Optimizing Metal Film Measurement on IGBT and MOSFET Power Devices with Picosecond Ultrasonic Technology

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In recent years, power semiconductor applications have expanded from industrial and consumer electronics to renewable energy and electric vehicles. Looking to the future, the most promising power semiconductor devices will be insulated gate bipolar transistor (IGBT) and power metal oxide semiconductor field effect transistor (power MOSFET) modules.

During the manufacturing of these devices, metal films are deposited on the die of MOSFET and IGBT power devices. These layers of film have two main functions: they connect the elementary cells constituting the power dies to the source (power MOSFET) or emitter (IGBT) and allow for the welding of bond wires on the chip or for the solder bonding, facilitating thermal conduction. Because power devices run high currents at high-operating temperatures, the metal layers need to be properly controlled for electrical properties and thickness to enhance thermal conductivity.

Furthermore, power devices are transitioning from 6-inch to 8-inch wafers; this is happening at the same time as process windows are shrinking. As a result, measuring multi-layer metal thickness accurately and characterizing the uniformity of metal film deposition at the wafer edge has become increasingly important. For example, the front side of wafers requires deposition of a thick metal layer, typically 5µm or more of aluminum alloy. The uniform coverage of aluminum to conduct high currents across the entire wafer is key to device yield and reliability.

Power devices also require backside metallization (BSM) to provide good electrical and thermal contacts. The quality of this significantly contributes to the reliability of the operation and the lifetime of the device. In addition, various combinations of metal films are used in these devices, each serving a specific purpose in the stack. Missing layers or non-uniform films have an impact on performance. With all of this in mind, reliable, robust measurements are critical especially when measuring on product wafers.

In this blog, we will discuss the application of picosecond ultrasonic metrology to measure metal films on IGBT and MOSFET power devices following frontside and BSM.

About Picosecond Ultrasonic Technology

The picosecond ultrasonic technique is well understood and described extensively in literature. It has been a workhorse in semiconductor wafer fabs for over 20 years. (Figure 1) This is a first principles, non-contact, non-destructive technique that relies on a pump beam for generating acoustic sound waves that reflect off various interfaces and a time-delayed probe beam that monitors the change in surface reflectivity of the returning echo.

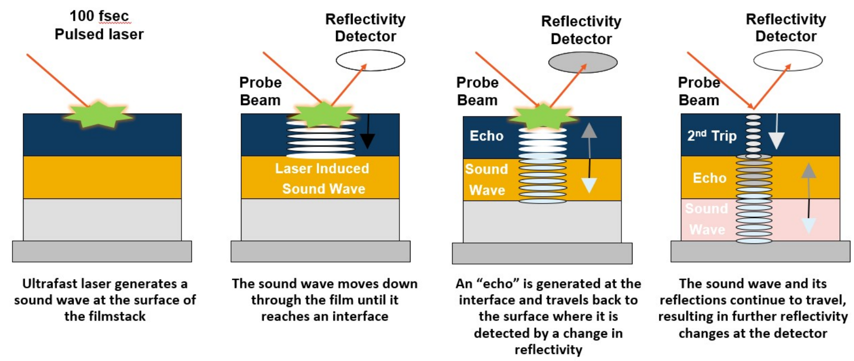

Figure 1: Picosecond ultrasonic technology explained.

Thickness is extracted from this acoustic signature using the arrival time of the echo and the longitudinal speed of sound in the material. The metallization films used in power devices are generally rougher, either as deposited or post-etch. In some niche applications, they also tend to be ultra-thick (30µm of Cu, as an example).

Recent improvements to the picosecond ultrasonic hardware have extended the upper thickness limit, while simultaneously enhancing the signal-to-noise (SNR) ratio when measuring rough surfaces. This allows device manufacturers to rapidly map within-wafer uniformity and obtain necessary feedback to optimize their process. Also, the small spot size of the technique enables measurements up to a 0.5mm edge exclusion and in small sites on product wafers. The time-resolved signals obtained from the power device's multi-layer stacks provide discrimination of the individual layers in the multi-layer metal film stack, even if they include repeating metal layers of the same material. Competing metrologies cannot resolve these layers and optical techniques or profilers cannot measure these complex stacks.

We present two select examples in this blog to highlight these capabilities of picosecond ultrasonic technology.

Multilayer Measurement for Gate Metallization

For power devices, gate metallization often requires multiple metal layers. With picosecond ultrasonic technology, device manufacturers have widely adopted the tool to monitor gate/source metallization.

As mentioned previously, one of the biggest advantages of picosecond ultrasonic technology is the ability to measure the multilayer metal thickness of repeating materials simultaneously. For example, in a layer

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stack comprising of Ti/TiN/AlCu/TiN, we are able to individually discriminate the top TiN layer from the bottom TiN layer. Alternative metrology tools cannot discern such a difference. As a result, they are not useful for actual device monitoring.

Picosecond ultrasonic technology displays excellent repeatability of static and dynamic measurements for a multilayer stack of Ti/TiN/AlCu/TiN, with the 3 sigma for thickness of all top three layers being less than 0.5%. (Table 1) The 3 sigma for the bottom Ti layer is less than 1%.

Layer	BTM Ti 300Å	BTMTiN 500Å	AlCu3500Å	Top TiN350Å
Static Repeatability(3σ)	0.95%	0.27%	0.04%	0.38%
Dynamic Repeatability(3σ)	0.52%	0.13%	0.03%	0.47%

Table 1 Typical static and dynamic repeatability performance of picosecond ultrasonic measurements for a commonly used multilayer metal film stack of Ti/TiN/AlCu/TiN in power devices.

BSM tri-layer stack

Several metal layers are used for BSM. These offer good adhesion and electrical properties and long-term reliability. The most commonly used stacks for BSM are Ti/NiV/Ag or Al/Ti/NiV/Ag. Quite often, the backside metal surfaces feature rough grain structures compared to the front side.

With improvements made to the hardware, we have been able to demonstrate excellent static and dynamic repeatability for the measurement of the films.

Layer	Ti 1000Å	NiV 3000Å	Ag 1500Å
Static Repeatability(3σ)	0.73%	0.42%	0.46%
Dynamic Repeatability(3σ)	0.57%	0.09%	0.21%

Table 2. Static and dynamic repeatability performances for picosecond ultrasonic technology when measuring commonly used multilayer Ti/NiV/Ag film stacks in power devices.

Conclusion

Picosecond ultrasonic technology has been widely adopted in the process control of semiconductor power devices because of its first principles, non-contact, non-destructive nature and its ability to measure multilayer film simultaneously, even when those layers are of the same material. With current enhancements, picosecond ultrasonic technology now enables additional applications for more challenging BSM stacks, such as films with rough surfaces.

As the demand for power semiconductors continues to surge as a result of the ongoing pivot to electric vehicles, metrology systems using picosecond ultrasonic technology will better position power device makers to meet the unique manufacturing challenges of this segment.

About the author
Johnny Dai is a principal characterization scientist at Onto Innovation. He has been with Onto Innovation, previously Rudolph Technologies, for more than 15 years, and he holds a Ph.D. in Applied Physics from Fudan University. To further this discussion, please reach out to a member of our sales team.

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