**Freiberg Instruments GmbH** Delfter Str. 6, 09599 Freiberg, Germany

# Full characterization of semiconductor (SC) materials using the Wafer XRD200 (SC) tool

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Among the many XRD tools in the Freiberg Instruments GmbH XRD product portfolio, the Wafer XRD200 (SC) is probably the versatile tool in respect of how many additional metrology tools can be added in order to get a complete quality analysis of the crystalline material.

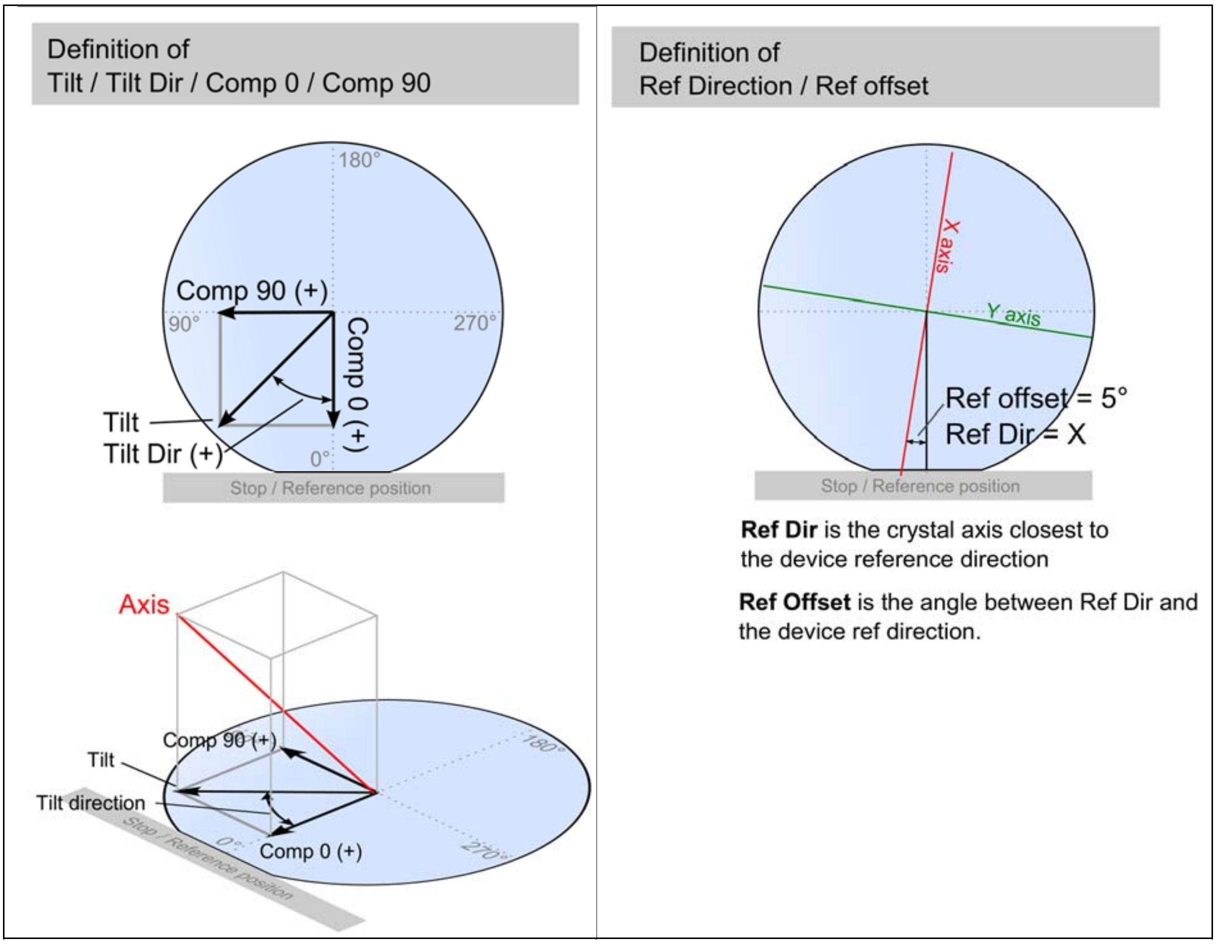
The patented XRD Omega-scan operation (see figure below) itself is very accurate and for a full analysis of almost any crystalline material you need less than 30 seconds, incl. handling. Freiberg Instruments is the only company offering this high-end technique for production floor XRD tools with focus on high throughput high and quality measurements. Wafer throughput in excess of 3000 wafers/day have been demonstrated.

