



Confocal Raman Imaging for Stress Measurements in Semiconductors

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To demonstrate the capabilities of confocal Raman imaging for semiconductor applications, a strained Si film on a relaxed SiGe film has been investigated. The strain introduced into the Si film changes the Si band structure, which leads to a higher mobility of charge carriers. Knowing the stress in these films and the underlying SiGe layer is crucial for optimizing the device properties.

Experimental and Results

The Confocal Raman Microscope alpha300 R used in this study combines a highly sensitive confocal microscope and a high-transmission Raman spectroscopy system, and it is equipped with AFM capabilities. With a resolution down to 200 nm at each image pixel, a complete spectrum is typically acquired in 10 ms to 100 ms. An image consists of 10,000 (100×100) to 65,536 (256×256) spectra. From this multispectrum file, an image is generated by integrating over a specific Raman line or a region in all spectra. As all spectra are stored in memory, a variety of properties such as peak-width, center of mass, or peak position of certain Raman lines can be calculated. By combining Raman imaging with AFM, it is possible to link chemical with ultra-high spatial and topographical information.

The sample is a 50 nm SiGe layer on a silicon substrate with a 10 nm cap layer of epitaxial silicon. The lateral homogeneity of strain in strained Si/SiGe materials is very important for the production of high mobility IC that use these materials. The SiGe layer has a certain lattice mismatch to pure Si which depends on the Ge concentration. This strain relaxes partially if the layer thickness exceeds the critical layer thickness. This critical thickness is not only a function of the Ge concentration, but also a function of process temperature and time. The lattice mismatch results in the formation of misfit and associated threading dislocations which lead to the characteristic cross-hatch pattern typically seen on the strained Si epilayer surface.

An example of this cross-hatch pattern is shown in the AFM image of Figure 1a. (Scan range: $20 \mu\text{m} \times 20 \mu\text{m}$, topography scale: 30 nm). The scan is rotated by 45° with respect to the $\langle 110 \rangle$ directions of the pattern.

When performing a Raman analysis of this structure, the penetration depth of light into the structure has to be taken into account. For this excitation wavelength (532 nm), a penetration depth of 760 nm for pure silicon, and 540 nm for Si_{0.7}Ge_{0.3} can be calculated. Therefore, the main contribution comes from the Si substrate. This is clearly visible in Figure 1c, which shows a single Raman spectrum obtained at this structure. The three peaks corresponding to the SiGe layer: the Ge-Ge ($200\text{--}300 \text{ cm}^{-1}$), Si-Ge ($380\text{--}450 \text{ cm}^{-1}$) and Si-Si (502 cm^{-1}) stretching modes are indicated, along with

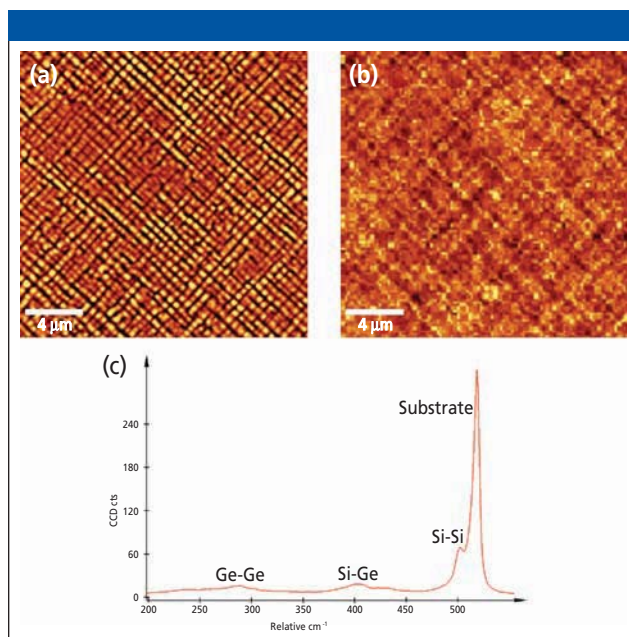


Figure 1: (a) AFM image of the cross hatch pattern of a Si/SiGe strained epitaxial film on silicon. (b) Raman shift of the Si-Si stretching mode of the SiGe layer at 502 cm^{-1} . (c) Single Raman spectrum.

the Si-Si (502 cm^{-1}) peak of the substrate. If the top silicon layer is to be analyzed, a shorter excitation wavelength with shallower penetration depth can be used.

The stress in the partially relaxed SiGe layer can be measured by analyzing the variation of the peak position of the Si-Si peak at 502 cm^{-1} , which is shown in Figure 1b. Scan range is $20 \mu\text{m} \times 20 \mu\text{m}$ with $100 \times 100 = 10,000$ spectra. The full range of the peak shift of the silicon Raman line is $\pm 1.5 \text{ cm}^{-1}$. From these values, a residual stress of up to 0.6 GPa in the SiGe layer can be calculated.

Conclusion

The results presented show that the combination of confocal Raman microscopy and AFM is a powerful tool for the characterization of stress in semiconductor materials. Even quantitative stress values can be calculated from the measured Raman data. Surface roughness and deformations of the silicon surface can be measured with an accuracy of 0.1 nm.

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