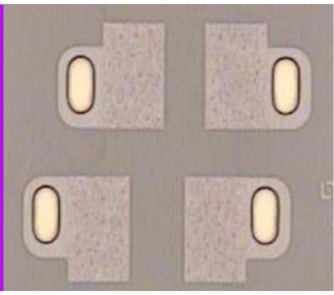
Characterization of HEMT Vias

Zeta™ Optical Profilers



Introduction

Wide bandgap semiconductor materials are extremely attractive for use in power electronics, due to their performance capability at high temperature, power and frequency. Among wide bandgap semiconductors, Gallium Nitride (GaN) is used in power device manufacturing (a) to exceed the performance of silicon high-voltage devices and (b) to be more cost effective than silicon carbide (SiC) power devices. The properties of GaN high-electron mobility transistor (HEMT) devices using a SiC substrate are optimized for high temperature electronics, radio frequency (RF) power amplifiers and power microwave applications.

The GaN/SiC HEMT manufacturing flow typically consists of the following steps: SiC substrate formation; GaN epitaxy; etch; front side device development; wafer bonding to carrier; wafer thinning; hard mask fabricating; via-hole etching; Au electroplating; wafer debonding/cleaning, packaging, via-hole etching process and Au electroplating. Figure 1 shows the backside via structure before (top) and after (bottom) the Au electroplating step. Monitoring the via etch process is critical because the quality of the etch directly impacts HEMT device performance. The key metrology parameters at this step include the opening diameter and average depth of the via holes. Although scanning electron microscopes (SEMs) can be used to measure hole depth of high aspect ratio (~ 1:3) structures, SEM techniques are either destructive or have low throughput. In contrast, 3D optical profiling offers a non-destructive, high-thruput means of measuring the critical dimensions vias.

The KLA Instruments™ Zeta™ optical profilers provide 3D imaging and metrology capabilities in a flexible, cost-effective, multi-function package. Combining White Light Interferometry (WLI) with the Zeta-proprietary ZDot™ technology enables rapid and quantitative analysis of surfaces for off-line product inspection. The Zeta software includes recipes for via hole applications that automatically gather data on depth, opening size and bottom roughness across multiple sites. It is a reliable and efficient technique for process monitoring and optimization of HEMT vias.

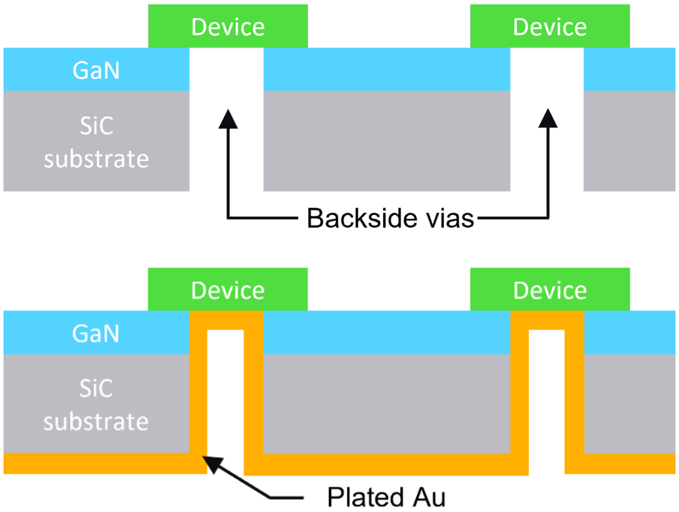


Figure 1. GaN/SiC HEMT backside via structure (top) and Au-plated GaN/SiC HEMT backside via structure (bottom).

WLI Theory of Operation

The Zeta optical profiler is a fully integrated microscope-based system that uses WLI (also known as Vertical Scanning Interferometry, or VSI) and other optical techniques to provide non-contact 3D imaging and metrology capability. The WLI objective schematic is shown in Figure 2 (top). The interferometer objective is mounted on either a piezoelectric transducer (PZT) or a motorized stage so that it can be moved vertically. The reference mirror is used with the white LED light source, and during the vertical scanning movement, the distance from the objective lens to the reference focus plane surface remains fixed. The interference of light reflected from the reference mirror and the sample surface results in fringes, which are used to measure sample geometries. The white light generates each CCD camera pixel's contrast peak position as its z position, based on these fringes, as shown in Figure 2 (bottom). After scanning in the vertical direction, the software detects the z information to form a 3D topographic image, which can then be used to ascertain dimensional and step height information. The WLI technique is also capable of high z resolution measurement of the topography of smooth surfaces.

