

# Investigation of high voltage induced damage of GaN grown on Si substrate by terahertz nano-imaging and spectroscopy<sup>1</sup>

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## Introduction

GaN is a wide band-gap semiconductor, important for high power and high temperature device applications. In this note, we report on a large-domain-size polycrystalline gallium nitride grown on silicon substrate (Fig. 1) that was investigated by ARP’s terahertz nano-imager and spectrometer. The sample, as received, was subjected to a high voltage stress experiment; thus, it is expected that lattice level damage might have occurred. Especially, some areas with black spots are visible under light microscope. It is suspected that lattice damage might have occurred in these areas. The GaN layer is 2  $\mu\text{m}$  thick but no further details are known about this sample. However, available Raman spectra (Fig. 2) do not yield any indication regarding the nature of this anticipated damage, except for slight temperature dependent shift. Since terahertz is highly sensitive, it is expected that a combination of terahertz multispectral imaging and spectroscopy will help identify the damage and shed light regarding the nature of damage. Terahertz multispectral imaging has been described elsewhere [1–3] that breaks the wavelength barrier for sub-nanometer resolution imaging in a non-destructive and non-contact mode.

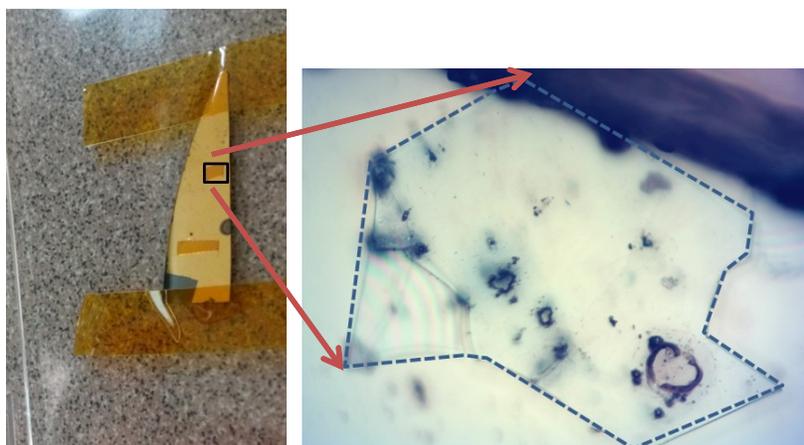


Fig. 1. Photographs of the sample as received. Left: Sample as received. Right: area of interest for imaging.

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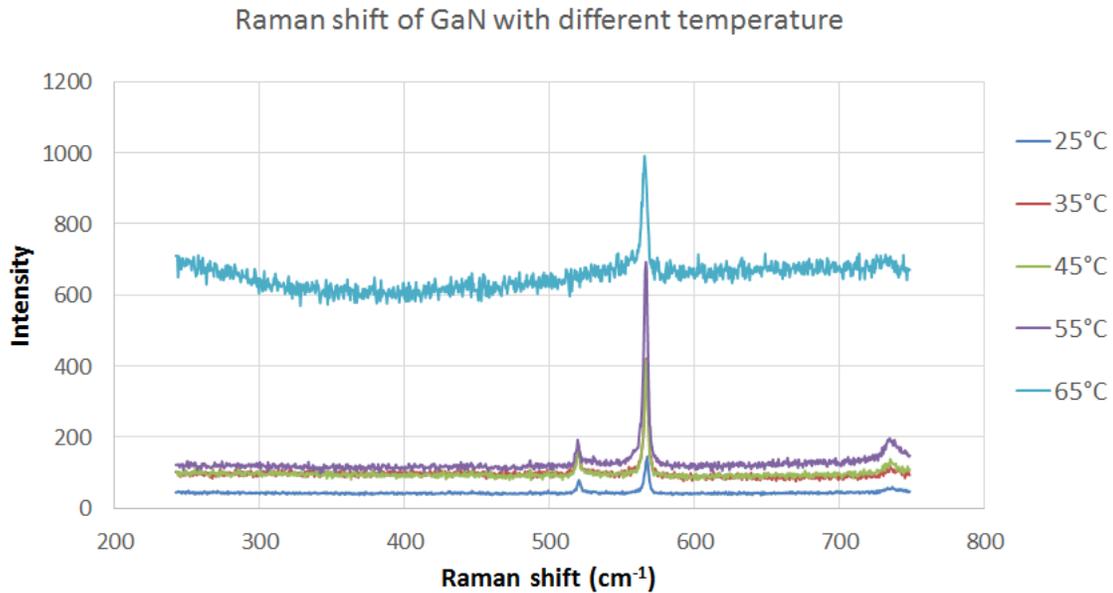


Fig. 2. Raman spectra shows prominent peak at  $567.9 \text{ cm}^{-1}$  at room temperature ( $25^\circ\text{C}$ )

## Experimental

A small selected volume of the sample was scanned with ARP's terahertz nano-imager system. Terahertz spectra were also acquired. The results are described below.

