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Using FTIR to Improve SiC Power Device Performance

By: Nick Keller,
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The figures alone are impressive: SiC power devices are experiencing an annual average growth rate approaching 34% through 2027, according to the Yole Group. However, the potential for this amongst other compound semiconductor-based power devices such as gallium nitride (GaN) to change the world around us is even more impressive.

Thanks to the role that SiC-based devices play in the increased electrification of automobiles and the sustainable energy movement, the effort to make this world a cleaner, greener place is no longer a wished-for science fiction fantasy. It may one day be our reality. Perhaps even soon.

Manufacturers in the automobile and clean energy sectors want power devices that are more efficient and can accommodate higher voltages, faster switching speeds and lower losses than traditional silicon-based power devices. To accomplish this, they are turning to higher efficiency silicon carbide (SiC)-based devices.

When it comes to SiC power devices, most manufacturers have adopted a trench-based architecture. This reduces on-resistance and increases carrier mobility. However, these improvements come at the expense of rising fabrication complexity.

To address this issue, high-volume manufacturers of SiC power devices are, at several key steps, adopting inline process control methods, including optical metrology techniques like Fourier transform infrared (FTIR). With a system supporting FTIR optical metrology at their disposal, manufacturers can more accurately measure epi layer growth and the depth and accuracy of implanted dopants across the wafer, key challenges posed by the increased fabrication complexity of SiC power devices. In this blog, we'll discuss how FTIR technology can help manufacturers successfully address these challenges.

Measuring Epi Layer Growth

Let's begin by looking at why SiC power device makers are turning to FTIR. By using this particular optical metrology method with advanced algorithms, SiC manufacturers can extract epi layer thickness and carrier concentrations for two- and three-layer stacks. Additionally, FTIR can non-destructively characterize, across wafers, post-implant dopant profiles directly on SiC substrates before and after annealing. The benefit? This removes the need to rely on secondary ion mass spectroscopy to monitor silicon wafers for implant characterization and enables earlier detection of process excursions.

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In the manufacturing of SiC power devices, FTIR spectroscopy is used to obtain infrared spectra (from near-IR to far-IR) by using a Michaelson interferometer, broadband light source and fast Fourier transform (FFT) algorithm. But with an FTIR metrology system, SiC power device makers can measure both transmission and reflectance spectra, thus enabling elemental composition measurements and epitaxial layer thickness measurements with a single tool. This is even more impactful when such a system can measure up to five epitaxial layers in one scan.

Due to free carrier absorption, the IR region of the electromagnetic spectrum is sensitive to the carrier concentration of doped semiconductors. With wavelengths above the plasma frequency, the electric field oscillation is too fast. In this case, the material acts like a dielectric; below this frequency, the carriers can absorb the electric field energy. With wavelengths below the plasma frequency, the absorption coefficient is directly proportional to the carrier concentration, which is in the IR region for doped semiconductors.

This brings us to the differences between measuring for SiC trench MOSFETs and SiC IGBT. In the SiC trench MOSFET process, measuring the thickness and carrier concentration of the drift layer is important because it directly determines the breakdown voltage of the transistor, while in the SiC IGBT process, buffer layer thickness and free carrier concentration are critical because they determine key parameters like switching speed and conduction losses. Both types of measurements are important for power device manufacturing.

To model complex epitaxial film stacks in compound semiconductors, Onto Innovation developed a new analysis engine. This analysis engine enables the direct modeling of carrier concentrations and the film thickness of multiple layers, including the substrate. These models accurately indicate the carrier concentration transition versus depth that occurs during the diffusion and implantation process (Figure 1).

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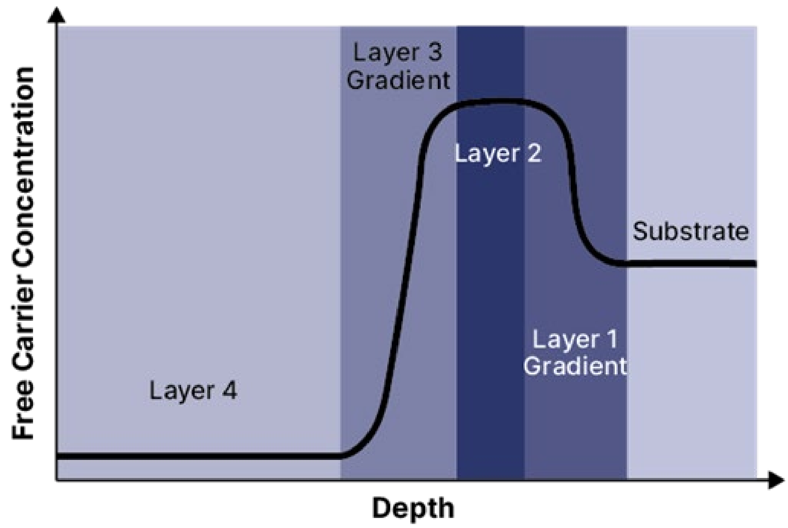

Figure 1: Carrier concentration transition versus depth.