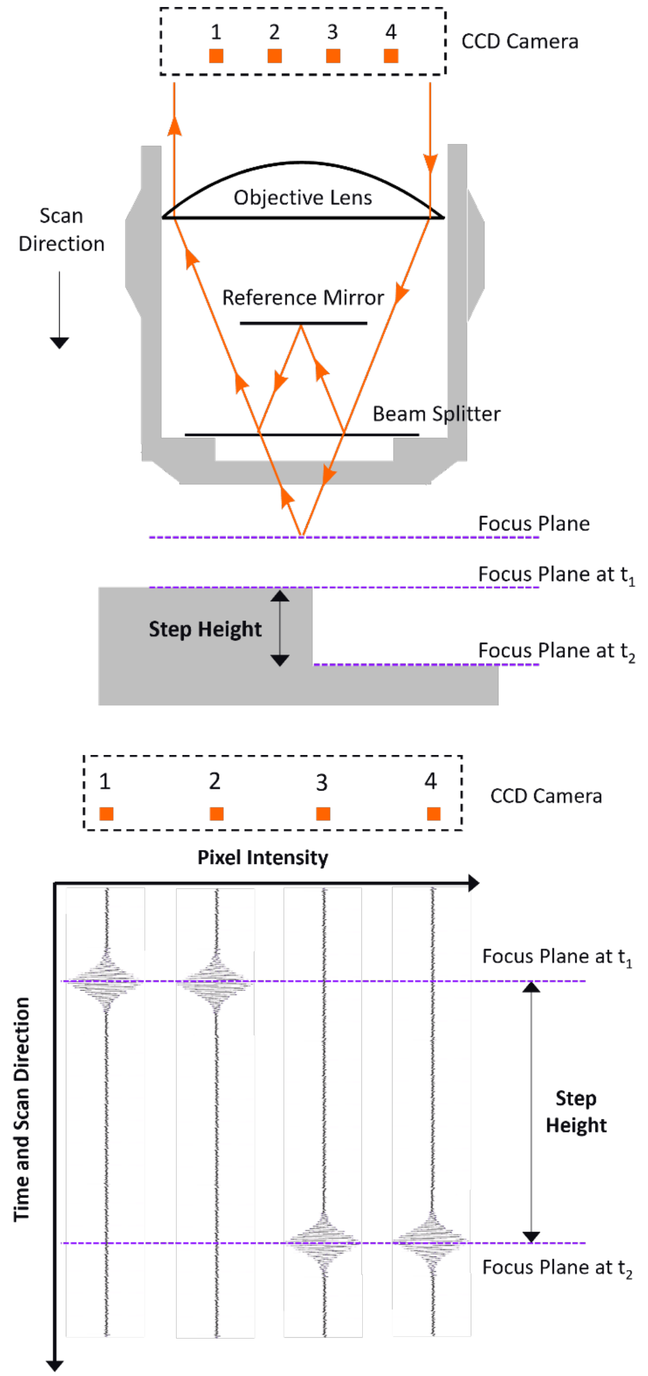


Figure 2. White Light Interferometry (WLI) schematic. The top figure shows the reference mirror and light paths of a Mirau interferometer objective. The bottom figure shows the intensity of each CCD camera pixel, which is maximized when the sample surface is in focus.

ZDot™ Theory of Operation

The KLA Instruments Zeta optical profilers also incorporate proprietary ZDot technology in the same optics system. ZDot uses two high-intensity white LED light sources, as shown in Figure 3. Light from source 1 passes through the ZDot grid and generates each pixel's contrast peak position as its z position, while light from source 2 preserves the sample's True Color imaging information at each pixel. ZDot technology enables accurate measurement of a broad range of sample topography while simultaneously generating a 3D True Color image.

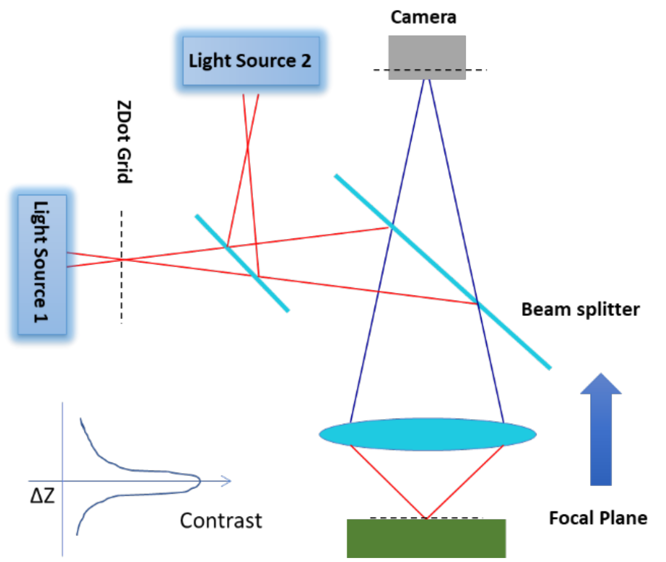


Figure 3. ZDot technology schematic.