## Results and Discussion

### A. Image analysis

Fig. 3 shows a 3D view of a small volume ( $5 \mu\text{m} \times 5 \mu\text{m} \times 2 \mu\text{m}$ ) from the top of the sample. The top surface of Fig. 3 is shown in Fig. 4. Here, the undamaged area is identified by regular lattice pattern while the upper area exhibits distorted pattern. It is presumed that the crystalline structure of GaN has been damaged and distorted under the high voltage stress. Fig. 5(a) shows a 3D image of another area of the same sample showing some details of the GaN layer. The thickness of the GaN is  $\sim 2 \mu\text{m}$ . Fig. 5(b) exhibits two different slices from Fig. 5(a) along the YZ plane. Variation of patterns in the layers along the Y-axis is visible. Fig. 6(a) shows a single slice of the YZ plane of Fig. 5(a); layers of crystalline area and distorted area are also visible. Fig. 6(b) displays a graphical analysis of Fig. 6(a) along the vertical line. The crystalline layers' and distorted layers' thicknesses are plotted on a grey scale. The thicknesses may be quantified from this profile plot.

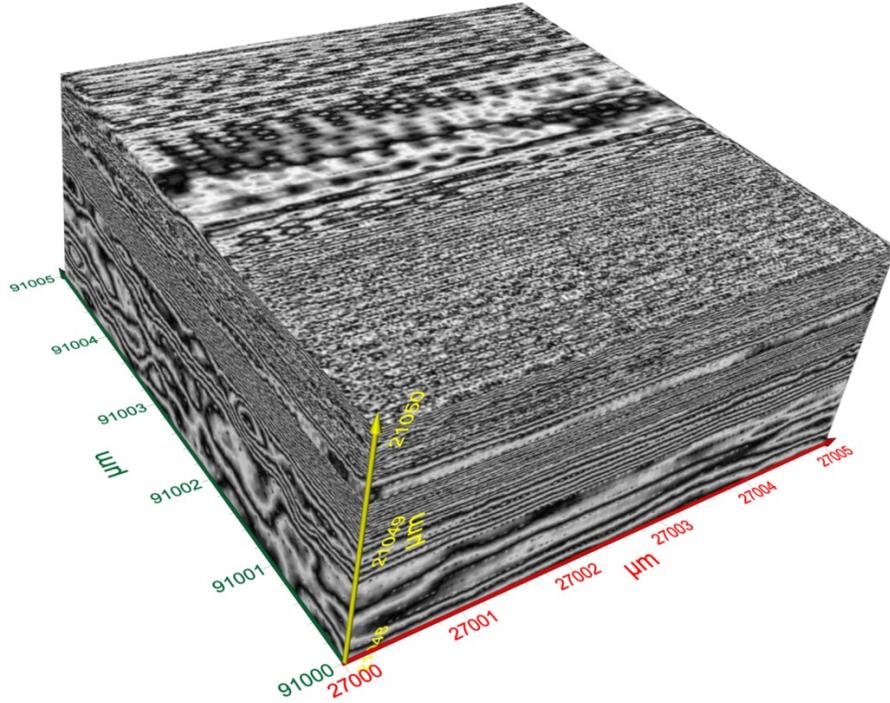


Fig. 3. A 3D view of  $5\ \mu\text{m} \times 5\ \mu\text{m} \times 2\ \mu\text{m}$  volume from the top of the sample. Crystalline area is identified by regular lattice pattern. Damaged area is also shown as identified by distorted lattice pattern.

