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Application of interference methods for determination of curvature radius in metal–oxide–semiconductor (MOS) structures

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The paper deals with the measurement of the radius of curvature of silicon wafer surface. The aim of these measurements was to determine stresses generated during oxidation of silicon wafers. A greater molar volume of SiO_2 layer in relation to the substrate material causes changes in the shape of oxidized surface, which results in stresses in both silicon dioxide layer and silicon. These changes are detected by Fizeau interferometer. In order to find the local value of curvature radii, deformations of the wafers under investigation approximated by corresponding interpolation formulas have been determined.

Keywords: Si–SiO_2 system, interferometry, radius of curvature, stress.

1. Introduction

Interferometry is a precise and non-destructive tool for both determination of optical parameters (such as thickness, refractive index and radius of curvature) and controlling optical surfaces [1, 2]. Appreciable commercial interest and usefulness are due to variations in optical and structural properties of the materials under investigation.

Interferograms can be obtained using many techniques including *inter alia* Michelson and Fizeau interferometers. Each of these instruments has appropriate applications and virtues. Interferometers of Michelson and Fizeau are broadly used tools for examining optical systems and media including surface information.

In our investigations, the Fizeau interferometer has been applied for determination of local curvature radii of silicon wafers after the thermal oxidation process and removal of the oxide layer. Thus, the main goal of our work was to estimate both the radius of curvature of dielectric layer and silicon substrate, and then stresses in the oxide layer.

2. Experimental procedures

We started with $\langle 100 \rangle$ oriented *n*-type silicon wafers of 4 inches in diameter, polished on both sides. Subsequently, the wafers were subjected to thermal oxidation at 1000°C in both dry oxygen and water vapour atmosphere in order to grow the oxide layers of thicknesses of approximately 50, 90, and 170 nm.

We proceeded with the technological process and measurements observing the following steps:

– oxidation of the silicon wafers;

– the interferometric measurements of oxidized wafers;

– the removal of both front-side SiO_2 layer and back-side SiO_2 layer of each wafer by etching in HF solution;

– the interferometric measurements of the as-etched wafers.

– determination of local stresses of the wafer connected with different local curvature radii obtained before and after removal of both front-side and back-side oxide.

3. Results and discussion

Examples of the results of interferometric measurements are illustrated in Figs. 1–4. Interference patterns and their sections along horizontal axis and the center of Fizeau fringes for front-side and back-side of the oxide layer of thickness about 50 nm after dry oxidation are presented in Fig. 1. The interference patterns and their sections along horizontal axis and the center of Fizeau fringes for front-side and back-side of wafer after removal of about 50 nm thick dry oxide are shown in Fig. 3.

On the basis of interference patterns, their sections (Figs. 1 and 3) and corresponding approximation function of the curve of the sections as well as using formula for curvature radius [3]:

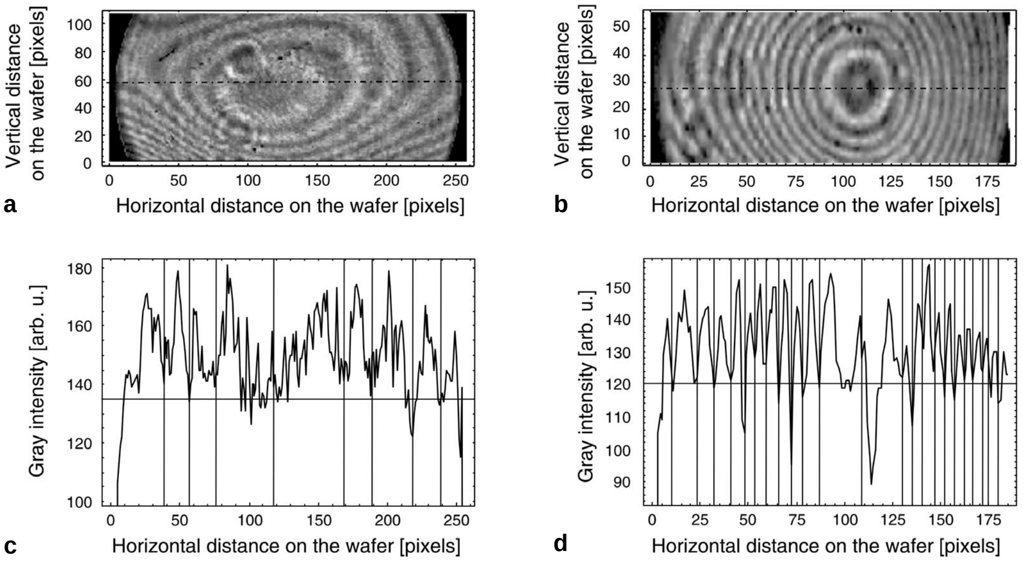

Fig. 1. Interference patterns and their sections along horizontal axis and the center of Fizeau fringes for front-side (**a**, **c**) and back-side (**b**, **d**), respectively, of the oxide layer after oxidation of wafer in dry oxygen.

