Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 378-379

P-2-2

Raman Spectroscopic Stress Analysis of Single Crystal Silicon (001) Specimen Tensioned Along the [100] Direction over 1000 MPa

Mamoru Komatsubara[1], Yuji Nagai[1], Takahiro Namazu[1], Nobuyuki Naka[2], Shinsuke Kashiwagi[2], Kunio Ohtsuki[2], and Shozo Inoue[1]

[1]Department of Mechanical and Systems Engineering, University of Hyogo 2167 Shosha, Himeji, Hyogo 671-2201, Japan
Phone: +81-79-267-4962, E-mail: namazu@eng.u-hyogo.ac.jp(T.Namazu)
[2]Semiconductor Systems R&D Dept., HORIBA, Ltd., 2 Miyanohigashi, Kisshoin, Minami-ku, Kyoto 601-8510, Japan

1. Introduction

Recently, micro components made of single crystal silicon (SCS) in electron devices and micro electro mechanical systems (MEMS) have being shrunk in size as the rapid progress in semiconductor microfabrication technology[1]. Evaluation of stress and strain applied to the components leads to improvement of the performance and reliability of such the silicon devices. Raman spectroscopy is a promising method for measuring local stress on SCS micro components.

We have so far reported evaluation method for local surface stress on SCS microstructures using Raman spectroscope along the [110] direction[2][3]. The [110] direction in the (001) plane has been used for semiconductor transistor due to its high carrier mobility. Recently, however, some techniques that improves the mobility along the [100] direction have been developed. So, evaluation of stress and strain along the [100] direction is needed.

In this study, we conducted the uniaxial tensile testing along the [100] direction with tensile stress of over 1000MPa and discussed usefulness of the Raman spectroscopic stress determination method using uniaxial tensile testing and finite element analysis (FEA).

2. Experimental Procedure

Fig.1 shows photographs of SCS specimen and a schematic of line scan measurement. The specimen was fabricated from SOI wafer with device layer thickness of 4 μm. The device layer and the supporting layer are oriented along the [100] and [110] directions at orientation flat, in the (001) plane, respectively. The specimen has the nominal width and length of 35 μm and 690 μm at the gauge section, respectively. Convex structures that have 10 μm-square, 510 nm in height and sloped 960 nm-radius at sidewall are fabricated on the gauge section. The longitudinal direction of the specimen corresponds to [100] direction during the tensile test.

Fig.2 shows a photograph of the commercial Raman spectroscope (HORIBA Jobin Yvon, LabRAM HR-800) with compact tensile tester. The tester was set onto the stage in Raman spectroscope. We performed two types of experiments;

(1) Raman spectroscopy on a flat section for determination of the relation between the peak shift of spectrum and the applied tensile stress.

(2) Raman spectroscopy around a SCS convex structure for investigation of surface stress distribution.

After these experiments, the stress distribution obtained from one and two-curve fittings of Raman spectra were compared with those from FEA.

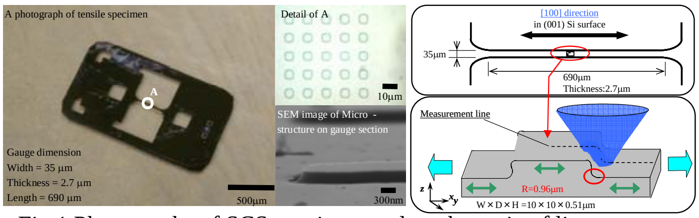

Fig.1 Photographs of SCS specimen and a schematic of line scan measurement.

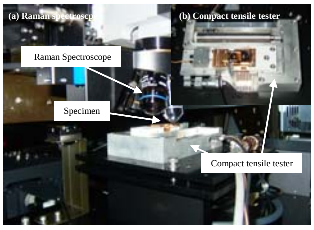

Fig.2 A Raman spectroscopic tensile test system.

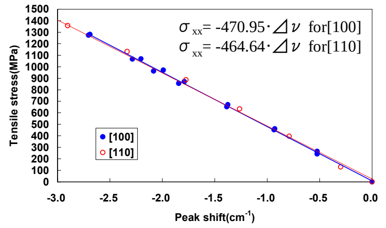

Fig.3 Relationship between Raman shift increment and applied tensile stress.

