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Micro Area Stress around Trench Structure

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Stress analysis in a sub-micron area around trenches filled with poly-Si and/or SiO_2 was performed by a combination of computer simulation and Raman measurement. The local stress distribution was found strongly depending on their geometry, such as line and space ratio and the radius of curvature for the trench bottom, and also depending on the material filled with. Here suggests an appropriate structure for reducing process-induced crystal defects.

1.INTRODUCTION

Local stress concentration, induced during device processing in non-planar geometry, such as a trench capacitor, trench isolation or LOCOS isolation, has become a serious problem which influences device performance for sub-micron VLSIs. These stresses, which will induce crystal defects, are mainly caused by difference in thermal expansion coefficients between silicon and silicon dioxide during thermal processes for a device fabrication. Raman microprobe technique was used to measure actual local stress in V grooves with 1 um spatial resolution, while stress simulation was used to estimate fine distribution of stress in the sub-micron region.[1] The combination of these techniques made it possible to evaluate the stress distribution in sub-micron geometry.

Extending the above techniques to the trench structure, we made it clear how the local stress distribution around it depends on its geometry and materials filled with. Suggestions based on sub-micron stress analysis are useful to design an appropriate trench structure for reducing process-induced defects.

2.EXPERIMENTS

Local thermal stresses around trench in a silicon wafer were computed by the finite element method program MARC (Nippon-MARC Co.), which has been frequently used in a structural analysis. The stress field was assumed to be elastic under a generalized plane strain state.

Sample preparation was as follows. Trenches on the (100) silicon wafer surface were made by the reactive ion etching technique. Etched silicon surface was oxidized to 1000 Å thick in dry O_2 at 950 °C. Then poly-Si or SiO_2 layer about 1.2 μm thick were deposited by the chemical vapor deposition (CVD) technique at 630 and 730 °C, respectively.

A Raman spectrometer (JEOL TRS-400T) equipped with a microscope was employed to measure local stresses in a silicon wafer. Raman spectra were measured on the (011)

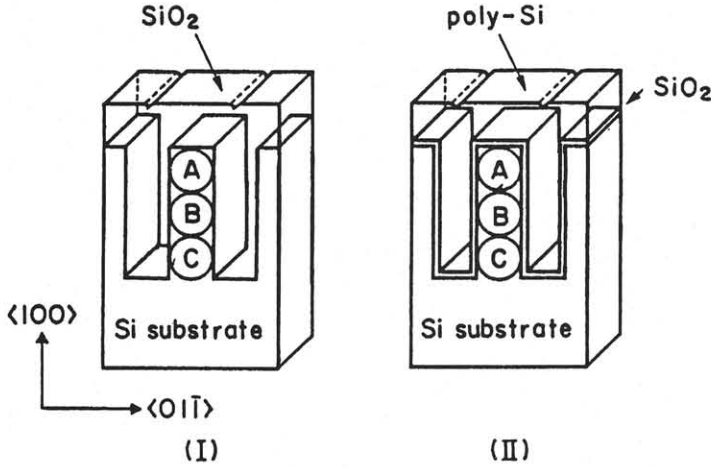

Fig.1 Sectional view of two kinds of samples.

plane cleaved carefully, so as not to induce additional stress, as shown in Fig.1. Stress was determined from the observed Raman shift using the equation derived by Englert et al.[2] The details are shown elsewhere[1].

3.RESULTS AND DISCUSSION

3-1 Stress distribution and trench geometry

Figure 2 shows shear stress simulation around trench filled with CVD-SiO_2 (Structure I). At process temperature, zero stress is assumed in the silicon wafer. When the wafer was cooled from deposition temperature to room temperature, stress was due to the difference of thermal expansion coefficients between silicon and silicon dioxide. It depends strongly on a space of trench to trench, when their line width was kept constant. The stress concentration along the trench side wall increases greatly as the trench space becomes less than the trench width. On the other hand, when the trench width was changed from 1.5 to 0.5 μm under a constant line and space ratio (1:1) for trenches, the maximum stress along the trench side wall was almost constant. It is considered that maximum stress around the trench structure was determined by the thermal properties and the volume of silicon dioxide to silicon substrate. Stress value decreased as a function of distance from the side wall.

