Application of Raman Spectroscopy for Local Stress Methodology and Characterization of Amorphous Carbon and SiGe Films in Semiconductor Process Development

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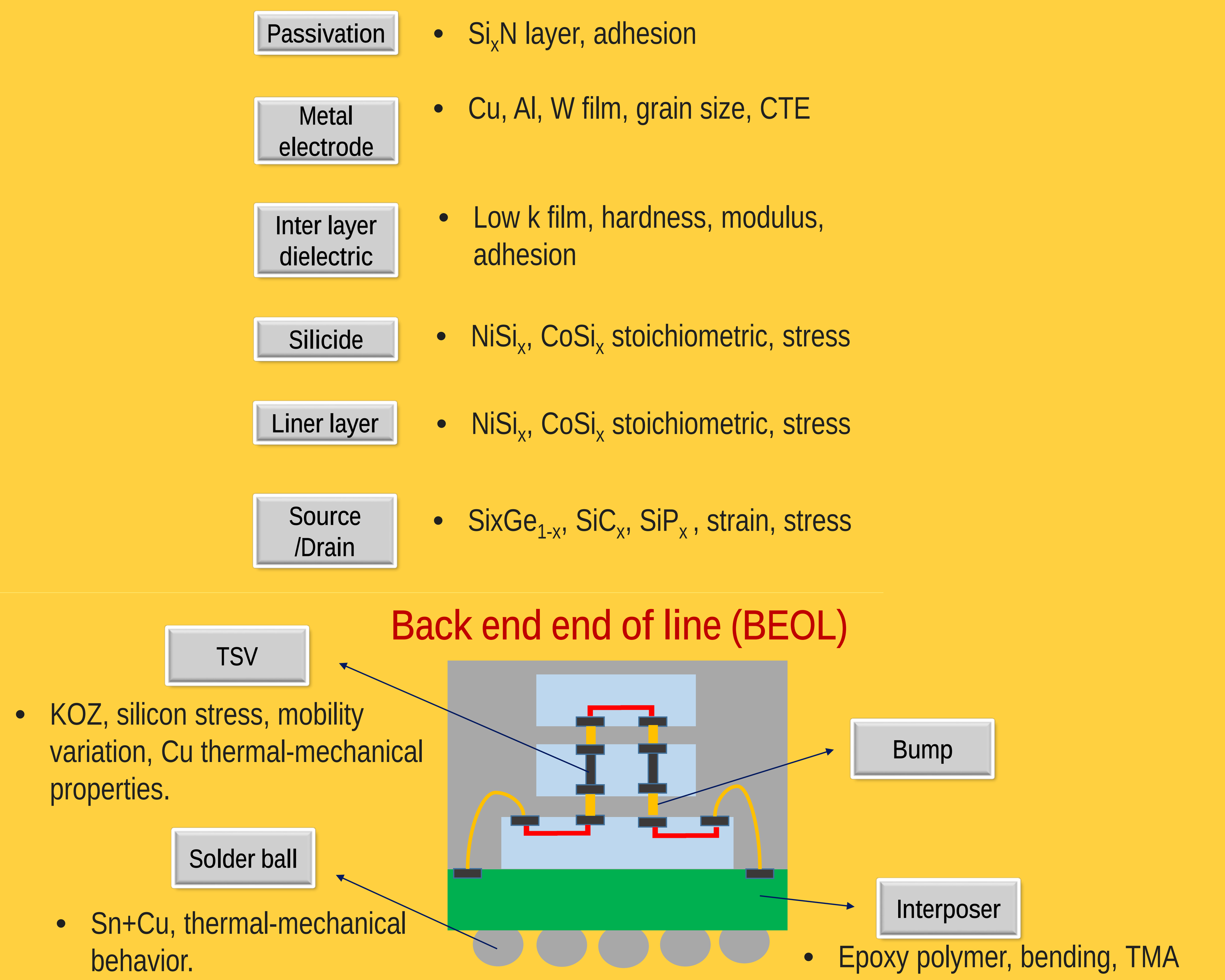
Introduction

Silicon complementary metal-oxide-semiconductor (CMOS) devices have been continuously scaled down to the 10 nm logic industry technology node defined by the international technology roadmap for semiconductors (ITRS). However the industry is facing more technical challenges.

