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Erratum to: Comparative Studies of the Growth and Characterization of Germanium Epitaxial Film on Silicon (001) with 0° and 6° Offcut

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**Erratum to: Journal of ELECTRONIC MATERIALS, Vol. 42, No. 6, 2013, pp. 1133–1139
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In the original article we presented results that show that the strain in germanium (Ge) epitaxial films grown directly on a silicon (Si) (001) with 6° offcut has a tensile strain of 0.6%.[1] This strain value is much higher than the typical tensile strain value of 0.2% reported for Ge/Si.[2] This discrepancy is due unintentional omission of the Si offcut angle and azimuth angle (φ) of the sample during high-resolution x-ray diffraction (HRXRD) measurement, and it has unfortunately resulted in a misleading result.

The peak position in a standard 2θ-ω curve and its intensity strongly depend on the way the sample is placed during the HRXRD measurement, especially for the offcut sample.[3] Figure 1 shows that the shift in the Ge peak position and its intensity variation is a function of the azimuth angle of sample (φ) during the HRXRD measurement. The angular shift of Ge peak position, from one azimuthal orientation to another, can be as large as 0.6344°, and thus single azimuthal scan may be misinterpreted to indicate strain anywhere in the range of +0.75% (tensile) to −0.40% (compressive). In addition, the Ge peak intensity changes significantly by more than two orders of magnitude.

In order to calculate the strain of Ge epitaxial film which is grown directly on the Si with offcut substrate (6° offcut in this case), an equation that has factored in the azimuth effect (φ) is used. The angular separation between the epitaxial film and the substrate peak in the (004) rocking curve at an azimuth angle φ, is given by

$$\begin{aligned} &\Delta\theta_{004}(\varphi) = \Delta\theta_{B004} + \Delta\varphi\cos(\varphi - \varphi_0) \\ &\text{where} \\ &\Delta\theta_{B004} = \Delta\theta_{B004,\text{epitaxial}} - \Delta\theta_{B004,\text{substrate}} \end{aligned} \tag{1}$$

$\Delta\theta_{B004}$ is the difference in Bragg angles between the epitaxial layer and the substrate. $\Delta\varphi$ is the crystallographic tilt between the [001] axes of the epitaxial layer and the substrate. φ_0 specifies the direction of this tilt.

The points (pairs of the Ge peak position and its respective φ) can be fitted by a linear equation (Fig. 2). The interception on the vertical axis and slope of the straight line represent $\Delta\theta_{B004}$ and $\Delta\varphi$, respectively. The confidence level of the fit to our data set is 92.3 %. From the linear fitting, $\Delta\theta_{B004}$ = 1.5203 and $\Delta\varphi$ = 0.1658 are obtained. The out of plane lattice constant is then determined by the Bragg angle of the epitaxial layer.

$$a^{\perp} = \frac{2\lambda}{\sin\left(\frac{\omega_{\text{Si}}}{2} - \Delta\theta_{B004}\right)} \tag{2}$$

The online version of the original article can be found under doi:10.1007/s11664-013-2538-7.

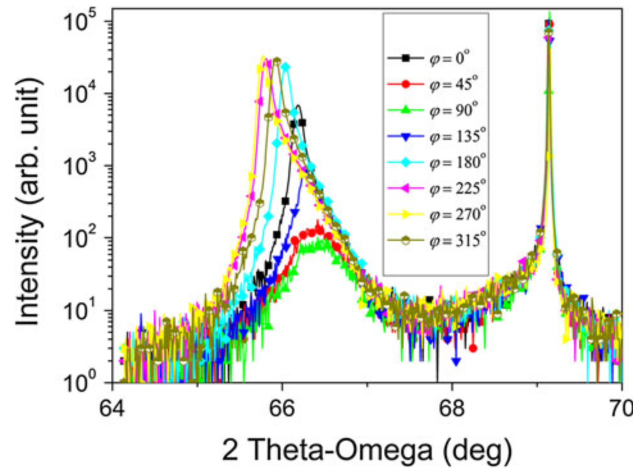

Fig. 1. The high resolution x-ray diffraction (HRXRD) measurement of Ge film grown on 6° offcut Si substrate with different φ positions.

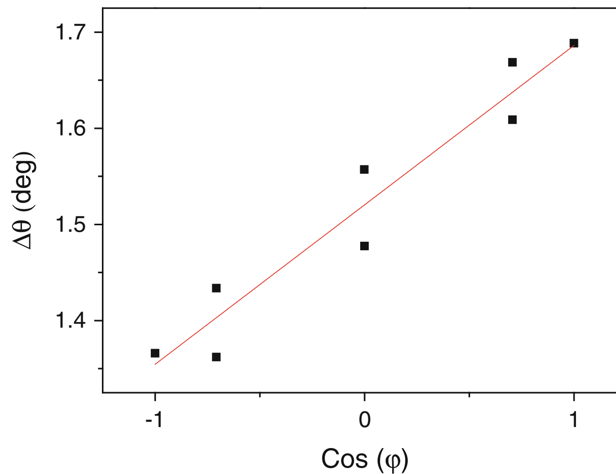

Fig. 2. The fitting of the points (the pairs of the Ge peak position and its respective φ) using a linear equation.

Using the Eq. (2), $a^{\perp}$ of the Ge on Si 6° offcut sample can be estimated as 5.6489 Å.

The in-plane lattice constant, $a^{||}$ of the Ge epilayer can be calculated using Eq. (3) by taking the elastic modulus of Ge, υ = 0.271, and the unstrained Ge lattice constant, a_{Ge} = 5.6576 Å.

$$a^{\|} = \left(\frac{1+\upsilon}{2\nu}\right)\left[a_{\mathrm{Ge}} - a^{\perp}\left(\frac{1-\upsilon}{1+\nu}\right)\right] \tag{3}$$

Therefore, the estimated $a^{||}$ of the Ge epilayer on 6° offcut Si is 5.6698 Å. The residual strain of the Ge epilayer can be calculated from Eq. (4):

$$\varepsilon = \frac{a^{\|}_{\mathrm{Ge}} - a_{\mathrm{Ge}}}{a_{\mathrm{Ge}}} \tag{4}$$

Hence, the Ge layer on 6° offcut substrate has a tensile strain of 0.21% which is comparable to the strain value that is typically reported for Ge epilayer directly grown on Si (i.e. 0.2% of tensile strain).

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