Strain characterization in SiGe epitaxial samples by Tip-Enhanced Raman Spectroscopy

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Introduction

The progressive downsizing of semiconductors is driving information processing technology into a broader spectrum of new applications and capabilities. Strained silicon has become one of the best solutions for integrated circuits thanks to the advantages in terms of miniaturization. Indeed, a biaxial tensile stress applied to the silicon in the channel region of a MOSFET increases the mobility of carriers. This stress can be imposed by doping the silicon underneath with germanium, causing a mismatch between the lattice constant, thus improving the electrons' mobility [1]. Over the years, there has been an increasing need, especially in the industrial sector, to develop faster and non-destructive characterization techniques to monitor strain during the manufacturing phases of semiconductor devices. Currently, Tip-Enhanced Raman Spectroscopy (TERS) is one of most powerful methods for strain characterization, as it is a non-contact and non-destructive technique with a lateral resolution of a few nanometers and the capability of analyzing and collecting signals from the most superficial layer of a sample. The enhanced field is strongly restricted to the surface plasmons region, just a few nanometers deep [2], thanks to the simultaneous use of a nanometric tip of an Atomic Force Microscope (AFM) and a laser from a Raman spectrometer (Figure 1) [3].

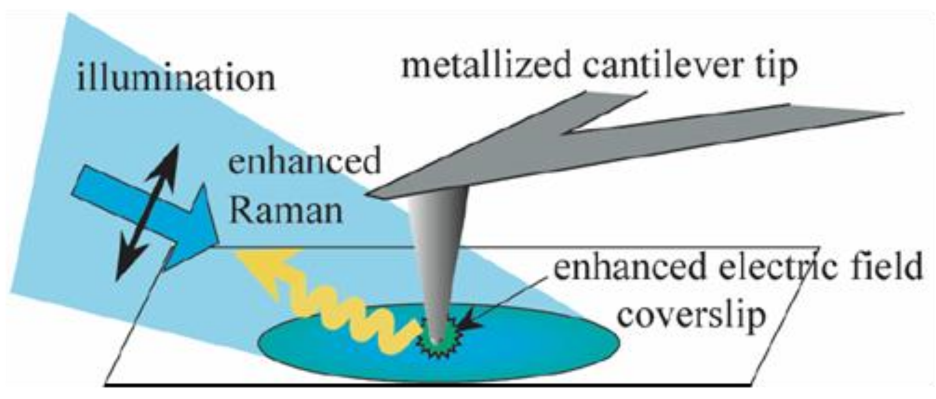


Figure 1. *Scheme of TERS configuration in Reflection Mode.*

Methodology

The analyzed sample was provided by CEA-Leti (Laboratoire d'électronique des technologies de l'information, Grenoble) and consists of a (001) silicon substrate where an epitaxial layer of $Si_{0.7}Ge_{0.3}$ (Figure 2a) with thickness of 17 *nm* (Figure 2b) is grown following several patterns.

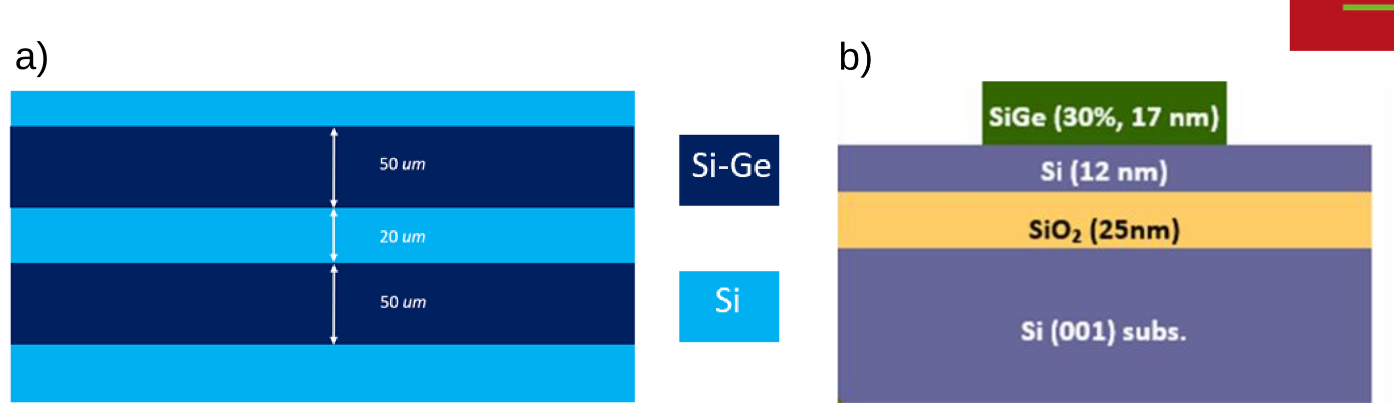


Figure 2. *(a) section and (b) top view of the analyzed sample.*

The AFM-TERS probe produced by ScanSens Gmbh is characterized by a coating in an innovative material which enables its implementation in the clean room for in-line characterization (Figure 3). TERS is used to map the variation in the position of the silicon peak in the local Raman spectrum (≈520.5 cm^{-1}) along the sample pattern in order to identify the strain profile with a resolution of a few nanometers.

