Using Picosecond Ultrasonic Technology for AI Packages, Part 2

By Cheolkyu Kim,
Onto Innovation

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Heterogeneous integration is a key enabler of today's AI innovations. By bringing together multiple chips with different functionalities, a.k.a., chiplets, AI devices have been able to achieve tremendous performance gains. However, the heterogeneous integration of advanced packages has its own set of process control obstacles that must be addressed, including new interconnect challenges involving redistribution layers (RDL) and bond pads.

Recently, Onto Innovation and Samsung Electronics Co., Ltd., teamed up to explore how picosecond ultrasonic technology could be used to measure the metal thickness of RDL and bond pads in high performance AI packages. In this blog, the second in our series on the advanced packaging applications of picosecond ultrasonic technology, we will show how this technology can be used to measure metal films during RDL and bond pad processes.

But first, a word about picosecond ultrasonic technology, a widely adopted non-contact, non-destructive acoustic technique that can be used to measure film thickness.

Measuring Films

Picosecond ultrasonic technology measures film thickness by tracking the round-trip travel time of ultrasonic waves generated and detected using an ultrafast laser pump probe technique. A short laser pulse (pump) creates an acoustic wave that travels through the film, reflects at material interfaces, and returns to the surface. A second laser pulse (probe) detects the returning wave.

Two detection methods can be used to determine film thickness or properties:

- REF mode senses changes in surface reflectivity caused by the returning wave.
- PSD mode detects surface deformation by measuring shifts in the reflected probe beam.

By measuring the time it takes for the wave to return and knowing the speed of sound in the material, the film thickness can be accurately determined to sub-angstrom levels.

This level of layer-specific metrology, precision, and measurement repeatability is increasingly critical as AI-driven packaging pushes the limits of interconnect density and uniformity.

Accuracy and Repeatability

For the purpose of our exploration, we conducted a test to confirm the accuracy of picosecond ultrasonic technology when measuring the films typically used in advanced packaging. These metals include Au, Ni, physical vapor deposition (PVD) seed Cu, and RDL Cu (EP). For each film we used picosecond ultrasonic technology to measure wafers of varying thicknesses. Then we cut the wafers for cross-section analysis and estimated the correlation with the picosecond ultrasonic results for the four films (Figure 1). In this scenario, the correlation factor R^2 was higher than 0.99 for all four cases, with the slope close to one, demonstrating the accuracy of picosecond ultrasonic measurements.

This level of correlation is not only impressive, it is essential. Competing technologies such as four-point probe (4PP) or contact profilometry often fall short in multilayer structures or non-planar surfaces, where mechanical contact can distort results or damage delicate features.

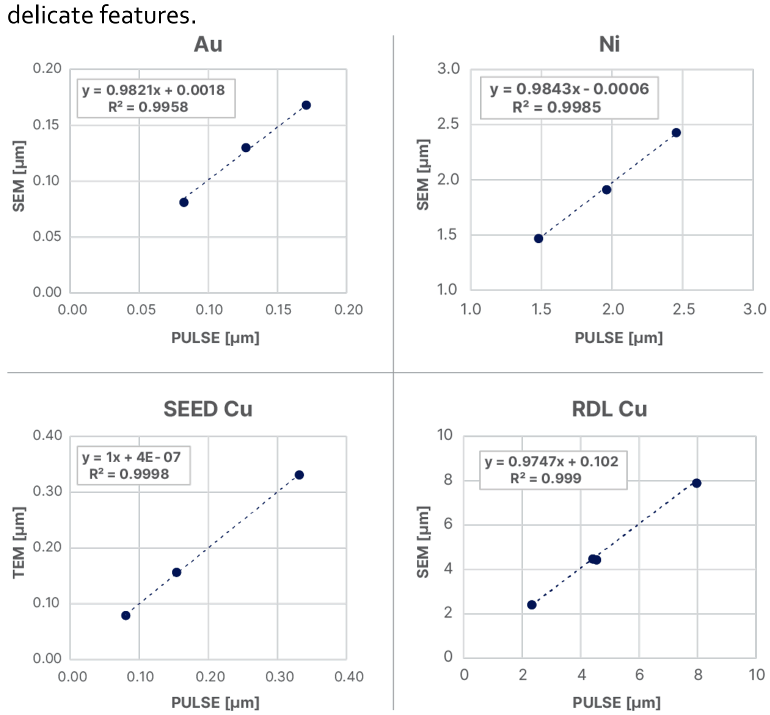

Fig. 1. Correlations between picosecond ultrasonic measurements and cross-section analysis for Au, Ni, seed Cu (PVD), and RDL Cu (EP). The excellent correlation factors demonstrate the accuracy of picosecond ultrasonic technology.