$$R = \frac{\left[1 + \left(\frac{\mathrm{d}y}{\mathrm{d}x}\right)^2\right]^{3/2}}{\frac{\mathrm{d}^2 y}{\mathrm{d}x^2}} \tag{1}$$

values of the radius of curvature R *vs*. distance for front-side and back-side of the oxide layer of thickness about 50 nm after dry oxidation (Fig. 2) as well as for front-side and back-side of wafer after removal of this dry oxide have been determined (Fig. 4).

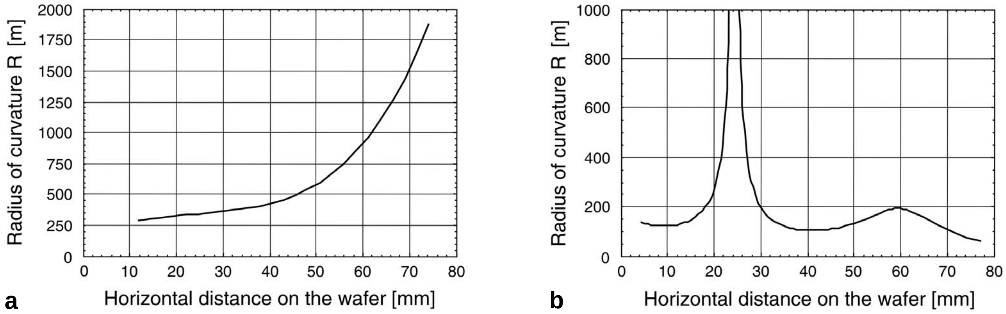

Fig. 2. Radius of curvature *vs*. distance for front-side (**a**) and back-side (**b**) of the oxide layer after oxidation in dry oxygen.

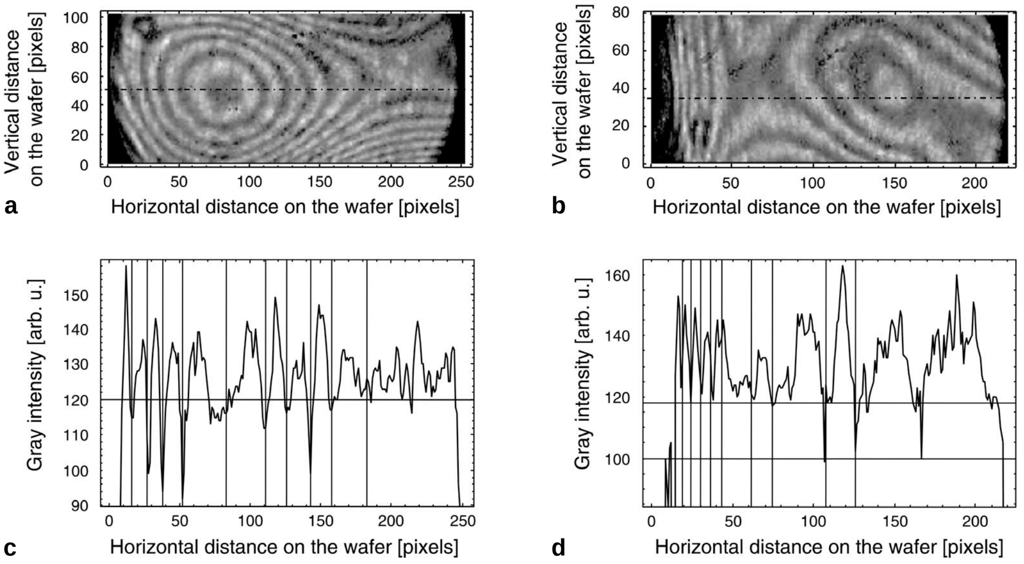

Fig. 3. Interference patterns and their sections along horizontal axis and the centre of Fizeau fringes for front-side (**a**, **c**) and back-side (**b**, **d**), respectively, of wafer after removal of dry oxide.

