Elastic Relaxation Evaluation in SiGe/Si Hetero-Epitaxial Structures

M.B. Gonzalez1,2, N. Naka1, A. Hikavyy1, G. Eneman1,2,4, R. Loó1, E. Simoen1, C. Claeyss2
1IMEC, Kapeldreef 75, 3001 Leuven, Belgium
2EE Dept., KU Leuven, B-3001 Leuven, Belgium
3HORIBA Ltd., 601 Kyoto, Japan
4Postdoctoral fellow of the Research Foundation-Flanders

Introduction. A key concern in strained CMOS technology is the channel stress optimization with the device scaling foreseen by the ITRS roadmap [1]. In this paper, the impact of the geometry on the stress levels and Ge content of Si1-xGex/Si hetero-epitaxial structures will be evaluated by Raman spectroscopy for several active area dimensions. The analysis will be complemented by Spectroscopic Ellipsometry (SE), High Resolution X-Ray Diffraction (HR-XRD) Nomarski optical microscopy and eventually finalized by stress simulations.

Experimental. The strained Si1-xGex/Si hetero-structures were fabricated on 300 mm diameter n-type Czechralski silicon wafers with Shallow Trench Isolation (STI). Before the selective epi deposition, an HF dip was performed to remove the native oxide and was followed by an H2 bake at 850 °C for 2 min. Subsequently, without Si recess, in-situ highly boron-doped Si1-xGex epitaxial layers were selectively grown using an ASM Epsilon TM 3x3 reactor, targeting B levels up to 5x1019 cm-3 (confirmed by Spreading Resistance Probe). The active area dimensions of the studied SiGe/Si hetero-structures ranges from 3x3 μm2 to 100x100 μm2. It should be noticed that no evidence of plastic relaxation was detected in the SiGe layer by Nomarski inspection. The Raman measurements are done in backscattering geometry on a HORIBA Jovin Yvon LabRam HR-800 micro-Raman system using the 488 nm line of an argon ion laser (0.5 mW) as an excitation source. The penetration depth of 488 nm line is ~150-200 nm in the SiGe layer. The Raman analysis enables us to characterize the strain in both the SiGe alloy and the Si substrate.

Results and Discussion. The thickness and the Ge composition of some splits were evaluated by spectroscopic ellipsometry (SE) (see Table I), where a close agreement was observed between the experimental and nominal values.

<table>
<thead>
<tr>
<th>Splits</th>
<th>Ge content (%)</th>
<th>Thickness (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 nm Si1-xGex</td>
<td>23.5</td>
<td>97.1</td>
</tr>
<tr>
<td>150 nm Si1-xGex</td>
<td>25.3</td>
<td>147.4</td>
</tr>
</tbody>
</table>

Table I. Extracted Ge content and epitaxial thickness by spectroscopic ellipsometry. From Raman measurements the Ge content and strain in the SiGe layer were determined from the Si-Si and Si-Ge phonon frequencies of the corresponding Raman modes and following the dependence with the in-plane strain and Ge content given by Pezzoli et al. [2], where Ge content values of ~24.3% and 24.4% are observed for the 100 nm and 150 nm cases, respectively. These values are independent of the active size and, are within 1% of the nominal value (25%). Figure 1 shows the compressive strain vs. active area size, where ~13% strain reduction was observed for the smallest studied window of 3x3 μm2 and 150 nm thickness as compared to the strain present in larger windows. This stress reduction could be attributed to a decrease of the effective compressive stress levels at the edges of the SiGe epilayers. Additionally, it is shown that for a small window size the split with a thicker epitaxial layer (150 nm) shows a higher relaxation than the 100 nm thick layer.

Fig.1. Compressive strain vs. active area size in SiGe/Si hetero-structures. The values have been extracted from the experimental Si-Si and Si-Ge peak shifts in the SiGe layer, following the model of [3]. Furthermore, from Raman analysis it is also possible to evaluate the stress forces for the underlying biaxially stressed Si substrate. This can be derived from the Si-Si phonon peak shifts in the Si substrate with respect to the stress free Si-Si bond (520.5 cm-1) and following the model of [3].

Furthermore, from Raman analysis it is also possible to evaluate the stress forces for the underlying biaxially stressed Si substrate. This can be derived from the Si-Si phonon peak shifts in the Si substrate with respect to the stress free Si-Si bond (520.5 cm-1) and following the model of [3].

References