Optimising SiCr deposition for high-yield bipolar-CMOS-DMOS manufacturing with picosecond ultrasonics

With picosecond ultrasonic technology, manufacturers have a powerful, non-destructive tool for monitoring thickness and reflectivity at the ready, one that ensures that SiCr films meets stringent performance standards.

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FROM THE CARS we drive to the devices we hold and the medical systems that safeguard our health, bipolar-CMOS-DMOS (BCD) technology is at the heart of many modern electronics.

Today's vehicles are packed with electronics like power engine management, anti-lock braking systems (ABS), airbag controllers, and electric vehicle (EV) charging infrastructure, each one demanding a seamless integration of analog, digital, and power functions. In the case of smartphones, audio amplifiers, and smart home devices, BCD devices help balance power efficiency with high performance.

Meanwhile, medical imaging systems, such as ultrasound, and advanced power management solutions, rely on semiconductor technologies like BCD devices to handle diverse electrical requirements without compromising accuracy or safety.

Important as BCD devices may be, what exactly are they?

BCD devices are an advanced semiconductor process technology that integrates three distinct types of transistors – bipolar, CMOS, and DMOS – onto a single chip. The integration of these three transistors enables the simultaneous handling of analog, digital, and power functions within a compact and high-performance platform, with each transistor type contributing unique strengths:

- Bipolar transistors offer high current handling and precise analog control.
- CMOS transistors provide low power

consumption and high integration density for digital logic.
- DMOS transistors are optimized for high-voltage and high-current power applications.

For BCD devices to meet performance expectations, proper process control measures are needed, especially in the case of silicon-chromium (SiCr) thin films.

SiCr films play a critical role in BCD technology, primarily as precision resistive elements within analog and power management circuits (Figure 1.). SiCr resistors offer high stability, low temperature coefficient resistance (TCR), and excellent linearity, making them ideal for applications requiring accurate voltage and current control. Given the stringent reliability standards for BCD technology as demanded by the automotive industry and others, SiCr deposition must exhibit high reproducibility and minimal defectivity to support high-yield manufacturing and robust device performance under thermal and electrical stress.

Uniformity across the wafer and repeatability between lots are critical. After all, minor thickness or compositional variations can lead to resistance drift which impacts analog accuracy and long-term reliability. Tight process control during the deposition step—including chamber stability, target conditioning, and plasma uniformity—ensures consistent film morphology and stoichiometry.

During SiCr sputtering, the precise regulation of specialty gas flow, in particular reactive gases such as nitrogen or oxygen, is critical, as their partial pressures influence plasma chemistry and the kinetics of silicide formation on the substrate. This silicide layer governs nucleation and grain growth, which directly affects grain boundary spacing and, consequently, TCR. Variations in gas flow can alter the stoichiometry and microstructure of the SiCr film, leading to shifts in TCR behavior, including the onset of a pronounced negative coefficient if the process is not tightly controlled.

Given the importance of these demands, manufacturers need the right tools on hand to maintain proper process control and optimize the performances of their BCD devices. In this article we will discuss the application of picosecond ultrasonic technology in two parts: one as a robust thickness metrology solution for qualifying SiCr deposition process and the second for excursion monitoring in BCD devices.

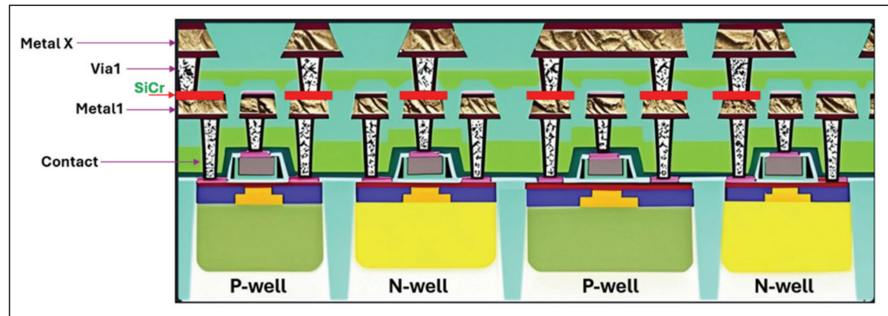


Figure 1. Schematic of the BCD process, with SiCr film identified.

