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Ge nanocrystallites grown on SiC

Report:

The aim of the experiment has been to characterize Ge nanocrystallites grown on 6H-SiC(0001) substrates by mean of high resolution x-ray diffraction methods (HRXRD). Preferred crystallographic orientations in respect to the substrate lattice, the size of the grown nanocrystallites as well as the chemical phase are of special interest for both the nanocrystallites producers and optoelectronic device developer.
Ge-nanocrystallites has been produced on the Si-side of on- and off-axis oriented 6H-SiC(0001) surfaces by means of molecular beam evaporation [1]. Substrate temperature from 470° to 550° C and evaporation rate of Ge from 0.1 to 1.5 nm/min have been used. At first, on the Si-terminated $(\sqrt{3}\times\sqrt{3})$R30° reconstructed 6H-SiC(0001) surface a mono-atomic Ge wetting layer established with homogeneously distributed 2D-islands of 2-3 nm diameter from which 3D-Ge-nanocrystallites grew according to the Stranski-Krastanov s theorem. Finally, these were covered with SiO_2 in order to get a long-term stability. Fig. 1 shows the corresponding AFM image.

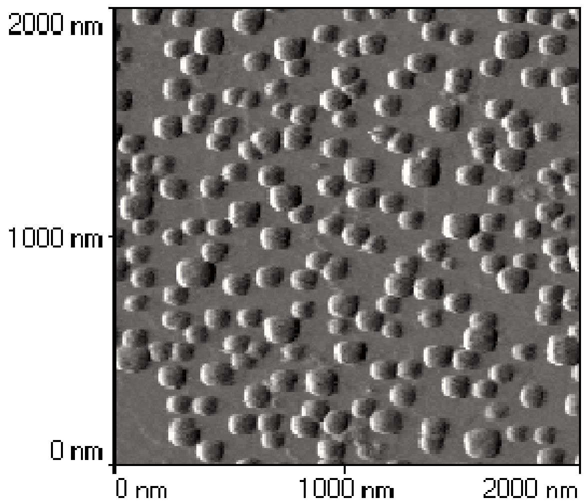

Fig. 1: AFM image of the Ge nanocristallites grown on 6H-SiC(0001) at 550 °C at a rate of 1.5nm/min

The scattering volume of the grown nanocrystallites is very small, particularly with regard to substrate volume. For this reason, high-intensity synchrotron radiation, which should be well collimated and monchromated, is required to analyse the nanocrystallites by X-ray diffraction methods. Furthermore, a x-ray diffractometer set-up equipped with an Eulerian cradle is essential in order to adjust symmetric, asymmetric as well as oblique crystal reflections. These requirements are well accomplished by the new material research diffractometer at the CRG-beamline (ROBL) at the ESRF [2].

The x-ray diffraction pattern (Fig. 2) taken up by using the coupled $\omega/2\Theta$ -mode proves the crystalline phase of the Ge nanocrystallites which were produced on the 6H-SiC(0001) with the above indicated parameters. Besides the strong directly and umweg- excited substrate

peaks, the diffraction pattern shows also peaks which could be explicitly assigned to the Ge nanocrystallites. These peaks are the 111-, 220-, 311- and 400-reflections. They point out to the different orientation of the Ge nanocrystallites in respect to the substrate surface. These “orientation diversity” suggests a homogenous orientation distribution of the grown Ge nanocrystallites. However , the rocking curves taken up with each of the hkl-reflections indicate a distinctive alignment of the corresponding crystallites in respect to the substrate (Fig. 3). The growth of exclusively (111)-oriented Ge nanocrystallites could successfully be realized by using a special sample preparation.

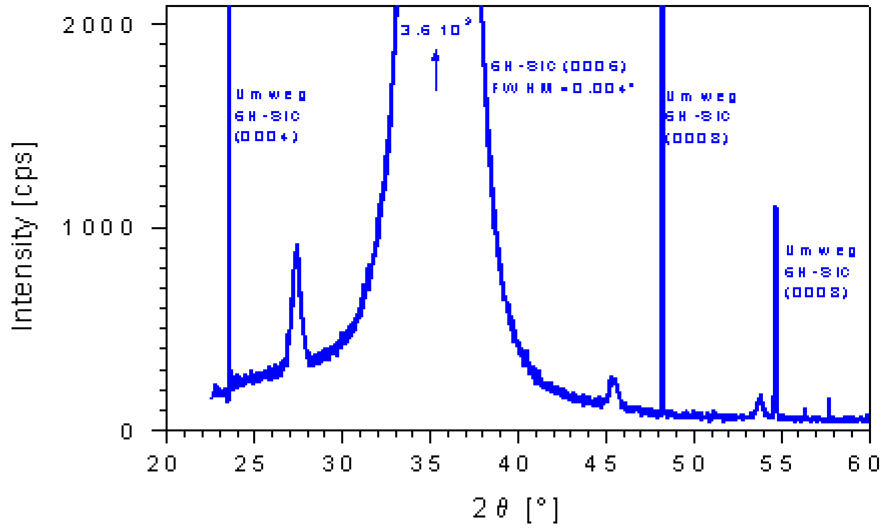

Fig. 2: Large area $\omega/2\Theta$ -diffraction pattern of Ge nanocrystallites grown on the *6H*-SiC(0001). The little peaks arising from the Ge nanocrystallites point out that they are differently oriented in respect to the substrate.

