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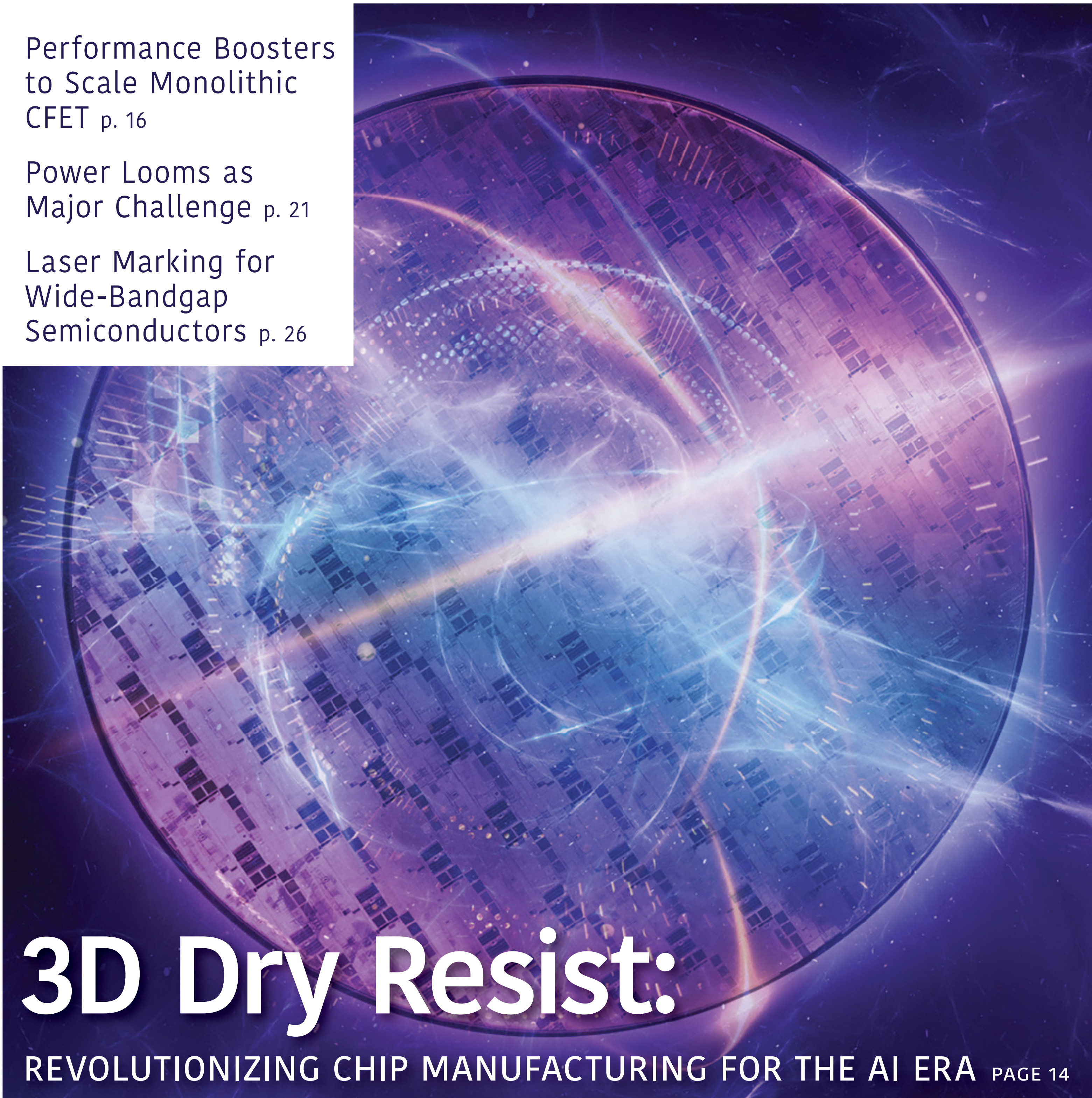

3D Dry Resist:

REVOLUTIONIZING CHIP MANUFACTURING FOR THE AI ERA PAGE 14

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Features

COVER: AI's demands have forced a rethinking of not only materials and processes but also fundamental design principles and architectural choices and prompted generational shifts in the traditional ways semiconductors have been designed, engineered, and manufactured. *Source: Lam Research*

Laser Marking for Wide-Bandgap Semiconductors: Meeting the Demands of SiC and GaN

