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Cross Sectional Local Stress Distribution for Trench Isolation

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Cross sectional local stress distributions for trench isolation were measured on (110) cleaved plane by micro-probe Raman spectroscopy and the result was compared with measurements from the (001) surface. The following were found: (1) Micro-probe Raman measurements from cleaved active regions provide cross sectional stress distributions in a semi-quantitative manner. (2) Compressive stress caused by the trench isolation can be detected as deep as 2μm below the bottom of the trenches. (3) The stress distribution peaks at the center of the active area, which is in contrast to the M-shaped distribution reported for LOCOS isolation without deep trenches. (4) Strain in the (110) cross section is very symmetric in the plane.

1. Introduction

Trench isolation is a very important technology for advanced VSLI fabrication. Stress distribution around trench and LOCOS (LOCal Oxidation of Silicon) structures at the wafer surface has been reported by several authors. [1-3] The distribution of stress as a function of depth within the trench isolated silicon island is also of great interest. Previous reports of stress around trenches are primarily based on computer simulation.[4,5] In this study, Stress distribution in cross section was measured by micro-probe Raman spectroscopy and the result compared with measurements from the surface.

2. Raman measurement

Rectangular active regions (bare silicon) approximately 4.5x7.5μm surrounded by trench isolation were formed on (001) silicon substrates (Fig. 1). The trenches were etched to a target depth and width of 3.5μm and 1.0μm, lined with oxide and filled with polysilicon. After polysilicon planarization, field oxide (polybuffered LOCOS) was grown over the trenches and between the active regions.[6] Following wet etch to clar the active areas, wafers were then cleaved so that (110) plane was exposed for cross sectional measurement. Raman spectrum measurements were performed in the backscattering configuration with the excitation from an Ar^+ laser operating at 488.0nm, which was polarized parallel to [$\bar{1}$10] and [110] on the sample for the cross sectional and surface measurements, respectively. According to the Raman selection rules,[7] what we observed in this study were primarily backscattered Raman radiation along the [$\bar{1}$10] and [110] silicon axes respectively for the cross sectional and surface measurements, although no polarization analysis was done. Raman spectra were observed together with a Ne emission line to cancel out the peak shift due to the temperature deviation of the system. The beam size was less than 1μm in diameter. The system was equipped with a 1μm spatial resolution stage.

Three types of measurements were carried out as shown in Fig. 1:[1] two dimensional mapping from (110) cross section around the active island, [2] one point measurement from (001) surface at the edge of the cross section, and [3] one dimensional mapping across an active island far from the cleaved edge.

3. Stress calculation and result

In order to estimate the stress from Raman peak shifts, we assumed that the stresses were biaxial in the

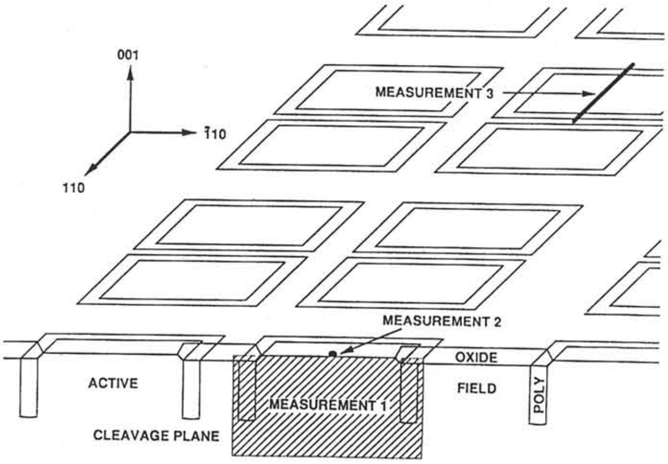

Figure 1 Schematic diagram of the specimen and the areas measured. Field oxide is shown only in the cross section.

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planes observed. Then the following relationship[8] between the stress, τ, and the Raman shift, $\Delta\omega$, can be applied for the (001) surface measurements:

$$\tau = 2.49\times10^9 \text{ cm}^2/\text{dyne } \Delta\omega \text{ (cm}^{-1}).$$

This coefficient may be different for the (110) cross sectional measurement, since the phonons are different for the two measurements. However, we are not aware of any data reported for the (110) plane. Thus, the stresses were calculated by the above equation even for the cross sectional measurement in this study.