*The Omega-scan principle. The X-ray source and detector have fixed angles and is not moving. The sample to be measured is rotated (Ω) and because of the geometry multiple diffraction peaks are being recorded in one revolution. One revolution takes 5 seconds, after which the compete crystal structure can be computed.*

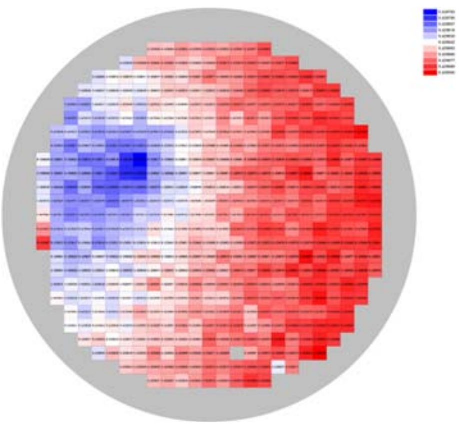
On the basis of the measured crystalline structure of the material relative to the surface and the notch or flat, the tilt vector and the offset between the projected main crystalline axis and the notch or flat can easily be measured (see figure below). All FI XRD tools use the Omega-scan principle and there are practically no limitations in material form and dimensions; i.e. wafers, seeds, ingots, boules and pucks can be characterized using the Omega-scan principle.

The crystalline structural parameter relative to the geometrics of the semiconductor material is one of the most important parameters to control in the semiconductor manufacturing industry, because the output of many critical processes in the chain of making semiconductor electronic devices are dependent on the crystalline structure. The Wafer XRD200 (SC) tool has as a standard a high precision geometry recognition tool integrated that measures the shape and dimension of the sample-to-be-characterized. In this way the crystalline structure can be referenced to the sample shape and dimensions. This is very important for semiconductors round wafers that have notches or flats that point to the main crystalline axis of the semiconductor (see figure below).

The wafer XRD200 (SC) can also be used for defect and dislocation density analysis. The X-ray and detector are thereby arranged in a Θ-2Θ configuration and the X-ray beam is shaped in a way that results in a narrow, symmetrical, delta function diffraction peak positioned according to a particular {hkil}–plane of a unit cell. The aberrations from the ideal peak are perceived as peak broadening. The quantification of dislocation density via the XRD method relies on this broadening of diffraction peaks that occurs when atoms in crystal unit cells are displaced from their ideal position due to small crystallite (size broadening) below one micrometre and an abundance of lattice defects (strain broadening) such as dislocations. In order to evaluate the stress and the dislocation density, the Full Width at Half Maximum (FWHM) of the peaks, together with the crystal tilt is measured and mapped across the sample (see example below).




*Output from the combined XRD and geometrics measurement. The Stop/Reference position can be a notch or flat*



*Results from a combined Ω-scan/Θ-2Θ crystalline analysis across a polished 150mm Si (001) Wafer*

*Range of Lattice constants: a = 5.429783….5.429900 Å, which indicate a very high-quality material with few dislocations in the bulk of the material.*

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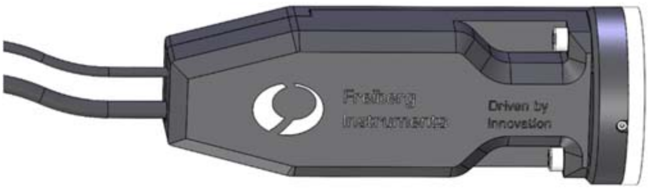
The resistivity of the semiconductor material is another important parameter in the semiconductor industry that needs a high of controlling. Quality control measures and resistivity tolerance management is the key to for instance well performing vertically designed power semiconductors. Freiberg Instruments has developed an OEM non-contact resistivity measurement head (see below) that can be integrated into most metrology tools, for instance the Wafer XRD200 (SC), and which can be used to make accurate resistivity measurements of the semiconductor material. In the Wafer XRD200 (SC) tool, the semiconductor sample is moved between the different metrology stations (XRD, resistivity & HR-SPS (see below)) and therefore parallel operation is possible in order to increase the productivity and throughput.