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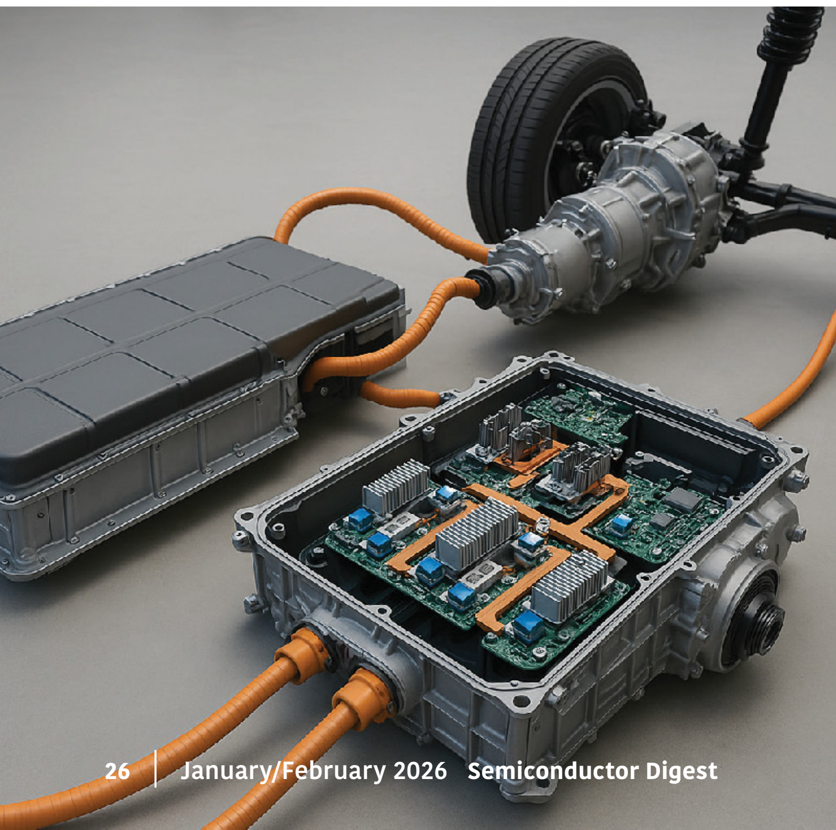
The transition to wide-bandgap materials like SiC and GaN necessitates adjustments to laser marking processes due to their distinct material characteristics.

WIDE-BANDGAP (WBG) semiconductor materials such as silicon carbide (SiC) and gallium nitride (GaN) are gaining increasing importance in a growing number of demanding applications. Especially in power electronics they are gradually replacing traditional silicon (Si) as they allow devices to operate at much higher voltages, frequencies, and temperatures than conventional semiconductor materials. Significant advantages such as higher switching speeds, lower energy losses and superior thermal stability are associated with those so-called wide-bandgap semiconductors. However, as SiC and GaN materials become increasingly prevalent in semiconductor manufacturing, they introduce new challenges—particularly in marking for traceability. Especially when it comes to marking applications in space constrained applications, the size and the usability of the laser comes into play. To identify the most efficient method for marking wide-bandgap semiconductor materials, a team of MKS experts conducted a series of tests in the purpose-built industrial laser applications lab.

High precision in marking

In high-volume production environments, precise marking for wafer traceability is essential for quality assurance and process control. Serial numbers, batch codes, or 2D matrix identifiers are marked directly onto the wafer surface using laser-based systems. Traditionally, diode-pumped solid-state (DPSS) lasers operating in the green or ultraviolet (UV) spectrum are used for marking



silicon wafers, where high precision and minimal thermal impact are critical. Characters are commonly formed using dot matrix patterns—typically 5×9 or 10×18 configurations—depending on the required resolution and data density. Each dot is created by a focused, pulsed laser beam.

Typically, a distinction is made between 'deep' and 'soft' wafer marks. Unpolished wafers are generally inscribed with deep marks to ensure visibility during subsequent processing steps, whereas polished wafers are marked using soft marks to minimize surface disruption and preserve wafer integrity. The two marking methods differ primarily in terms of the dot depth and the dot diameter. With traditional silicon materials, a deep mark usually penetrates between 50 and 150 µm into the material and has a dot diameter of 25-110 µm; a soft mark is only 0.3–5 µm deep with a diameter of only 30–70 µm. At each successive processing stage of the wafer, the requirements for the markings become more challenging. For example, excessive removal of material could lead to contamination of the wafer, which is just as important to avoid as a heat-affected zone that is too large.

The transition to wide-bandgap (WBG) materials like SiC and GaN necessitates adjustments to laser marking processes due to their distinct material characteristics. All materials come with a unique set of physical, chemical and thermal properties: many WBG materials, especially SiC, are extremely hard and brittle, thus making the marking process more complex. The laser pulses have to be applied carefully to avoid micro-cracks or surface damage. Additionally, the materials are sensitive when it comes to localized heat induced within the laser marking. The whole process becomes even more challenging due to the ongoing miniaturization of the components. Power electronics often use densely packed devices with very limited space for durable marking. Considering the need to comply with industry standards for traceability and identification, the focus of process development efforts was on how to balance readability and effectiveness in the laser marking process.

