FORMATION OF BURIED HIGH-RESITANT LAYERS IN SILICON BY TWO-STEP SUBSTOICHIOMETRIC IMPLANTATION OF NITROGEN IONS

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The implantation of nitrogen at an elevated temperature with a dose of (2,5-4)·10^{16} ions/cm^2 at 200 keV and higher energies was carried out. The elevated temperature of the substrate results in reduction of damage in the top surface layer and prevention of it from contamination due to hydrocarbons and atomic recoil processes. Then the implantation at room temperature with dose necessary for the formation of buried amorphous layers was also carried out. The temperature of subsequent annealing was below the threshold at which complete crystallization of the amorphous layers is possible. By means of N_2^+ ions implantation at an energy of 200 keV and higher with subsequent annealing at 900°C buried amorphous layers with resistance up to 10^6 Ω·cm were formed.

1. Introduction

lSilicon-on-isolator (SOI) structures are serious competition to the traditional silicon plates and epitaxial structures as a choice of the initial material for manufacturing of ultralarge integrated circuits with submicron-sized elements. Alongside with the implantation of oxygen, the attempts are undertaken to use nitrogen and oxygen with nitrogen ion implantation for the creation of nitride and oxynitride layers in silicon.

The application of nitrogen ion implantation for the formation of buried insulating layers in semiconductors is attractive for some reasons. Firstly, the nitrogen ion dose required in this case is 40–50% of the oxygen ions dose necessary for the formation of a buried oxide layer with a sharp Si-SiO_2 interface [1]. Secondly, it is excluded the generation of superfluous Si interstitial atoms appearing as the result of internal oxidation that has place in case of the oxygen implantation and causes the formation of dislocations in the surface layer of silicon. Thirdly, the buried Si_3N_4 layer behaves as an improved diffusion barrier for basic doping impurities. At last, in the case of nitrogen implantation a service life of the ion source is much longer.

2. Results

Earlier [2] we have revealed that the layers of silicon amorphised with implantation of 5×10^{16} cm^{-2} N_2^+ ions, as against the case of implantation of other ions, including O_2^+, keep amorphous state after annealing at temperatures on some hundreds degrees exceeding the temperature of epitaxial crystallization of the amorphous pure Si. This dose is 4–5 times less than the dose necessary for the formation of continuous stoichiometric nitride layer. It is meaningful to name such doses as substoichiometric ones. Later the range of doses necessary for the increase of the amorphous Si:N thermal resistance was determined in [3] to be within the limits of 10^{16}–10^{17} cm^{-2} for 40 keV N^+ ion implantation. Considering the fact that the amorphous silicon has high electrical resistance, we have applied substoichiometric ion implantation of nitrogen to the creation of buried insulating thermo-resistant layers. The conditions to be fulfilled are the role of the crystal seed for partial epitaxial crystallization at the subsequent annealing should be kept. In the case of 'hot' implantation these conditions are rather easily carried out, as the dynamic annealing of radiation damage is most effective just in the surface area [4]. In the case of 'cold' (at room temperature) implantation for this purpose the rather high energy (230 keV) was applied and no special measures were undertaken for the suppression of channeling effect, so at least on the initial stage of ion implantation the accumulation of defects in surface area should occur to smaller rate.

Implantation was carried out in the n-Si (001) wafers. Post-implant annealing was carried out at 900°C within 0.5 hour. The Rutherford backscattering (RBS) of channeled He^+ ions, diffraction of fast electrons, measurement of leakage currents were used for the investigation of the formed buried layers.

The 'cold' implantation (at room temperature) rather easily results in formation of buried amorphous layers. With the dose increase there is an expansion of the amorphous layer both in to the silicon target, and towards the surface. However, even in a case of the maximal dose it was observed a monocrystal surface layer, though strongly damaged. At the annealing temperature (900°C) epitaxial crystallization of surface layer occurs (Fig.1). The relative minimal yield χ_{min} (ratio of the absolute signal for oriented analyzing beam near to a surface to the signal for non-oriented beam) is about of 13 % (it is about 3 % for an initial crystal), testifies the relatively good quality of the crystallized layer. It is necessary to note that there is a film on surface with thickness not less than 30 nm, which components are carbon, silicon (in insignificant amounts) and, what is most interesting, nitrogen. It is possible to make a conclusion that the migration of nitrogen to a surface occurs during the annealing in defective regions of the crystal, first of all, along the dislocation lines. Thus, at least three circumstances can be the constraining factors in application of usual 'cold' implantation for obtaining of the buried layers: 1) the formation of carbon-containing film 2) the migration of nitrogen to a surface, 3) the reduction of ion energy can result in complete amorphisation of the surface layer, so the