We used the model to measure buffer and drift layer thickness, as well as the carrier concentration for the buffer layer and substrate, following the SiC epitaxial layer growth step in the IGBT process flow. We processed a design of experiment by varying drift layer thicknesses from 5µm to 30µm; other parameters of interest were kept constant. Figure 2 shows an example of the model fitted to the experimental spectra from the FTIR system and the wafer maps for all parameters of interest. A further look at the correlation of the measured drift layer thickness to the expected thickness indicated that the predictive capabilities of the model are accurate.

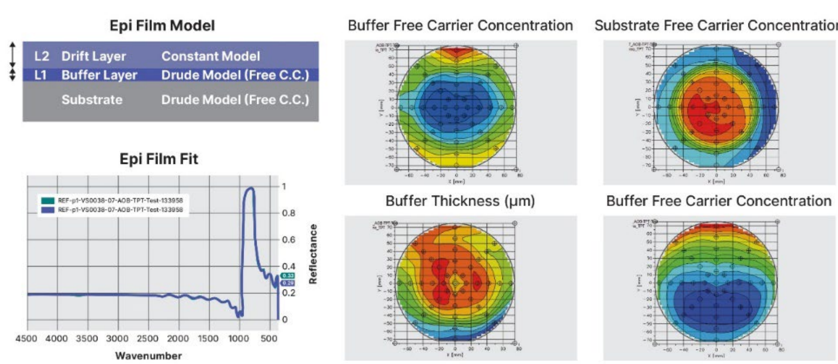

Figure 2. The model fitted to the experimental spectra from the FTIR system and the wafer maps for all parameters of interest.

In addition, we were able to determine that FTIR is capable of measuring implant depth and detecting dose variations in aluminum species after the ion implantation process and before annealing.

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Normally, dopants need to be activated for FTIR to detect the effects, but the model enables manufacturers to conduct measurements prior to dopant activation, thus allowing for the earlier detection of process excursions and reducing scrap.

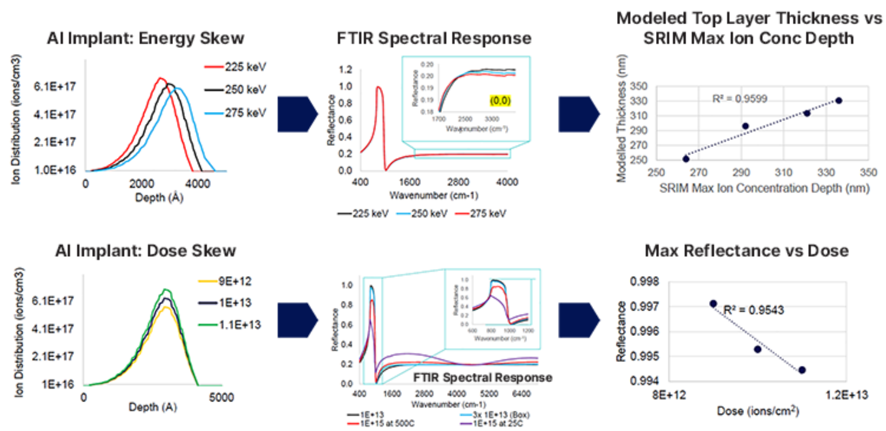

Figure 3. SRIM simulations for energy and dose skews, then raw FTIR spectral response to those skews and finally correlation of FTIR measurements to SRIM.

To demonstrate this, we measured dose and energy skews with FTIR. Stopping range of ions in matter (SRIM) simulations were performed to model the implant depth and carrier concentrations. We used this model as a reference for the FTIR measurements. Figure 3 shows the results of the SRIM simulations for energy and dose skews, the FTIR measurement response to the skews, and, finally, the correlation of the measurements to the SRIM simulations. We used an oscillator model in the new analysis engine to model the free carrier concentration and thickness simultaneously. We then utilized the model's thickness results to correlate peak implant depth; that correlation is roughly 0.96. The maximum reflectance was then used to correlate to the dose. Again, excellent correlation was shown.

Conclusion

For manufacturers of SiC power devices, the ability to accurately measure epi layer growth and the depth of implant layers is of paramount concern, especially when faced with ever-increasing fabrication complexity. By using an FTIR-based system equipped with both reflectance and transmission channels and an analysis engine enabling the direct modeling of carrier concentrations and film thickness, SiC power device makers will be better equipped to measure epi layer growth, implant layers and composition, all in a single platform.

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In our following blogs, we first will explore how high-volume manufacturers of SiC power devices are adopting inline optical metrology methods like optical critical dimension and then follow up with a blog focused on picosecond ultrasonic solutions. We hope you join us as we discuss new and existing techniques for improving power device performance.

The era of electric vehicles and renewable energy is just over the horizon. SiC will help us get there.

About the author

Nick Keller has been with Onto Innovation since its founding in 2019 and prior to that Nanometrics, which merged with Rudolph Technologies to become Onto, since 2007. Keller is now a Director of Applications Development and has been instrumental in developing infrared critical dimension technology and providing pathfinding simulations in support of other new products at pre-initiation phases. He has seven issued patents and over 25 publications.