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Princeton Instruments

Raman on SiGe Superlattice using TriVista

$Si\text{-}Si_xGe_{1\text{-}x}$ superlattices are usually grown in Chemical Vapor Deposition (CVD) or Physical Vapor Deposition (PVD) process by depositing nanometer-thick alternating layers of pure Si and $Si_xGe_{1\text{-}x}$ alloy on top of the silicon substrate. Uniformity of layer thickness is a critical parameter governing the unique superlattice properties, crucial in the development of microelectronic and optoelectronic devices as well as low –dimensional thermoelectric and thermionic devices. Available structural characterization methods include TEM, STM, XRD and Raman. The latter was found to be the most suitable for the express-analysis of the $Si\text{-}Si_xGe_{1\text{-}x}$ structural quality in laboratory environment because of less sample preparation required and lower equipment cost.

Light scattering on the $Si\text{-}Si_xGe_{1\text{-}x}$ superlattice results in series of peaks in low-frequency domain of Raman spectrum related to the Folded Acoustic (FA) phonons. Damping of the higher order FA modes can be used for structural quality control of $Si\text{-}Si_xGe_{1\text{-}x}$ superlattices.

Experimental Setup

The TriVista 555 - triple Raman spectrograph from Princeton Instruments, consisting of three 500 mm focal length stages (Figure 1) was used for effective excitation line rejection. Since the FA modes of $Si\text{-}Si_xGe_{1\text{-}x}$ superlattices are in the low-frequency spectral range of typically 0-100 cm^{-1}, it is impossible to use a notch filter for excitation line rejection. The TriVista was used in subtractive mode where the first two stages were limiting the spectral bandpass and rejecting the excitation line, while the third stage was performing signal dispersion.

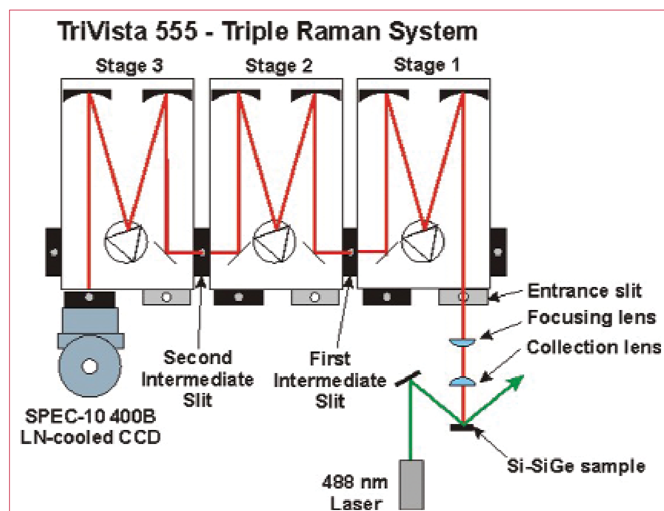

Figure 1: Schematic drawing of the Raman experimental setup

Sample excitation was done by 488 nm Ar-ion 60mW laser under inert gas flow to prevent superposition of low-frequency Raman modes from the air. The first stage entrance slit of TriVista was opened to 30 µm to ensure the sharpest resolution of Raman peaks. The first intermediate slit between the first and the second stages was opened to a few mm allowing a certain spectral bandpass through but rejecting the excitation line, while the second intermediate slit between the second and the third stages was also set to 30 µm to reject as much residual stray light as possible. Ruled gratings were used (900 g/mm blazed at 550nm) on the first and the second stages and a holographic grating (1800 g/mm) optimized for the visible region was used on the third stage.

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Experiments were performed using a SPEC-10: 400B LN back-illuminated CCD detector from Princeton Instruments which consists of a 1340×400 pixel array with 20×20 μm pixels. The CCD was cooled with liquid nitrogen down to -120ºC to minimize the dark charge. The spectra were fully vertically binned in order to maximize the sensitivity, and all spectra were taken with 60 s exposure and 10 accumulations.

Experimental Results

A Raman spectrum of Si-$Si_{0.25}Ge_{0.75}$ superlattice with thickness of Si layer d_{Si} = 13.5 nm and thickness of $Si_{0.25}Ge_{0.75}$ layer d_{SiGe} = 3.9 nm in the Stokes range 5-600 cm^{-1} was obtained. The high-frequency portion 80-600 cm^{-1} of this spectrum can be seen in Figure 2. The four Raman peaks present are related to the Si-Si vibration modes in the substrate and superlattice, as well as Si-Ge and Ge-Ge phonons. Identification of Raman peaks was done by comparison with the Raman spectra from the literature obtained for various SiGe alloys (Figure 3).

