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Stress Measurement of LOCOS Structure using Microscopic Raman Spectroscopy

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Abstruct- The stress distribution in silicon surface with LOCOS structure was evaluated using the micoscopic Raman spectroscopy which was improved by about one order in accuracy. It was found that there were the large tensile and compressive stresses adjacently at field edges. And the active area width was narrower, the compressive stress was larger in the active area. Measurement results were in agreement with the calculated values using the thermal stress model.

1. Introduction

The stress induced at field edges is a serious problem for the LOCOS (LOCal Oxidation of Silicon) method due to scaling down sizes of LSI's(1)-(5). This stress makes reduction of bird's beek difficult and degrades gate oxide films. But the evaluation of the stress could not be enough because there was no means to measure the stress in such a micro area.

In this study, we took notice of the stress concentration at field edges and narrow active areas. And the stress distribution in silicon surface with LOCOS structures was measured by using the microscopic Raman spectroscopy with the spatial resolution of 0.8umϕ. Results were compared with SEM observation of an anomalously etched region of chemically etched silicon substrate. The stress distribution was also studied by simulation using the thermal stress model.

2. Experimental

LOCOS structures were fabricated on a 3.0-7.5 Ωcm N-type (100) silicon wafer. At first, the pad oxide film (~30nm) and the silicon nitride film (~50nm) were grown. After the nitride film was patterned, the field oxide film with a thickness of 780nm was grown by pyrojenic oxidation at 950 °C. The nitride film and the pad oxide film were removed. Finally the field oxide film thickness was 680nm.

The active area was rectanglar forms with W um wide and 1000um long, as shown in

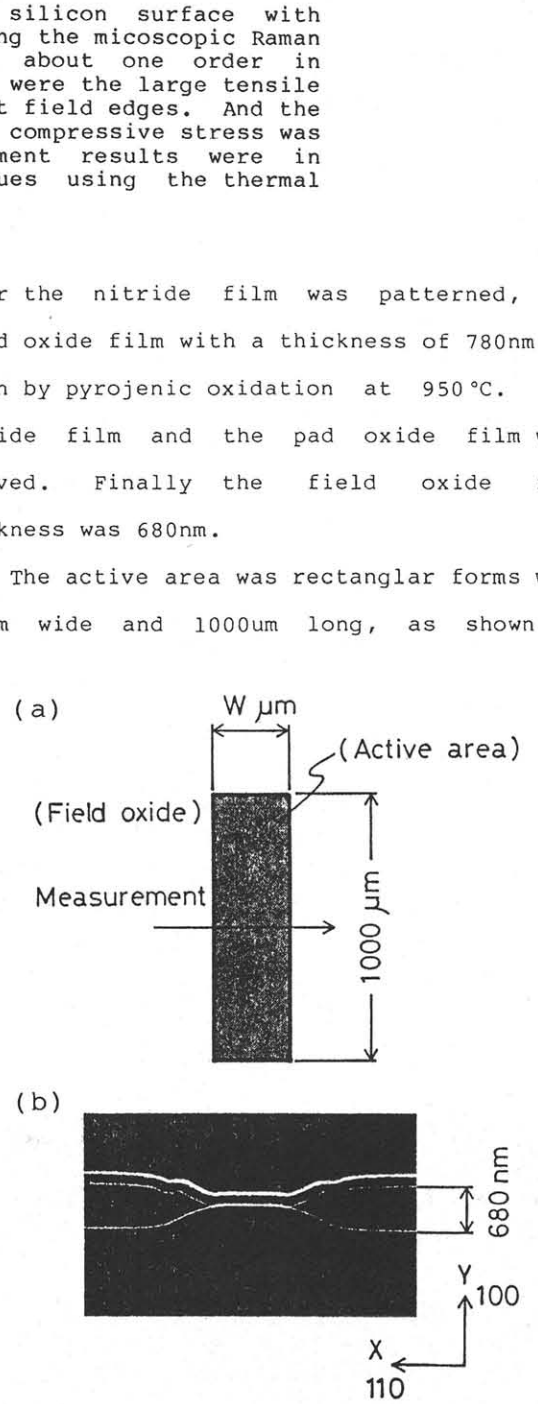

Figure 1. Sample structure. (a) Top view. (b) Side view by SEM observation.

