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Short Communication

Formation of porous germanium layers with various surface morphology in dependence on mass of implanted ions

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ABSTRACT

The surface morphology of nanoporous Ge (PGe) layers formed by low-energy high-dose implantation with transition metal ions depending on their mass ($^{52}Cr^+$, $^{55}Mn^+$, $^{56}Fe^+$, $^{59}Co^+$, $^{59}Ni^+$ and $^{63}Cu^+$) was studied by high-resolution scanning electron microscopy. Ion implantation of single-crystal *c*-Ge substrates was carried out using similar conditions with an energy of $E = 40$ keV and a dose of $D = 5.0{\cdot}10^{16}$ ion/cm^2. Additionally, *c*-Ge was also implanted with heavier ions $^{108}Ag^+$ and $^{122}Sb^+$ at $E = 30$ keV for comparative experiments on the surface PGe morphology. It was observed that the morphology of the PGe layers changed with increasing mass of the irradiated ion from a labyrinth, hole type, three-dimensional network to spongy structure.

1. Introduction

Developing of anode electrodes made on nanostructured Ge martials, for example, porous germanium (PGe) layers for rechargeable lithium batteries [1] and photodetectors as well as for solar cells [2], was increasingly studied during recent years for electronic industry applications. The history of fabrication and research of PGe begins from the first work presented in 1971 [3], which analyzed the vapor deposited thin amorphous Ge films with voids (pores) in their structure. Later, various techniques were applied to obtain PGe layers, such as electrochemical electrolyte processing and pore etching [4,5], surface templating [6], plasma-stimulated chemical vapor deposition [7], spark discharge method [8], thermal annealing of GeO_2 ceramic films in hydrogen atmosphere [9] and others.

High-dose implantation with various ions in a vacuum proved to be an effective specific technique for creating nanoscale thin PGe layers on single-crystal *c*-Ge substrate surface. According to the literature review, the first report describing this approach was published in 1977 [9]. The formation of craters on the Ge substrate implanted with heavy $^{128}Te^+$ ions at $E = 20$ keV and $D = 1.0{\cdot}10^{13}$ ion/cm^2 and $^{128}Te^{2+}$ at $E = 40$ keV and $D = 0.5{\cdot}10^{13}$ ion/cm^2 was observed using scanning electron microscopy (SEM). The key and the most cited publication on this subject published in 1982 [10] demonstrated the fabrication process of a spongy like PGe structure on the surface of *c*-Ge implanted with relatively light $^{73}Ge^+$ ions at $E = 50$–300 keV and doses $D = 2.0{\cdot}10^{15}$–$4.0{\cdot}10^{17}$ ion/cm^2. Also, a PGe development mechanism was proposed, which consisted in combining point cluster vacancy defects in the implanted surface region made of cascades of accelerated ion collisions with Ge substrate atoms.

As it was discussed in the review article [11], the structural features of the PGe layer critically depend on various parameters and conditions of ion implantation, namely, dose, current density in the ion beam, acceleration energy and ion mass, temperature of the irradiated material, etc. The purpose of present work is to demonstrate the formation of the surface PGe layers with various morphologies by low-energy high-dose implantation with transition metal ions of different masses. Recently [12,13], it was shown that the low-energy implantation of *c*-Ge with heavy $^{108}Ag^+$ ions at $E = 30$ keV lead to PGe layers with spongy morphology structure consisting of Ge nanowires coated with Ag nanoparticles. On the other side, implantation of lighter $^{63}Cu^+$ ions at 40 keV showed the formation of a neuron-like three-dimensional network structure of PGe [14]. Separate Cu nanoparticles were localized in the network nodes. This article addresses the formation of PGe layers with various surface morphologies after implantation of *c*-Ge with Cr^+, Mn^+, Fe^+, Co^+, Ni^+ and Cu^+ ions (in order of mass increasing). Also, some examples of PGe layers formed with heavy Ag^+ and Sb^+ ions are also presented for comparison.

2. Experimental

Nanostructured PGe layers were formed on a 0.5-mm-thick *c*-Ge

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