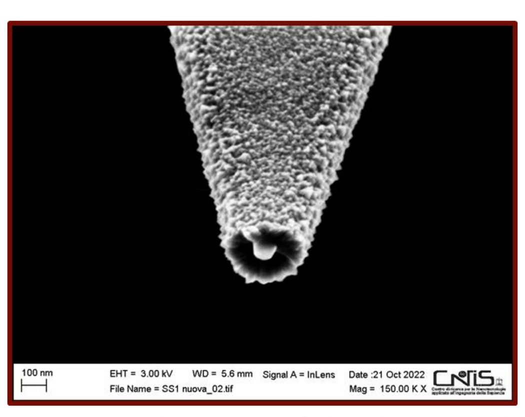


Figure 3. *SEM image of the* innovative TERS-tip.

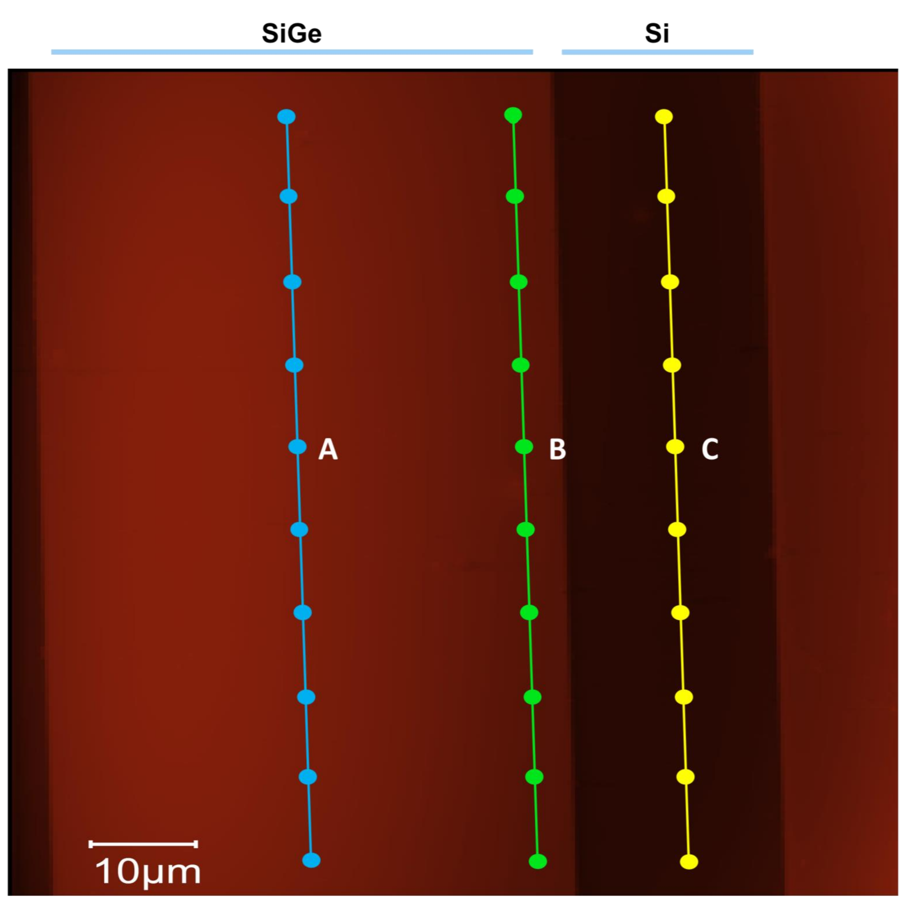
Instrumental setup

Tip-Enhanced Raman spectroscopy (TERS) characterization has been performed using a Renishaw confocal inVia™ Raman Spectrometer, with 250 *mm* focal length and a 50× magnification objective from Mitutoyo (NA = 0.42, M-PLAN, APO SL type, WD = 0.5 *mm*) coupled with a Bruker Atomic Force Microscope Innova™. The source is a Nd:YAG continuous-wave diode-pumped solid-state laser from Renishaw (λ = 532 *nm*, output power of 50 *mW*).

