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Ion-beam formation of nanopores and nanoclusters in SiO_2

F.F. Komarov*, L.A. Vlasukova, O.M. Milchanin, P.I. Gaiduk, V.N. Yuvchenko, S.S. Grechnyi

Belarussian State University, F. Skorina Ave. 4, Minsk 220050, Belarus

Abstract

We studied nanopores and nanoclusters formation in thermally oxidized silicon wafers (SiO_2/Si) by means of ion-beam technique. RBS, SEM, TEM and TED were used to characterize the SiO_2 layers after the ion-beam processing. Nanopores were formed by high-energy Kr ions irradiation followed by chemical etching of latent tracks zones in SiO_2 matrix. Holes with diameters of ~10–15 nm and length/diameter ratios of up to 22 have been etched through the SiO_2 film. The results of computer simulation of the track formation processes in SiO_2 based on the modified thermal spike model are also presented. Calculated radiuses of molten regions along swift Kr ion trajectories in fused silica have been compared with etched tracks dimensions. Nanoclusters were formed by co-implantation of As and In ions followed by high-energy Kr ions irradiation and thermal annealing. The high-energy Kr ions irradiation as a thermal annealing alternative was carried out to induce nanoclusters formation in swift ions tracks zones. TEM investigations of annealed samples demonstrate the presence of amorphous nanoclusters located at the depth of 40–190 nm. Their sizes vary from ~2.5 to ~6 nm. No influence of swift ion irradiation on the oriented precipitation of dopants (In + As) in the tracks region was revealed.

Keywords: Silicon dioxide; Ion irradiation; Latent tracks etching

1. Introduction

In the last decade, nanometer wires and crystallites are investigated intensively to study the effects of quantum confinement and to create nanoelectronics devices integrated into the silicon substrates. Inexpensive method of nanowires formation is electro-replication of nanoporous template structures. Multi-porous alumina or ion track polymer membranes were used as the template structures [1,2]. The technique is based on nanoscopic pores, embedded in a solid matrix and serving as a template for the growth of three-dimensional structures. It enables to prepare very

*Corresponding author. Institute of Applied Physics Problems, Belarussian State University, Kurchatova Street 7, Minsk 220064, Byelorussia. Tel.: +375 172 124833; fax: +375 172 780417.
E-mail address: komarovf@bsu.by (F.F. Komarov).

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fine metal, semiconductor and oxide structures with specified geometry and aspect ratio. Amorphous SiO_2, grown by thermal oxidation of monocrystalline Si (SiO_2/Si), is well studied and convenient for investigation material, completely compatible with silicon technology. The structures SiO_2/Si, irradiated with swift ions, may be useful for the creation of nanopores system. The swift ion irradiation of dielectrics can lead to the formation of latent tracks along the ion trajectories [3,4]. These tracks are the matrix regions which are in the form of elongated cylinders with diameters of 5–20 nm with a modified density and chemical bond. A chemical treatment in the suitable solution leads to the formation of nanometer holes in the latent tracks area, which may be useful for etching of pores in the SiO_2 film.

One method of nanocrystallites synthesis is the high-dose ion implantation with the following annealing. This method allows the formation of nanometer precipitates that are embedded in the host matrix. Nanoclusters of semiconductors of the VI group, some II–VI compounds and most of the III–V compounds have been synthesized by this method in the amorphous SiO_2 and crystalline Si and Al_2O_3 [5–8]. It seems to be interesting to check the possibility of the swift ion irradiation as an alternative for the thermal annealing of the nanocluster creation in the SiO_2 implanted layers. After the swift ion passes through an insulator, very fast heating and cooling of the target material occurs in the narrow (with a diameter of a few nanometers) cylinder along the ion track [9]. Thermal non-equilibrium processes may lead to the preferred precipitation and crystallites formation in the tracks region. Nanocrystallites formed by such a method, would be notable for their well-ordered location in the matrix (in the tracks region) and their sizes that are of several nanometers. Earlier, we have observed dopant redistribution on the surface of the layer of solid solution of Si⟨In⟩ under the influence of swift Bi ion irradiation [10].

In this work, we present the results of the investigation of the structure and morphology of nanometer pores and clusters formed by the ion-beam methods in amorphous SiO_2 on Si. We also present the results of the calculation of the track formation in fused silica based on the modified thermal spike model.

2. Experimental

Samples used in this work were thermally oxidized n-doped (1 0 0) Si wafers. SiO_2 film thickness was 460 nm. SiO_2/Si structures were irradiated normal to the surface with 253 MeV Kr ions with fluences of 1×10^{10}, 5×10^{10} and $2.25\times10^{11}\,cm^{-2}$ at the Joint Institute for Nuclear Research (Dubna, Russia) to form nanopores. The ion flux was kept constant and equal to $2\times10^{8}\,cm^{-2}\,s^{-1}$. To provide reliable thermal contacts, the samples were fixed on a massive metallic holder with a heat conducting paste. Irradiated samples SiO_2/Si were treated in buffered hydrofluoric acid (30 g NH_4F + 10 ml HF + 50 ml H_2O). Then the samples were investigated by the scanning electron microscope Hitachi S-806. The thickness of SiO_2 layer was evaluated from ellipsometry measurements and by the color table.

The SiO_2/Si structures were implanted at room temperature with the As^+ ions first and In^+ ions later to form nanoclusters. The multiple energy implantation regime is described in Table 1. The implantation regime was calculated to obtain 150 nm thick near-surface layer uniformly doped with In and As atoms up to equal concentrations $\sim4.5\times10^{20}\,cm^{-3}$. Then the (As + In)-implanted SiO_2/Si were irradiated with 253 MeV Kr ions

Table 1
The regime of the multiple energy implantation of arsenic and indium into SiO_2

Energy (keV)	Fluence (cm^{-2})
Arsenic	
200.0	4.5×10^{15}
100.0	1.6×10^{15}
50.0	9.7×10^{14}
Indium	
300.0	3.6×10^{15}
170.0	1.4×10^{15}
100.0	1.0×10^{15}
50.0	7.0×10^{14}