Stress Field and Defect Evaluation with Shallow Trench Isolation Structure after Transistor Fabrication Processing by Raman and Cathodoluminescence Spectroscopies

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1. Introduction

Stress engineering related to the frontend process as well as the backend process of LSI is required [1-7]. As for shallow trench isolation (STI) structures, it was reported that a high stress field in the structure causes a variation in electrical characteristics [8]. We reported that overall estimation of stress fields with a STI structure was successfully performed by cathodoluminescence (CL) spectroscopy, Raman spectroscopy, and finite element method (FEM) analyses, showing a good correspondence one another [9]. In ref. 9, we analyzed the STI structure filled with a SiO2 film before CMP processing, where the SiO2 film also deposited on active area (AA). However, the SiO2 film on AA should be removed by CMP, and transistor fabrication such as film deposition or ion-implantation processing on the AA area is followed. Thus, we attempted to evaluate stress fields after CMP and the transistor fabricating processing, applying Raman and CL spectroscopies. Moreover, CL spectroscopy is useful to detect some defects in Si substrates with a STI structure [10]. Therefore, in this study, we also attempted to estimate defects in the Si substrate after transistor fabrication because it is important to understand defects in the Si substrate.

2. Experiments

STI structures were fabricated on a 300 mm diameter Si substrate, where a SiO₂ films was deposited on the surface followed by SiO₂ removal using CMP and transistor fabrication including ion-implantation. Before Raman and CL spectroscopies, all transistors on the substrate were stripped by wet processing. Stress measurements were performed by Raman spectroscopy (HORIBA, Ltd., FR-3000) for the Si-substrate, and by CL spectroscopy (HORIBA, Ltd., MP32-FE) for the SiO₂ film. An excitation laser of the Raman spectrometer was water cooled Ar with 363.8 nm excitation line. The detailed conditions of there spectroscopies are same as in ref. 9. The principle of stress detection by CL spectroscopy is as follows; an electron beam irradiation on a specimen causes an excitation of optically active parts, and their photon energy (CL wavelength) is altered by the amount of residual stress. All stress measurement by CL spectroscopy was carried out in room temperature. The detailed principle and outline of CL spectroscopy and stress analysis are explained in elsewhere [9, 11-14]. On the other hand, throughout defect detection in the Si substrate was performed at 18 K to obtain clear spectrum by the CL system (Horiba Ltd.).

3. Results and Discussions

Two results of Si stress distribution obtained by Raman spectroscopy are shown in Figs. 1 and 2. Figure 1 shows the results of our former study with SiO₂ film on an AA area [9], while Fig. 2 shows those of this study without SiO₂ film or CMP-stop layer on the AA. Comparing these results, we confirmed that removal of SiO₂ film from the AA surface induced stress release at the trench bottom area as well as the AA center area. At the trench bottom area, up to 650 MPa tensile stress (before SiO₂ removal) was relaxed to around 300 MPa tensile stress (after SiO₂ removal). In the center area of the AA, up to 200 MPa tensile stress (before SiO₂ removal). Moreover, at the AA/STI boundary, stress shift toward compressive side (up to 50 MPa) was detected.

Furthermore, the stress distribution in the SiO₂ film of the same area was obtained by CL spectroscopy (Fig. 3). This result shows that photon energy shifted toward the higher energy side at the AA/STI boundary. This shift indicates stress shift more on tensile side at the boundary. As a result, we found that the tensile side stress shift in the SiO₂ film and the compressive side stress shift in the Si substrate around the AA/STI boundary are keeping balance each other. Moreover, we also confirmed that these stress fields both in SiO₂ and Si were changed according to intrinsic stress alteration of the SiO₂ film.

Figure 4 shows the CL spectra of Si substrate detected at 18 K. Observed areas were STI structures with different width AA line on n+/p or p+/n. The most prominent peak around 1.1 eV (TO) is equivalent to the band-edge emission followed y a transverse optic (TO) photon emission [10]. In addition, faint peaks at 1.04 eV and 1.135 eV were observed, which might be induced by ion-implantation. There peaks are slightly shifted according to the AA width or condition of the substrate. In addition, we confirmed that intrinsic stress alteration of the SiO2 film also caused these CL peaks although the data are not shown. It is noted that *no peaks* such as D1 (0.81 eV), D2 (0.87 eV), D3 (0.94 eV), or D4 (1.00 eV) originated from dislocation or defects was observed.

4. Conclusions

We performed estimation of stress fields with a STI structure after transistor fabrication. It is confirmed that the stresses are released by CMP of SiO_2 film and that stress fields both in SiO_2 and Si are balanced each other. Moreover, CL spectroscopy at 18 K revealed that there are only faint peaks of dislocation or defects in Si substrate after transistor fabrication, which shifted according to the pattern layout and condition of the substrate.

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Fig.1 Results of Raman spectroscopy with Si-substrate (our former study). (a) Stress distribution. (b) Cross sectional model. (c) Top SEM image of observed area.



Fig.2 Results of Raman spectroscopy with Si-substrate (this study). (a) Stress distribution of 3 times measurement with same pattern. (b) Cross sectional model. (c) Top SEM image of observed area.







Fig.4 CL spectra of Si substrate at 18 K.