Figure 2 shows the cross sectional stress distribution calculated from measurement 1. A single stress level for the surface (measurement 2) is shown for comparison. Near the original silicon surface (0.5μm deep), a maximum compressive stress of 1.6×10^9 dynes/cm^2 is observed. The stress peaks at the center of the active tub and declines as the trench boundary surrounding the active region is approached. With increasing depth, the peak stress declines but the shape of the stress distribution is retained. The profile becomes essentially flat at a depth of 5.5μm, approximately 2μm deeper than the isolation trenches. At this depth, the stress is effectively zero within the experimental error.

Hu estimated cross sectional distribution of each stress tensor component around trenches by an analytical solution.[5] Our result does not give us any information on the components by itself. Comparing the distribution in Fig. 1 and their result, s_{xx} could be a dominant stress tensor component in our sample from the similarity of the shape of the distribution. However, this conclusion needs verification, since Hu assumed trenches filled with silicon dioxide and trench dimensions are different.

The stress measured from the top surface of the cleaved edge (measurement 2) was 1.2×10^9 dynes/cm^2. The sample depth for the laser Raman measurement in silicon is approximately 1μm. The value obtained from the surface agrees well with the levels measured in cross section at 0.5μm (1.6×10^9 dynes/cm^2) and at 1.5μm (1.2×10^9 dynes/cm^2). This coincidence suggests that the stress data from cross section are reliable, although we have assumed biaxial stress distribution both in the cross section and the surface and the same Raman shift/stress conversion coefficient.

The effect of cleaving the trench isolated structure on the stress in the active region must be considered. Figure 3 shows the stress distribution across the active area measured from the surface (measurement 3) far from the cleaved plane. The shape of the stress distribution is very similar to the cross sectional measurement shown in Fig. 2. However, the magnitude of the maximum stress in the center of the active region was 4.0×10^9 dynes/cm^2 (Fig. 3). The ~2.5 times lower stress observed in cross section (Fig. 2) may be explained by a stress relaxation at the cleavage plane.

A M-shaped stress distribution measured by Raman from the surface has been reported for LOCOS isolated active area (active width: 9.2μm) without the trenches,[1] which is a contrast to the distribution in Fig. 3. We also have observed similar distribution for the same type of structure. This difference should be noted for the future investigation.

4. Linewidth data and strain symmetry

Figures 4 and 5 indicate linewidth distribution of Raman spectra corresponding to Figs. 2 (measurements

