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利用課題名（日本語）　:シリコン単結晶のナノ変形特性評価と環境脆化機構の解明
Program Title (English)　:Mechanical Properties of Nano-scale Silicon and Survey of the Environmental Brittle Behavior
利用者名（日本語）　:泉隼人, 位田裕志
Username (English)　:H. Izumi, H. Inden
所属名（日本語）　:名古屋工業大学　大学院工学研究科　機能工学専攻
Affiliation (English)　:Graduate School of Engineering Dep. of Engineering Physics, Electronics and Mechanics, Nagoya Institue of Technology.

1. 概要（Summary）

This paper reports the mechanical properties of single crystal silicon surface changed with hydrogen atoms trapped by underwater boiling treatment. Nanoindentaion test using a Berkovich indenter in six different indentation loads ranging from 100 μN to 1000 μN was conducted to obtain the load-displacement curve. The energy dissipated in plastic deformation, i.e. plasticity energy, during indentation on silicon wafers with different carrier concentration (undoped, lightly and heavily boron doped silicon) were compared. After boiling treatment, increment in the plasticity energy was observed on silicon containing boron. This result suggests that hydrogen atoms trapped inside silicon enhanced dislocation mobility leading to larger plastic deformation.

2. 実験（Experimental）

The material tested was single crystal silicon with polished (100) surface. Boron-doped p-type silicon was subjected to the experiment in this study. To investigate the effect of boron and thus carrier concentration, three different types of silicon wafers were selected for the present study: 1) undoped Float-zone (FZ) grown silicon (resistivity higher than 20000 Ωcm), 2) boron-doped Czochralski (CZ)-grown silicon with light doping level (resistivity of 100-200 Ωcm, carrier concentration of 6 to 15×10^{13} atoms/cm^3), and 3) heavily boron-doped CZ silicon (resistivity of 0.001-0.005 Ωcm, concentration of 2 to 10×10^{19} atoms/cm^3). The thickness of these wafers was 400 μm. The test samples were cut into specimens with a rectangular form of 2×6 mm^2. Method of boiling in deionized water (DI water) was employed to introduce hydrogen without any damage for the evaluation of mechanical properties. To investigate the effect of hydrogen, untreated specimens were also prepared and compared with those boiling-treated for 30 min. To investigate the depth dependence, the load-displacement plots of indentation were made with 100, 200, 300, 500, 700, 1000 μN peak indentation loads for each type of specimens.

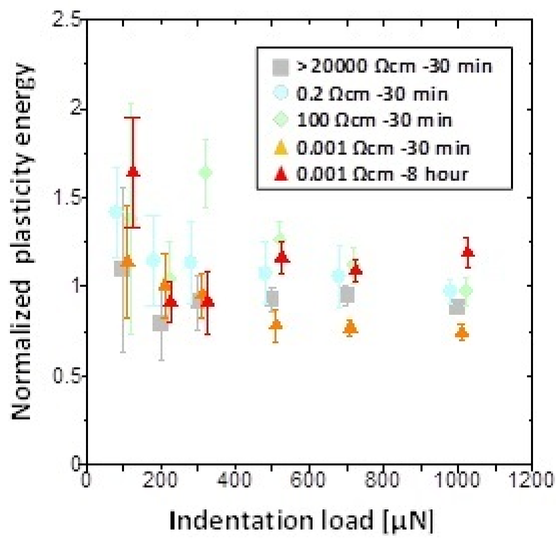

Fig.1 Normalized plasticity energy versus indentation load

3. 結果と考察（Results and Discussion）

Fig. 1 were plotted with normalized plasticity energy as the vertical axis and indentation loads as the horizontal axis. Compared with untreated silicon, the averaged value of plasticity energy under 100μN indentation loads was approximately 1.6 times larger in the case of boiled light doped silicon. In summary, the hydrogen effect on plastic property of silicon crystal surface with different resistivity was experimentally investigated using force sensing indentation. The effects of boil treatment to enhance plastic deformation of boron doped silicon were observed certainly. The plasticity energy of undoped silicon did not change at all. From these experiments, the plastic response of silicon was found to depend on the diffusion depth of hydrogen, and carrier concentration of boron. These results suggest that hydrogen trapped inside silicon lead to softening of silicon surface, playing an important role for the enhancement of the mobility of dislocations.

4. その他・特記事項（Others）

none.

5. 論文・学会発表（Publication/Presentation）

H.Izumi et al., Effect of Hydrogen on the Mechanical Properties of Silicon Crystal Surface, Proc. ASME 2013 International Technical Conference & Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, 2013, IPACK2013-73324.

6. 関連特許（Patent）

none.