3. Results and Discussions

Fig.3 shows a relationship between Raman shift increment at the peak position and the applied tensile stress to SCS specimen. This indicates that the Raman spectrum peak shifts by -1 cm^{-1} when the tensile stress of 470.95 MPa is applied to specimen. Almost the same value of 464.64 MPa has been reported when a specimen is tensioned along the [110] direction[2][3]. This indicates that the tensile direction does not affect on the relationship.

Fig.4 (a)-(c) show the distributions of peak shift, intensity, and full width at half maximum (FWHM) of Raman spectra around a convex structure at various tensile stresses, respectively. As tensile stress increases, all the parameters around the convex structure, especially at the edge, take the different values from those on a SCS flat section. This indicates that a nonuniform stress occurs around the convex structure. The same tendency is obtained when the tensile stress was applied to the [110] direction[2][3].

Fig.5 shows tensile stress distribution obtained by one-curve fitting of Raman spectra and FEA at 1300 MPa. The one-curve fit stress distribution is in good agreement with FEA distribution at the flat section. However, at the edge, the one-curve fit result differs from the FEA. So, we supposed that Raman spectrum around the edge included information of both the top and the bottom corners of the convex structure.

In order to separate the top from the bottom and information in the Raman spectrum obtained near the edge, two-curve fitting was performed. Fig.6 shows Raman

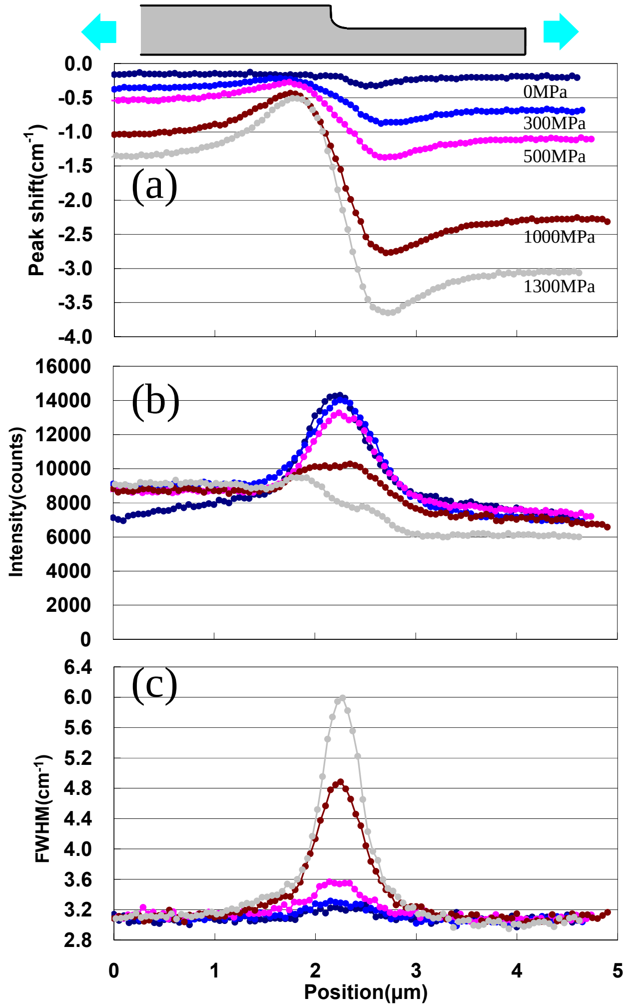

Fig.4 The peak shift, intensity, FWHM at the SCS convex structure when various tensile stress were applied.

spectra at the flat and the edge sections at 1300 MPa. The spectrum at the edge has a broad peak as compared with that at the flat section. The peak at the edge was separated into 2 curves clearly. Fig.7 shows the obtained stress distribution at the edge by one and two-curve fittings, and FEA. The difference in stress distribution between them is clearly seen. At the bottom and top corner of the convex structure, the stress distribution in two-curve fitting exhibit better approximation to FEA by 35% and 45% than that in one-curve fitting, respectively. This indicates that the two-curve fitting method for analyzing a Raman spectrum would be effective for evaluation of stress distribution at micro/nanoscale SCS structures in MEMS.