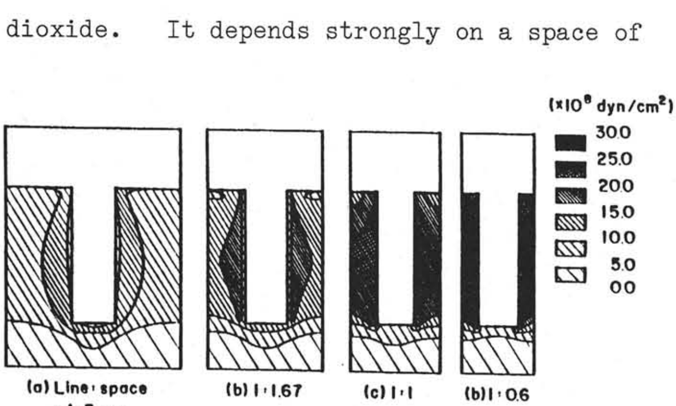

Fig.2 Shear stress distribution when trench space was changed keeping line width constant.

Figure 3 shows shear stress distribution at changing a film thickness of thermal silicon dioxide inside the trench filled with poly-Si (Structure II). Structure II gave lower stress as compared with Structure I, but stresses were concentrated at the trench bottom corner in stead of side wall. It was found that the stress increased and its area extended from bottom to top side wall by increasing the film thickness of silicon dioxide.

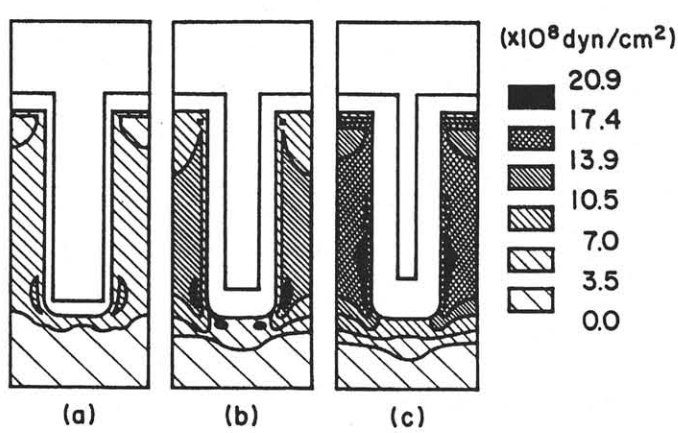

Fig.3 Shear stress distribution when oxide film thickness was changing.

In Structure I, the rounding-off effect at the bottom corner was negligible for the reduction in stress and gave little influence the stress distribution. Figure 4 shows shear stress distribution, when changing the radius of curvature at bottom corner in Structure II. As the radius of curvature became larger, stress concentration at the corner became smaller. If the radius of curvature were larger than half width of trench, stress concentration at sub-micron area of bottom corner disappeared.

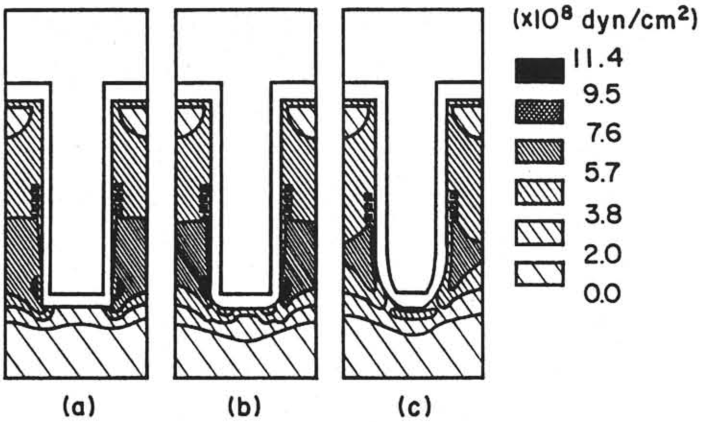

Fig.4 Shear stress distribution when the radius of curvature was changed.

When the shape of the bottom center comes sharp, new stress concentration appeared around the bottom center. It is effective to make round-bottomed trench with its diameter equal to trench width for stress dispersion around it.

3-2 Shrinkage in CVD-SiO_2 and stress concentration

Local stress around those trench was examined by Raman microprobe technique. In Structure I, the $(5\pm2)\times10^8$ dyn/cm^2 tensile stress and $(5\pm2)\times10^8$ dyn/cm^2 compressive stress were observed in <01$\bar{1}$> direction at the points A and C, respectively, but no stress was detected at center point B. In Structure II, stress was not detected at any points on the (011) cleaved surface. Raman microprobe technique has been proved to be applicable for the stress measurements [1,3], but the spatial resolution is limited by the diffraction of incident laser beam and cannot be reduced less than its wavelength.