Fig.1(a). The side view of the typical LOCOS structure was shown in Fig.1(b).

The stress was evaluated by SEM observation of chemically etched silicon substrate and by measurement of Raman shifts of the optical phonon with T2g symmetry using the microscopic Raman spectroscopy. This spectroscopy was improved by about one order in accuracy as compared with conventional method. The Raman spectra were analyzed by back-scattering configuration and the 488 nm line of Ar ion laser served as the excitation source. The error of Raman shift was ± 0.05 cm^{-1} and the spatial resolution was 0.8umϕ.

3. Result and Discussion

(a) SEM observation of chemically etched sample

The cross-sectional view of SEM micrograph of chemically etched silicon substrate was shown in Fig.2. An anomalously etched region was observed and it denotes the large stress-induced strain in the silicon crystal. It was found that there was large stress in the regions of about 0.9um long under the bird's beek and of about 0.1um long ahead it.

(b) Measurement of Raman shifts

It is known that the $q \approx 0$ optical phonon of silicon exhibits linear shifts by the stress for the constant crystallographic direction(6)(7). Typical spectra of Raman scattering measurements for the silicon surface with LOCOS structure are shown in Fig.3. The phonon of the isolation area exhibited a shift to lower Raman frequency. It corresponded to the tensile stress to the silicon. At the active area, the phonon exhibited a shift to higher frequency, corresponding to the compressive stress.

Figure 4 shows the active area width dependence of Raman shifts serially measured along the arrow as shown in Fig.1(a). The Raman shifts in the isolation area exhibited negative values in every case of W. It corresponds to the tensile stress due to the difference between the field oxide film and silicon substrate. The maximum values of negative shifts corresponding to the tensile stress peaks appeared at the both field edges. This result was in good agreement with the anomalously etched region of SEM observation.

In Fig.4(d), the positive shifts of 0.2 cm^{-1} were observed at the both edges of the active area. As the distance from the edges increased, the positive shifts decreased and almost became stress free. In addition,

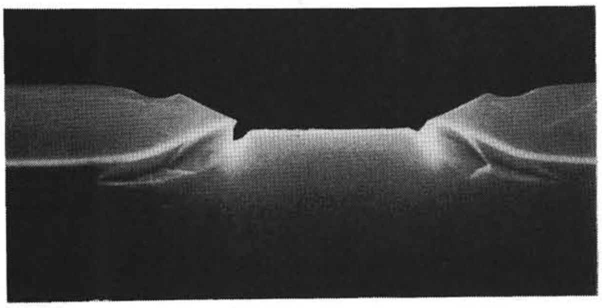

Figure 2. The cross-sectional view of SEM micrograph of chemically etched sample. The active area width is 1.2um.

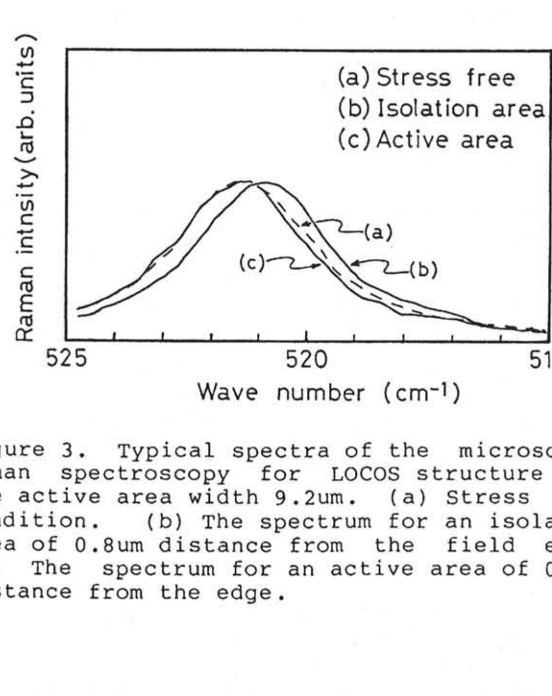

Figure 3. Typical spectra of the microscopic Raman spectroscopy for LOCOS structure with the active area width 9.2um. (a) Stress free condition. (b) The spectrum for an isolation area of 0.8um distance from the field edge. (c) The spectrum for an active area of 0.6um distance from the edge.