Measurement of High Aspect Ratio Vias

3D optical profiling is powerful since it enables non-destructive measurement of narrow openings and deep vias of high aspect-ratio structures- features whichare traditionally a challenge to measure with non-optical measurement metrology. Low numerical aperture (NA) objectives are recommended for these types of high-aspect ratio measurements since they present a smaller percentage of blocked angles of reflected light compared to high NA objectives, as shown in Figure 4. Using low NA objective

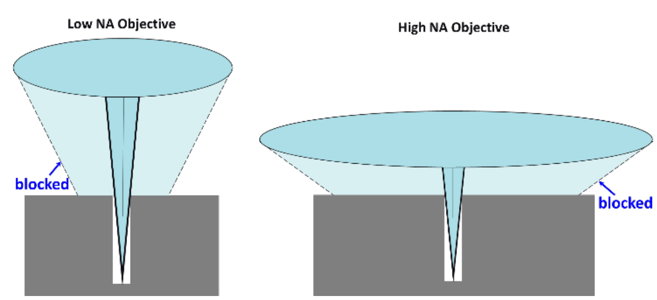


Figure 4. The reflected light in a deep hole is shown for low NA (left) and high NA (right) objectives. The low NA objective has less light blocked than the high NA objective, resulting in a greater reflected signal.

enables greater light intensity to reach the camera from the bottom surface of the via resulting in improved imaging quality to measure the deep structures. The Zeta optical profiler with low NA and WLI technology with vertical scanning can measure a square via of 30µm x 30µm opening size and 90 – 110µm depth. The Zeta software has powerful automatic analysis algorithms for characterizing high aspect ratio HEMT vias using WLI technology. A 2D cross-section of an HEMT via is shown in Figure 5.

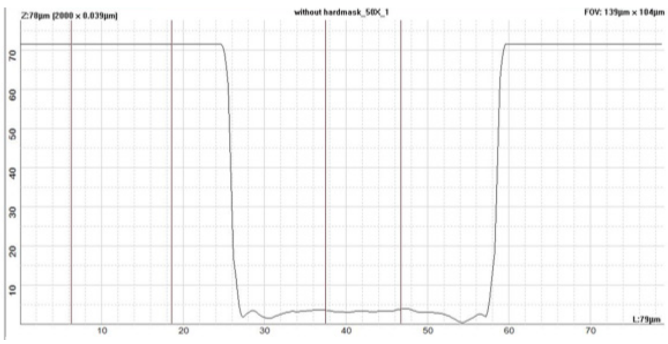


Figure 5. 2D profile from a 3D HEMT via scan, showing the via cross-section and depth measurement.

Tapered sidewalls can also be measured by the Zeta optical profiler using the 2D profile. Usually, the via sidewalls are vertical during the etch process; reflected ions cause a localized increase in the ion flux at the bottom of the feature, leading to a localized increase in etch rate. After optimizing etch process parameters (e.g., plasma pressure, chemistry, bias), the sidewall taper can be greatly reduced. The presence of tapered sidewalls is illustrated in the SEM image shown in Figure 6. It is important to account for sidewall taper when defining robust hole metrology recipes.

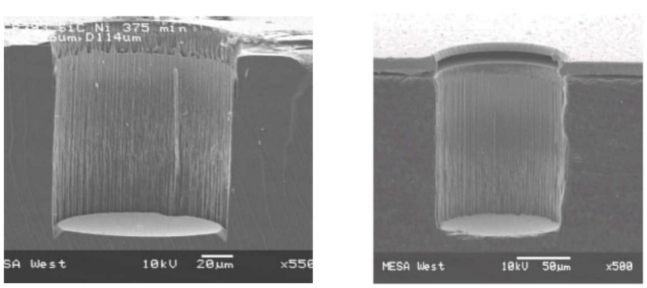


Figure 6. Vias as imaged by SEM.

