Strain measurements on Si/SiGe heterostructures using HRTEM

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The use of strain in Si/SiGe heterostructures has become an important feature of current Si CMOS devices. To allow further downscaling for the next technology nodes, advanced characterization techniques with high spatial resolution at high accuracy are required. Although high resolution transmission electron microscopy (HRTEM) coupled with advanced image processing methods has been widely used to fulfill these demands, optimization of experimental conditions are crucial for accurate strain measurements.

A 30 nm thick SiGe film with 30% Ge was grown by molecular beam epitaxy on a (001)-oriented Si substrate and subsequently capped by a 200 nm Si layer. HRTEM experiments were performed on JEOL ARM 1250, JEOL JEM 4000EX and Zeiss SESAM microscopes. Image processing algorithms "LAttice DIstortion Analysis" (LADIA) [1,2] and "Geometric Phase Analysis" (GPA) [3,4] were employed for strain measurements. The two methods were compared with respect to sensitivity to noise, local crystal bending, and thickness/defocus variations in order to identify the sources of error in strain measurements. It has been found that strain gradients may introduce defocus dependent spurious strain oscillations at the interfaces measured by GPA. The optimum conditions were analyzed by comparing strain maps obtained from experimental and simulated single defocused lattice images and complex-valued exit face wave functions as reconstructed from focal series using the FRWR algorithm [5].

Figure 1a displays the phase image of the coherent Si/SiGe interface obtained from 15 HRTEM images along the [110] orientation at 10 nm defocus steps. The 2D out-of-plane strain, ε_{yy}, with respect to the Si reference calculated by LADIA is shown in Figure 1b. For GPA analysis, the geometric phase images are calculated from the complex-valued exit face wave function using a script implemented in DigitalMicrograph (Gatan). The resulting strain map at 2nm resolution is given in Figure 1c. Although both algorithms reveal similar average strain values within the layer, $1.7 \pm 0.2\%$, strong oscillations at the interface are observed for GPA strain maps obtained from images at different defoci. Figure 1d shows the integrated line scan profiles at the interface to illustrate the variation of measured strain values with respect to defocus steps.

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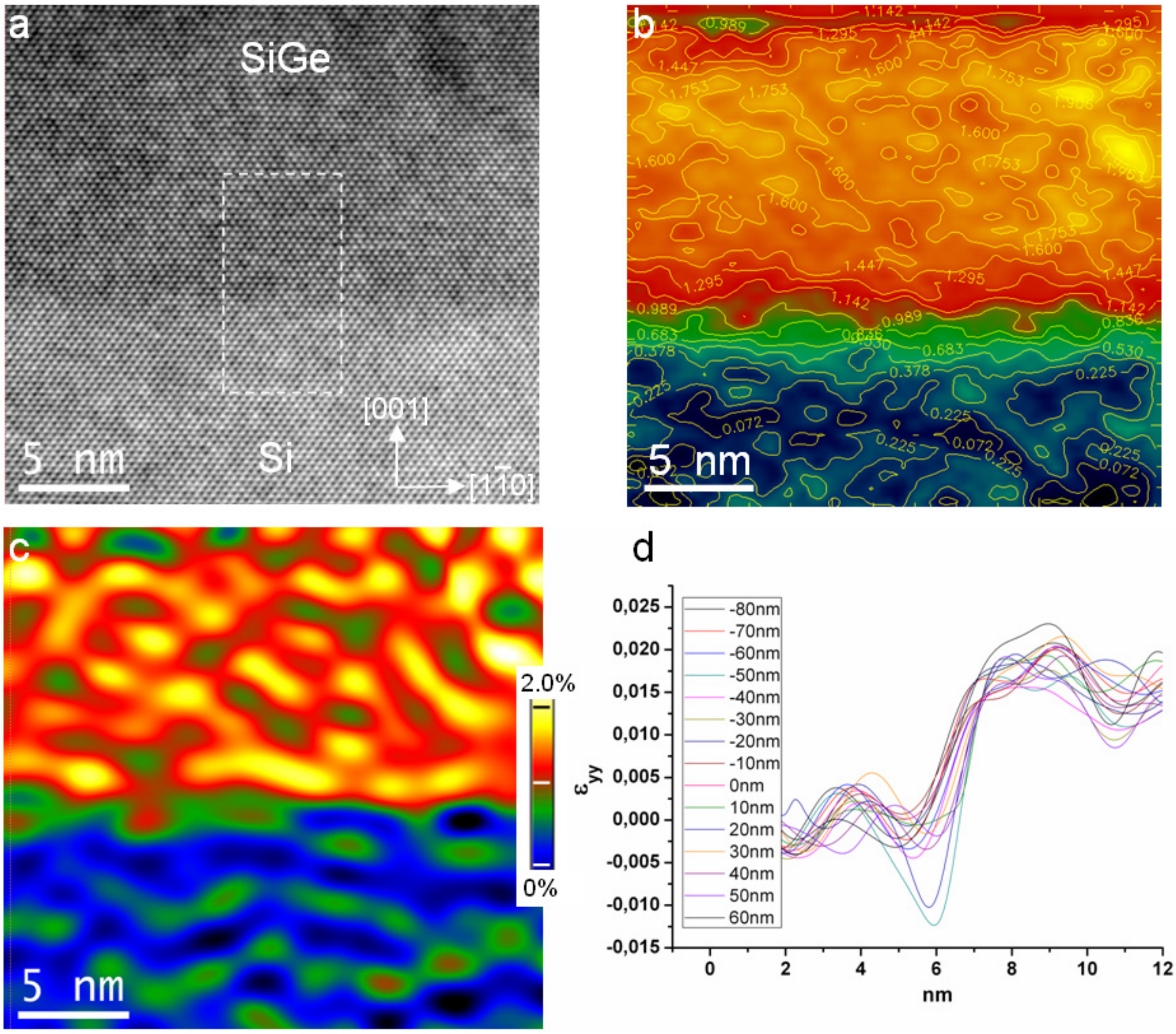

Figure 1. a) Reconstructed phase image of the coherent Si/SiGe interface along the [110] zone axis. b) 2D out-of-plane strain map in the growth direction obtained from LADIA. c) 2D strain map calculated by using GPA on complex-valued exit face wave function. d) The measured strain values from GPA with respect to varying defocus is given as integrated line scan profile from a region indicated as dashed square in a).

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