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THE STRUCTURE INVESTIGATION OF NEAR-SURFACE LAYERS IN SILICON – DIOXIDE SILICON SYSTEMS

The near-surface silicon layers in silicon – dioxide silicon systems with used modern method of research are investigated. It is shown that these layers have compound structure and their parameters depend on oxidation and initial silicon parameters.

1. INTRODUCTION

Investigations of SiO_2 – Si structures is still give a great consideration due to principal position of this structure in micro and nanoelectronics. The technological importance of SiO_2 – Si systems stems from their ubiquitous presence in Metal-Oxide-Semiconductor (MOS) structures. In consideration of the fact that major processes in SiO_2 – Si electronics happens in near-surface layers of silicon it is necessary to investigate surface morphology of these layers. As shown in modern researches there is transition layer under the oxide which different from the monocrystalline silicon in structure and composition [1]. But it still not fixed this structure and the depth of these layers. And it still not detects the relation between difference of these layers and other parameters such as oxidation process and characteristics of initial silicon.

The aim of this work is the definition of silicon near-surface structural composition in SiO_2 – Si and the determination parameters of these layers on oxidation and initial silicon parameters.

2. EXPERIMENTAL DETAILS

Investigation of silicon surface after removal of dioxide was carried out by scanning electronic microscopy (electronic scanning microscope "Cam-Scan" with "Link-860" X-Ray microanalyser, used ZAF program for calculation), by optical methods (metallographic microscope MMR-2R), by Auger spectrometer LAS-3000 (beam diameter — 5 micron), by X-ray technique on DRON-2 with silicon grating monochromator (voltage = 16kV, intensity of a current = 2mA). Silicon wafers with different dioxide thickness (range 0.1–1.5 micron) grown in dry oxygen environment on 1100°C temperature were researched (oxygen consumption was about 10 liter in minute).

The SiO_2 was etched off in hydrofluoric acid followed by washing in deionized water. To detect structural defects, the silicon surface layer-by-layer etching away with selective Sekko (for surface 100) and Sirtl (for 111) etchants with preliminary treatment in Karo intermixture and peroxide-ammonia solution was led [3].

3. RESULTS AND DISCUSSION

Fig. 1 shows the typical picture of a silicon surface, received after 5 minutes oxide (the thickness of oxide was 1 micron) etching in selective Sirtl etchant. It's well visible, that typical etch pits dislocation and stacking faults are absent. Presence on a silicon surface such pits is connected with etching oxide which appears at the accelerated thermodiffusion it along structural defects of silicon. Attempts to receive the image of surface Si with the help of the electron microscope "Cam - Scan" turned out unsuccessful. The irradiated silicon surface was strongly charged by an electron beam and there was no opportunity to receive an electron image of the surface. These two facts have enabled to conclude, that the surface of silicon under oxide had strongly disordered structure close to finely polycrystalline or even amorphous. If to consider, that mechanical pressure decrease deep into silicon under the law 1/r, it is possible to conclude, that more disordered layer adjoins directly to the silicon dioxide. Thickness of these layers are proportional to thickness grown up oxides, that it is possible to explain increase mechanical pressure on border of section at increase in thickness of oxides.

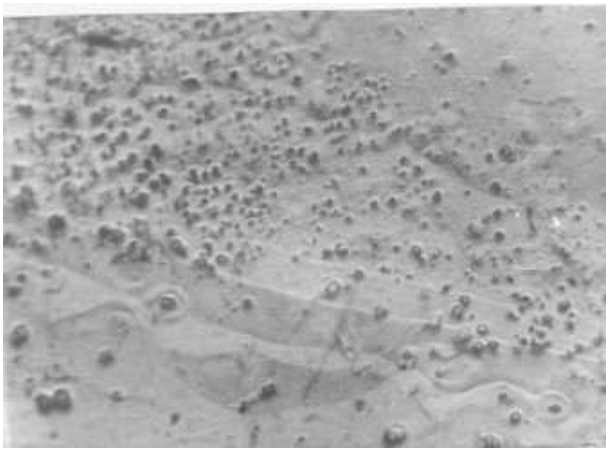

Fig. 1. Optical image of silicon surface (microscope MMR-2P)

At the further etching of a silicon surface (till 3 minutes) were revealed dislocation network (a dislocation density make up to 10^{10} m^{-2}), which have included 60° and partial dislocations and were decorated oxygen (fig. 2). The appeared typical structural defects testify to occurrence of normal crystal structure Si. After 5 minutes etching separate dislocations and glide lines appeared instead of dislocation networks (fig. 3).