Micro Raman spectroscopy can be effectively measured as the process control of semiconductor device materials. Due to small beam size, the light is penetrated into active silicon area on patterned wafer, and then scattered Raman signal gives a stress state information. Also, it has been effectively used for characterization of composition analysis on unknown thin film. In Raman spectroscopy, non-contact optical metrology offers a fast and cost saving monitoring of dielectrics in IC manufacturing process.

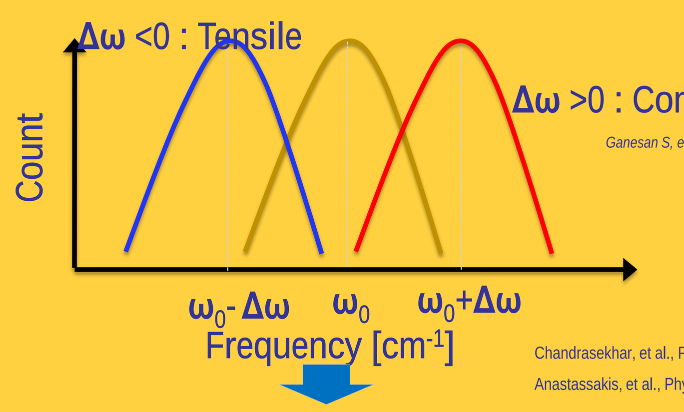
Stress issue and materials characterization



Converted stress of Raman frequency changing

▪ Mechanical strain or stress may affect the frequency of the Raman modes

• Stress free silicon exhibits a sharp and strong Raman peak at 520.3 cm^{-1}



Ganesan S, et.,al., 1970 Ann. Phys. 56 556–94

Chandrasekhar, et al., Phys. Rev. B 17, 1623–1633 (1978)

Anastassakis, et al., Phys. Rev. B 41, 7529–7535 (1990)

Converts Raman peak shift to Stress

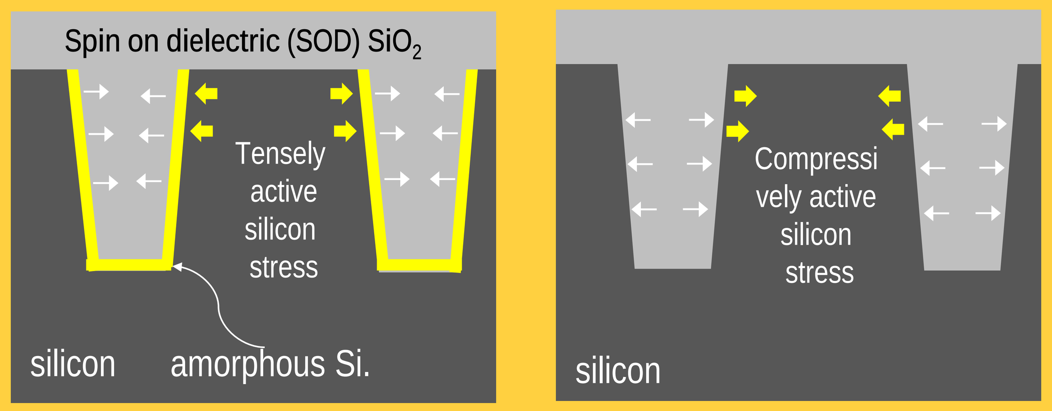
In plan Stress($\sigma_r + \sigma_\theta$) =(470MPa/cm^{-1}) X Δω

Methodology of stress measurement around active silicon

The stress in the active area influences the structural shape made in the area and the performance of the device. And, as the pattern size in semiconductor devices reduces, the control of the stress applied to active area in "STI structure" is needed. Furthermore, accurately understanding the stress components that applies on the active area is becoming important in the device manufacturing process.