4. Conclusions

In this study, we evaluated local surface stress on a SCS microstructure along the [100] direction using Raman spectroscope. As the result, same tendency was obtained at comparison of the [100] with [110] direction. Two-curve fitting method was effective to evaluate near the edge section of a convex structure, especially when the tensile stress of over 1300MPa was applied. So, the Raman spectroscopy with the two-curve fitting would be effective method so as to evaluate a local surface stress on SCS microstructures.

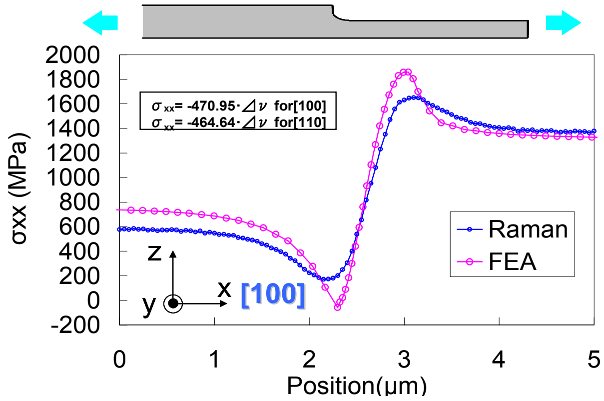

Fig.5 Tensile stress distribution obtained by one-curve fitting of Raman spectra and FEA.

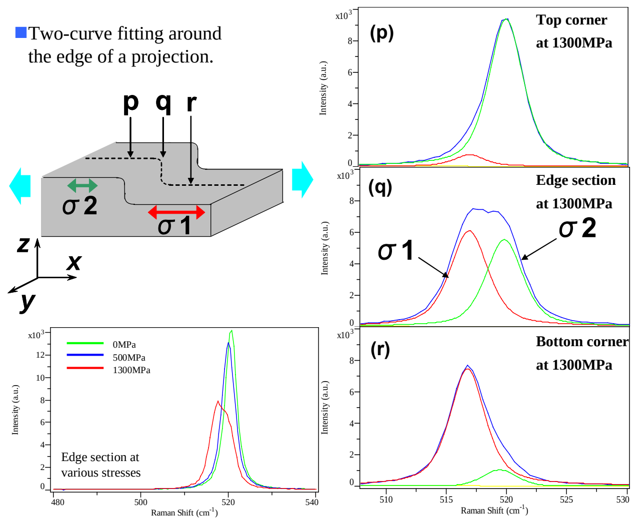

Fig.6 Raman spectra at the flat and edge sections.

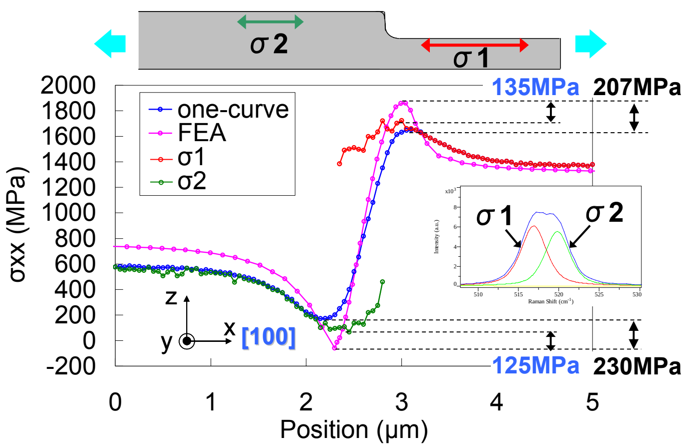

Fig.7 Stress distribution at the edge by two-curve fittings and FEA.

References

[1] T.Namazu, Y.Isono, and T.Tanaka, *Journal of Micro ElectroMechanical Systems*, 450-459(2000)Vol.9, No.4.

[2] Y.Nagai, T.Namazu, N.Naka, S.Kashiwagi, K.Ohtsuki, and S.Inoue, ATEM (2007) OS5-3-2

[3] T.Namazu, Y.Nagai, N.Naka, S.Kashiwagi, K.Ohtsuki, and S.Inoue, Transducers, 627-630 (2007)