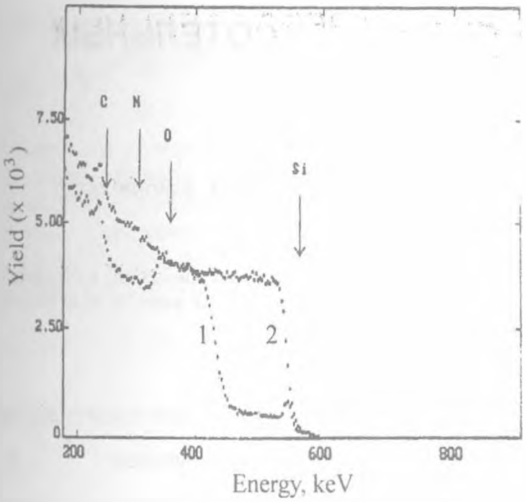

Fig.1. RBS spectra of 1 MeV He^+ ions for Si crystal after implantation of 230 keV N_2^+ ions with dose $5{\times}10^{16}$ cm^{-2} at 20°C and subsequent annealing at 900°C within 30 minutes: 1 – oriented <100>; 2 – non-oriented.

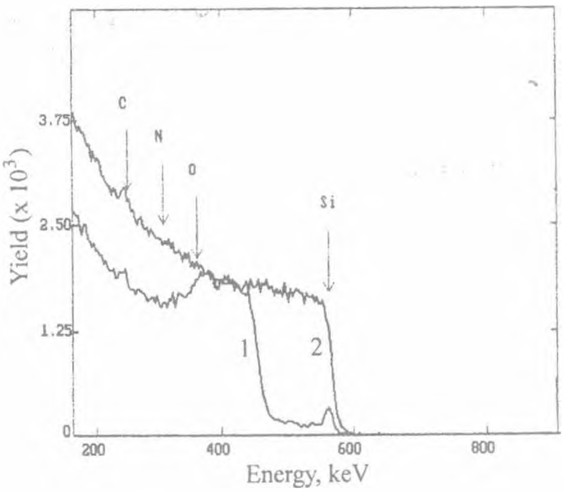

Fig.2. RBS spectra of 1 MeV He^+ ions for the Si crystal after 'hot' (400°C) substoichiometric implantation of 200 keV N_2^+ at dose $5{\times}10^{16}$ cm^{-2} and additional low-dose 'cold' implantation and subsequent annealing at 900°C within 30 minutes: 1 – oriented < 100 >; 2 – non-oriented.

the substoichiometric implantation (with additional perature) results practically in suppression of the influence of first and, largely, of third factor. Hydrocarbons in this case are not condensed on the surface of the hot target, and dynamic annealing of radiation defects in surface areas appears extremely effective. The annealing procedure results in some reduction of the amorphised layer thickness caused by partial epitaxial crystallization from the substrate and surface sides (Fig.2). The buried layer is located in the region of maximum of the implanted nitrogen distribution. The thickness of the buried and surface monocrystallic layers (about 180 nm) are within the limits of values desirable for SOI-structures [3]. Certainly, varying the energy of ions and the ion dose, that allows to keep main advantage of substoichiometric ion implantation, can control this thickness. The electrical properties of the buried layers represent the doubtless interest. The average meaning resistance of $1.1{\times}10^6$ Ω-cm is obtained from measurements of so-called pass-through resistance, when the voltage was applied to contacts on the working and backward sides of the sample, and the leakage currents were measured. The measured value is on three order of magnitude higher than the value achieved recently in SODL (Silicon-on-Defect-Layer) technology [5], where insulating layers were formed with proton implantation with subsequent annealing.

3. Conclusion

By means of N_2^+ ions implantation at an energy of 200 keV and higher with subsequentivity up to 10^6 Ω-cm were formed such layers are of interest for the microelectronic applications technology due to low dose and low temperature procedure needed. It is a competitive procedure in a comparison with the routine technology of SOI-structures.

References

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