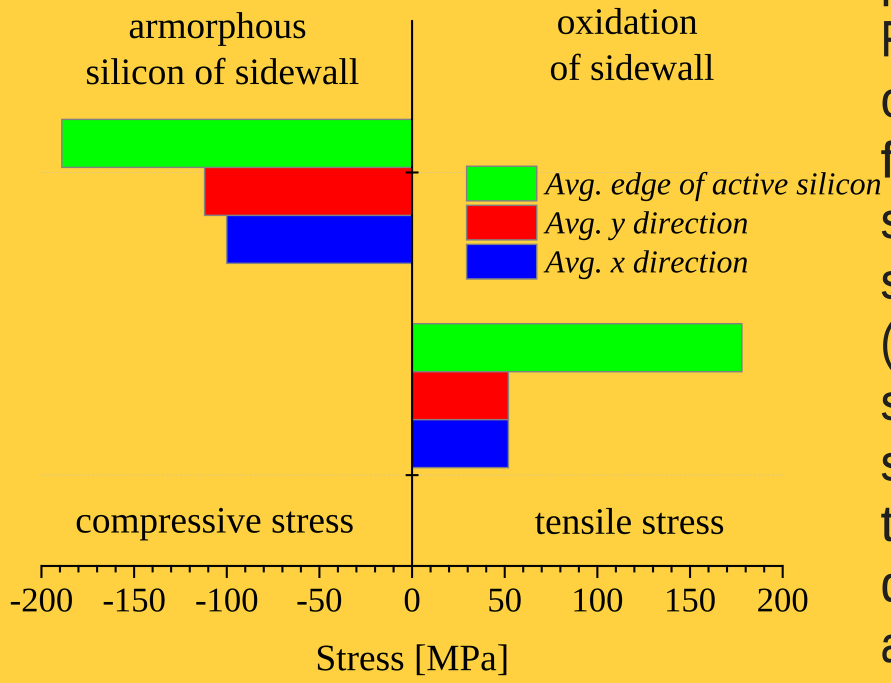
Schematic diagrams on a cross section image of the shallow trench isolation is fabricated on the silicon wafer. The stress state in Si is expected to be different after the oxidation and/or amorphous silicon deposition processing of the side walls in silicon structure.

Deposited amorphous Si of side wall | *Oxidation of side wall*



The spin-on dielectric (SOD) material of gap-filled isolation can contract significantly upon thermal annealing.

Converted stress from the Raman frequency change as a function of the position on the active silicon area



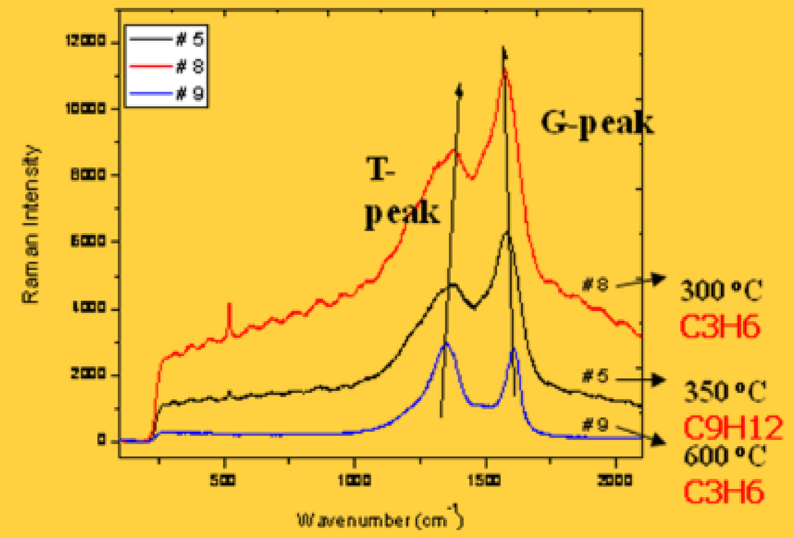
The Raman can be effectively used to characterize the local mechanical stresses in the trench structures as a function of the processing parameters.