In confirmations such complex structure of silicon near-surface region X-ray diffraction method was

made. X-ray diffraction method has shown that near-surface layers of silicon consist of some one which has different structure. Rocking curves presented on Figs. 4a, 4b. The slope of a curve change is explained to presence of the second reflective layer. By means of Gaussian function approximation was determined the maximum and the half-width of "little" curve that could calculate other parameters of silicon. The shift of maximum and the curve broadening comparative the ideal standard specimen are determined of some physical causes such as the macrostress and the microstress. Macrostresses are counterbalanced in volume of all samples and cause the diffraction maximum shift and for this one we have such expression as [3]:

$$\frac{\Delta d}{d} = \frac{\beta}{4tg\theta}, \qquad (1)$$

where $\Delta d/d$ – the relative deformation of lattice constant, β – the half-width of the curve, θ – the angle of reflection.

Microstresses are caused by polycrystalline structure and they can be associated with dislocations. And for this stress we have such expression as

$$D = \frac{\lambda}{\beta\cos\theta}, \qquad (2)$$

where λ – the wavelength, we calculated D – the crystallite size.

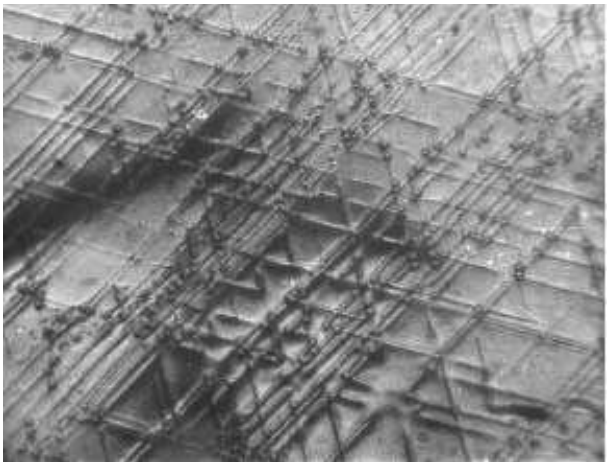

Fig. 2 The electronic image of dislocation networks (1x2300)

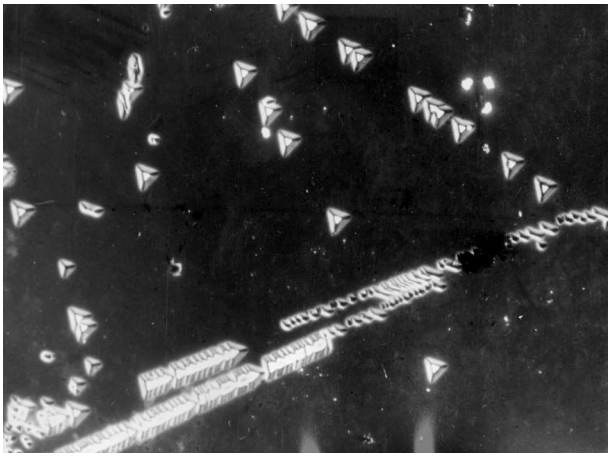

Fig. 3 The electronic image of separate dislocations

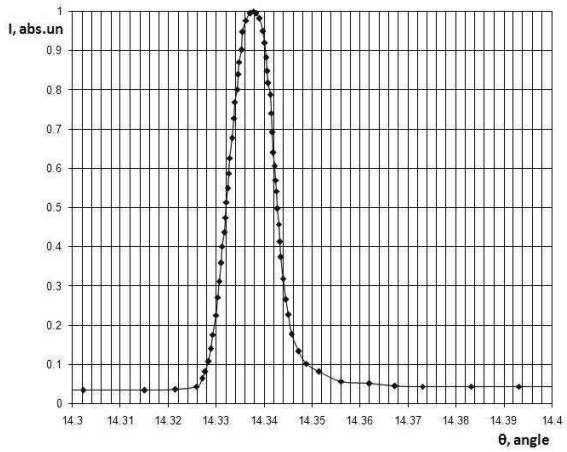

Fig.4 *a*. The rocking curve (oxide thickness 0.15 micron)