The Zeta software can automatically detect the via hole and define the measurement cursor positions. This feature detection algorithm offers three methods to detect specific features based on image RGB information, pixel intensity and height. Analysis of a via is based on the height information from the 3D measurement. The software automatically identifies hole features in the field of view and marks the centers with a red cross and the boundaries with a red line, as shown for the square hole in Figure 7. In this example, the recipe defines a blue box inside the red box by decreasing the number of measurement pixels in a direction perpendicular to the surrounding red contour, to avoid the influence of sidewall slope and bottom shape caused by the etch process on the measurement result. A user-defined reference box is shown at the upper left of the image, and the average depth is calculated as the height difference between the reference box and the blue box.

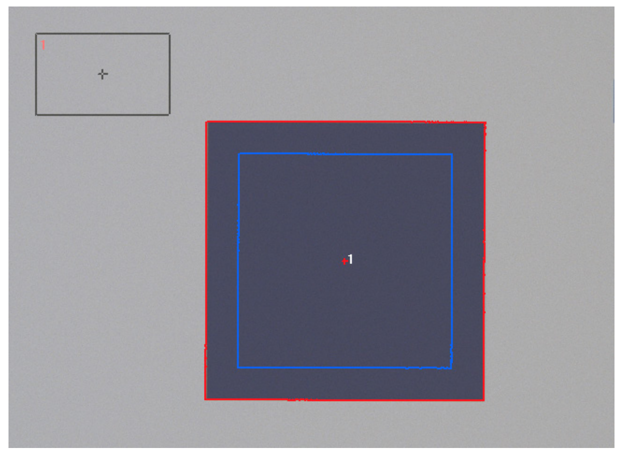
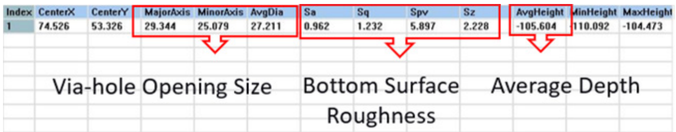


Figure 7. Top-down True Color image of a square hole, where the software automatically defines the feature edges in red. The hole depth is calculated as the difference between the reference z height (gray box at upper left) and the bottom surface z height (blue box at center).

The analysis results include the following parameters, which are displayed in Figure 8:

- *MajorAxis* is the long axis diameter of the structure, in microns, based on the red box boundary lateral dimensions.
- *MinorAxis* is the short axis diameter of the structure, in microns, based on the red box boundary lateral dimensions.
- *AvgDia* is the average of the long axis and short axis diameters, in microns; this value is used to calculate the top opening size for openings that are not strictly circular. Data is based on the red box boundaries.
- *Sa* is the areal surface roughness, in microns, based on the blue box boundaries.
- *AvgHeight* is the average depth, in microns, relative to the reference surface height, based on the grey box and blue box boundaries.



Index	CenterX	CenterY	MajorAxis	MinorAxis	AvgDia	Sa	Sq	Spv	Sz	AvgHeight	MinHeight	MaxHeight
1	74.526	53.326	29.344	25.079	27.211	0.962	1.232	5.897	2.228	-105.604	-110.092	-104.473

Figure 8. Data report from the Zeta optical profiler displays the measurement results, including hole diameter, roughness of bottom surface, and average depth.

All parameters are displayed in the reporting section and can be exported as a *.txt or *.csv file. These parameters can also be exported automatically to a remote host using SECS/GEM with the Zeta-388 fully-automated optical profiler for higher volume production type measurement applications.

Measurement of Obround/Elliptical Vias

HEMT vias may be patterned with different shapes, including circular, square, elliptical, and obround (also known as stadium or racetrack). Figure 9 shows a top-down image of obround HEMT structures. The opening of the vias is 75µm x 35µm with a depth of 90 – 110µm. The Zeta optical profiler uses the WLI technique combined with the powerful automatic analysis algorithms to measure and report via parameters such as Depth, Bottom Roughness, MajorAxis and MinorAxis.

