Aberration corrected STEM for interfacial strain and vacancy characterization

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Epitaxial heterostructures consisting of two or more semiconductors are widely used in micro- and nano-electronics such as transistors, quantum cascade lasers, infrared photodetectors, and light emitting diodes. A critical engineering parameter in designing an epitaxial heterostructure is strain, which arises from the lattice mismatch between dissimilar materials. For example, strained silicon, coupled with $Si_{1-x}Ge_x$, is used to enhance the effective carrier mobility in the channel of a metal-oxide-semiconductor field effect transistor (MOSFET). The control over unconventional electronic and magnetic properties of semiconductor and oxide heterostructures also relies on strain. It is experimentally challenging to measure strain in such heterostructures, especially the interfacial strain, since the region of interest is on the order of nanometer. The determination of strain in epitaxial heterostructures in general requires both high resolution and precision in order to develop a detailed understanding of strain-property relationships.

Here we will report on the progress that has been made in atomic resolution strain mapping using Z-contrast images acquired with aberration corrected scanning transmission electron microscopy (STEM) using a high angle annular dark field detector (HAADF) [1]. Compared to high resolution TEM, the contrast in Z-contrast images is more uniform and less sensitive to thickness and defocus values, which is beneficial for quantitative strain measurement. By directly measuring atomic column positions, strain can be measured with reliability, resolution and precision at unprecedented level for interfacial strain and point defects characterization. Several application examples will be demonstrated. One is the determination of atomic vacancies in the InAs/GaSb strained layer superlattice [2] (also see Fig. 1). We show that cation and anion vacancies in the InAs/GaSb SLS give rise to local lattice relaxations, especially the nearest atoms, which can be detected using a statistical method and confirmed by simulations. The second is a study of Sb substitution for As in an MBE grown InAs/InAsSb strained layer superlattice, which we show is accompanied by significant strain fluctuations. Strain analysis based on atomic column positions reveals asymmetrical transitions in the strain profile across the SLS interfaces. The averaged strain profile is quantitatively fitted to the segregation model, which yields a distribution of Sb in agreement with the scanning tunneling microscopy result. The subtraction of the calculated strain reveals an increase in strain fluctuations with the Sb concentration, as well as isolated regions with large strain deviations extending over ~ 1 nm, which suggest the presence of point defects [3].

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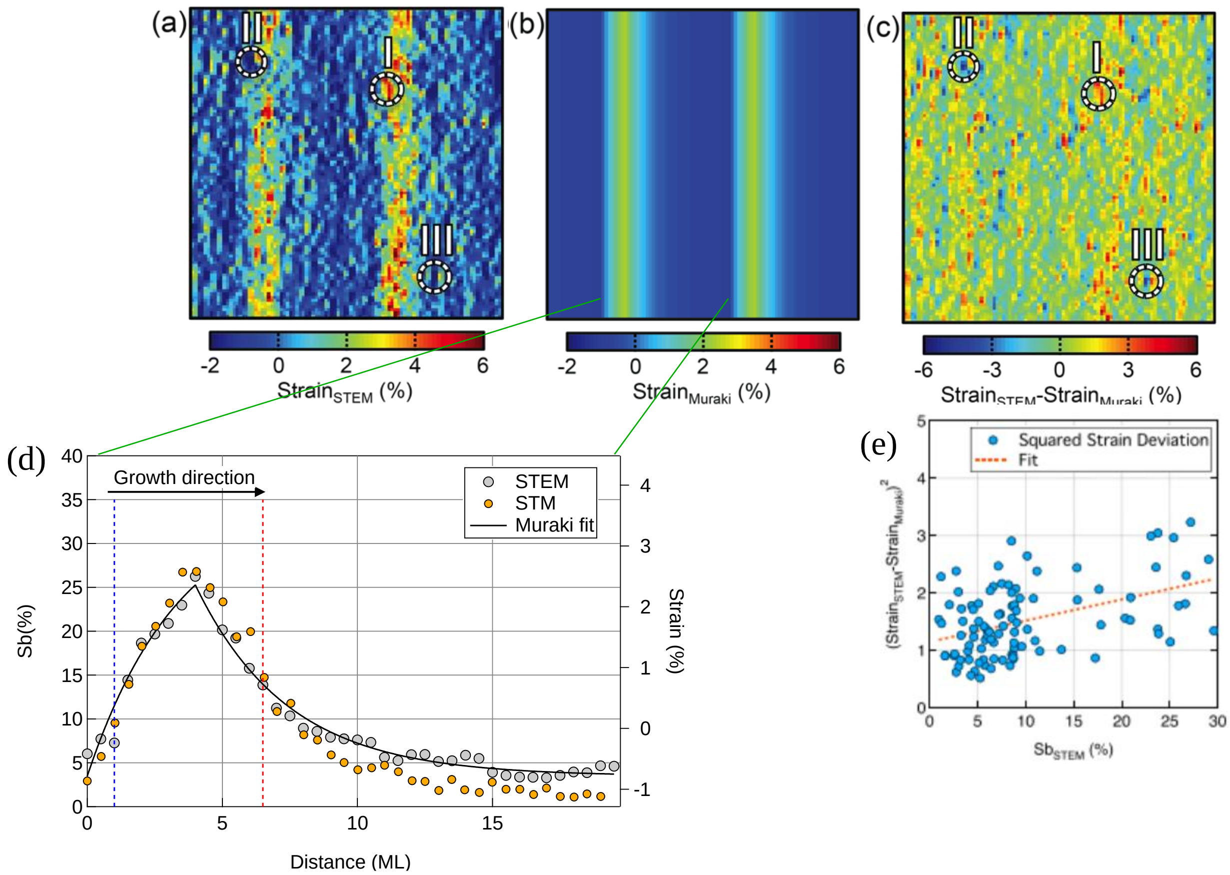

Figure 1. Atomic resolution strain mapping using STEM in an InAs/InAsSb superlattice. (a) Strain map along x (horizontal) obtained using template matching. (b) calculated strain based on the average Sb composition in (d). (c) Difference between experimental strain and computed strain maps, showing deviations from the average strain. (e) A plot shows the correlation between strain fluctuations and Sb composition (data from [7]).