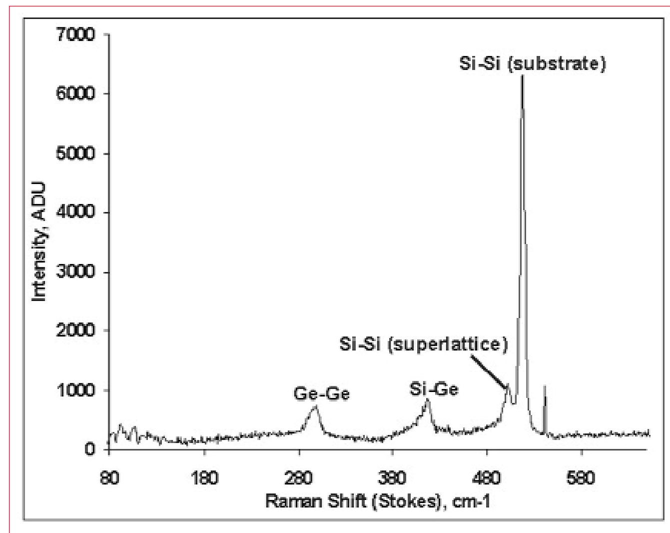

Figure 2: High-frequency portion of measured Raman spectrum of Si-$Si_{0.25}Ge_{0.75}$ superlattice.

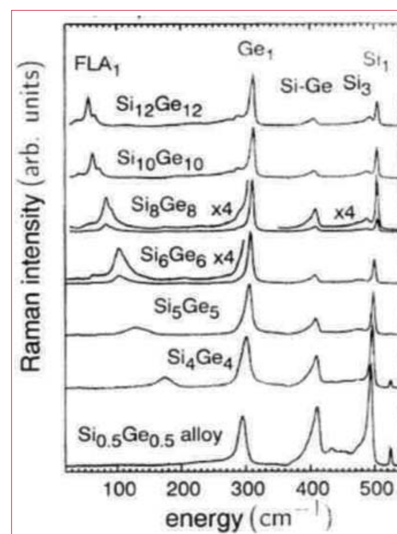

Figure 3: Raman scattering of SiGe alloys. Courtesy of Abstreiter et. al., Physical Review B, V.50, N.24, pp.211-218, 1994

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The low-frequency 5-70 cm^{-1} portion of the Raman spectrum which demonstrates the doublets of Folded Acoustic modes can be seen in Figure 4. The exact position of the doublets is determined by the thickness of superlattice individual layers. The S_{+1} mode of the first doublet as well as both S_{-2} and S_{+2} modes of the second doublet were resolved very well with a signal to noise ratio over 5 and with comparable intensity levels. The third and the forth doublets intensities decreased gradually until finally the S_{+4} mode was practically indistinguishable from the noise level. This was to be expected, as the higher order FA phonons intensity is sensitive to the superlattice quality.

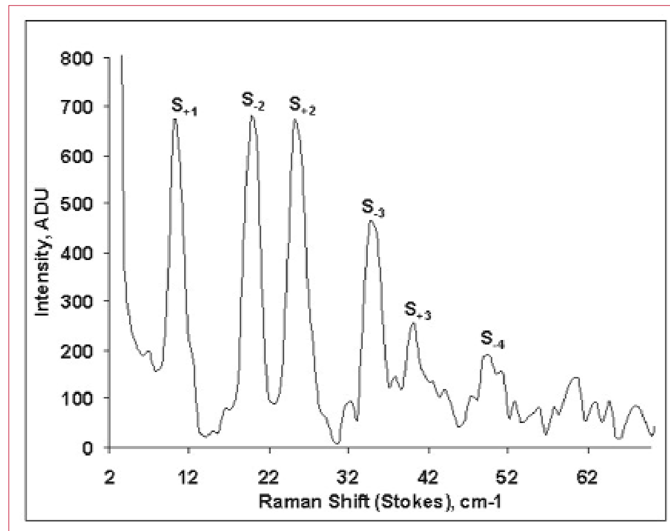

Figure 4: Low-frequency portion of measured Raman spectrum demonstrating FA modes of Si-$Si_{0.25}Ge_{0.75}$ superlattice. The sample is a courtesy of Dr. B. Kamenev from Department of Electrical and Computer Engineering, New Jersey Institute of Technology

Conclusion

The experimental results show that the TriVista Raman system is an excellent tool for measurin glow-frequency Raman spectra of semiconductor superlattices down to 5 cm^{-1}. The exceptiona stray light rejection capabilities of the spectrograph coupled with the low noise performance of the deep-cooled CCD, offers a high S/N ratio for Raman spectra of even the most difficult samples.

Besides its primary usage as a Raman system in Subtractive mode, the TriVista is also capable of switching to Additive mode, simply by changing the software settings. The Additive mode adds together the linear dispersion of all 3 stages so that one can achieve a very high resolution, in order to analyze individual peak shapes and other narrow spectral features.

Through simple software selection, the first two stages of the TriVista can also work as a double monochromator and the third stage as a single spectrograph, giving the ultimate experimental flexibility. In this configuration, the TriVista can be used for photoluminescence and fluorescence applications, where the double spectrograph acts as a tunable excitation source and the single spectrograph is used to disperse the emission signal.

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