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# Polarized Raman study of mechanical stress distribution in W/TiN metal gate MOSFETs

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## 1. Introduction

Control of the mechanical stress in Si transistors is one of the key issues to improve device performances, since the stress in the device areas strongly affects the electronic properties. Therefore it is important to measure the local stress distribution in channel and source/drain (S/D) regions in MOSFET structures.

Raman spectroscopy is one of the powerful techniques to measure the local stress of Si [1-7]. However, in poly-Si gate MOSFETs, the Raman signals from the poly-Si gate and S/D regions are overlapped, making it difficult to analyze the stress distribution in the S/D regions near the gate.

In metal gate MOSFETs, the Raman signals of Si do not overlap with those of the metal gates, allowing us to analyze the stress distribution in the S/D regions near the metal gate in detail.

In this work, we have studied the stress distribution in the S/D regions near the metal gate using polarized UV Raman micro-spectroscopy techniques in W/TiN gate MOSFETs.

## 2. Experimental

The sample structure used in the present work is illustrated in Fig.1. SiN/W/TiN/HfSiON/$SiO_2$ gate stacks were fabricated on 300 mm Si wafers with shallow trench isolations. The thicknesses of the SiN, W, and TiN layers were 50 nm, 70 nm, and 10 nm, respectively. The distance between the gate edge and the STI was 3 μm. The tungsten gate electrodes were deposited with either physical vapor deposition (PVD-W) or chemical vapor deposition (CVD-W). The PVD-W film had compressive stress and the CVD-W film had tensile stress, which was determined by wafer bending measurements.

Polarized Raman measurements were performed using a UV confocal Raman microscope (Nanofinder 30, Tokyo Instruments) equipped with an Olympus 1.3 numerical aperture (×100) oil immersion micro-objective lens with *aa*- (both the polarization directions of excitation and detection light are perpendicular to the side wall of the gate electrode) or *cc*- (both the polarization directions of excitation and detection light are parallel to the side wall of the gate electrode) configuration. The excitation wavelength was 364 nm. The diameter of the probed area was about 150 nm. The peak positions of the measured spectra were determined by Lorentz curve fittings.

## 3. Results and Discussion

We measured the Raman spectra of Si near the gate edges for the PVD-W. The gate length was 600 nm. The spatial variation of the Raman shifts along line A is plotted as a function of the probe position measured with the *aa*- (△) and *cc*-configurations (○) in Fig.2. The peak position of the unstrained Si is ~520.5 $cm^{-1}$. As seen, the Raman shifts increase as the probe positions come closer to the gate edge. This means that the PVD-W gate had compressive stress, and induced the compressive stress in the S/D regions near the gate edge, which is consistent with the result of the wafer bending measurement. However, the Raman shift for *cc*-configuration is much smaller than that for *aa*-configuration near the gate.

To investigate this polarization effect on the Raman spectra, we made the finite difference time domain (FDTD) simulation (Oscillated Recall Technology, Nessie) of the 364 nm light intensity distribution around the tungsten stripe ($n$=3.39, $k$=2.66, 100 nm wide and 100 nm high) on the Si layer ($n$=6.52 , $k$=2.71 ). The structure was immersed into the medium with $n$=1.5 and $k$=0. A plane wave light source (100 nm wide) is placed right above the tungsten top by 100 nm. The *a*-polarization is perpendicular to the side wall of the gate and *c*-polarization is parallel to the side wall of the gate.

Figure 3 shows the 2D maps of the light intensity calculated with the FDTD simulations for the light sources of *a*- and *c*-polarizations. As seen, the light intensity for the *c*-polarization is very week near the bottom corner of the tungsten stripe, in contrast to that for the *a*-polarization.

To see it in more detail, the 1D distributions of the light intensities at 5 nm below the Si top surface are plotted for *a*- (●) and *c*-polarization (▲) light sources in Fig.4. The ratios of the light intensity for *a*-polarization to that for *c*-polarization (○) are also plotted. The intensity for the *c*-polarization decreases as the probe point approaches the tungsten stripe, while the *a*-polarization intensity increases. This indicates that the signals from the S/D regions near the metal gate contribute little to the Raman spectra measured with the *cc*-configuration since the excitation light intensity is very weak near the gate. Thus, the experimental result that the positive Raman shift for the *aa*-configuration is much larger than that for the *cc*-configuration means that the compressive stress is localized very close to the gate edge.

Note that the intensity difference between the *a*- and *c*-

polarizations becomes significant when the distance from the tungsten edge is within ~50 nm, i.e. approximately half the electrode height. This indicates that we can analyze the stress distribution within an area narrower than the probe diameter by comparing the Raman spectra measured with *aa*- and *cc*-configurations.