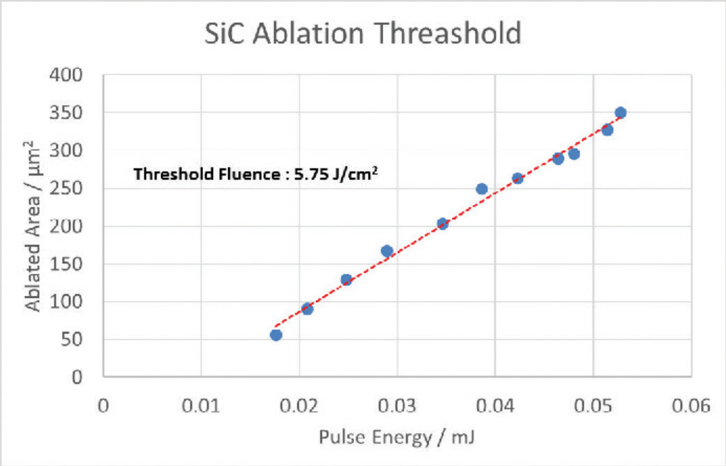


Figure 1. A minimum fluence of more than 5.75 J/cm² is needed to remove material from the SiC wafer.

Choosing a laser

Marking SiC and other wide-bandgap semiconductors can be performed with a variety of laser sources. Infrared fiber lasers are commonly chosen for their low cost and industrial robustness, while diode pumped solid state (DPSS) ultraviolet (UV) lasers are preferred for high precision and minimal thermal stress. Green DPSS lasers serve niche applications where absorption and contrast are critical. Due to space constraints in the automated production lines, there is a rising demand for compact lasers for marking wide-bandgap semiconductors. The key question is whether the marking results are clear and resilient enough to fulfill the high industry demands.

To answer this question, several tests were performed with an MKS Spectra-Physics model Explorer One HE 355-200 laser. This high-energy, compact UV nanosecond laser delivering pulse energies of 200 µJ was used to generate an 18×9 dot pattern marking on a SiC wafer. The dot diameter was intended to be approximately 44 µm, as this a commonly used size in marking processes.

As part of the early investigations, the threshold fluence (energy per unit area) for UV ablation on SiC itself was experimentally determined, which allows one to establish the minimum laser fluence required to remove material from the surface with a single laser pulse. The incident pulse energy was varied between 15 and 55 µJ and the resulting ablated dot diameters were measured and subsequentially analyzed using regression techniques. This systematic approach revealed a threshold fluence of 5.75 J/cm², providing a reliable basis to conduct further tests (**FIGURE 1**).

Next, the Explorer laser was used to create the 18×9 dot pattern by moving across the SiC wafer and firing a single pulse at each position (**FIGURE 2**). Each pulse produced a clean, spherical segment with a depth of about 0.4 µm. This shallow yet well-defined geometry ensures minimal thermal impact and preserves the structural integrity of the wafer surface.

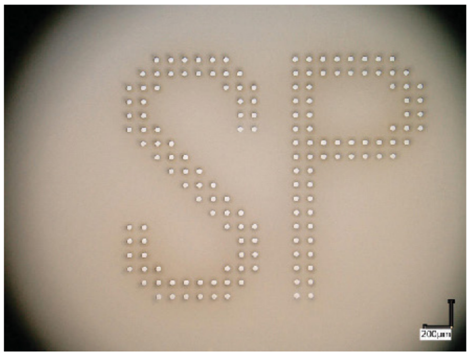


Figure 2. The letters on the wafer are clearly structured and can be easily read under a microscope.

Even under high magnification (**FIGURE 3**), the microstructures exhibit sharp definition and maintain their geometric integrity. The pattern shows the homogenous form of each dot that can already be achieved with a single

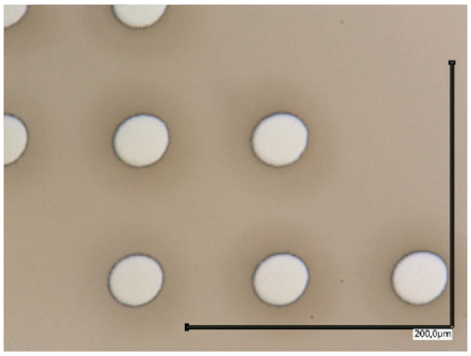


Figure 3. Close inspection reveals a homogeneous and repeatable marking dot size.

laser pulse.

