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PHYSICAL SCIENCE OF MATERIALS

Analysis of Surface Morphology and Chemical Composition of Silicon Implanted with Copper Ions

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Abstract—We report on the results of analysis of the structure and chemical composition of the surface of *c*-Si single crystal substrates implanted with Cu^+ ions with energy of 40 keV and doses in a range of 3.1×10^{15}–1.25×10^{17} ions/cm^2 for a current density of 8 μA/cm^2 in the ion beam. It has been established using scanning electron microscopy and probe microscopy combined with X-ray photoelectron and Auger spectroscopy that at the initial stage, the implantation with Cu^+ ions to a dose of 6.25×10^{16} ions/cm^2 induces the formation of Cu nanoparticles with an average size of 10 nm in the Si surface layer. Upon a further increase in the implantation dose, beginning with 1.25×10^{17} ions/cm^2 and higher, the nucleation of the η phase of copper silicide (η-Cu_3Si) is observed. This is due to heating of the surface layer of the Si substrate during its irradiation to a temperature facilitating the formation of the η-Cu_3Si phase.

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INTRODUCTION

Various technological methods used in practice for the implantation or deposition of the Cu impurity for a targeted modification of the surface properties of *c*-Si change the morphology, the phase composition of the surface, as well as electrochemical, electric, and optical characteristics of Si. Such technologies include, for example, immersion chemical deposition of Cu from the $CuSO_4 \cdot 5H_2O$ solution on the plane wafer surface or on a porous Si (PSi) layer [1], which leads to the coating of Si with an almost continuous layer of Cu nanoparticles of a size of ~10 nm. Another approach to PSi modification is the electrochemical deposition of Cu nanoparticles from colloidal solution on the sample surface [2]. In these publications, partial oxidation of Cu nanoparticles was observed without the formation of any copper silicide phase.

In addition to chemical deposition of Cu on Si, a physical method of implantation of metal impurities (e.g., ion implantation) is used [3]. It is well known that this approach is widely employed in semiconductor technology in fabrication of electronic devices [4]. Apparently, publication [5], in which the implantation of Si was performed with relatively small doses ($D < 5 \times 10^{15}$ ions/cm^2), was one of the first works on implantation of Cu^+ ions into Si.

In this study, we have carried out experiments on the implantation of *c*-Si single-crystal substrate by Cu^+ ions with energy of 40 keV in various doses D for estimating the possibility of Cu nanoparticles controllable formation in Si and investigated the peculiarities in the change of the structure and chemical composition of irradiated Si surface.

1. EXPERIMENTAL

As the initial substrate, we used polished *c*-Si single-crystal wafers. Implantation was performed with Cu^+ ions with energy $E = 40$ keV and dose D in the range 3.1×10^{15}–1.25×10^{17} ions/cm^2 for ion beam current density $J = 8$ μA/cm^2. The implantation was carried out using an ILU-3 ion-beam accelerator at the room temperature of irradiated substrates. The structure of the sample surface was analyzed using a Merlin scanning electron microscope (SEM) (Carl Zeiss) and a Dimension FastScan scanning probe microscope (SPM) (Bruker). The element analysis was performed using an X-Max energy-dispersive X-ray spectrometer (EDX) (Oxford Instruments) integrated into the SEM. The chemical composition of the samples and the valence state of the implanted Cu impurities in Si were analyzed using X-ray photoelectron spectroscopy (XPS) and Auger electron spectroscopy (AES) with the profiling of the sample surface with