Next we measured the spatial variation of the Raman shifts for the CVD-W gate sample with the *aa*-(▲) and *cc*-(●) polarization configurations (Fig.2). The peak positions near the gate are lower than 520.5 $cm^{-1}$, which shows that the CVD-W gate had tensile stress, exerting a tensile stress in the S/D regions near the gate. Here again, the Raman shift for *cc*-configuration is much smaller than that for *aa*-configuration near the gate, indicating that the tensile stress is localized very close to the gate edge.

## 4. Conclusions

We have studied the stress distribution in the S/D region in the vicinity of the W/TiN metal gate using polarized Raman spectroscopy technique. We observed the compressive stress was induced in the S/D region by PVD-W gate and the tensile stress induced by the CVD-W gate. The FDTD simulations indicate that the signal from the S/D regions near the gate contributes little to the Raman spectra measured with the *c*-polarization while it is enhanced for the *a*-polarization. Thus, we can analyze the stress distribution in detail by comparing the Raman spectra measured with *aa*- and *cc*-configurations with even higher spatial resolution than the diffraction limit of the excitation probe.

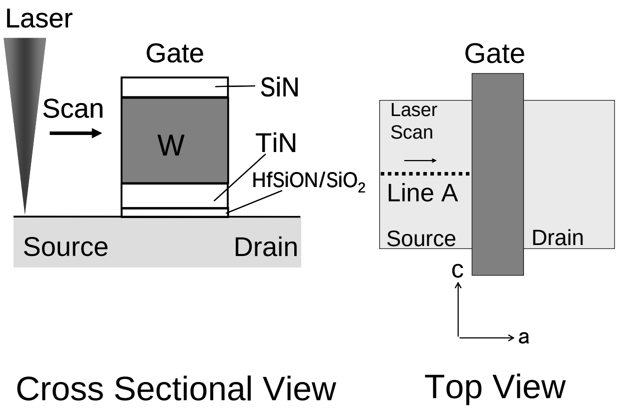


Fig.1 The sample structure used in the present work

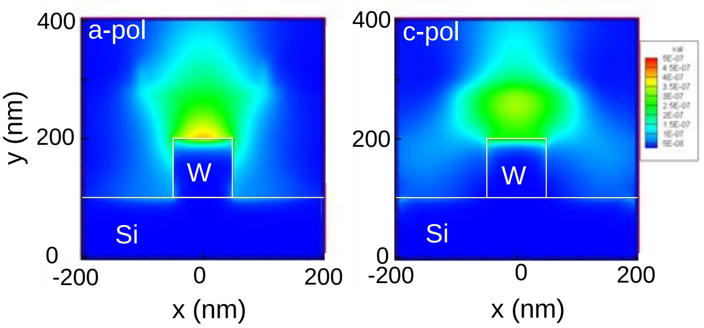


Fig.3 2D maps of the light intensity calculated with the FDTD simulations for the light sources of *a*-polarization and *c*-polarization.


## Acknowledgements

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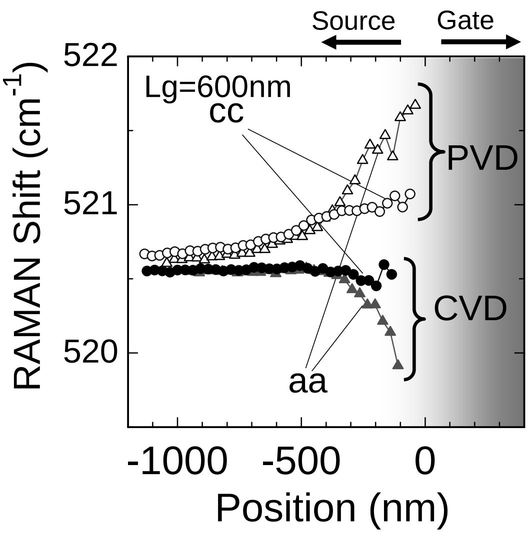


Fig.2 The spatial variation of the Raman shifts along line A in the S/D regions for PVD-W and CVD-W gates samples.

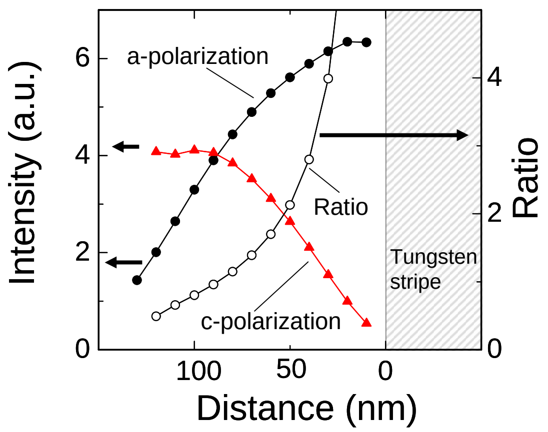


Fig.4 The light intensities at 5 nm below the Si channel surface for *a*- (●) and *c*-polarization (▲) light sources, and the ratios of the light intensity for *a*-polarization to that for *c*-polarization (○) are plotted as a function of the probe distance from the gate edge.