# OPTICAL PROPERTIES OF $SiO_2$/Si LAYERS ENRICHED IN GERMANIUM BY ION IMPLANTATION

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Germanium ions have been doubly-implanted with different energies and fluences to obtain a quasi-rectangular depth distribution of Ge atoms in a 700 nm thick $SiO_2$ layer on Si. Subsequently, the samples were annealed at temperatures in the range from 700°C to 1100°C for 1h. The depth distribution of Ge atoms in these layers were determined from the Rutherford backscattering (RBS) measurements. For the samples annealed at temperatures higher than 800°C the diffusion process of Ge atoms takes place in two directions: towards the implanted surface and to the $SiO_2$/Si interface. The refraction index *n* and extinction coefficient *k* are materials parameters important from the point of view of optoelectronic applications. Their values were obtained with a help of the Multiple Angles of Incidence Ellipsometry (MAIE) investigations. It was observed that the value of refraction index of the $SiO_2$/Si layer increases about 2% after implantation in a comparison with the unimplanted $SiO_2$ material. Subsequent annealing reduces the refractive index, but the pre-implantation value is not attained. is noticed with the increase of the annealing temperature. This effect can be explained by defect dependent volume change in implanted layer and the change of atomic bond polarizability.

## Introduction

In the last decade, there has been observed increasing interest in study of nanostructures formed by implantation of group IV ions into $SiO_2$ layers on Si [1-4]. These nanocomposite materials have a potential for developing integrated optoelectronic and electronic memory devices directly on silicon substrates. Ion implantation provides a precise means to modify the material properties according to our wishes. The technique, fully compatible with silicon technology is nowadays widely used in electronic device industry. In this paper, we present the results of ellipsometric investigation of $SiO_2$ layers implanted by germanium ions, and subsequently thermally annealed. Rutherford Back Scattering (RBS) study has shown that redistribution process of Ge atoms in $SiO_2$ took place after annealing. Three layers structures in the Ge depth profiles are observed. The values of optical constants of $Ge^+$ implanted $SiO_2$ at different annealing temperatures were determined on the basis of ellipsometric studies.

## Experiment

Germanium ions were implanted at room temperature with two energies: 480 keV and 280 keV and fluences of $4.2x10^{16}$ $cm^{-2}$ and $1.7x10^{16}$ $cm^{2}$, respectively, into a 700 nm-thick $SiO_2$ layer on crystalline Si. After this process the samples have been annealed at temperatures from 700°C to 1100°C for 1 hour. This process has been carried out in a dry nitrogen. Multiple Angle of Incidence Ellipsometry (MAIE) measurements [5] were performed at incidence angles of a laser beam (λ=632.8 nm) ranging from 45 to 86 degs. Subsequently, the RBS investigations for all samples were carried out using $He^+$ particles of 2.035 MeV energy and at the scattering angle of 170 degs. The detector resolution was not worse than 15 keV. All the samples were studied at such two angles Φ, that the target surfaces were tilted 30° and 60° with respect to the analyzed beam, and the solid angle was 0.001 sr in the RBS experiment.

## Results and discussion

In Fig.1 the typical spectrum of scattered α particles is presented, collected for the implanted sample before annealing. The maximum between 1.3 MeV and 1.6 MeV can be attributed to the α particles scattered on germanium atoms. Shapes of the spectral features in this energy region are different for samples annealed at different temperatures.

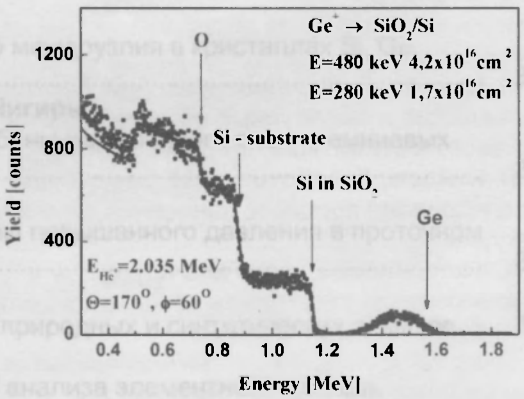


Fig. 1 RBS spectrum of $Ge^+$-implanted $SiO_2$/Si layer

For example, there are at least three components in this region for samples annealed at 1000°C (Fig.2). This effect can be related to diffusion process of germanium atoms during thermal annealing. On the basis of the RBS measurements the depth distributions of Ge atoms in implanted layers have been obtained. The results are presented in Fig.3 and Fig.4.