Following this, we measured product wafers in various interconnect processes with picosecond ultrasonic technology, including seed Cu/Ti measured in REF mode (Figure 2) and RDL in PSD mode (Figure 3).

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RDL thickness can be measured both in pre- and post-seed Cu removal.

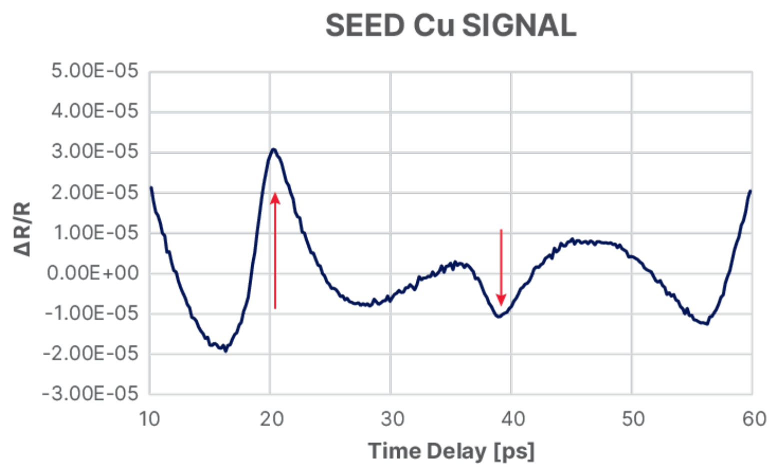


Fig. 2. Measurement signal of seed Cu/Ti in REF mode. Delay time for seed Cu and Ti are indicated by the red arrows.

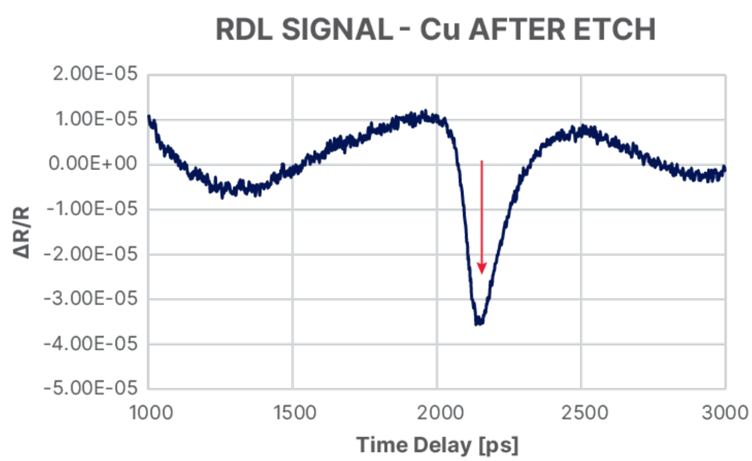


Fig. 3. RDL Cu signal after the seed Cu etch process. The red arrow shows the round-trip time of an acoustic wave within RDL Cu film.

The horizontal axis in Figures 2 and 3 represents the time delay of the probe pulse with respect to the pump, while the vertical axis represents the change of reflectivity (ΔR/R) caused by the travelling acoustic wave. The sharp change of reflectivity in the signal, as demonstrated in Figures 2 and 3, is mostly due to the acoustic wave reflected from the film interface returning to the surface. In addition, the position of the peak and trough is shown with red arrows. These arrows are directly related to the thickness of the films, seed Cu, barrier Ti, and EP Cu. From the position of the peak and trough, the thickness of each film can be calculated. For seed Cu and barrier Ti, the repeatability of each layer is 0.3% or less of the thickness for all innovation® onto

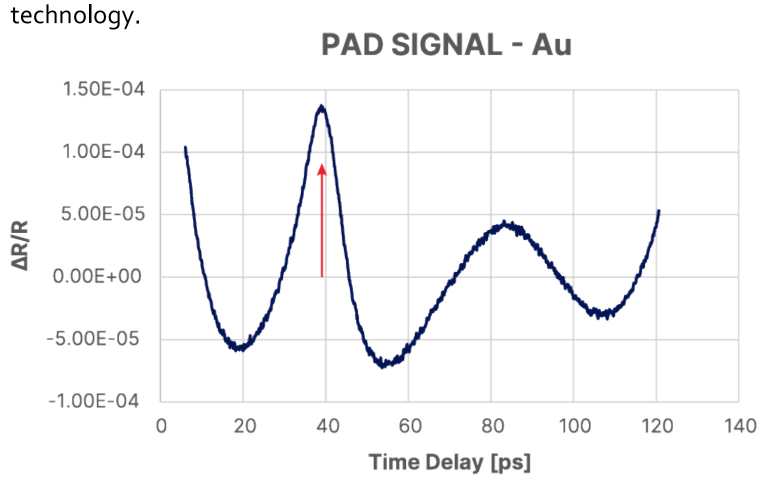
measurements. This demonstrates the capability of picosecond ultrasonic technology to meet 10% gage repeatability and reproducibility requirements.