About Picosecond Ultrasonic Technology

Picosecond ultrasonic technology (PULSE™ technology) is a non-contact, non-destructive pump-probe laser acoustic technique for the measurement of metal film thickness. It is a proven workhorse in semiconductor fabs around the world. A 0.1ps laser pulse (pump) is focused to a small (~ 8´10mm2) spot onto a wafer surface to create a sharp acoustic wave. The acoustic wave travels away from the surface through the film at the speed of sound. At the interface with another material, a portion of the acoustic wave is reflected and comes back to the surface while the rest is transmitted.

The probe pulse detects this reflected acoustic wave as it reaches the wafer surface. One can detect the change of optical reflectivity that is caused by the strain of the acoustic wave or alternatively detect, using a position sensitive detector (PSD), the deflection of the reflected probe beam that is

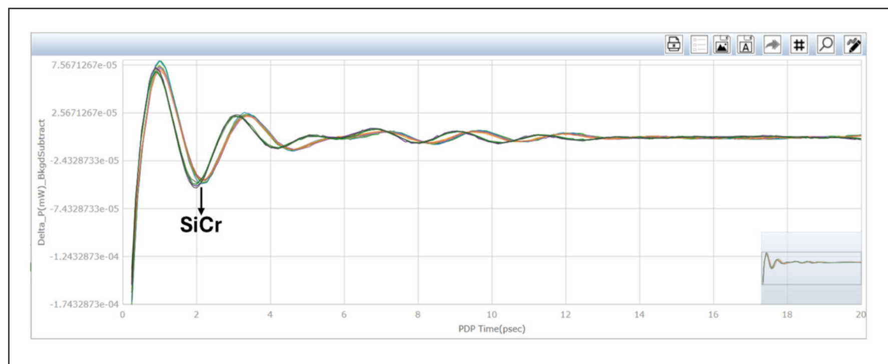


Figure 2a. Raw data of reflectivity change vs time shown. The cross-wafer variation is identified by the shift in acoustic echoes.

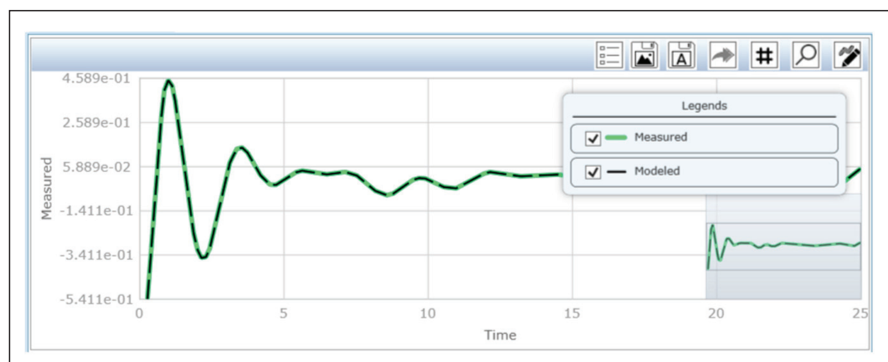


Figure 2b. Modeled fit to measured data shown. The green curve represents the measurement, and the black curve represents the fit.

caused by the deformation of the surface due to the acoustic wave. Both modes, reflectivity (REF) and PSD, are used in characterizing metal films. Knowing the speed of sound in the material, and the arrival time of the echoes, thickness is readily extracted using the first principles technique.

Film Thickness

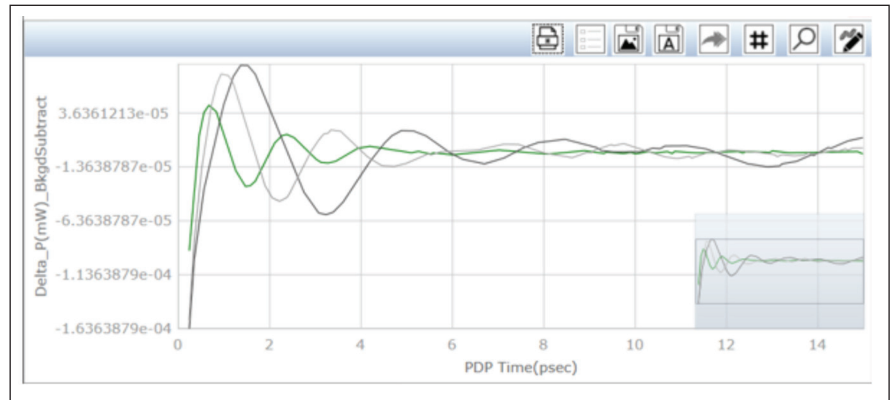
With background on picosecond ultrasonic technology out of the way, we will turn our attention to the application of this technology as a robust thickness metrology solution for qualifying SiCr deposition process in BCD devices. To demonstrate this, we measured the nominal thickness of SiCr thin films using picosecond ultrasonic technology.