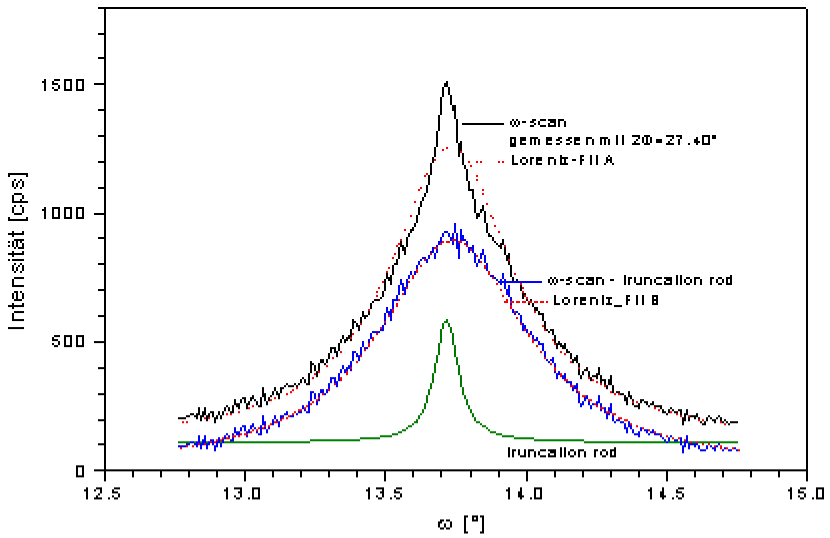

Fig. 3: Rocking curve (ω-scan) recorded with the 111-Ge reflection of Fig. 2. The trail of the strong 0006-SiC substrate reflection (truncation rod) had been eliminated in order to obtain the reflection broadening caused by size of the nanocrystallites. $FWHM_{\omega}$ = 0.65° $\longrightarrow$ lateral size of the Ge-crystallites $D_{lateral}$ = 25.3 nm.

The “littleness” of the crystallite dimension causes a diffraction peak broadening both in the $\omega/2\Theta$ -diffractogram and in the ω scan diffractogram. From this and neglecting the inherent crystallite strain, which here is fulfilled for the epitaxially grow crystallites, one can evaluate their size in-plan and normal to the surface, $D_{lateral}$ and D_{normal} respectively. The modified Scherrer equation can be used:

$$D_{normal} = \frac{0.88 \cdot \lambda}{\cos\Theta \cdot \Delta(2\Theta)_{FWHM}}$$ applicable to the $\omega / 2\Theta$ scan mode

$$D_{lateral} = \frac{0.44 \cdot \lambda}{\sin\Theta \cdot \Delta\omega_{FWHM}}$$ applicable to the ω scan mode

Hence, the complete set of the measured values for the Ge crystallites with (111), (110) and (311) orientation, respectively, gives the crystallite sizes indicated in Fig. 4. The diagram shows the similarity of the differently oriented crystallites in respect to their average size and aspect ratio.

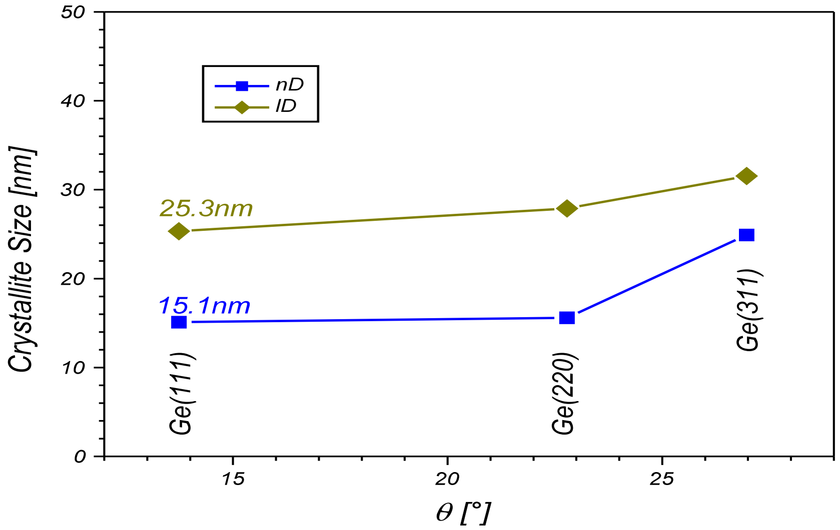

Fig. 4: Average crystallite size of Ge nanocrystallites differently oriented grown on the *6H*-SiC(0001): D_{normal} – crystallite size perpendicular to substrate surface, $D_{lateral}$ – crystallite size parallel to substrate surface.

Note, that the results acquired by the x-ray diffraction methods represent integral values averaged over the area at the wafer surface of approximately 1 mm^2 defined by incident x-ray cross section. They characterize a large ensemble of same type nanocrystallites. Therefore, the results due to the x-ray diffraction are useful in supplementation and for comparison to the TEM and AFM investigations which characterize only a single or a few nanocrystallites, respectively.

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