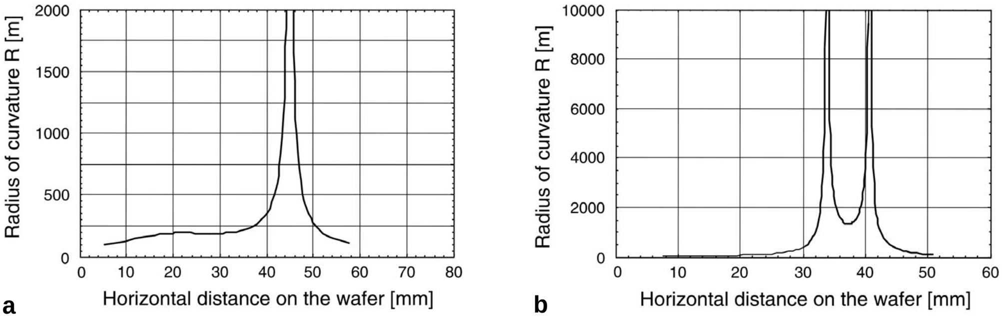

Fig. 4. Radius of curvature *vs*. distance for front-side (**a**) and back-side (**b**) of wafer after removal of dry oxide.

Observing the results obtained for wafer after oxidation and after etching, we find that the curvature of oxidized wafer is greater than that of the etched wafers (Figs. 2 and 4). In general, these results are expected values.

Stresses in the oxide layers have been determined by Stoney formula [4]

$$\sigma_{\mathrm{ox}} = \frac{1}{6R}\frac{E_{\mathrm{Si}}}{(1-\nu_{\mathrm{Si}})}\frac{t_{\mathrm{Si}}^2}{t_{\mathrm{ox}}} \tag{2}$$

where σ_{ox} is the stress in the oxide layer, E_{Si}, ν_{Si}, t_{Si}, t_{ox} stand for the Young modulus (for $\langle 100\rangle$ orientation, E_{Si} is equal to 130 GPa [5]), Poisson ratio (for $\langle 100\rangle$ orientation, ν_{Si} is 0.28 [5]), thicknesses of silicon and oxide layer, respectively.

In Figure 5, stress in SiO_2 layer as a function of horizontal distance for front-side and back-side of the wafer after oxidation is presented.

For yield of high quality surface flatness, silicon wafers as semiconductor substrates have very disadvantageous ratio of substrate thickness (t_{Si} = 700 μm) to

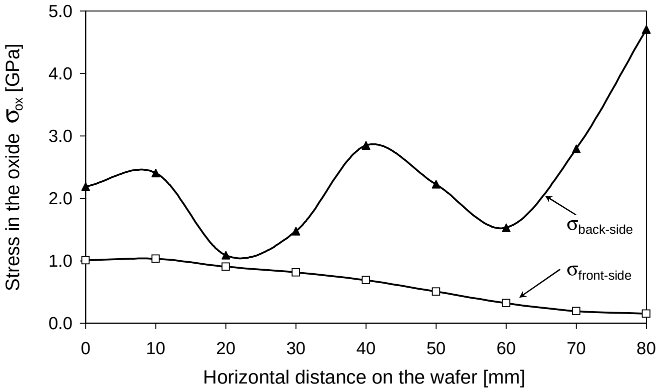

Fig. 5. Stress in the oxide *vs*. horizontal distance for front-side ($\sigma_{\text{front-side}}$) and back-side ($\sigma_{\text{back-side}}$) of the wafer after oxidation.

diameter (100 mm). Therefore, stresses generated during technological process are detectable as surface deformations which can be easily estimated by interferometry. These deformations, and connection with this stress, are changed during oxidation because of the molar volume of SiO_2 being greater than that of substrate material. These stresses can have influence on the values of stresses resulting from the treatment.

4. Conclusions

Interference methods have turned out to be a useful tool for determination of surface geometry. Our results confirmed that oxidation of surface strongly affects the change of the above mentioned shape. Then, these changes caused also the change in values of stresses of wafers (as shown in Fig. 5). In almost all cases, relatively big values of stresses give rise to the worsening of optical parameters (*e.g.*, refractive index). During our last ellipsometric investigation, we observed such behaviour at the Al-SiO_2 interface in metal–oxide–semiconductor (MOS) structures.

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