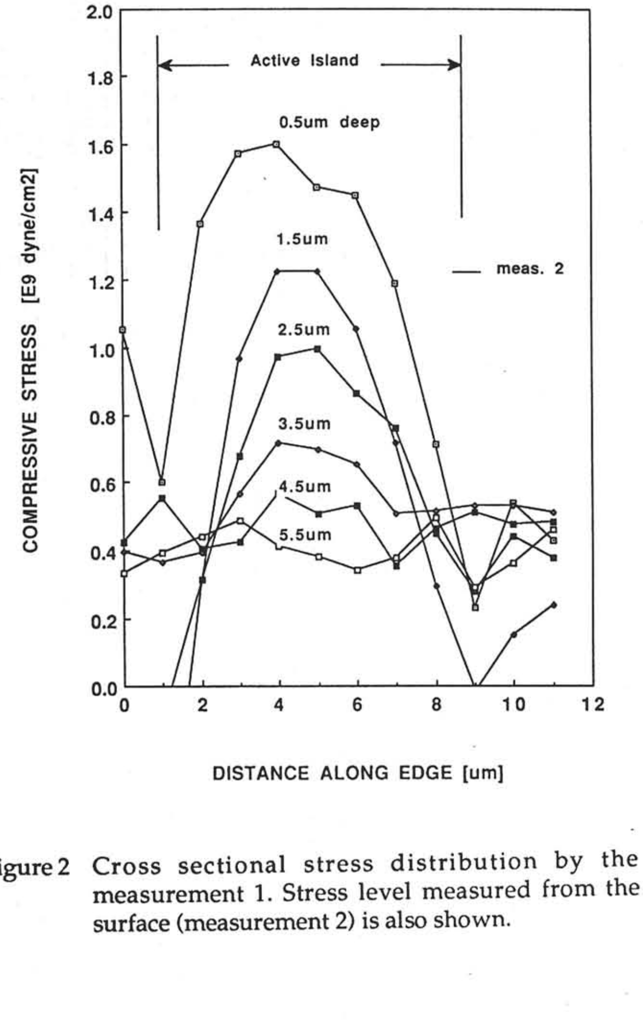

Figure 2 Cross sectional stress distribution by the measurement 1. Stress level measured from the surface (measurement 2) is also shown.

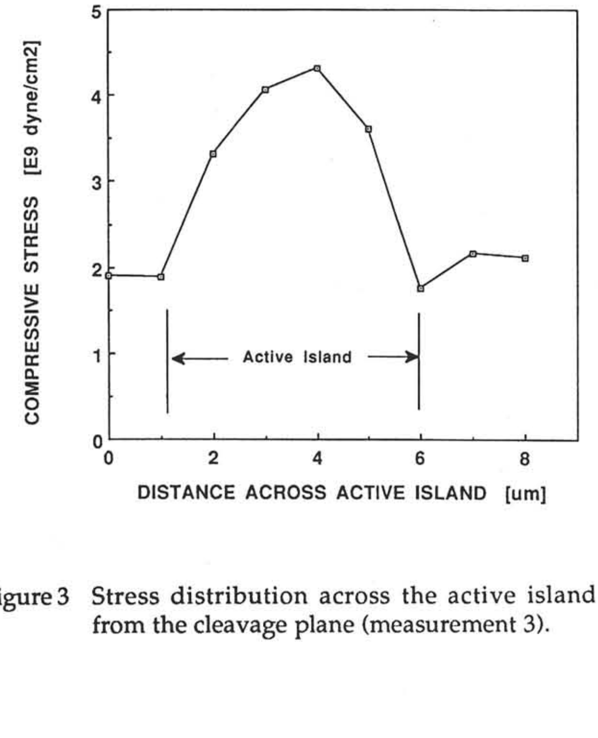

Figure 3 Stress distribution across the active island far from the cleavage plane (measurement 3).

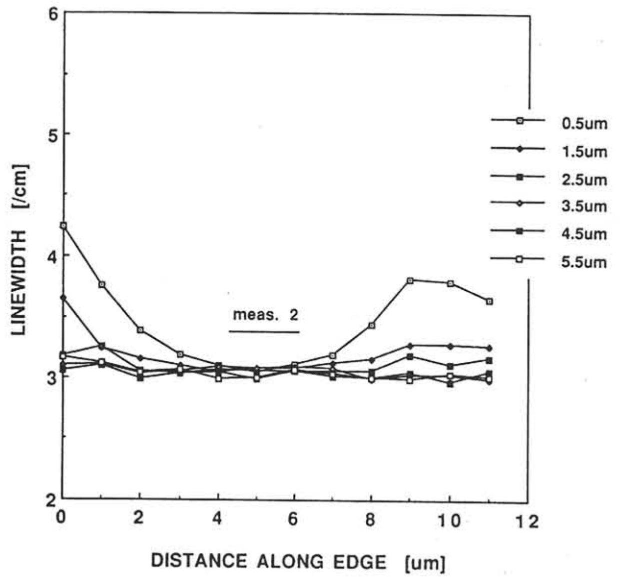

Figure 4 Cross sectional distribution of Raman spectrum line width by the measurement 1. Also shown is linewidth measured from the surface (measurement 2).