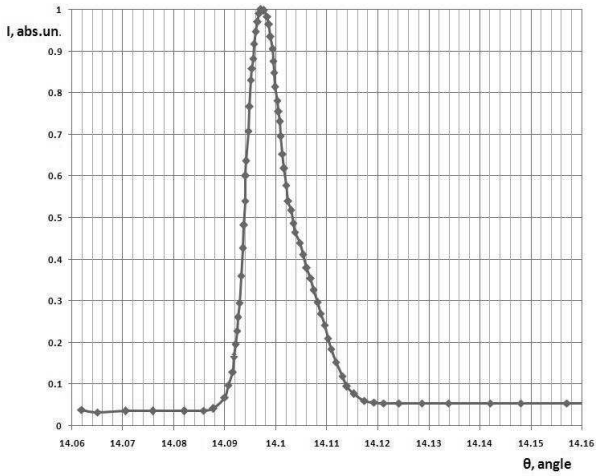

Fig.4 *b*. The rocking curve (oxide thickness 1.5 micron)

Generally the width of lines depends also on cleanly geometrical factors of conditions of shooting, from divergence of a bunch, incomplete splitting of a doublet.

Thus, on broadening of spectral line it is possible to define structural features of a studied crystal. The made calculation of parameters for second curves (Fig. 3 *b*) has shown the following:

Table 1

	Δa (the change of lattice constant) [A]	σ (the stress) [dyne/cm²]	D (the crystalline size) [micron]
The main maximum	0,013	2,2 109	0,87
The "little" maximum	0,019	3 109	0,61

Thereby if we know the curve broadening of 2 orders of reflection for the same reflection plane we can make qualitative evaluation and determine what parameters influence on the curve broadening. Using the following expression

$$\frac{\cos\theta_1}{\cos\theta_2} < \frac{\beta_2}{\beta_1} < \frac{tg\theta_2}{tg\theta_1}, \qquad (3)$$

where θ — angle of reflection, β – half-width of the rocking curve. We obtained 1<1.11<3.35Therefore

the layer structure dispersion has the main influence on curve broadening and the near-surface layer of silicon has complex structure and consists of at least two layers, layers differing by thickness and the crystalline sizes.

4. CONCLUSIONS

Thus, proceeding from the received experimental data, it is possible to draw following conclusions:

1. As have shown researches, the near-surface area of silicon in structures silicon - dioxide silicon consists of disordered area adjoining to the silicone dioxide, having complex structure, and the areas containing dislocation networks.

2. The given structure is formed to those residual pressures, caused by the sum of contributions of the interface stresses, and stresses caused by oxygen which diffused deep into silicon in the line of structural defects.

3. More stressed area of silicon adjoins to the interface and leads to dispersivity of this structure. The crystalline sizes increase in process of removal from the interface and pass in not stressed monocrystalline silicon.

4. The depth and block parameters of the given structure depend on dioxide thickness grown up, from quality of initial monocrystalline silicon, from conditions of oxidation.

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ИССЛЕДОВАНИЕ СТРУКТУРЫ ПРИПОВЕРХНОСТНЫХ СЛОЕВ КРЕМНИЯ В СИСТЕМАХ КРЕМНИЙ – ДИОКСИД КРЕМНИЯ

В данной работе на основе проведенных с помощью современных методов исследования показана сложная структура приповерхностных слоев кремния в системах кремний – диоксид кремния. Выявлены зависимости параметров этих слоев от условия оксидирования и характеристик первоначального кремния.

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ДОСЛІДЖЕННЯ СТРУКТУРИ ПРИПОВЕРХНЕВИХ ШАРІВ КРЕМНІЮ В СИСТЕМАХ КРЕМНІЙ – ДІОКСИД КРЕМНІЮ

В роботі на основі проведених за допомогою сучасних методів досліджень приповерхневих шарів кремнію в системах кремній – діоксид кремнію показано їх складна структура. Показано залежність розмірів ціх шарів від параметрів окислення та характеристик кремнію.