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Modification of properties of the glass–Si_3N_4–Si–SiO_2 structure at laser treatment

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Abstract. We studied the effect of laser treatment on the glass–Si_3N_4–Si–SiO_2 structures. It is shown that laser treatment causes appearance of an additional band in their transmission spectra as well as smearing of grain structure at their surface.

Keywords: glass–Si_3N_4–Si–SiO_2 structure, laser treatment, transmittance.

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1. Introduction

Until now, considerable experience has been gained in application of laser irradiation at different stages of manufacturing of semiconductor devices and integrated circuits [1-3]. Laser treatment is profitably employed to anneal the crystal structure defects in semiconductor layers and improve the silicon surfaces and, accordingly, the "silicon–oxide–metal" interfaces when producing integrated circuits [4]. One of the promising lines in technological applications of laser radiation is recrystallization of amorphous silicon layers deposited onto dielectric substrates to polycrystalline state. Such a technology enables one to obtain silicon layers with high mobility of charge carriers. This makes them promising for manufacturing of solar panels, IR detectors and display panels in micro- and nanoelectronics. Several requirements are imposed on the lasers intended for the above purposes. The most important ones are those of big diameter of laser beam and uniformity of radiation density over the beam diameter. Fulfillment of those requirements enables one to perform high-quality annealing of semiconductor structures on big-diameter substrates.

Here we present the results of our investigation of the effect of laser treatment on the optical properties of the glass–Si_3N_4–Si–SiO_2 structures with a 1 μm amorphous silicon layer.

2. Experimental procedure

Laser annealing of the structures under investigation was made using a multipurpose laser facility LIMO-100-532/1064-U (at wavelength of 532 nm) produced by LIMO-Lissotschenko Mikrooptik GmbH (Dortmund, Germany). The laser pulse duration was 45–100 ns; the pulse repetition frequency was 1–30 kHz. The optical system of the laser facility enabled us to form a narrow focus as a line 60 μm long and 0.01 mm wide; its nonuniformity was less than 1.5% RMS.

Surface morphology was studied with an atomic-force microscope NanoScope IIIa (DJ) in the periodic contacting mode. We used silicon needles with rated edge radius up to 10 nm. Structural perfection of the Si layer before and after laser treatment was studied using x-ray diffraction (XRD). The absorption spectra of the samples in the 350–800 nm region were taken at room temperature with a plant SPECORD UV VIS.

3. Results and discussion

Our studies of morphology showed that laser annealing makes sample surface smoother (see Fig. 1). Before the laser treatment, the surface was made of close-packed grains 30–80 nm in diameter. Its RMS roughness was 2.28 nm, while height drop was 16.41 nm (Fig. 1a). After the laser treatment, the surface practically did not demonstrate grain structure. The RMS roughness decreased to 0.62 nm, while the height drop became equal to 10.31 nm (Fig. 1b).

Shown in Fig. 2 are the transmission spectra of the glass–Si_3N_4–Si–SiO_2 structure taken before the laser treatment (curve 1; the absorption edge is ~3 eV) and after the laser treatment (curve 2; the absorption edge is ~3.4 eV). In this case, the laser treatment not only shifts the absorption edge towards higher energies but also

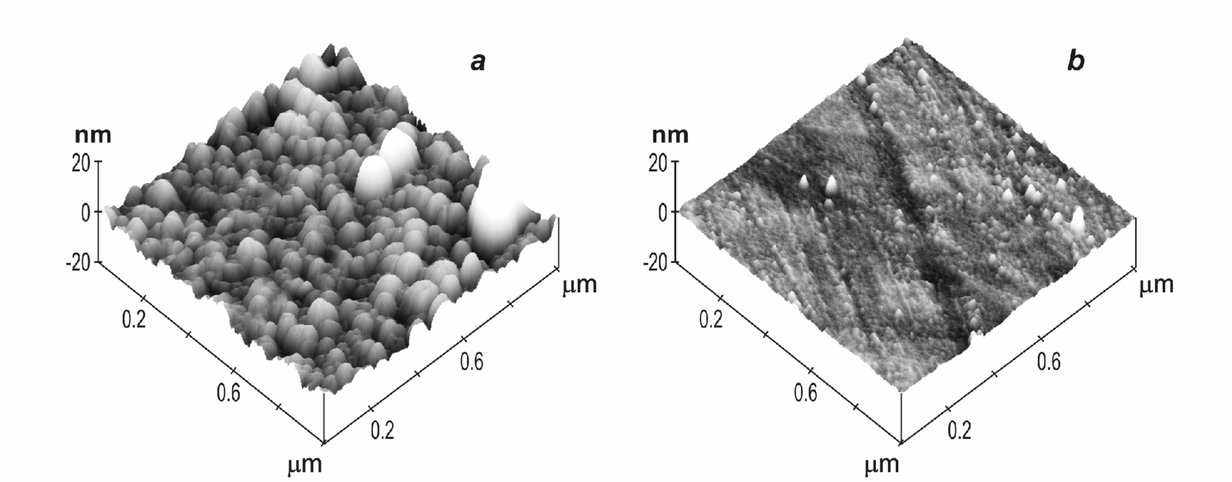

Fig. 1. Morphology of the glass–Si_3N_4–Si–SiO_2: structure surface: a – initial sample; b – after laser treatment.

leads to appearance of a broad transmission band in the 400–500 nm region (Fig. 2).

