Morphology Change in System "SiO_2/Si-Substrate" after Irradiation by High Power Ion Beam of Nanosecond Duration

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Abstract – The formation of periodic wave-like structures on the surface system "SiO_2/Si-substrate" induced by irradiation with nanosecond pulse of high power ion beam was investigated. The surface topography of the irradiated samples was inspected by optical microscopy and atomic-force microscope. The influence of the ion current density and the number of pulses on features wave-like structure was studied. The probable mechanism of formation was discussed.

1. Introduction

The interest in research of the influence concentrated flow energy on system "dielectric-semiconductor" is determined by possibility of their using for making different microelectronic devices. The influence on similar systems of the pulsed laser radiation was studied a more detail. Laser-induced periodic surface structure (LIPSS) has become an important research topic in the area of laser-materials interactions for about three decades [1, 2]. The mechanisms of wave-like structure formation in SiO_2/Si structure are more related to the surface waves caused by surface roughness and inhomogeneity, freezing of capillary waves, and generation of transient periodic heating pattern.

In present paper the changing of surface morphology in the system "SiO_2/Si-substrate" after irradiation by high power ion beam (HPIB) of nanosecond duration was investigated for the fist time.

2. Experiment

The samples used in this study are n-type silicon with the (111) orientation and a resistance of 10 Ω cm. SiO_2 films were grown on the samples by thermal oxidation in dry air at the temperature 1150 ˚C for 3 hours.

High power ion beam was generated by the "Temp" accelerators. The compositions of beam were 70 % C^+ and 30 % H^+. The ion accelerating voltage was 300 kV, averaged ion current densities were 50–150 A/cm^2 and pulse duration was 50 ns. After high power ion beam irradiation surface morphology of samples was observed by atomic-force microscope "Solver Pro" and optical microscope "Neophot-2". In experiments the averaged ion current density and the number of HPIB pulses was varied.

3. Results and discussion

It was found that HPIB irradiation with the ion current density >30 A/cm^2 can produce the wave-like structure in SiO_2/Si sample by single pulse (Fig. 1).

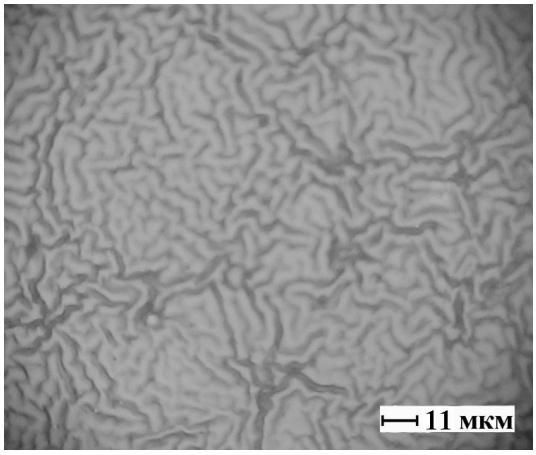

Fig. 1. Optical image of surface system "SiO_2/Si-substrate" after irradiation by HPIB with j=100 A/cm^2

The average period of this wave-like structure is around 5 μm (Fig. 2).

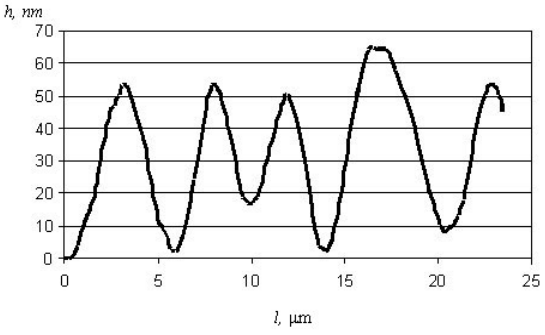

Fig. 2. Profile of the of surface system "SiO_2/Si-substrate" after irradiation by HPIB with j=50 A/cm^2

The increase of the ion current density does not change the period of this wave-like structure, but enlarges the height of these structures (Fig. 3). If "SiO_2/Si-substrate" system is irradiated by HPIB with ion current density 150 A/cm^2 then local removal of the SiO_2 layer is observed.

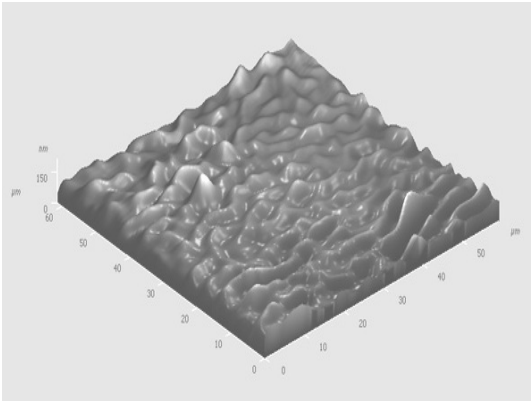

Fig. 3. AFM image of surface system "SiO_2/Si-substrate" after irradiation by HPIB with j=120 A/cm^2

Under HPIB irradiation with the ion current density in the range 30 –150 A/cm^2 the thickness of SiO_2 layer reduce. This reduction is confirmed by the change of interference coloration of the SiO_2 layer.

Furthermore, similar reduction of the thickness SiO_2 layer take place under the frequentative irradiation even for the ion current density <30 A/cm^2, when the wave-like structure is not formed. For small density of the ion current density (~30 A/cm^2) this reduction of thickness is determined sputtering of SiO_2 layer by ion carbon obviously. For greater the ion current density the thermal evaporation is added to sputtering process. In these cases a change of the period wave-like structure is not observed though not uniform thickness of SiO_2 layer originated because of non uniform HPIB irradiation of system "SiO_2/Si-substrate". Repeated HPIB irradiation of the this system does not leaded to the change performance of the wave-like structure as this is observed for excimer laser irradiation [3]. The HPIB irradiation with the ion current density 150 A/cm^2 causes the local damage in the surface layer of Si substrates in the form of cracking along cleavage plane and removal of the separated fragments from surface layer. The fracture is caused by generating quasistatic stresses which exceed of the fracture threshold of Si-substrate.

For excimer laser irradiation of like system the period of the wave-like structure linearly depends on the SiO_2 thickness [1, 4]. Under irradiation HPIB such the dependence is not found. In our experiments the shape of the wave-like structure in system "SiO_2/Si-substrate" is not depended from the magnitude of the ion current density.

4. Conclusion

Thus the wave-like periodic structures produced HPIB irradiation on surfaces of the system "SiO_2/Si-substrate" can not be explained by excitation of the surface waves in system "SiO_2/melt Si" and the following their solidification. The probably appearance the wave-like periodic structures can be connected with the action on the heated SiO_2 layer the quasistatic stresses.

References

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