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# Measurements of stress during ion irradiation

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The exemplary results obtained with a simple optical set-up for the measurement of curvature radius during ion implantation are presented. The Kr ion irradiation was performed for silicon substrate without a film. After the irradiation the implanted region of silicon was under compressive stress. Maximum of the stress was evidenced for a dose of $1\times10^{14}$ ions/cm$^2$. The optical set-up is very flexible and may cooperate with various apparatus.

## 1. Introduction

Silicon is widely used in many devices as a substrate material, as well as a component of complex systems like multilayers. A stress in a film/substrate system is always present and can cause important changes in work of the devices. There are many sources of stresses, therefore description of the phenomena is complex and requires complementary methods employed in their analysis. The technique used for producing thin films or the parameters of the technique, such as pressure or contamination may have influence on the stress in the film/substrate system. It is also possible to modify the stress. Thermal treatment or ion irradiation modifies the stress in a system. In most cases the stress relaxation effect is observed for tensile and compressive stresses [1], [2]. But the build up of compressive stress was also observed [3]. We equipped the ion implantation chamber with the external optical system which enables the measurements of curvature radius of a sample during its implantation. In this paper, we present the results of ion irradiation of the Si (100 μm) without a film.

## 2. Experimental

Figure 1 shows a scheme of the apparatus used in the experiment. The measurement of the sample curvature radius is based on the popular optical set-up described by FLINN *et al.* [4]. The laser beam reflects from the back surface of a sample without a film. Thus, it is necessary to use double-side polished silicon substrates. A camera with CCD is used as a detector of the laser beam position. An image from the camera is captured and analyzed by a computer program. The program also controls a step motor which changes the angle of the scanning mirror. The whole optical part of the apparatus is fixed on the stone table. The sample position may be adjusted using vacuum manipulators during ion irradiation.

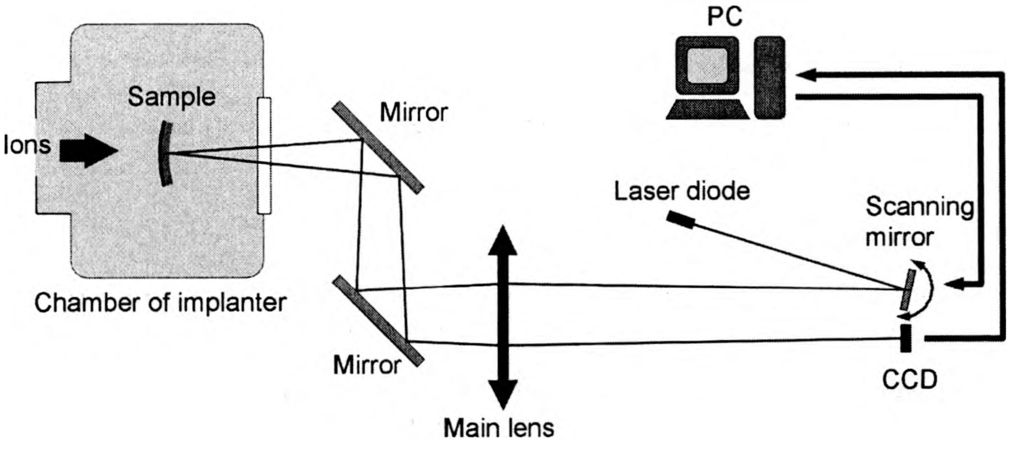


Fig. 1. Scheme of the optical set-up for the curvature radius measurements during ion implantation.

The average stress in the irradiated region was determined by measuring the sample curvature radius. According to the Stoney's formula [5] the value of corresponding stress equals

$$\sigma = \frac{Et_s^2}{6(1-\nu)t_f}\left(\frac{1}{R_2} - \frac{1}{R_1}\right) \tag{1}$$

where $\sigma$ is the Young's modulus of the substrate, $\nu$ is Poisson's modulus of the substrate, $t_s$ is the thickness of the substrate, $t_f$ is the thickness of the irradiated region, and $R_1$ and $R_2$ are the sample curvatures radii before and after ion implantation. Our calculations were performed for the biaxial elastic modulus $E/(1 - \nu)$ of 180.4 GPa for the silicon substrate.

Ion irradiation of the silicon substrate was performed with 300 keV Kr ions to a dose of $1.3\times10^{15}$ ions/cm$^2$.

## 3. Results and discussion

Variations of the stress are caused by the changes in the structure induced by bombarding ions. There are many structure factors that may influence the stress in a film, like creation of hillocks, shrinkage of grain boundary voids or amorphization of the substrate. We did not perform any additional investigations applying a different technique of examining the samples after the irradiation, therefore it was very difficult to determine the physical process which caused the changes in the stress.

The average stress during irradiation of the silicon substrate with 300 keV Kr ions is shown in Fig. 2. The thickness of the implanted region was estimated using the SRIM (stopping and range of ions in matter – http://www.srim.org) calculations and equals 257 nm. The first stage of implantation brings the development of compressive stress. The maximum of the stress (79 MPa) is for a dose of $1\times10^{14}$ ions/cm$^2$. After that the stress diminishes and at the end of implantation reaches the value of 19.5 MPa. As reported by others authors [6], [7], the shape of the curve is general for silicon and does not depend on ions or the temperature of a sample. In the first stage when the stress increases, heavily damaged or amorphized regions are formed. After reaching the maximum, the stress decreases due to further amorphization and plastic flow.

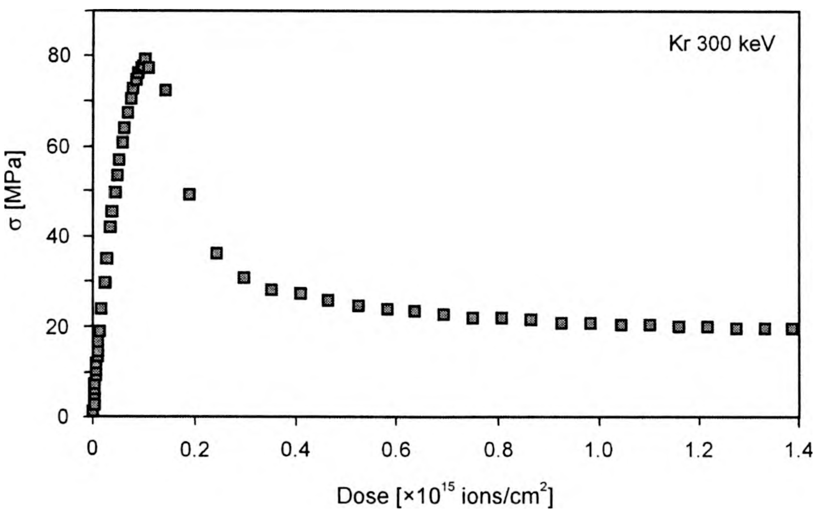


Fig. 2. Compressive residual stress in the implanted region of silicone substrate as a function of ion dose.

A detailed investigation of stresses evolution in the irradiated region or the interpretation of the phenomena was not the main goal of performed measurements. The silicon substrate was used to test the performance of our system. The obtained agreement with results presented by VOLKERT [6] confirms the usefulness of the method. It will be used for investigations of stress evolution during ion irradiation of metallic thin films deposited on silicon substrates. Results will be reported soon.

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