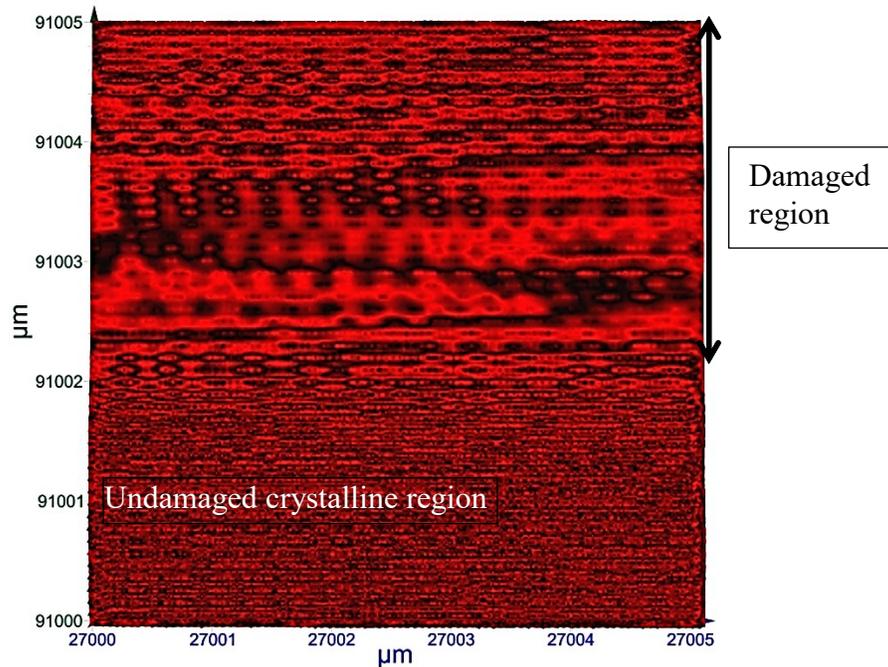


Fig. 4. Top surface ( $5\ \mu\text{m} \times 5\ \mu\text{m}$ ) from Fig. 2 shows single crystalline area and areas with modified patterns.

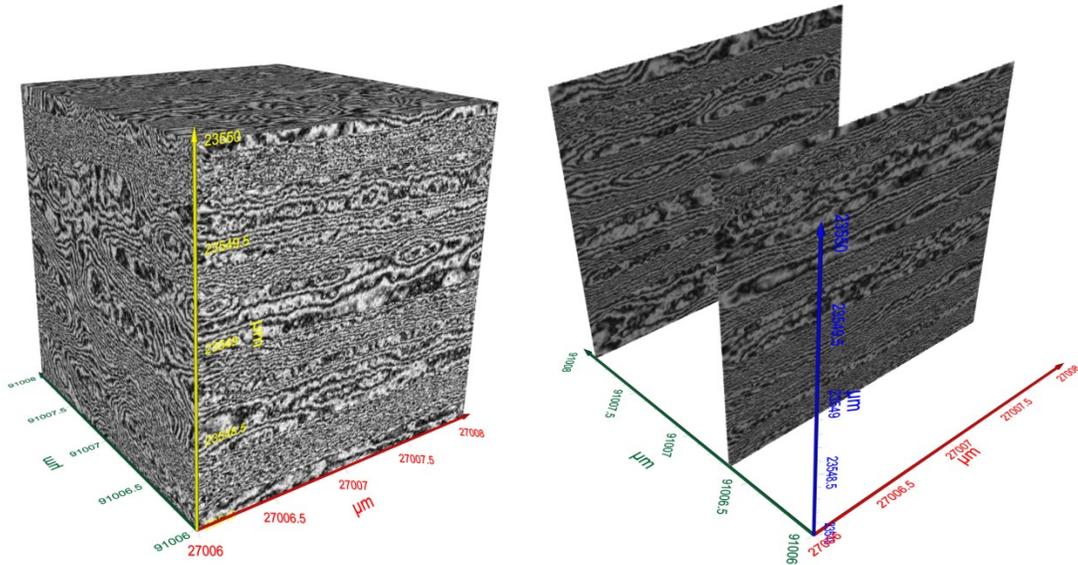


Fig. 5. (a) A 3D image of another area of the same sample showing the details of the GaN layer. The thickness of the GaN is  $\sim 2 \mu\text{m}$ . (b) Two single plane slices from Fig. 5 (YZ plane).

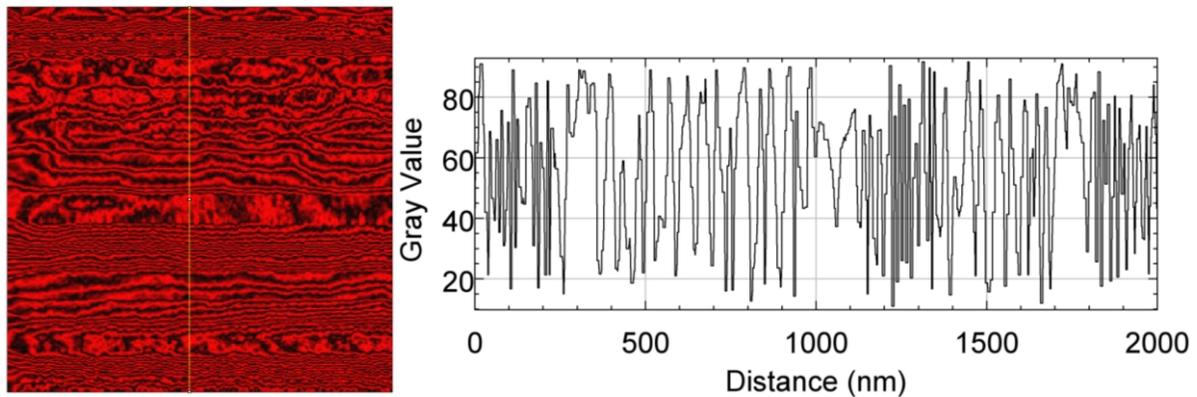


Fig. 6. (a) A single slice (YZ plane) is used for graphical analysis. Layers of crystalline area and distorted area are visible. (b) Graphical analysis of (a). The crystalline layers' and distorted layers' thicknesses are quantified via a grey scale profile plot.

