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Electron channeling pattern imaging – a novel approach for the determination of wafer offcut angles

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Background incl. aims

The epitaxial growth of semiconductor multilayers can benefit from the use of wafer substrates with different offcut angles. The offcut angle of a wafer refers to the angle between the wafer surface normal and the chosen zone axis. These offcuts can be precisely controlled on monocrystalline wafers such as silicon or sapphire according to the growth needs. A possible application consists in tuning the strain in the epitaxial stacks by growing the layers on single-crystal wafers with precisely controlled offcuts. However, improper wafer offcuts can lead to the undesired formation of grains, anti-phase boundaries and uncontrolled growth modes. These offcuts must therefore be accurately controlled. To characterize wafer offcuts, methods based on high-resolution X-ray diffraction (XRD) [1] and electron backscatter diffraction (EBSD) [2] can be used to characterize the wafer offcuts with sub 0.1° angular resolution. However, such measurements are complex and time-consuming (several hours). Therefore, the availability of a fast and accurate method for wafer offcut angle determination is highly desirable to enable efficient quality checks of incoming wafers and to support the growth of high-quality materials for advanced semiconductor devices. In this contribution we propose a novel workflow based on applying electron channeling pattern imaging (ECPI) techniques and successfully utilized this method to measure wafer offcut angles.

Methods

ECP is based on the diffraction of backscattered electrons (BSE) inside crystalline materials [3]. The variation of the BSE yield as a function of the incident beam direction results in a distinctive band pattern on the sample surface. This generates a set of electron channeling bands (ECB) appearing as dark lines, which forms the ECP superposed on the BSE image. For monocrystalline samples, the ECP is determined by the crystal structure and orientation. While ECP represents the reciprocal space projection onto the detector plane, the sample rotation causes the respective rotation of the ECP. The beam center can be determined by the sample rotation. Having a sample with an offcut angle deviated from the zone axis means that the ECP rotation center is not fixed to the nearest zone axis. Upon sample rotation, the ECP center forms a circular trajectory as the sample is rigidly fixed with the zone axis. As a result, the precise wafer offcuts can be directly measured from the analysis of ECP images.

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Results
In this work, we successfully applied this method to Si(001) wafers with and without offcut angles. After sample loading into the chamber, the sample surface normal is first properly aligned to the primary electron beam. For the zone axis (offcut angle < 3°) present on one ECP image, a rotation series is needed to determine the wafer offcuts. During the sample rotation the whole ECP including the zone axis moves around the surface normal along a circular path. The resulting radius of the zone axis trace is determined as the wafer offcut angles. In case the zone axis is not present in the field of view, additional tilts are required to determine the zone axis position and thus the wafer offcut. Following this approach, the achieved angular resolution is 0.1°, which agrees well with reference XRD results. With the routine procedure established in this work, the results can be obtained within 1 hour. Compared to the XRD and EBSD methods, it is faster and provides an acceptable accuracy, without requiring any specific sample preparation.

Conclusion
We demonstrate a new approach based on ECP images to determine wafer offcuts. The wafer offcut angle is characterized rapidly with an angular resolution of 0.1º. As a fast, accurate, and easy-to-use solution, the technique has wide applications, especially in the semiconductor field.

Graphic:

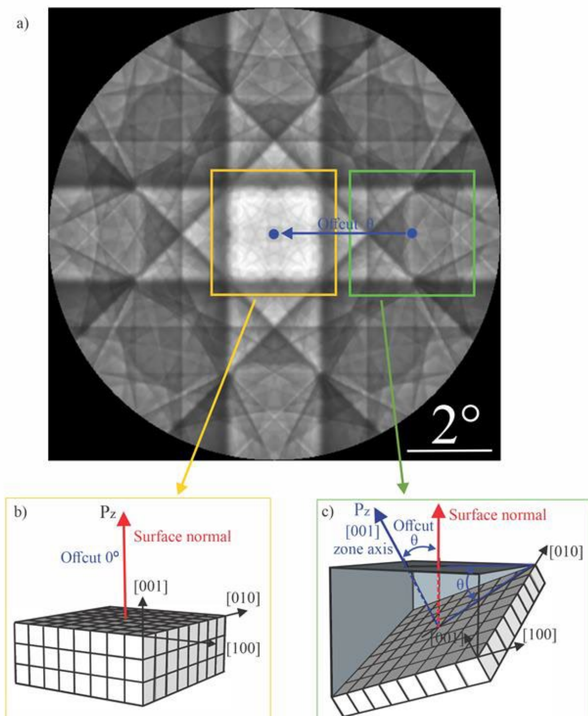

Fig.1 Schematic illustration showing the principle to determine wafer offcuts using ECPI. (a) Simulated ECP on a Si(001) wafer. (b) sample without offcut and (c) sample with offcut. For the sample without offcut (b), the ECPI is marked by the blue box on (a). The surface normal is identical to the [001] zone axis. For the sample with offcut (c), the corresponding ECPI is marked by the red box on (a). The surface normal stays at the ECPI center whereas the [001] zone axis is shifted away from the surface normal. The ECPI center C is determined by the sample rotation. The angular distance in-between is defined as the offcut angle θ.

Keywords:

Wafer offcut, misorientation, ECPI

Reference:

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