It is observed in Fig. 4 that the depth distribution of Ge consists of three zones: the first centered at 150 nm below the surface, the next, wide between 280 and 600 nm, and the last one at the interface between oxide layer and crystalline Si substrate. The separation effect can be explained by diffusion of germanium atoms into areas where the defect concentrations are greater.

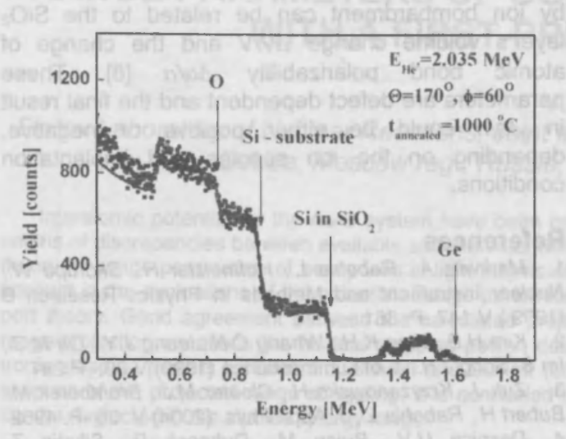


Fig. 2. RBS spectrum of Ge$^+$-implanted $SiO_2$/Si layer after annealing at 1000°C.

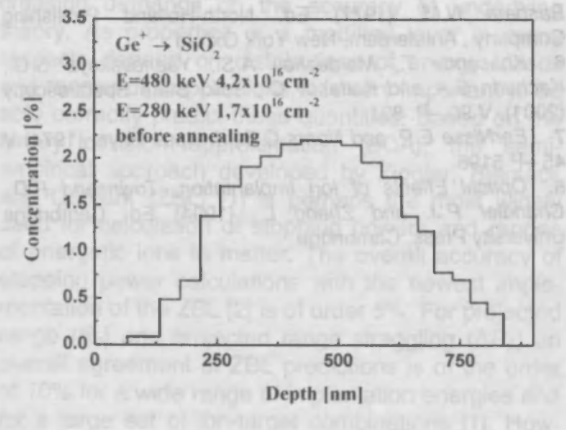


Fig. 3 Depth distribution of germanium atoms in implanted 700 nm thick layer of $SiO_2$

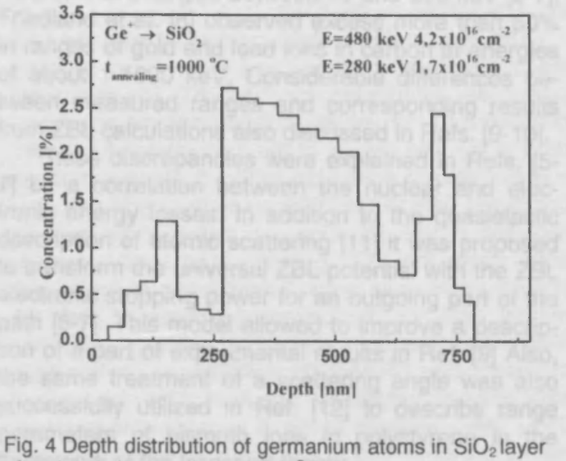


Fig. 4 Depth distribution of germanium atoms in $SiO_2$ layer after thermal annealing at 1000°C.

The ellipsometric parameters Ψ and Δ were measured as a function of the incidence angle, and the examples are presented in Figs. 5 and 6 for unimplanted and implanted samples, respectively.