## B. Spectral analysis

Terahertz time-domain investigation was conducted on the same sample. In particular, time-domain signals were acquired as a function of depth of up to 2500 nm at a step size of 50 nm. Fig. 7(a) exhibits the depth evolution of terahertz time-domain signal (interferogram) from the surface to inward. Two of these time-domain signals are analyzed by Fourier transform technique; one on the surface and one at a depth of 1 micron. Fig. 7(b) display the terahertz absorbance spectra of the GaN sample obtained via Fourier transform of the time-domain signals shown in Fig. 7(a). The absorbance spectrum at the surface (red curve) exhibits a water peak due to ambient moisture at low frequency while the spectrum at a depth of 1  $\mu\text{m}$  does not exhibit prominent water peak. There are shifts in the peaks between these two spectra presumably due to

distorted nature as seen in the images. Further analysis is necessary for making more conclusive remarks.

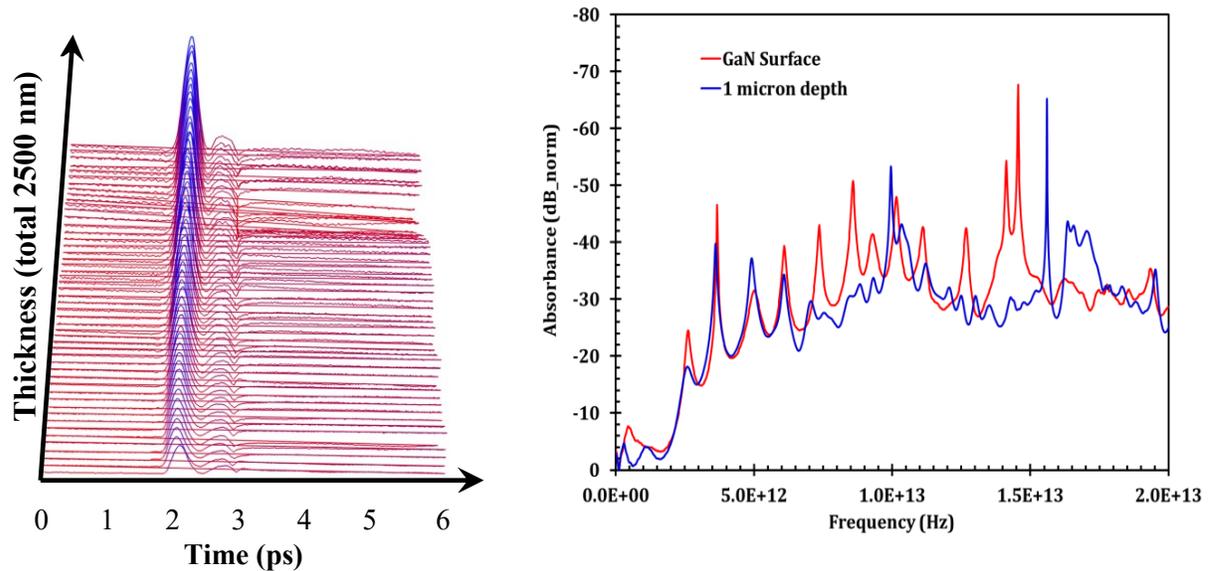


Fig. 7. (a) Evolution of terahertz time-domain signal (interferogram) as a function of depth from surface to inward. (b) Terahertz absorbance spectra of the GaN sample at the surface (red curve: GaN) and at 1  $\mu\text{m}$  depth from surface. The shifts in the peaks are presumably due to distorted nature as seen in the images.

## Conclusions

GaN grown on Si substrate has been investigated by terahertz nano-imaging and also by terahertz absorbance spectroscopy. It has been demonstrated that the lattice structure of GaN clearly shows the presence of damaged areas resulting from a high voltage experiment. Both the damaged and undamaged areas are observed. Graphical analysis of the lattice image may be used for quantifying the dimensions of the areas of interest. Three dimension images show the structure of the GaN layer on Si substrate. Additionally, terahertz spectral analysis shows significant differences between the absorbance spectra of GaN at the surface and that at a depth of 1  $\mu\text{m}$ . The spectra may be further analyzed to assign the nature of molecular change in the damaged area. An elaborate project may be undertaken for further quantitative imaging and spectroscopic analyses.

## References

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2. Rahman, A.; Rahman, A. K., Terahertz Spectroscopic Analysis and Multispectral Imaging of Epitaxially Grown Semiconductors with Nanometer Resolution. *J. Biosens Bioelectron* 2016, 7 (4), 1-6.
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