Figure 4. *AFM-Raman in TERS Setup.*

Contents and Results

All measurements were carried out by collecting the signal from different points along three vertical profiles. For each profile, 10 points spaced 10 *µm* were measured, for each of the following analysis parameters were used: 1s exposure time, 20 accumulations and all available laser power. As can easily be seen from Figure 5, the spectra acquired on each of the three vertical profiles show clear differences between them, displaying both the signal coming from the strained and unstrained Si, but with different characteristics. On the contrary, along the same vertical profile, the spectra do not show great variations and remain, within the limit of small variations, very constant.



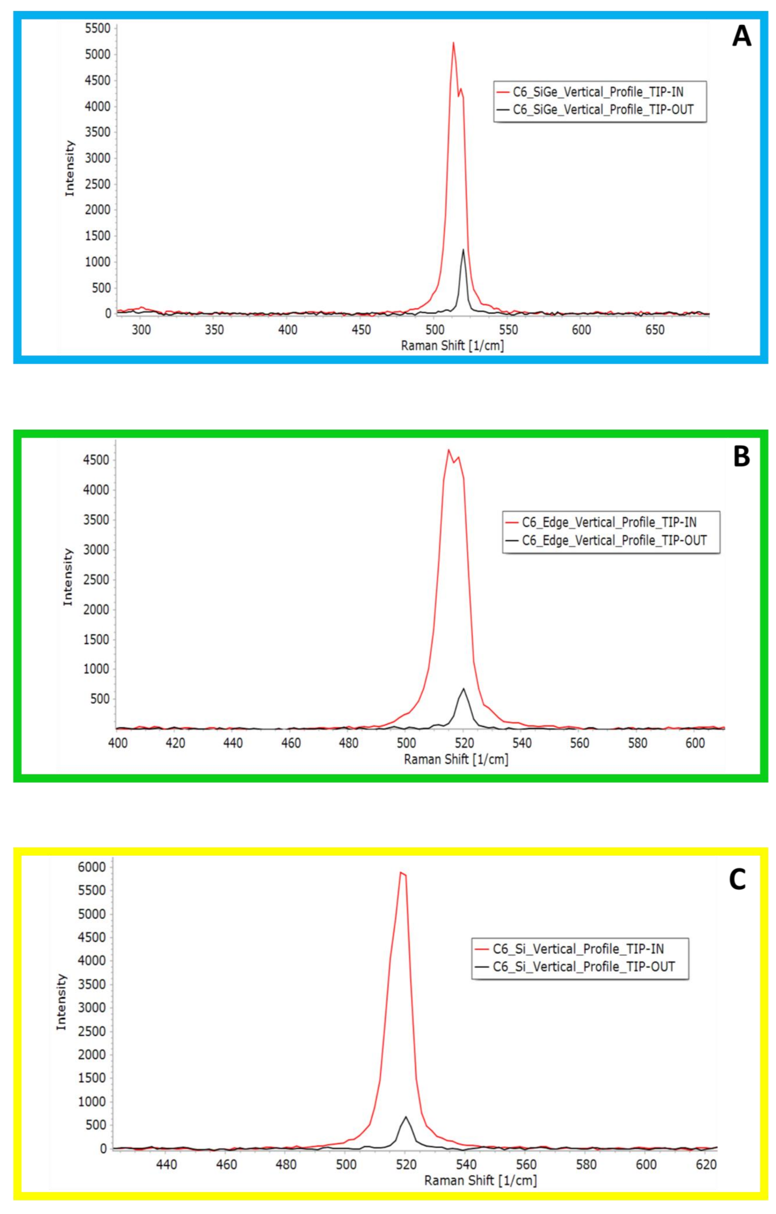


Figure 5. *The figure on the left shows the AFM topography with a 100x100 um dimension on a sample section with alternating SiGe and Si lines, and the the three vertical profiles; the three panels on the right illustrate a significant spectrum of three points collected from each different vertical profile (the first from the SiGe line, the second near the edge, the third from the Si line).*

From each of the spectra obtained as a result, through the calculation of the Δω (difference of the shift between the position of the unstrained peak and the strained one) and the known germanium concentration, the in-plane strain is calculated along the different sections following the models presented in the literature [4].

Conclusions

The results confirm how TERS represents a powerful tool for monitoring strain levels along SiGe epitaxial samples, enabling the technique to be introduced as an in-line control tool for the semiconductor industry, given its high resolution among the different Raman spectroscopic techniques and its non-destructive nature.

References

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