For RDL Cu, the sharp change of reflectivity near 2,200 picoseconds (ps) corresponds to the round-trip time of the acoustic wave within the RDL Cu film; Cu thickness can be calculated from the trough position. The sharpness of the trough, along with thickness, indicates the trough position can be calculated with good repeatability. In fact, the repeatability of RDL Cu measurements for each point is less than 0.1% of Cu thickness, once again exceeding the 10% gage repeatability and reproducibility requirements.

Such precision is a necessary technical achievement. As AI applications demand tighter control over signal integrity and power efficiency, the margin for error in interconnect thickness shrinks dramatically. Legacy tools simply cannot keep up.

Measuring Bond Pads with Dimple Structures

We also used picosecond ultrasonic technology to measure a bond pad with a dimple structure. The film stack is composed of Au/Ni/Cu, with Au being the top film. Although the height of the center region of the pad is lower than the surrounding region by a few microns, we successfully measured individual layer thicknesses by measuring a few sites in the outer ring area and selectively choosing ones with good signal-to-noise ratios. This is possible because the focused spot size of the picosecond ultrasonic beam is $8 \times 10 \mu m^2$, small enough for the direct measurement on the outer ring of the pad.
This is another area where contact-based methods struggle. The ability to selectively target small, non-planar regions without physical interference is a key differentiator of picosecond ultrasonic technology.



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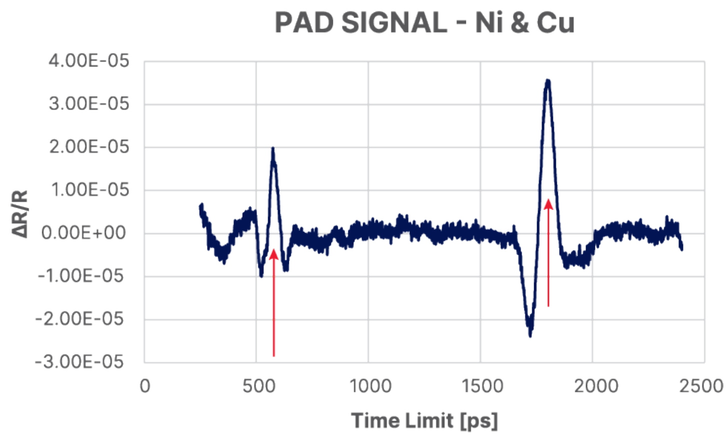

Figure 4: An example of an REF mode signal from the bond pad with a dimple structure for Au (a), Ni and Cu (b).

In Fig. 4 a-b, the red arrows indicate the reflectivity changes caused by the acoustic waves returning from the interface to the surface. With these peak positions, we were able to calculate each layer's thickness with good accuracy and repeatability. The repeatability of Au, Ni and Cu films for each measurement was less than 0.2%, 0.05% and 0.05%, respectively. As such, all three film measurements outperformed the requirement of 10% gage repeatability and reproducibility.

It should be noted that Au film is much thinner than the other two films. As such, there is a significantly higher repeatability for Au films compared with the other films.

Conclusion

The AI era is upon us, and it would not be possible without advanced packaging innovations. However, the complexity of today's advanced packaging is worlds away from traditional packaging. Today's back-end process involves a variety of technologies and requires new methods of process control. In addition, controlling metal thickness and within wafer uniformity in these processes is critical to meeting the requirements for signal integrity in advanced packaging.

Unfortunately, some fabs still rely on legacy metrology tools like 4PP or contact profilometry—technologies that were never designed for the complexity of modern AI packages. These tools often introduce mechanical stress, lack the resolution to resolve thin or buried layers, and cannot reliably measure non-planar or dimpled structures.

As we have demonstrated, picosecond ultrasonic technology is an ideally suited interconnect metrology solution for both RDL and bond

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pads. This technology offers excellent accuracy and gage capability for the control of interconnect processes in advanced packaging.

As back-end processes demand the same level of precision, uniformity, and control traditionally associated with front-end requirements, picosecond ultrasonic technology can play a major role in advanced packaging metrology, delivering the non-contact, high-resolution, and repeatable measurements that AI applications demand.

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About the author
Cheolkyu Kim, Ph.D., is director of product marketing at Onto Innovation with a focus on application development for picosecond ultrasonic (PULSE™) and inspection technologies. Prior to joining Onto, Kim was a postdoctoral research associate in the Physics Department of Brown University. During his three years at Brown, he spent time researching magnetically levitated superfluid liquid helium.