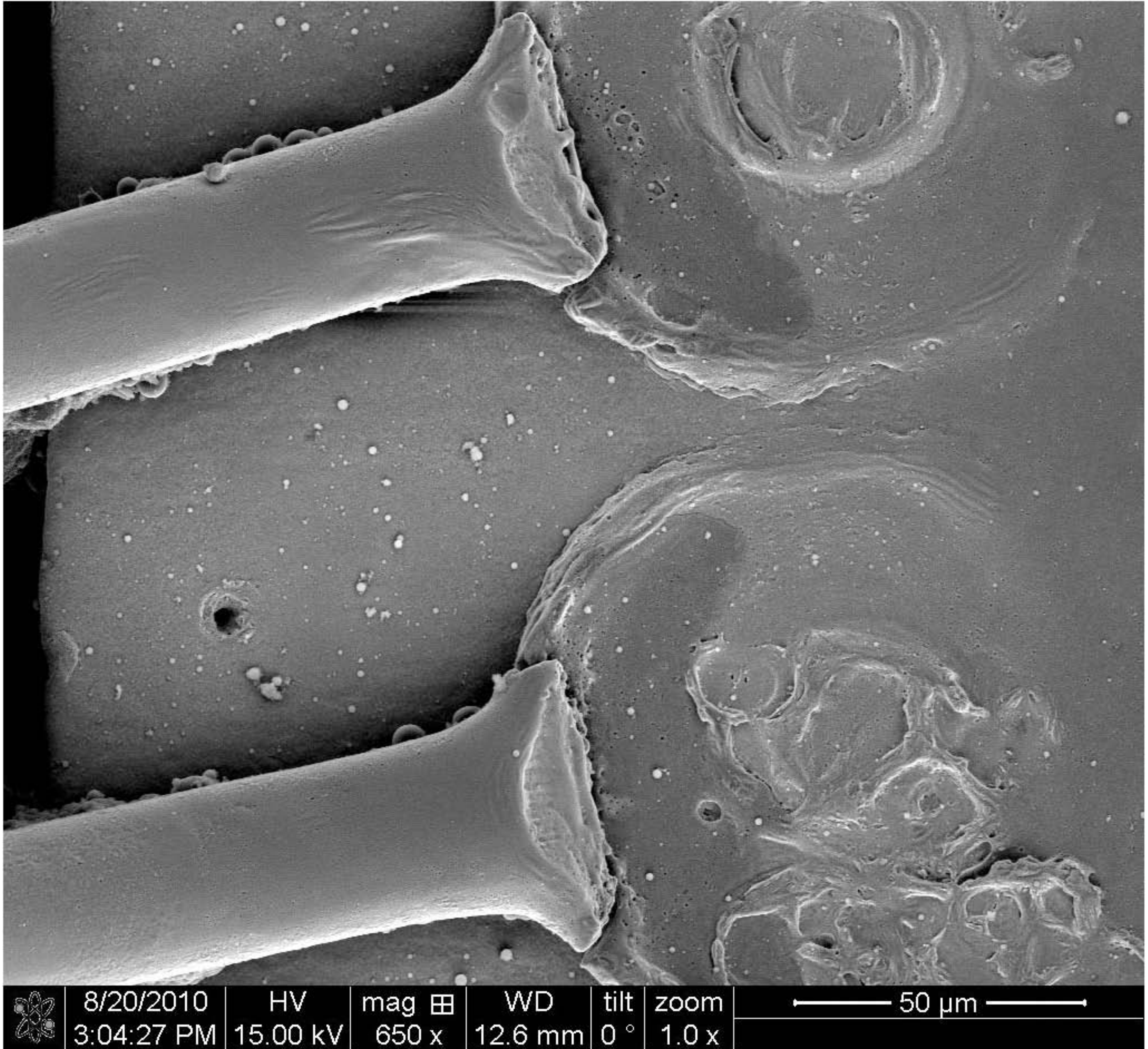


*Fig. 13. Enlarged picture of copper wedge bond cracks shown in Fig. 12.*

Next, we examined the copper wire bond and top metal interface by using a mechanical cross-section through the center of the copper wire bonds, followed by FIB fine polishing to eliminate the copper smearing. SEM analysis revealed a normal interface between the copper wire and aluminum top metal (Figs. 14 and 15.)

After examining both copper wire bonds and wedge bonds, we concluded that the high $R_{DS(ON)}$ failure could be attributed to the cracks in the copper wedge bonds.

