

The Specialty Device Surge Part 2: The Process Control Challenges of MEMS, Co-Packaged Optics, and More

By Christopher Haire,
Onto Innovation

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In a world where high-bandwidth memory, GPUs, and advanced AI packages are all the rage, it is easy to forget the important role specialty devices play. These unsung heroes of modern life perform critical functions across a wide range of industries, including automotive, telecommunications, data centers, emerging AI hardware ecosystems, and consumer electronics, just like the smartphone in your hands, on your desk, or in your pocket. You know, the little pocket computer that never leaves your side.

And with new functions being added to consumer electronics with each new generation, the demand for specialty devices is on the rise. On the other end of the spectrum, manufacturers are facing an increasing number of challenges brought on by the growing complexity of these devices. Examples of this include SiC and GaN power devices, MEMS sensors, RF filters, photonics, and CMOS image sensors. We will cover all of these device types in this blog, the second in our three-part blog *The Specialty Device Surge*.

As discussed in part one of our series, the specialty segment is moving to larger wafer sizes. Not only does this transition promise higher throughput and improved economies of scale, it introduces new manufacturing and process control challenges, many of which are unique to each device category. Why? Each type of specialty device relies on unique materials, architectures, and process steps.

Across the industry, this complexity shows up in different ways. MEMS devices rely on a variety of materials or key processes depending on their core function: thick piezoelectric films, suspended mechanical structures, and near perfect plasma etched sidewalls, each requiring highly specialized deposition and metrology techniques. CIS manufacturing spans multiple bonded layers—pixel, CMOS, and microlens—each with its own set of defect, CD, and uniformity challenges that directly shape image quality. Power devices such as SiC and GaN introduce further hurdles: crystalline defects, trench shape control, epitaxial thickness uniformity, and surface quality demands that grow more difficult as these materials scale toward larger wafers. Photonics and co-packaged optics push complexity even further, requiring precision across waveguides, doped films, microlenses, lasers, and the multi-die assembly process that integrates them into a single high-bandwidth module.

However, all these technologies share a simple truth: achieving high-volume production depends on advanced metrology, intelligent inspection, and tightly integrated feedback and feed forward control. Combined, these tools allow device makers to stay inside increasingly narrow process windows as specialty devices scale, diversify, and enter high volume production.

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But first, let's dive into the challenges facing specialty devices. We will begin by focusing on MEMS.

MEMS

The top five MEMS device types are pressure sensors, gyroscopes, accelerometers, microphones, and surface acoustic wave (SAW)/bulk acoustic wave (BAW) radio frequency (RF) MEMS. These are known as the Billion Dollar Club. And with good reason. Each of these devices is responsible for sales in excess of \$1 billion per year. Impressive.

MEMS devices rely on either a unique material or unit process to deliver their core functionality. In the case of pressure sensors and microphones, the unique material is typically polysilicon or dielectric membranes or piezo films, which require very specific chemical or physical vapor deposition techniques to achieve the required film thickness and orientation to maximize the piezo coefficient for the material. For gyroscopes and accelerometers, the device relies on the formation of what are called interdigitated comb fingers; these capacitors rely on precise plasma etch techniques to deliver vertical side walls. However, any tilt can result in poor device operation.

Finally, there are the class of RF filter devices known as BAW devices. These devices rely on precisely deposited piezo films of either AlN or scandium doped aluminum nitride. In BAW devices, thickness and film orientation control the frequency of operation; as such, thickness uniformity across the entire wafer is essential keeping each device operating at the required frequency.

CMOS Image Sensors (CIS)

Today's CIS devices are anywhere from 6 μ m to 10 μ m tall, with pixels in the image layer and separated from one another by approximately 100nm-wide isolation trenches.

Pixel formation relies on several dopant implant steps. The isolation trenches have sidewalls specifically engineered to increase total internal reflection, thereby increasing the light capturing efficiency of the pixel, and minimize so-called dark noise (the movement of electrons within the pixel when no light is present). The latter typically involves increasing the work function of the materials along the sidewalls of the isolation trenches.

In the formation of a pixel imager, multiple challenges, from epitaxial layer thickness and dopant uniformity metrology to isolation trench defect inspection and CD and shape metrology, exist. Each challenge must be addressed to create the perfect pixel for imaging.

Several unique metrology and inspection steps are needed for each layer. Layer 1 of the CIS is the pixel layer, layer 2 is the CMOS layer

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which is usually hybrid bonded to the pixel layer, and layer 3 features the microlens array which is either bonded or manufactured directly on the pixel wafer.

SiC and GaN Power Devices

In recent years SiC has seen a tremendous surge in popularity given its use for switching high voltages in EV motors. Today, SiC is in production at 200mm. However, some manufacturers have started to produce 300mm SiC wafers for applications that take advantage of the material's unique thermal conductivity.