as shown in Fig.4(a)-(c), W was smaller, the positive shift at the center of the active area was larger. The W dependence of Raman shift at the center of the active area is shown in Fig.5. It is supposed that the stress was induced in silcon substrate due to the difference of the thermal expansion coefficient between silicon and silicon dioxide. Because the isolation area is discontinuous along the x axis in this study, the compressive stress at the center of the active area is mainly parallel with the x axis and Raman shift in Fig.5 is proportional to this stress. Thus it is concluded that the compressive stress in the active area increases as the active area width decreases.

(c) Thermal stress simulation

In order to explain the stress distribution in LOCOS structure, thermal stress in this structure was calculated when the sample was cooling-down from 950 °C (oxidation temperature) to 25 °C (room temperature). The simulation results of the stress distribution are shown in Fig.6. It is found that the compressive stress in the case of small W is large as compared with the same stress in large W in the active area and the field edges.

Raman shifts, which were calculated from the stress distribution of Fig.6, are shown in Fig.7. The absorption of incident and scattered lights and the space distribution of incident light power were taken into account for these calculations. It was also assumed that the stress of $2.5 \times 10^9 dyn/cm^2$ was converted into Raman shift of $1.0\ cm^{-1}$. The calcurated results were in good agreement with the experimental values. For the case of 1.2um width, Raman shifts obtained by the experiment exhibited a little smaller values than the calculated one. Thus it is concluded that the stress distribution in the silicon surface with LOCOS structure can be explained by the thermal stress model as the first order approximation.

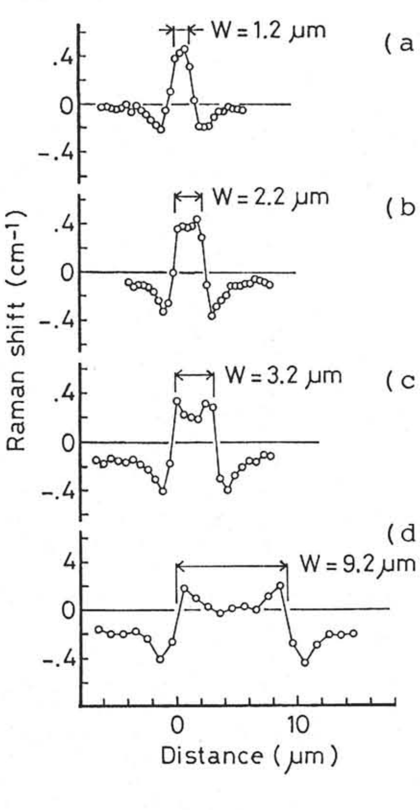

Figure 4. Raman shifts for LOCOS structures with the various active area width W. (a) W = 1.2um. (b) 2.2um (c) 3.2um (d) 9.2um .

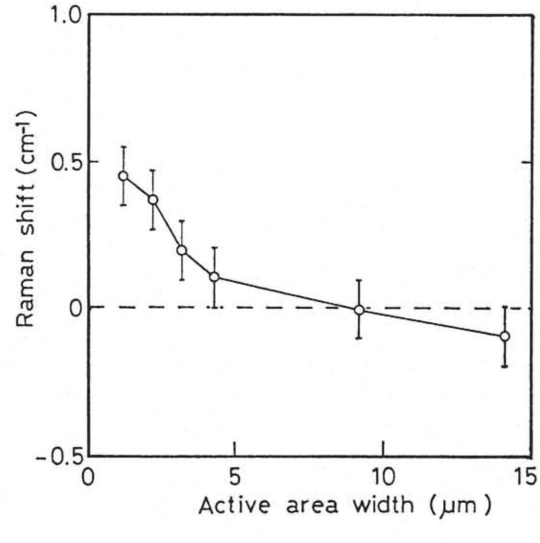

Figure 5. Dependence of Raman shift at the center of the active area upon the active area width W.

