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Optical and Tactile Measurements on SiC Sample Defects

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Summary:
The different defect types on SiC samples are measured with various measurement methods including optical and tactile methods. The defect types investigated include particles, carrots and triangles and they are analyzed with imaging ellipsometry, coherent Fourier scatterometry and atomic force microscopy. Each of these methods measures different properties of the defects and they all together contribute to a complete analysis.

Keywords: defects, silicon carbide, imaging ellipsometry, coherent Fourier scatterometry, atomic force microscopy

Introduction

Power electronics is a key technology in many areas of our daily lives, such as intelligent energy distribution or electromobility. It is currently dominated by silicon technology. However, there is an increasing transition to wide bandgap compound semiconductors, which also include gallium nitride and silicon carbide (SiC). These compound semiconductors offer many advantages over silicon as they can operate at higher temperature, switching frequency and voltage [1]. However, material defects can affect the long-term stability of these materials. During the manufacturing processes, it is difficult to identify and characterize these defects with existing techniques. For this reason, novel methods will be developed to make this possible. There are several approaches, all of which have in common that they are non-destructive. Imaging ellipsometry and coherent Fourier scatterometry are the optical methods used and atomic force microscopy is the tactile method used.

In the following, the different types of defects on SiC layers epitaxially grown on SiC substrates will be discussed as well as the measurement methods used and their respective measurements.

The SiC epitaxial wafers used for the measurements were grown in an AIXTRON Planetary Reactor®.

Defect types

Defects on SiC are distinguished between crystallographic defects within the wafer and surface defects. Crystallographic defects can expand onto the wafer surface during epitaxial growth and thus form the surface defects [2]. Various surface defects are found on the samples studied here, the most common being particles, carrots and triangles (see Fig. 1).

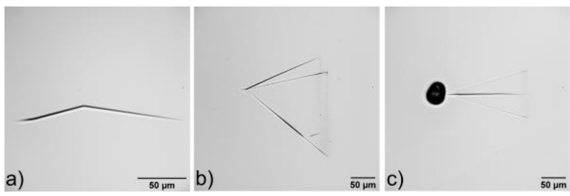

Fig. 1. Microscope images of the SiC defects. a) carrot defect; b) triangle defect; c) particle with triangle defect

Imaging Ellipsometry

An imaging ellipsometer combines classical ellipsometry with microscopy. In ellipsometry, changes in the polarization of light are detected after reflection or transmission at the sample. For the imaging setup, the data is evaluated for each pixel of the camera instead of being integrated over the entire illumination spot size as in the case of classical ellipsometry. This makes it possible to measure polarization features locally on the sample, areas much smaller than the illumination spot size and even non-periodic structures. However, it is an indirect method and requires numerical simulations to reconstruct structure parameters and to solve the inverse diffraction problem. [3]

Both Mueller matrix and Psi and Delta images are used for the data evaluation. Psi and Delta are the measured ellipsometric transfer quantities. The dielectric properties and the thickness of thin transparent and semi-transparent layers can be determined from them. The Mueller matrix is a 4 by 4 matrix with dimensionless values between -1 and 1 and represents the change in the polarization. Each matrix element consists of an image in which each pixel represents the value of the corresponding matrix element (see Fig. 2b)).

Coherent Fourier Scatterometry

Coherent Fourier scatterometry (CFS) is a measurement method based on scatterometry, where coherent light is focused on the sample and the scattered light is collected in the far field on a split detector. The data is collected by scanning the sample in a raster scan mode and recording the differential photocurrent of the split detector for each scan point. The scattered maps reveal all asymmetries in the scattered field and is thus sensitive to the presence of isolated defects on the sample. This technique has been applied for the detection of isolated spherical nanoparticles [4] and in this work we show that it can also be used for the detection of non-spherical defects as shown in Fig. 2c).

Atomic Force Microscopy

Atomic force microscopy (AFM) is a high-resolution tactile scanning method and is used for the measurement of the surface topography. It can be used for the mapping of the defects at different spatial scales, up to individual atomic plane resolution and it can include both the local defects and overall statistical parameters, like roughness.

Measurements

Different areas within the complex structure of SiC defects could be detected and analyzed by means of the imaging ellipsometer EP4 from Accurion. An ellipsometric microscope image is shown in Fig. 2a), a Mueller matrix image in Fig. 2b) and a CFS scattered map in Fig. 2c). These optical measurements show the ability of imaging ellipsometry and CFS to identify the surface defects with high contrast. In the Muller matrix image, a change in the polarization state is visible in some matrix elements, which simplifies the detection of these defects.

In Fig. 2d) an AFM measurement of a triangle defect is shown. Its surface topography can be clearly seen, and the dimensions of the defect can be derived from the topography. In this way, the AFM measurement supports the analysis of the SiC defects, which can be detected using the optical methods.

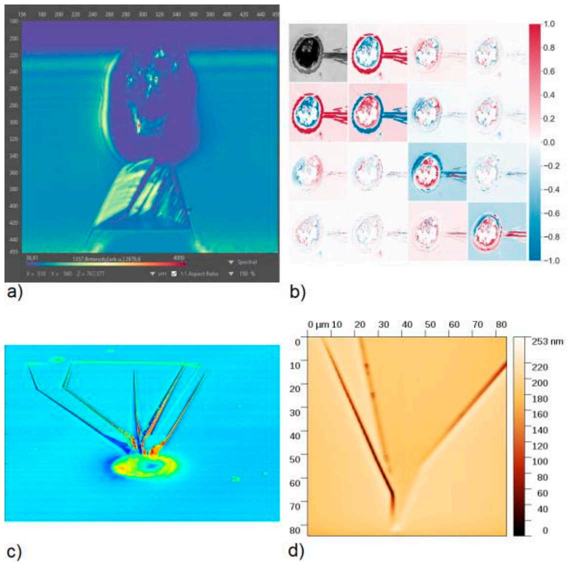

Fig. 2. Measurements on SiC defects. a) ellipsometric microscope image of a particle with triangle defect, 10x magnification; b) Mueller matrix image of a particle with triangle defect, 20x magnification; c) CFS scattered map of a particle with triangle defect; d) AFM measurement of a triangle defect

References

[1] N. Kaminaki, State of the art and the future of wide band-gap devices, *2009 13th European Conference on Power Electronics and Applications*, 1-9 (2009)

[2] H. Song, T. S. Sudarshan, Basal plane dislocation conversion near the epilayer/substrate interface in epitaxial growth of 4° off-axis 4H-SiC, *Journal of Crystal Growth* 371, 94-101 (2013); doi: 10.1016/j.jcrysgro.2013.02.011

[3] S. Liu, W. Du, X. Chen, H. Jiang, C. Zhang, Mueller matrix imaging ellipsometry for nanostructure metrology, *Opt. Express 23*, 17316-17329 (2015); doi: 10.1364/OE.23.017316

[4] S. Roy, A. C. Assafrão, S. F. Pereira, H. P. Urbach, Coherent Fourier scatterometry for detection of nanometer-sized particles on a planar substrate surface, *Opt. Express 22*, 13250-13262 (2014); doi: 10.1364/OE.22.013250

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