RAMAN MICROSCOPY IN CHARACTERIZATION OF Si DEVICES

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Abstract: Micro-Raman spectroscopy (*m*RS) is a very useful technique that can be used to study a variety of problems related to Si device fabrication. It provides unique information complementary to those achievable using the conventional techniques, such as FPP (four point probe), TEM, AFM, SEM and XRD. In this paper, several important applications of *m*RS in the study of silicides and SiGe are described, including phase identification of the technologically important titanium, cobalt and nickel silicides; thickness measurement of ultra-thin silicide films and Raman imaging of the NiSi film/Si substrate interface.

Silicon based IC fabrication has reached such a high level of complexity that it involves hundreds of processes. To ensure the highest possible yield, every process has to be vigorously tested and controlled. On-line, real-time and non-destructive characterization techniques are crucially important in the quest to develop new materials and devices. Compared with other traditional characterization techniques, *m*RS possesses a number of advantages such as fast and real-time, non-contact and non-destructive, no special sample preparation, easy in-situ or ex-situ observation a high spatial resolution of about 0.5 *m*m. In this paper, we present some applications of *m*RS in the study of salicide thin films for Si device fabrication, including phase formation identification, ultra-thin film thickness measurement and Raman imaging of film/substrate interface, local orientation characterization and stress mapping.

Phase identification and transformation: Silicides ($TiSi_2$, $CoSi_2$, NiSi) play an important role in high-speed CMOS technology by decreasing RC delay time of circuits and increasing performance speed as a result of reduction in resistance in the silicon gate and source/drain regions. $TiSi_2$ has three crystallographic phases, C49, C54 and C40, where only the low-resistivity C54 phase is useful. However, C54 formation shows a strong dependence on the $TiSi_2$ linewidth that limits the application of $TiSi_2$ to sub-quarter micron devices. Several alternative materials have been extensively studied in an attempt to replace $TiSi_2$. Among them, $CoSi_2$ is the most successful one that has already been applied for 0.18 *m*m technology and below. NiSi is another promising candidate which will be used for Si device fabrication in 2-3 years time. Phase identification is normally done using four-point probe (FPP). But this method becomes troublesome and inaccurate for device samples. Raman spectra good enough for phase identification of the three $TiSi_2$ phases C49, C54 and C40 can be recorded with 30 s integration time and 5 mW laser power. μRS has also been used to characterize Co and Ni silicides and study the phase transitions induced by thermal annealing.

Film thickness: Cross-section transmission electron microscopy (XTEM) provides an accurate thickness measurement of ultra-thin films and observation of interface roughness. However it requires extensive sample preparation and it is destructive. FPP is the simplest and most commonly used method. But it does not work well with ultra thin samples, since the probes can easily prick through and damage the film. Here we show that micro-Raman spectroscopy can be used to give an accurate measurement of film thickness using the Si substrate Raman peak at 520 cm^{-1}. Fig. 1 gives an illustrative diagram explaining the principle of thickness measurement using the Si Raman peak. The laser impinged on the sample surface shows exponential attenuation with the silicide film thickness following Beer Law, and the Raman signal of the Si substrate is again attenuated by the same layer. The attenuation is related to both the thickness and the absorption coefficient of the film. Fig. 2 shows the Si Raman peak attenuation for a series of NiSi samples on Si substrate, which clearly represents that thinner samples give rise to stronger Si Raman peaks. The sample thickness determined by ln (I/I_0) is listed in the insert figure, which demonstrates that the film thickness is proportional to the natural logarithm of the relative intensity of Si Raman peak. Samples with only 4 nm thick nickel film can be determined accurately.

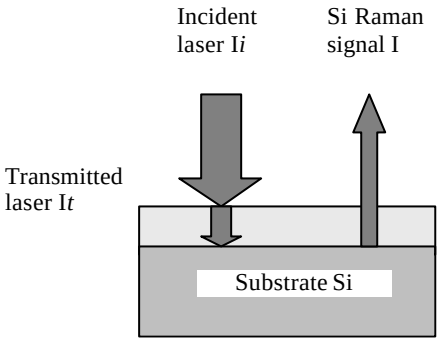

Fig. 1. Schematic diagram illustrating film thickness measurement by μRS. Both the laser and Raman signal are exponentially attenuated by the thin film.