Raman spectroscopy will be a measure of the out-of plane stress, where a positive shift in frequency is translated into a tensile stress state. Specimens with the oxidation sample of sidewall have out-of plane compressive stress (negative shift) within the measured active silicon area. Deposited amorphous silicon sample of side wall showed tensile stress in the measured area, where as the volume of deposited amorphous silicon to active silicon almost increased twice as much.

Raman frequency of amorphous carbon layer

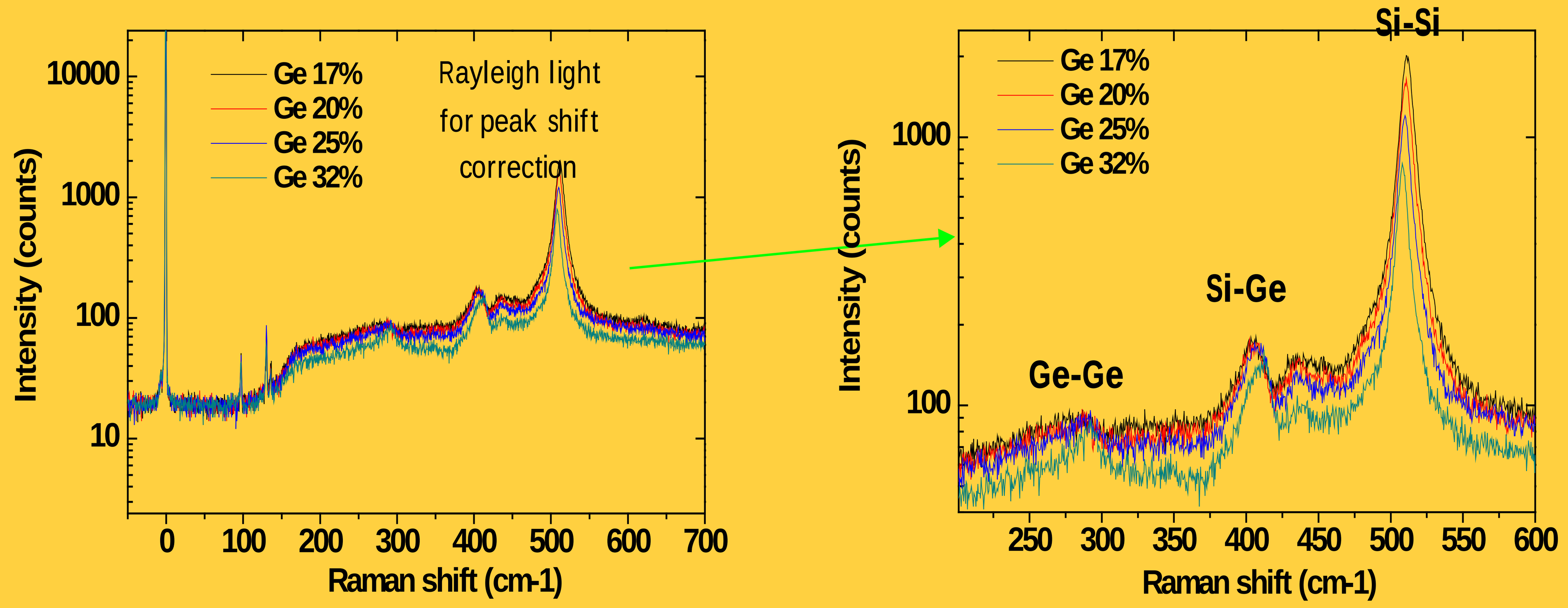
Carbon materials in semiconductor processes are applied to the passivation layer. Gate etching processes rely on the formation of a thin diamond like a carbon layer on the feature sidewalls to achieve profile control. The final gate profile results from competition between lateral etch rate and deposition rate and vertical etch rate.