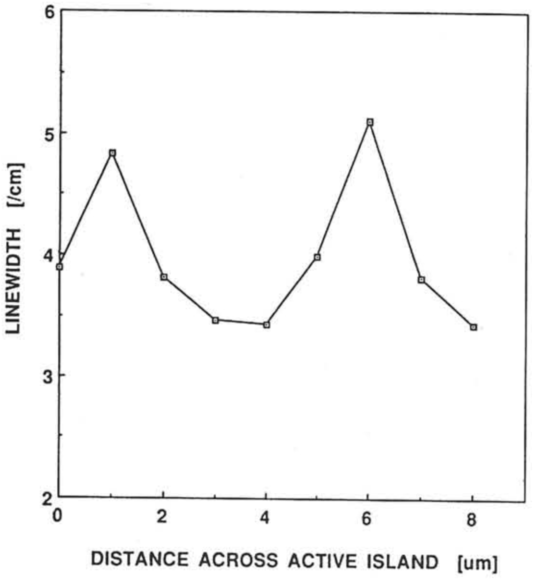

Figure 5 Linewidth distribution across across the active island in the bulk (measurement 3).

1 and 2) and 3 (measurement 3). In the cross sectional measurement, linewidth is about $3.0cm^{-1}$, which corresponds to that from bare silicon surface, and goes up toward the edge of the active island near the original silicon surface (Fig. 4). The distribution measured from the (001) surface has minimum linewidth also at the center of the island, however the value is $3.3cm^{-1}$, $0.3cm^{-1}$ larger than the (110) cross sectional measurement (Fig. 5). We observed the same linewidth also by measurement 2 at the cleaved edge from the surface (Fig. 4) .

Our system was not capable of performing the polarization analyses so that we didn't observe the phonon mode splitting due to less symmetric strain as Hu did.[9] However, we should observe it as linewidth broadening if there are such mode splitting.

Since the linewidth observed from the (110) cross section is identical to that of bare silicon surface, stress or strain is very symmetric in the (110) cross section. On the other hand, stress is less symmetric in the (001) surface, since the $0.3cm^{-1}$ larger linewidth was observed both by measurements 2 and 3. Even larger numbers toward the edge of the island may be caused by some combination of less symmetric strain and the crystal damage induced in silicon during the trench formation process.

5. Summary

We performed cross sectional local stress distribution measurement for trench isolation and compared the result with measurements from the surface. As the result, the following were found: (1) Micro-probe Raman measurement from cleaved active regions bounded by trench isolation provide cross sectional stress distributions. (2) The cross sectional stress distributions are useful for comparison of relative stress levels since the calculation of the absolute stress value may be affected by stress relaxation at the cleavage plane and the unknown Raman shift/conversion coefficient for (110) plane. (3) Compressive stress caused by the trench isolation can be detected as much as 2μm below the bottom of the trenches. (4) The stress distribution peaks at the center of the active area. The shape of this distribution is the inverse of the M-shaped distribution reported for LOCOS isolation without the deep trenches. (5) Judging from the linewidth data, the stress in the (110) cross section is very symmetric in the plane.

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References

1) K. Kobayashi, Y. Inoue, T. Nishimura, M. Hirayama, Y. Akasaka, T. Kato and S. Ibuki, J. Electrochem. Soc. **137**, 1987 (1990).
2) T. Ikeda, M. Yumoto and H. Okahana, Tech. Digest of Microbeam Analysis, 1988, pp159.
3) M. Sugiyama, T. Shimizu, H. Takemura, A. Yoshino, N. Oda, T. Tashiro, Y. Minato, Y. Takarashi and M. Nakamae, Symp. VLSI Tech Dig. papers, 1989, pp59.
4) S. Nadahara, S. Kambayashi, M. Watanabe and T. Nakakubo, Extended Abstracts of the 19th Conference on Solid State Devices and Materials, Tokyo, 1987, pp327.
5) S. M. Hu, J. Appl. Phys. **61**, 1092 (1990).
6) B. Vasquez and P.J. Zdebel, US Patent No. 431420 (1989).
7) S. Nakashima and A. Mitsuishi, Oyobutsuri **53**, 558 (1984).
8) Th. Englert, G. Abstreiter and J. Pontcharra, Solid State Electron. **23**, 31 (1980).
9) K. Brunner, G. Abstreiter, B.O. Kolbesen and H.W. Meul, Appl. Surface Science **39**, 116 (1989).