To better assess the homogeneity of the dot, the team analyzed the marking using a white-light interferometer. Both the 2D profile (**FIGURE 4**) and the 3D image (**FIGURE 5**) clearly show the smooth and homegenious structure of the marking.

Generating a soft mark by applying just a single laser shot proved to be a good option for marking SiC wafers. However, depending on the application, deeper marks may be required—for example, when the SiC wafer is coated or ground after the marking process. For such considerations, the marking depth can be easily increased by applying multiple shots per dot, allowing for flexible adaptation to specific manufacturing requirements without compromising precision or readability. The dot profile in **FIGURE 6** shows a dot produced with two-pulse process. The marking depth is increased to 0.9 µm while the shape of the dot stays remains smooth and symmetric.

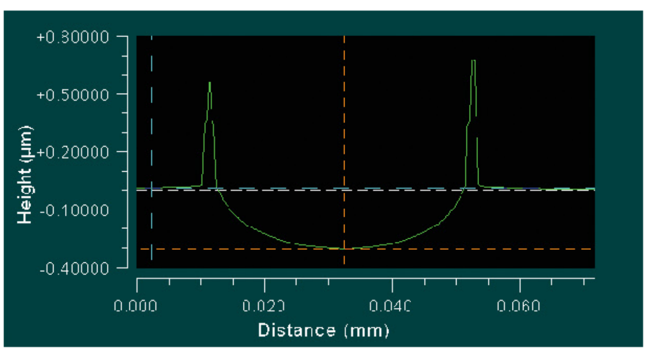


Figure 4. Profile Plot of a single-shot marking dot.

This scalability in depth control makes the laser marking process highly versatile, supporting both standard traceability needs and more demanding post-processing scenarios in advanced semiconductor production.

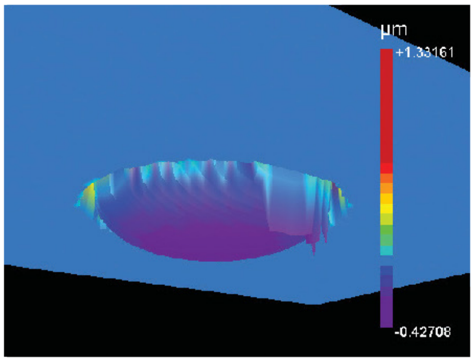


Figure 5. 3D Model of a single shot marking dot.

Advantages of compact laser designs

DPSS UV nanosecond lasers such as the MKS Spectra-Physics Explorer laser series (**FIGURE 7**) combine short nanosecond pulse durations with high peak intensities—an essential requirement for producing clean, high-contrast marks on wide-bandgap materials like SiC. In addition, the laser meets the key requirements in space-constrained industrial environments: it can be used without additional cooling and comes with relatively small dimensions. The compact design of the Explorer laser (280 x 130 x 85.1 mm) enables its cost-efficient integration into production lines, while low power consumption and minimal heat dissipation make it ideally suited for the sensitive environment of semiconductor manufacturing.

Conclusion

Wide-bandgap semiconductors like silicon carbide (SiC) and gallium nitride (GaN) outperform traditional silicon with higher efficiency, faster switching, and better thermal stability in many applications. However, this potential to further miniaturize components due to their unique optical and thermal properties also increases the demands placed on marking them. Clearly, SiC and GaN require tailored marking strategies. The tests by MKS using the Explorer One HE 355-200 UV laser demonstrate precise, high-contrast marking on SiC wafers. With 200 µJ pulse energy and short pulse durations, the laser achieved excellent dot uniformity with minimal thermal impact when applying just a single laser shot. The compact design makes this type of UV laser ideal for next-generation semiconductor production.

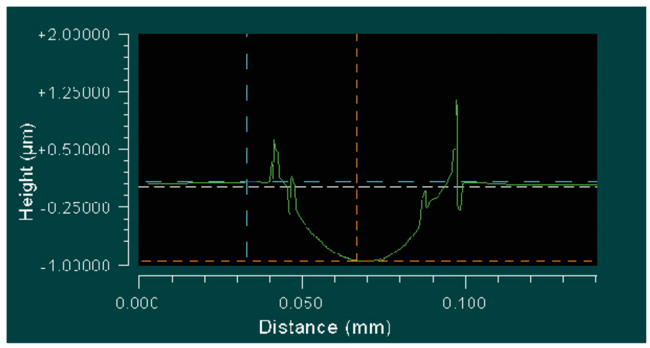


Figure 6. Applying two laser shots per dot results in a deeper yet symmetric mark.

Figure 7. The MKS Spectra-Physics Explorer series offers highly versatile lasers in a compact design.