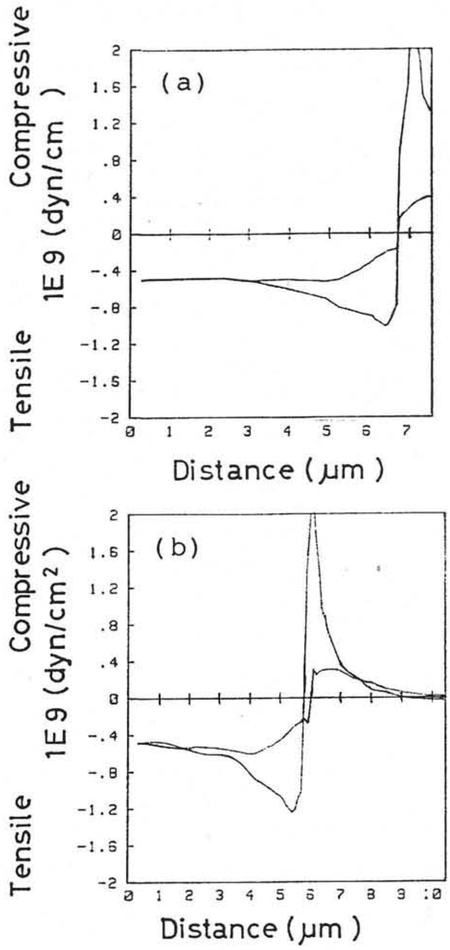

Figure 6. Calculated thermal stress distributions. 1 is a distribution near the silicon surface. 2 is one for 1.07um depth from the silicon surface. (a) W = 1.2um. (b) 9.2um.

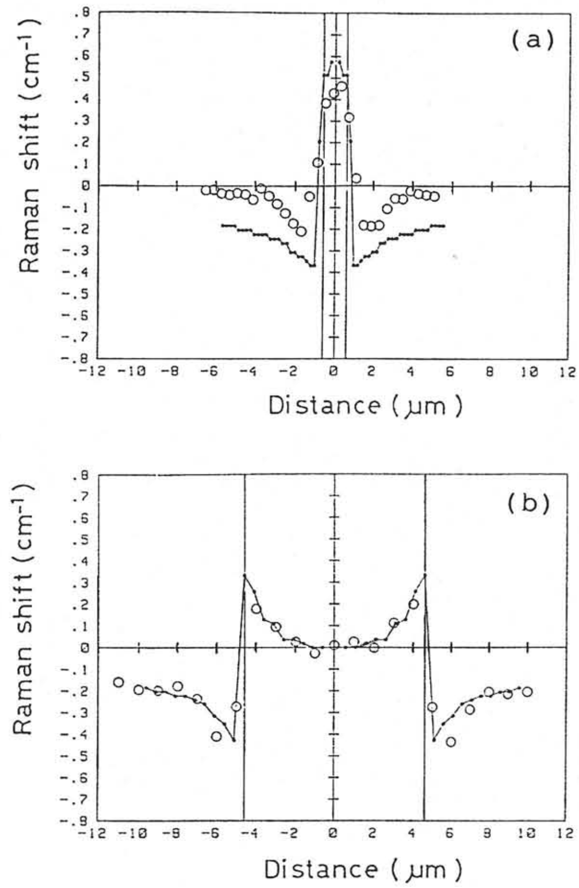

Figure 7. Comparison between the measurement result (○) and Raman shifts calculated from Fig.5 (—•—). (a) W=1.2um. (b) 9.2um.

4. Conclusion

The stress distribution in the silicon surface with LOCOS structure was evaluated using the microscopic Raman spectroscopy which was improved in accuracy. It was found that there was the tensile stress in the isolation area and it became the maximum value at the field edges. Also there was the large compressive stress at the active area edges and the compressive stress increased in the all active area with the active area width decreasing.

Measurement results were in good agreement with Raman shifts which were calculated using the thermal stress model. Thus the stress distribution in LOCOS structure is, as the first order approximation, explained by this model.

The distribution of the large stress coincided with the anomalously etched region of the chemical etched silicon substrate also.

From now on the method combined the micoscopic Raman spectroscopy and the simulation would offer a means to control the stress in LSI devices.

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