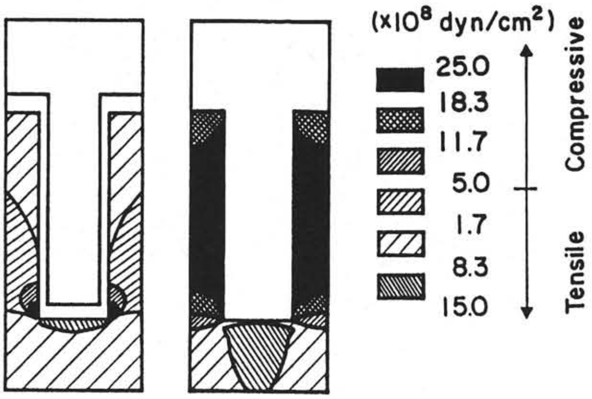

Fig.5 Distribution of <01$\bar{1}$> stress of samples in Fig.1.

Figure 5 shows <01$\bar{1}$> stress simulation. Local stresses, which could not be detected by Raman measurements, were found in Structure II by computer simulation, because stress concentration area is less than the spatial resolution and mean value in the area by Raman measurement is less than the detection limit. In Structure I, <01$\bar{1}$> stresses were concentrated along the side wall. Structure I is considered to be consist of stacked oxide layer. Stress in Structure I is superimposed of stresses of each oxide layer. However, simulated result is different from values measured by Raman microprobe technique. Thus, reverse of tensile and compressive stresses in the points A and C is not simply expected by difference in thermal expansion coefficients between silicon and silicon dioxide. It is considered that CVD-SiO_2 in the top part of the trench shrinks non-thermally. C.Meade et al.[4] have reported volume strain for fused silica as a function of hydro-static pressure. It is reasonable that 3 % non-thermal shrinkage resulted tensile stress in the point A. The shrinkage was simulated by adjusting the thermal expansion coefficient in the top part for non-thermal

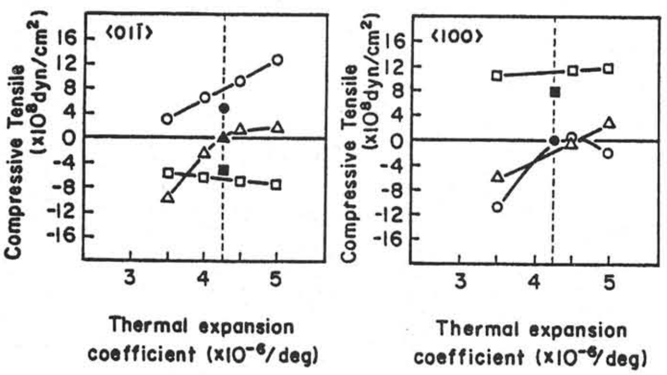

Fig.6 Measured and simulated stress for thermal expansion coefficients as a shrinkage parameter.

shrinkage parameter.

Figure 6 shows measured and simulated stress values for various thermal expansion coefficients used as a shrinkage parameter of the top part of the trench. Simulated stresses were in good agreement with the measured values in the both of <01$\bar{1}$> and <100> directions, when the simulation parameter used thermal expansion coefficient indicated by a broken line in Fig.6. In this way, partial volume shrinkage of materials in trench must be taken into consideration for stress evaluation.

The maximum shear stress was obtained using the fitting parameter, as shown in Fig.7. The maximum shear stress concentration occurred in the lower part of the trench side wall. This result agreed with the starting points of slip line around the trench. This fact proved that those stress were enough to induce crystal defects such as dislocations.

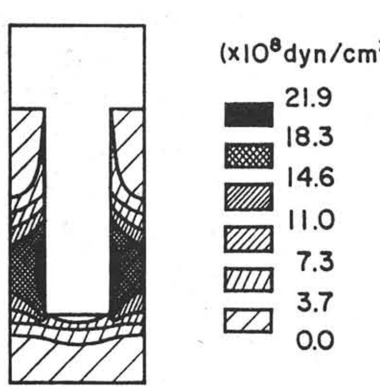

Fig.7 Shear stress distribution including a shrinkage parameter.

4.SUMMARY

The stress analysis in a sub-micron area around trench filled with poly-Si and CVD-SiO_2 was intensively studied by both of finite element simulation and Raman measurement. Results are summarized as follows.

(1) Stress along the trench side wall in Structure I increases according to a decrease in the distance of trench to trench under a constant trench width. On the other hand, the maximum stress concentrated along the trench side wall is almost constant in case of trench structure with a constant line and space ratio.

(2) It is effective to make trench bottom round for stress dispersion around the trench.

(3) It was observed that the CVD-SiO_2 in the trench shrank partially more than that expected by difference in thermal expansion coefficients between silicon and silicon dioxide. By this effect, remarkable stress concentration appeared at the lower part of the trench side wall.

5.REFERENCES

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SYMPOSIUM