Figure 2a shows the raw data from the SiCr thin film. The acoustic echoes identified in the figure are used to calculate the thickness of the film using the speed of sound and round-trip transit time through the film. Nominally, textbook values for the longitudinal speed of sound would be used. In the case of SiCr films, the longitudinal speed of sound will vary from the bulk material and depend on the deposition process (sputtering, evaporation, etc.) and specific film composition (stoichiometry, density, etc.).

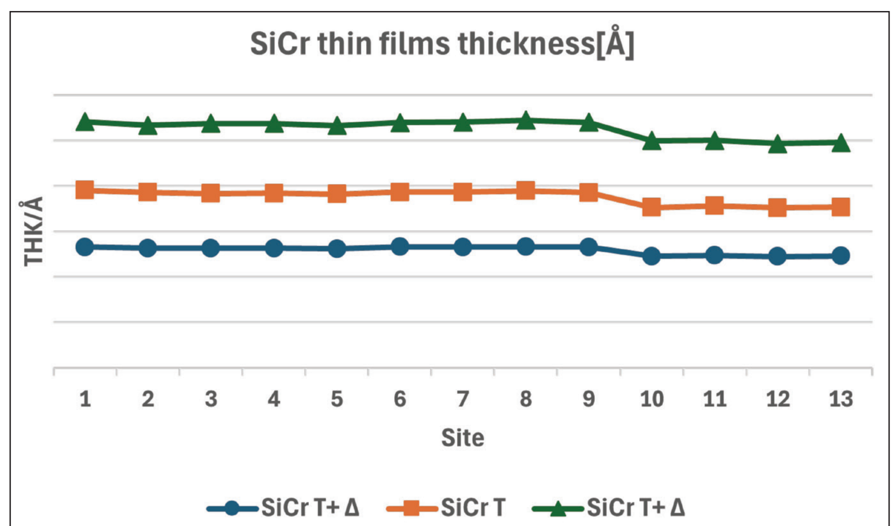
As a one-time calibration, we used cross-section transmission electron microscopy (TEM) to obtain SiCr film thickness and calculated the speed of sound for this specific process to be 69.7Å/ps. The modeled fit to the measurement is shown in Figure 2b.

In Figure 3a, raw data from the DOE skew is shown. The shift in echo position between the different wafers demonstrates the sensitivity of the technique for monitoring the process. Within wafer uniformity profiles from 13 points across the wafer show consistent trends (Figure 3b).

Given the critical function of SiCr films in BCD device architecture, it is imperative to maintain highly uniform deposition with stringent process control to meet electrical and reliability specifications. Yield optimization is directly correlated with film uniformity as variations can significantly degrade device performance and long-term stability. As part of chamber qualification, more extensive sampling across the wafer, including to the edge, was performed (Figure 4). Those profiles are also consistent across the thickness skew.



➤ Figure 3a. Raw data from the DOE thickness skew. Delta represents the skew in thickness from the target. The shift in echo position demonstrates the sensitivity for process monitoring.



➤ Figure 3b. Consistent cross wafer uniformity profiles for the three wafers.

Repeatability is a key metric in SiCr thin film metrology for ensuring robust process control and consistent device performance. Poor repeatability can obscure true process shifts, leading to incorrect corrective actions and potential yield loss. Gage capable repeatability measurements ensure compliance with automotive industry standards and are critical for long-term reliability. The dynamic repeatability data indicates performance is better than 0.5Å (1σ) and is more than sufficient to meet the process monitoring needs.