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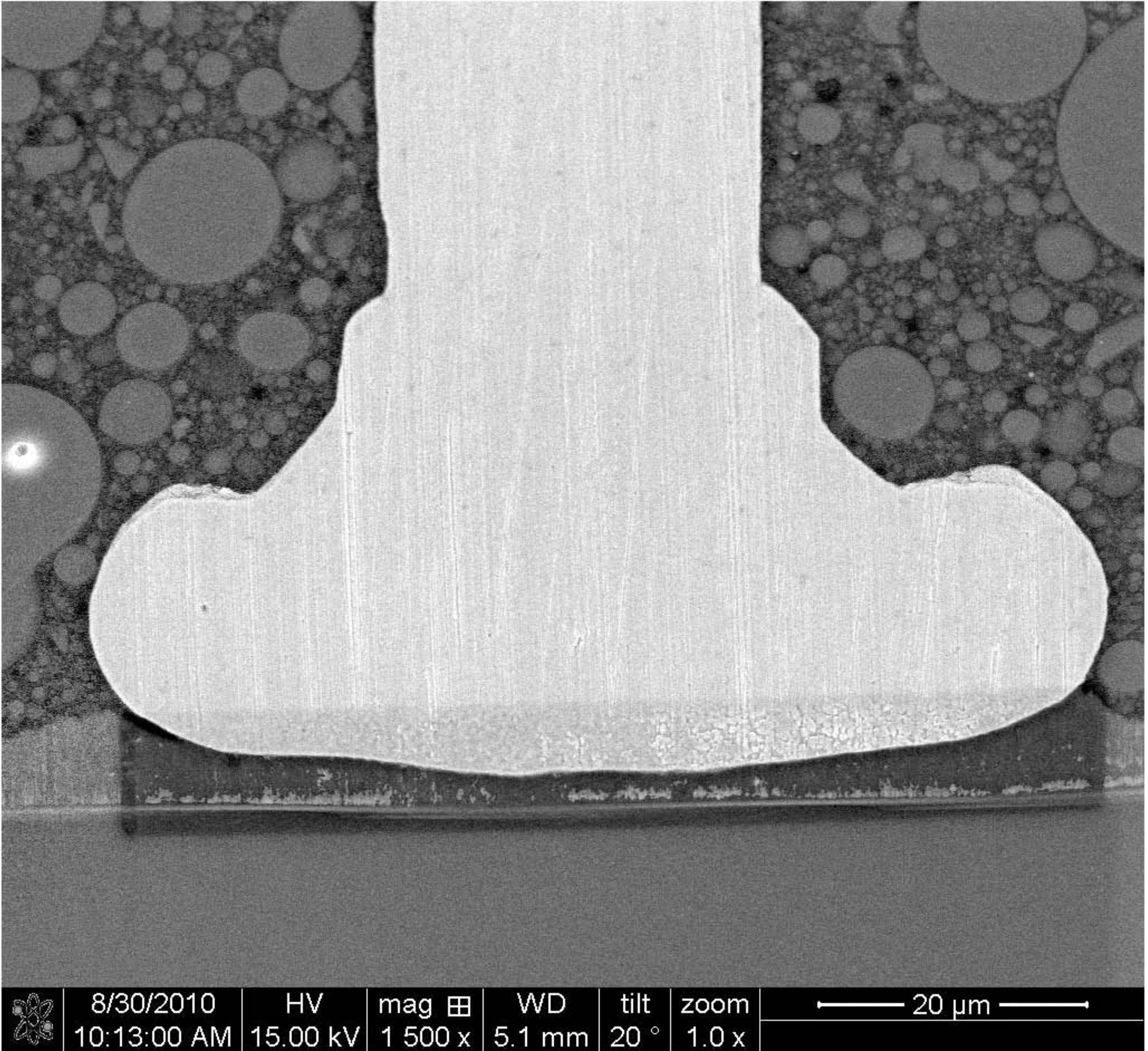


*Fig. 14. Overview of the copper wire bond and aluminum interface after FIB fine polishing.*