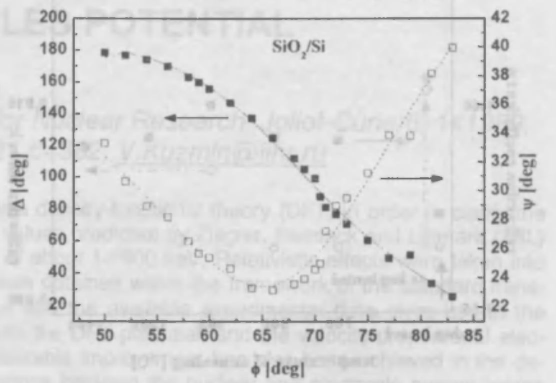


Fig. 5 Ellipsometric parameters as a function of the incidence angle for unimplanted $SiO_2$/Si: open squares-Ψ and black squares-Δ. The best fit results are represented by solid and dashed lines

From these measurements it can be noticed that the principal angle values are close to 65 and 70 degs for unimplanted and implanted samples, respect- ively (Figs. 5 and 6).

In the last step of our investigation the optical constants, i.e. refraction and extinction coefficients of Ge$^+$-implanted $SiO_2$/Si layers have been determined from the Ψ and Δ ellipsometric parameters. The coefficients were calculated using in the first approximation the three-phase model (an ambient, a parallel layer and a crystalline substrate) The results of the fits are presented in Fig. 5 and Fig. 6. They indicate a good agreement with the measurement data.

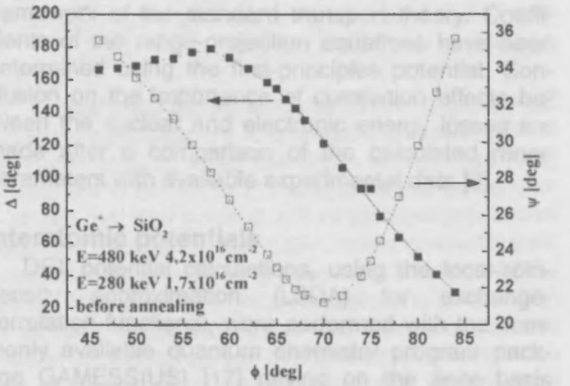


Fig. 6 Ellipsometric parameters as a function of the incidence angle for implanted $SiO_2$/Si: open squares-Ψ and black squares-Δ. The best fit results are represented by solid and dashed lines

Following Ge$^+$ implantation of the $SiO_2$ layer, the refraction coefficient and extinction index values increase and after thermal annealing the values of these parameters generally diminish with a (possible) local maximum at 900°C (Fig.7). Very similar effect was observed for $SiO_2$/Si layers implanted with Si$^+$ ions [6].

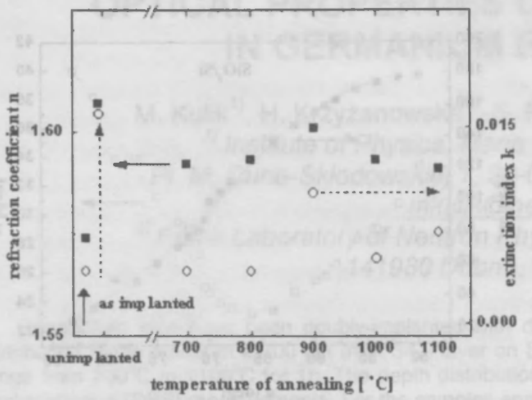


Fig. 7 Optical constants values for unimplanted and $Ge^+$-implanted $SiO_2$/Si layers, before and after annealing at different temperatures, refraction index – black squares, extinction coefficient – open circles

There are two mechanisms by which ion implantation creates structural damage in $SiO_2$ [7]. One involves atomic collisions displacement of Si and O from their sites and possible reordering over distances larger than the basic Si-O tetrahedral dimensions. The other is due to electron or ion ionization leading to structural defects within the Si-O tetrahedral, such as broken Si-O bands.

The refractive index increase $\Delta n/n$ (~2%) caused by ion bombardment can be related to the $SiO_2$ layer's volume change $\Delta V/V$ and the change of atomic bond polarizability $\Delta\alpha/\alpha$ [8]. These parameters are defect dependent and the final result in $\Delta n/n$ could be either positive or negative, depending on the ion species and implantation conditions.

## References

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