As demonstrated, picosecond ultrasonic technology provides a precise, non-destructive method for

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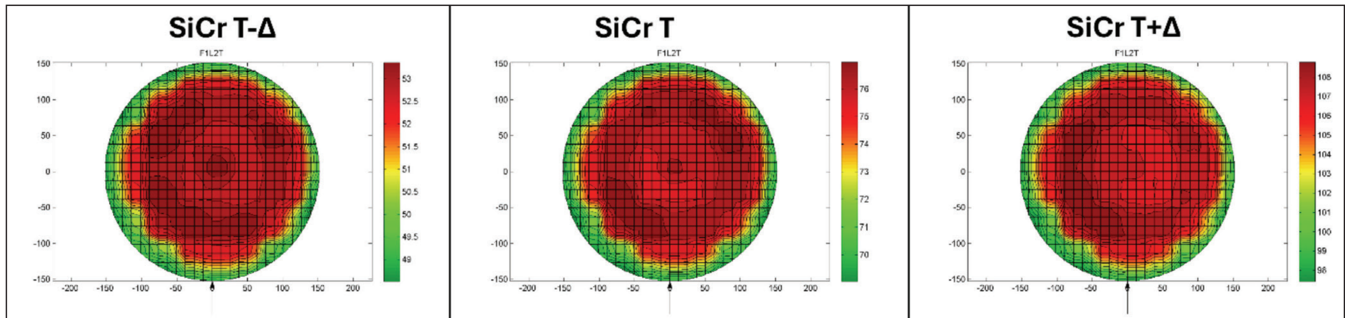

Figure 4. Forty-nine point wafer uniformity profiles for the three wafers, including measurements to the edge of the wafer. The profiles were consistent across the entire wafer.

measuring film thickness, validated against TEM calibration. The technique also offers exceptional repeatability and sensitivity, enabling manufacturers to monitor wafer-to-wafer and within-wafer uniformity with confidence. This capability is critical for maintaining tight process windows, as even minor deviations in thickness can lead to resistance drift and compromise analog precision. By integrating this metrology into chamber qualification and process monitoring, fabs can ensure consistent SiCr deposition, optimize yield, and meet stringent reliability standards.

Film quality

In picosecond ultrasonic technology, acoustic echoes are used to calculate SiCr film thickness. However, simultaneously available probe reflectivity data can be leveraged to provide information that can be used for process optimization (i.e., gas flow) and flagging process excursions. As such, this technique can be used to monitor the surface reflectivity of SiCr films; this application serves as a qualitative indicator of the film morphology and surface roughness and can be used for process control.

During the sputtering of SiCr films, gas flow has a strong influence on TCR as it impacts the film's microstructure and stoichiometry (density and composition). This, in turn, determines the film's stability, stress, and electromigration resistance in BCD applications. Uneven gas distribution causes local variations in thickness and composition leading to resistor mismatches and unpredictable TCR. The surface reflectivity of the target wafer at two different gas flow rates is shown in Figure 5. Reflectivity data was collected at the same time as the acoustic data and shows the variation in surface reflectivity. At gas flow rate (b), the surface was more