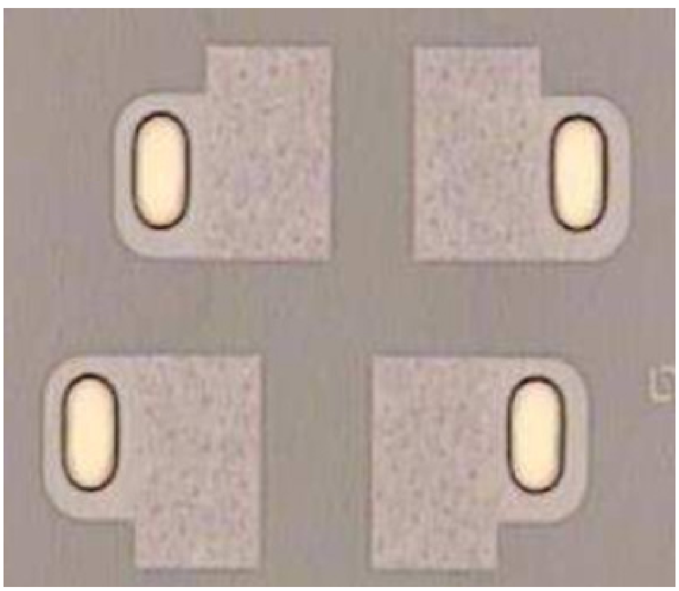
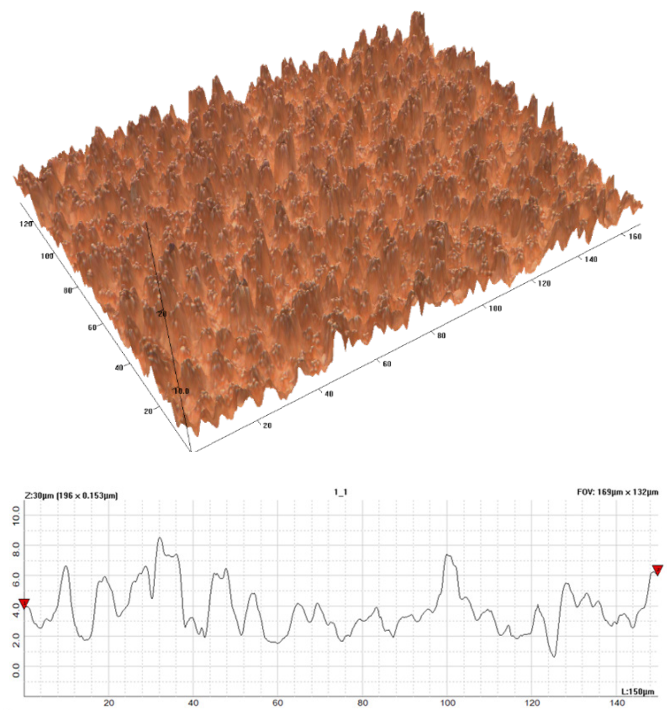


Figure 9. Obround HEMT vias measured by the Zeta optical profiler.

Measurement of Hard Mask Openings

Etching the hard mask opening is the first step in defining the via hole structure on SiC and GaN substrates. The size of the hard mask opening is a crucial parameter to monitor because of its impact on subsequent etch processes. For this application, use of WLI technology may be limited, due to the very rough surface. As discussed previously, the reference mirror will generate fringes when the surface is in focus. However, fringes are difficult to generate from rough surfaces due to large slopes, which result in an increased number of non-measurable pixels. Non-measured pixels impact the measurement result due to the loss of signal information in those high slope areas.

The multi-function nature of the Zeta optical profiler with ZDot technology complements WLI measurements by enabling it to accurately measure the 3D image on the rough hard mask surface. All parameters from the 3D hard mask opening measurement such as Depth, Bottom Roughness and diameter opening size can be detected by ZDot and reported. As an example, Figure 10 shows a 3D True Color image of a rough surface measured using ZDot technology.



Markers 1-2							
Ra	Rq	Rpv	Rp	Rv	Rsk	Rz	Rku
1.209	1.520	7.311	4.495	2.816	0.6833	5.418	2.949

Figure 10. Top: 3D image of a rough surface measurement taken using ZDot technology. Bottom: 2D profile across the surface with measured ISO roughness parameters. All dimensions are microns.

Conclusions

The Zeta optical profiler provides accurate measurement and automated analysis of high aspect ratio structures such as HEMT vias using non-destructive and high throughput metrology techniques. The multi-function nature of the Zeta allows the most appropriate metrology mode to be selected and tuned to the type of sample being measured.

The Zeta optical profilers from KLA Instruments are designed for maximum application flexibility. The multi-mode capability of the Zeta tools offers ZDot and True Color imaging, phase and vertical scanning interferometry, interference contrast imaging, shearing interferometry, film thickness and reflectance measurement, and defect inspection and mapping. Learn more at kla.com/products/instruments/optical-profilers.

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