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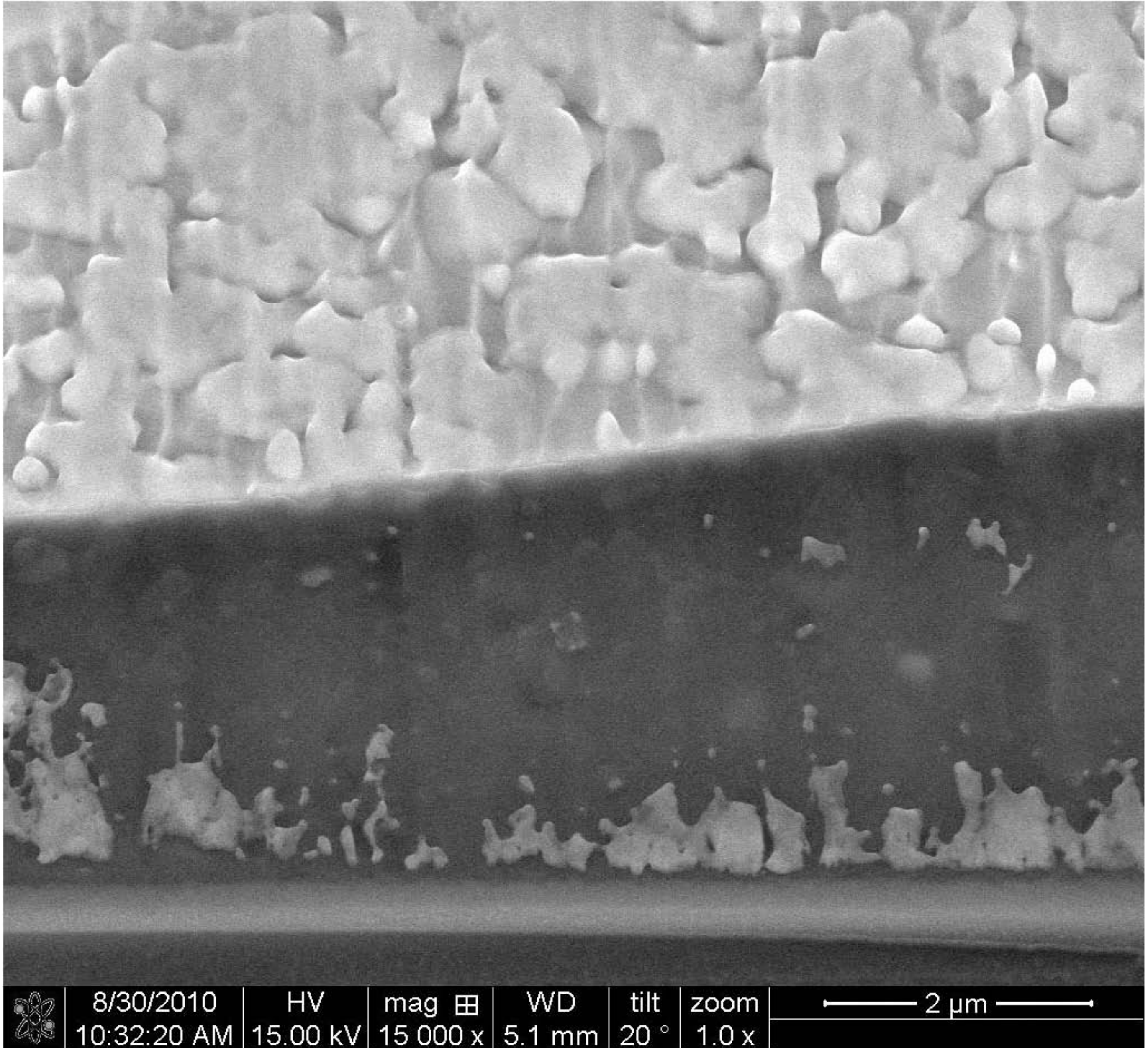


*Fig. 15. Enlarged picture of copper bond and aluminum interface shown in Fig. 14.*

**Case Study Two**

During the development and optimization of Vishay's high-reliability copper wire-bonding process, failure analysis played a crucial role in characterizing the bonding process parameters. FA techniques played a key role in helping us to characterize the minimum thickness of the residual aluminum under the copper wire bonds as a function of various bonding parameters. The table shows an example of an experiment where wire-bonding parameters were adjusted to cover some range around a set of nominal values.

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Table 1. Copper wire-bonding parameters. Note that the parameters are relative numbers that are typically wire bonder specific. A bigger number means either greater impact force or higher ultrasonic power used after the contact between bond wire and die surface is established.

| Leg | Copper Bonding Parameters | | |
|---|---|---|---|
| | Base Power | Base Force | Contact Force |
| A1 | 95 | 80 | 280 |
| A2 | 85 | 90 | 300 |
| A3 | 80 | 100 | 320 |
| A4 | 70 | 110 | 340 |

We used 63% nitric acid at 30°C to remove the copper wire bond without attacking the underlying aluminum layer. This was followed by FIB cross-section analysis to investigate the minimum remaining aluminum layer under the copper wire bonds.