*OEM non-contact resistivity measurement head*

Another FI unique metrology tool that can be integrated into the Wafer XRD200 (SC) tool is the new HR-SPS analysis tool that are used for advanced defect analysis, sometimes in combination with the XRD defect analysis tool, but in cases where the defects are small, the HR-SPS tool has advantages over the XRD defect analysis tool. The HR-SPS uses discrete light sources (range ~ 220 nm – ~ 1600 nm) that are used to generate electron-hole pairs in the semiconductor. The electron-hole pairs separate in space because of differences in mobility, build-in drift (electrical fields) or defects in the semiconductor bandgap and give rise to a measurable voltage across the semiconductor, the so-called surface photovoltage (SPV). The discrete light sources (up to 3 lasers in the HR-SPS measurement head) are chosen according to different criteria, such as, but not limited to, 1) Semiconductor bandgap, 2) what defects are expected and how is the semiconductor doped. For SiC material (ingots, pucks, wafers & epi-wafers), the combination of 3 light sources, namely 355 nm, 375 nm and 450 nm, has proven to be a very good combination for measuring the state of the surface (polishing quality & sub surface damage) as well as defects in the bulk of the SiC material (see below).

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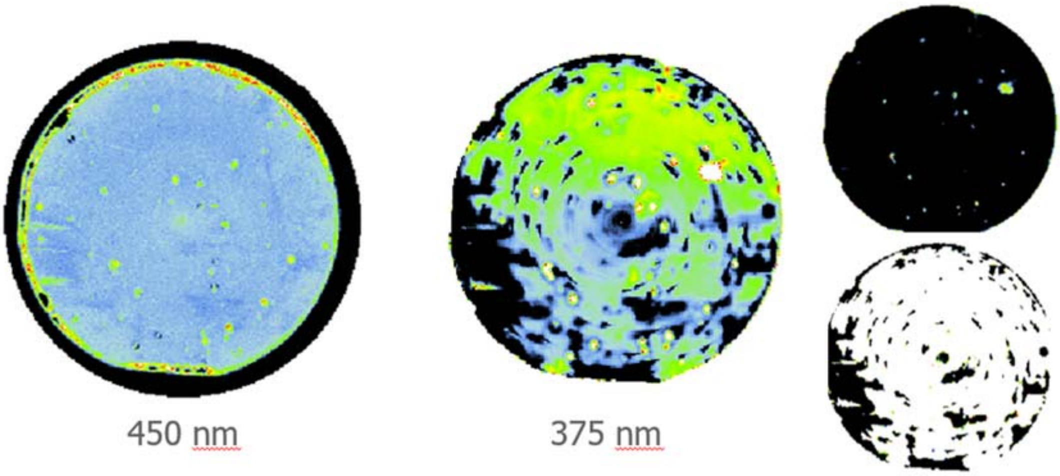


*Surface photovoltage signal height mapping @ 450 and 375 nm across a 100 mm 4H-SiC wafer with a ~ 30 µm SiC epitaxial layer on top (~ 1E15 cm$^{-3}$ doping level). The green spots in the 450 nm map (< 30 in total) are also seen (white spots) in the 375 nm map (see upper contrast map, right side). The lower contrast map has a rotational pattern suggesting surface related anomalies coming partly from the epitaxial process itself and partly from the defect history of the substrate*

Freiberg Instruments GmbH has expertise knowledge in many different metrology measurement techniques and when combining these, our customers can customize tools for specific needs. Here we have presented a very attractive for the semiconductor industry, namely the Wafer XRD 200 (SC) product, which as a basis measures the crystalline orientation of any known semiconductor within seconds (Ω-scan), but can be fitted with several other metrology tools relevant for the semiconductor industry. Some of these tools are a resistivity measurement tool, a geometry recognition & measurement tool and defect density measurement tools using XRD (Θ-2Θ) or SPV.

Freiberg Instruments GmbH also has expertise knowledge in sample management (shape and dimension) and Automation, which means that we can deliver fully automated systems with SECS/GEM interfaces. A lot of our customers use Freiberg Instruments GmbH as one-stop shop for the full project of measuring semiconductor properties with a high degree of Automation, high throughput and high-quality data management.

Contact us for more detailed information about the Wafer XRD 200 product:

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