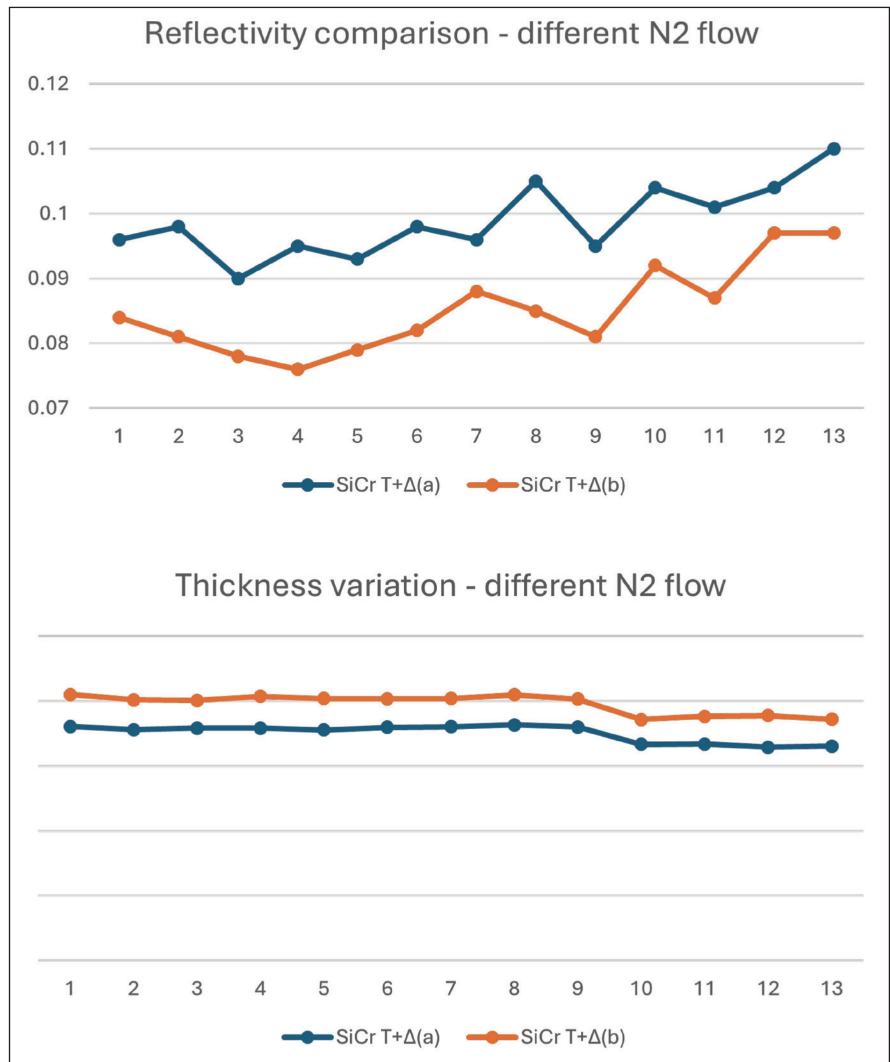

Figure 5. Surface reflectivity comparison for films having the same target thickness but different reflectivity. Average reflectivity variation (top) across wafer is much higher than the thickness variation (bottom). Orange represents the lower flow rate, and blue represents the higher flow rate.

reflective corresponding to a smooth, dense film, whereas at flow rate (a), the reduced reflectivity indicates increased surface roughness which can degrade resistor uniformity and TCR stability. Also, the thickness variation SiCr film is thinner at the higher N2 flow. N2 is known to affect silicide/nitride formation, grain spacing, etc., and impacts both thickness and reflectivity. Studies are underway to characterize the impact of annealing temperature. The results are promising.

In summary, the surface quality of SiCr films plays an equally critical role in device stability and long-term performance. The study highlights how reflectivity measurements, captured alongside thickness data using the same picosecond ultrasonic platform, serve as a powerful indicator of film morphology and density.

Variations in gas flow during sputtering were shown to significantly influence both reflectivity and thickness, underscoring the importance of precise control over deposition parameters. A smoother, more reflective surface correlates with improved resistor uniformity and predictable TCR behavior, while rougher films can degrade electrical performance.

Based on these results, we have demonstrated that reflectivity measurements, along with thickness measurements, can be leveraged for in-line monitoring to detect deviations in deposition parameters. By leveraging dual metrics – thickness and reflectivity – manufacturers gain a comprehensive, in-line process control solution that enables early detection of excursions and proactive corrections, ensuring robust SiCr thin film integration in advanced BCD architectures.

Conclusion

From automotive safety systems to medical imaging and consumer electronics, BCD technology enables the seamless integration of analog, digital, and power functions that modern applications demand. Yet, this versatility hinges on precise control of SiCr thin films whose stability and uniformity directly influence device reliability.

Achieving this level of integration comes with significant manufacturing challenges, particularly in controlling SiCr film thickness and gas flow during sputtering, factors which directly impact resistor stability and temperature performance, which are critical for reliability in demanding environments. To overcome these hurdles, we propose using picosecond ultrasonic technology.

With picosecond ultrasonic technology, manufacturers have a powerful, non-destructive tool for monitoring thickness and reflectivity at the ready, one that ensures that SiCr films meet stringent performance standards. In doing so, manufacturers will be able to safeguard the integrity of BCD devices while supporting the continued evolution of new technologies across the automotive, medical, and consumer electronics sectors.

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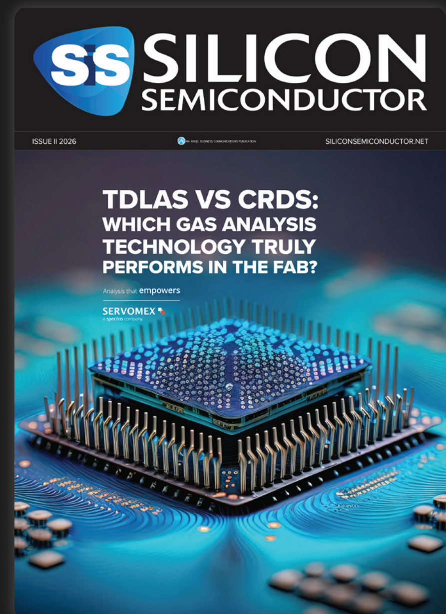

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