Fig. 16 shows the remaining aluminum thickness underneath the copper bond is around 2.06 µm on Leg A1. Fig. 17 shows the remaining Al thickness underneath the copper bond is around 3.97 µm on Leg A4. By using the minimum remained Al thickness as an indicator of safety margin for over-bonding, we found that the decreased base power dramatically decreased the risk of over-bonding of copper wires. We concluded that an optimized set of bonding parameters would provide good bond integrity with no over-bonding.

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*Fig. 16. FIB X-section on a sample with the A1 bonding condition.*

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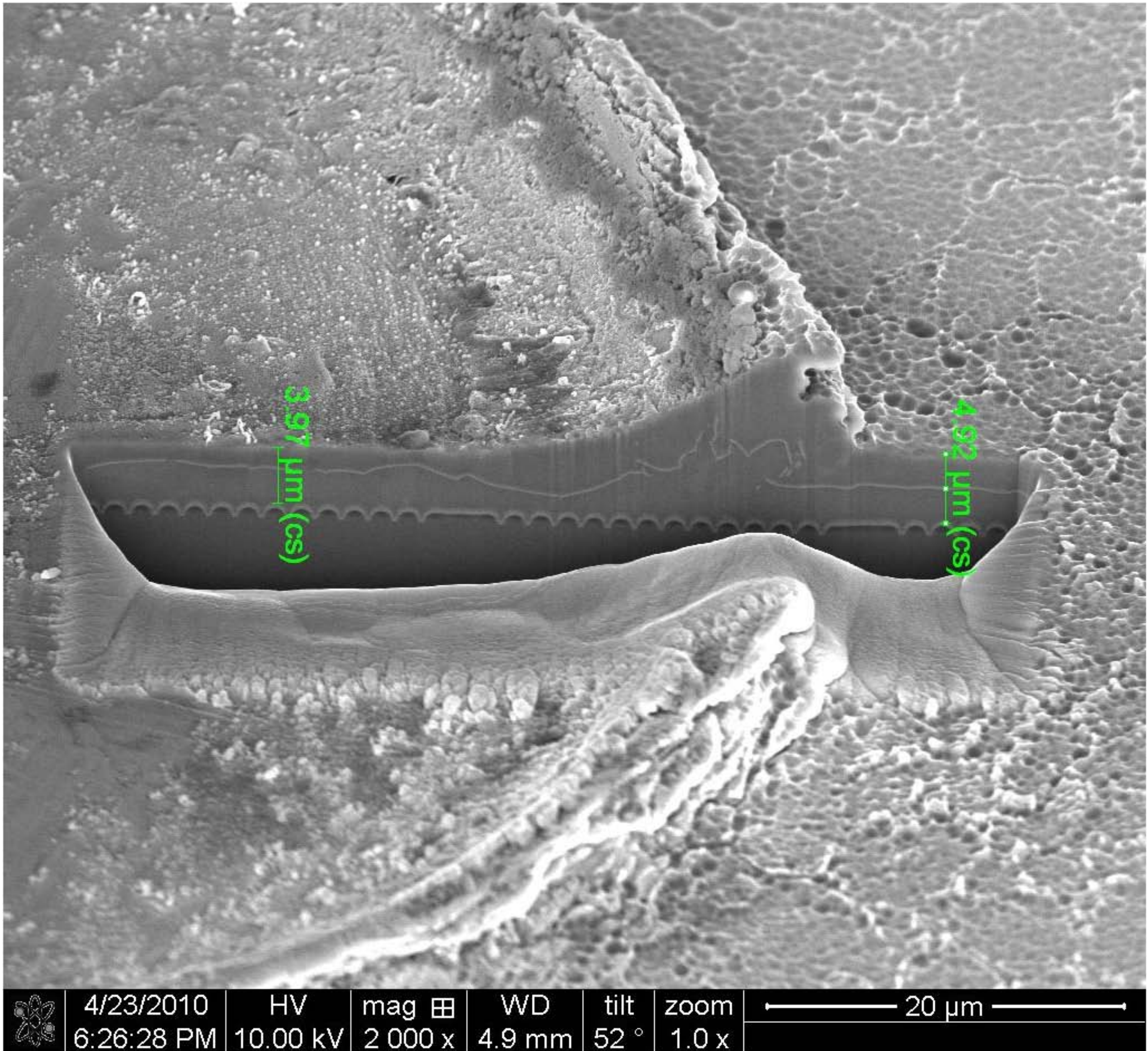


*Fig. 17. FIB X-section on a sample with the A4 bonding condition.*

## Further Reading

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For further reading on power device reliability, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category, and select "Reliability" in the Design Area category.

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