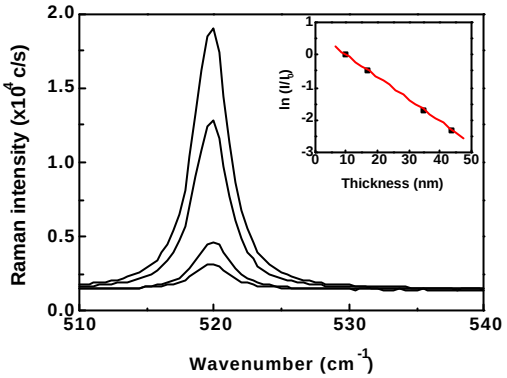

Fig. 2. Si Raman peak at 520 cm^{-1} attenuated by NiSi films. The insert shows the calculated NiSi film thickness.

Interface roughness: NiSi has a very smooth surface as determined by AFM. However the NiSi/Si interface is normally rough, severely limits its potential applications. Uniformity of salicide film can also be determined by the Si Raman peak at 520 cm^{-1} using the same principal as described above. Due to the exponential decay of the Si Raman signal, a small change in the film thickness results in a larger change in the Si Raman peak. Hence the Raman technique is intrinsically sensitive and accurate. Fig. 3 shows the Raman images of a NiSi film. The image on the left is plotted using the Raman peak of NiSi at 214 cm^{-1} and that on the right is generated by the Si substrate Raman peak at 520 cm^{-1}. The correspondence of the two images are clearly shown.

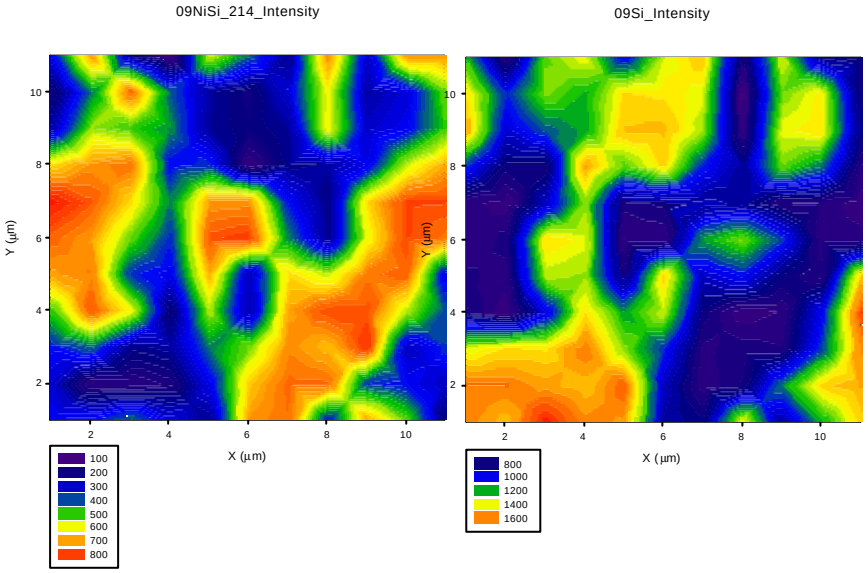

Fig. 3. Raman images showing the NiSi/Si interface roughness. Left: Image using the NiSi peak at 214 cm^{-1}. Right: Image using the Si substrate peak at 520 cm^{-1}.

Grain orientation and stress measurement: Transport properties are strongly related to the microstructure and local orientation. μRS has been successfully applied to characterize epitaxy degree of thin films. In this technique, polarized laser is used to interact with thin films and the interaction depends on the relative orientation between the polarization direction of the laser and the crystallographic axis orientations of the film, which can be employed to provide quantitative analysis of the epitaxy degree of the films on the sub-μm scale (the size of the laser spot on the sample).

Utilizing the Raman peak of Si substrate, μRS has been successfully used as a non-destructive tool for stress determination in Si devices. We have carried out Raman mapping of a Si device using an Ar^+ laser at 488 nm combined with a mapping stage. The device consists of poly-Si lines of 0.2-10 μm wide separated by 10 μm SiO_2 spacers. The Si Raman peak shift can be directly related to stress in the Si lines. Stress on lines as narrow as 0.2 μm can be measured even though the focus of the laser is ~0.5 μm.