For carbon films, the Raman spectrum of G band usually occurs between 1480 and 1580cm^{-1}, while the D band position appears between 1320 and 1440. Figure 3 shows that the G band position changes depending on the type of source and deposition temperature gas. In order to obtain DLC film, it requires a C_3H_6 gas and a deposition temperature of 300 degrees. It was possible to obtain the proper gate sidewall profile after etch process.



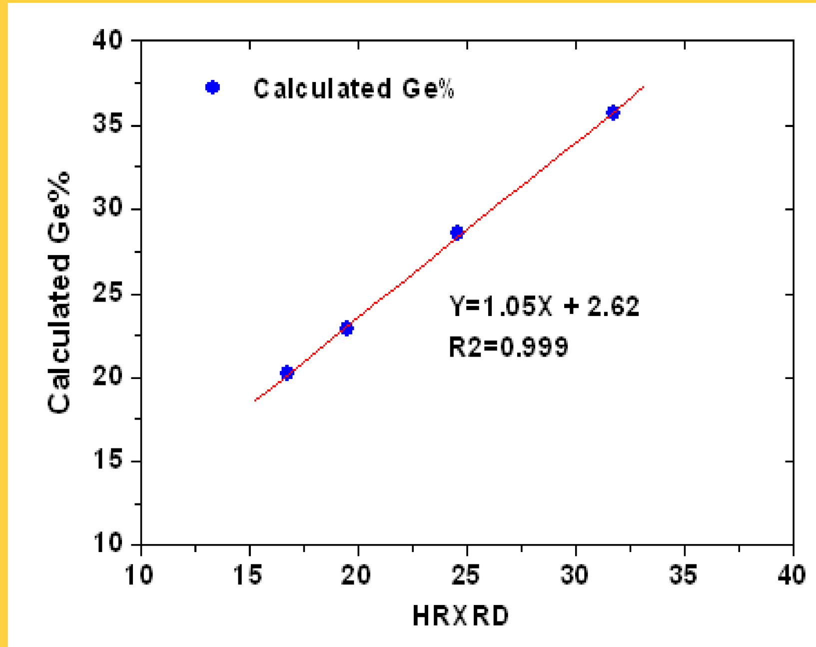
Raman frequency of SiGe layer

Recently, Raman spectroscopy is used to probe the lateral strain in the under layer SiGe of stained Si on $Si_{1-x}Ge_x$ substrate structures. It is found that there are clear differences on Raman spectrum of silicon germanium between samples.



Especially, for Si-Si band in SiGe (Band 1), all spectral parameters (Peak shift, Amplitude, Width) changed in each samples. Raman spectroscopy has a possibility to monitor Ge concentration and the degree of relaxation of SiGe layer in the manufacturing process.

Ge concentration calculated from measurement results (average) and above formulas.



Deconvolution of the SiGe bands is more difficult due to signal intensity, asymmetrical shape of the SiGe bands, and presence of amorphous forms spectra overlapping. Also, the formula used to calculate Ge% are empirical formulas determined by Tsang et al. in 1993 based on a set of samples of thick SiGe layers and poorer quality crystals than the ones measured here. Degree of relaxation in the SiGe layer, and Ge content are defined by the relationship.

$$\omega_{SiSi} = 520.5 - 62x - 815\varepsilon$$

$$\omega_{SiGe} = 400.5 + 14.2x - 575\varepsilon$$

The coefficients in formulas should be easily determined based on reference data of Ge concentration for each sample.

Summary

Micro Raman spectroscopy can be effectively measured as the process control of semiconductor device materials. Due to small beam size, the light is penetrated into active silicon area on patterned wafer, and then scattered Raman signal give a stress state information. Also, it have effectively used for characterization of composition analysis on unknown thin film. In Raman spectroscopy, non-contact optical metrology offers a fast and cost saving monitoring of dielectrics in IC manufacturing process.

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