Inspection and metrology play key roles in the production of SiC power devices. First of all, inspection is used to identify latent or killer crystalline defects in the initial substrate and subsequent epitaxial SiC layers. Then, regular particle defect inspection and all-surface inspection is performed to catch additional defects on the edge or backside of the wafers. Multiple particle defect inspections are carried out throughout the remainder of the high-volume manufacturing process.

Now on to metrology. The ability to conduct accurate measurements plays a key role in understanding the thickness, dopant concentration, and uniformity of the epitaxial layers grown on the initial substrate. The importance of metrology does not end there. Across the remainder of the process flow, CD metrology and trench shape metrology play a part in ensuring device yield and performance.

Unlike SiC, GaN technologies migrated to 300mm wafers earlier. For GaN power devices, the challenge involves identifying crystalline defects, surface roughness metrology, AlGaN layer homogeneity, and CD metrology.

The key need for original equipment manufacturers supporting customers in this segment is the ability to deliver inspection and metrology technologies that can handle these materials and associated wafer thicknesses, while also performing necessary inspection or metrology steps at cost-of-ownership price points for power devices. After all, these technologies need to offer manufacturers economically viable alternatives to ever-improving silicon power devices.

Photonics and Co-Packaged Optics

Photonics technologies have been around for decades, but they have evolved with the times. Now you can find photonics in a growing number of applications, including laser printing and xerography, facial recognition, and several telecommunication-based applications. Today, however, we're seeing a new demand driver for this technology: AI.

Current AI devices communicate via standard metal traces. However, the increasing bandwidth requirements of AI chipsets and the power dissipation incurred from the use of copper wiring within data centers have combined to create a demand for a high-speed technology that consumes little power: silicon photonics.

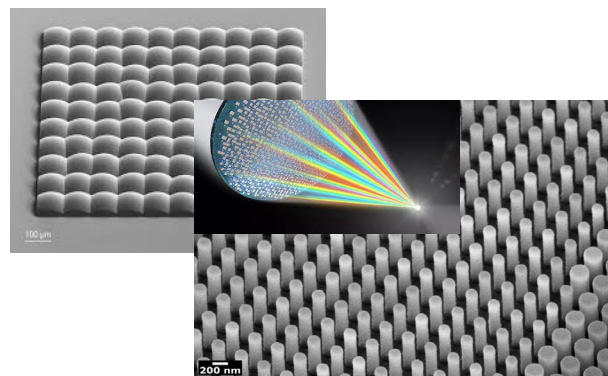
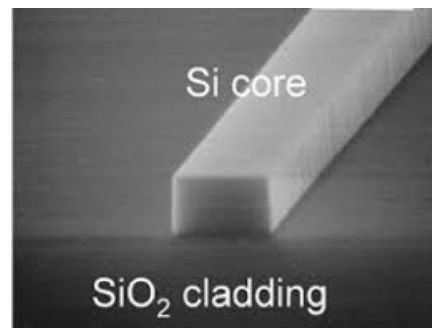
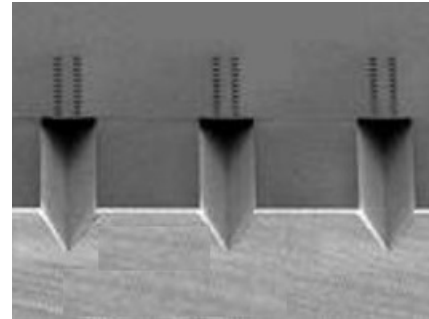


Figure 1: Top to bottom, examples of V-grooves, basic waveguide geometry, and refractive and diffractive micro-lens structures. Each physical device brings with it its own set of key inspection and metrology requirements.

Silicon photonics replace these metal traces with optical waveguides that use light, not electrons, to carry information. In the case of co-packaged optics (CPO) which are directly integrated with chips, photonics provides ultra-high-bandwidth, low-power, light-based data transmissions. CPO combines laser sources with waveguide-based silicon chips, micro-lenses, and opto-electronic

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converters in a package that fits neatly on the modern panel level AI package. This one small module represents the cumulative challenges of multiple manufacturing segments under the umbrella of photonics and optics. Addressing these challenges requires V-groove inspection and metrology, waveguide metrology, micro-lens inspection and metrology, and a number of other areas including dopant uniformity (Figure 1). In the end, the ultimate success of any given CPO module relies on the assembly of all the die that go into it.

Conclusion

Whether the subject is MEMS structures demanding near perfect sidewalls, CIS stacks spanning multiple bonded layers, power devices pushing wide-bandgap materials to their limits, or photonics and co packaged optics, the common challenge manufacturers face is control. Across every specialty device category, success hinges on advanced metrology and inspection solutions that can precisely measure what matters most—shape, thickness, uniformity, defects, and material properties—at high throughput and low cost.

In the final blog of this three-part series, we'll shift our attention from the challenges facing specialty devices to their solutions. We hope you will join us to learn more about these unsung heroes of modern life.

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Biography

Christopher Haire is a marketing content specialist at Onto Innovation and a former business journalist.