Figure 3 presents variation of sample transmission for different transmission spectral regions. The latter were chosen in the following way: ~380 nm – near the absorption edge; ~495 nm – the transmission band that appears after the laser treatment of the sample (see Fig. 2); ~555 nm – a weak transmission band (see Fig. 2), and ~650 nm – the transmission minimum (see Fig. 2). One can see from Fig. 3 that the laser treatment leads to increase of sample transmission at the wavelength of ~495 nm by the factor of four.

According to [5], the silicon nitride bandgap varies with the concentration of excess silicon. One can vary the silicon nitride bandgap within the ~1.6–3.4 eV range by varying the Si concentration [5]. Increase of silicon content in the silicon nitride films results in shifting the absorption band edge towards the red spectral region.

One can see from Figs. 2 and 3 that the structure demonstrates slight decrease of absorption in the 1.6–2.1 eV region after treatment. An additional band appears in the 450–500 nm (2.7–2.4 eV) region of the sample transmission spectrum. The variations in the absorption spectrum of the Si_3N_4–Si–SiO_2 structure may be related to changes in the phase composition of the near-surface layer. The following three reasons may lead to this.

1. According to [7], laser annealing results in decrease of absorption in the region above 2 eV owing to formation of silicon nanocrystallites in a thin layer of amorphous silicon. Recrystallization of the silicon layer occurs. Under laser annealing, a phase transition (amorphous silicon→polycrystalline silicon) may occur. In this case, the absorption edge of the silicon film shifts towards the high-energy (blue) spectral region. The assumption that the silicon layer is recrystallized under action of laser radiation is supported by the results of

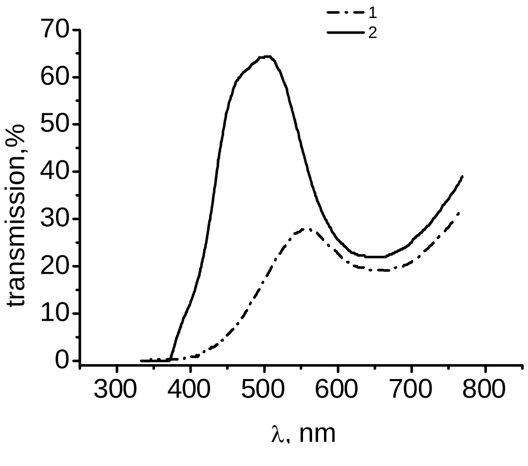

Fig. 2. Transmission spectra of the glass–Si_3N_4–Si–SiO_2 multilayer structure: 1 - initial sample; 2 - after laser treatment.

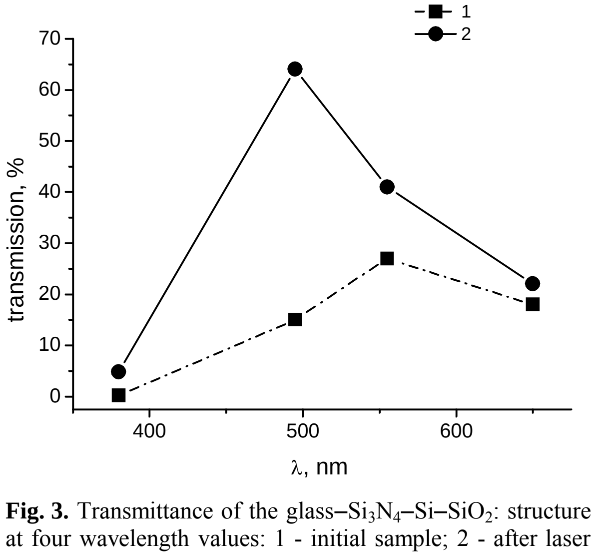

Fig. 3. Transmittance of the glass–Si_3N_4–Si–SiO_2: structure at four wavelength values: 1 - initial sample; 2 - after laser treatment.

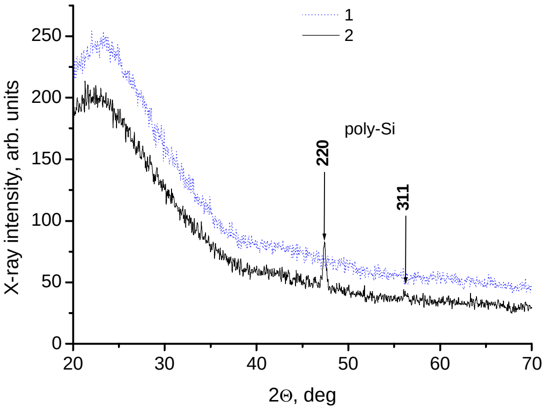

Fig. 4. XRD patterns of the glass–Si_3N_4–Si–SiO_2: structure: 1 - initial sample; 2 - after laser treatment.

XRD studies. Weak peaks from the reflections 220 (47.1°) and 311 (56.12°) that correspond to polycrystalline silicon are observed in the XRD pattern of the sample subjected to laser irradiation. There were no peaks corresponding to crystalline aggregations in the XRD pattern of the initial sample (Fig. 4).

2. Growth of transmission may be also because of decrease of silicon film thickness owing to partial dissolution of silicon in the oxide layer under laser annealing [7].

3. Under action of laser radiation, silicon concentration in the silicon nitride film may decrease due to silicon diffusion. According to [5], this shifts the absorption edge in the SiN_x films towards the blue region.

In addition, according to the data from [6], laser annealing may lead to variation of the thickness of silicon oxynitride (SiN_xO_y) junction layer, as well as to formation of stoichiometric Si_3N_4 layer. Both these factors can change the absorption spectra of the structures considered.

Thus, it is possible to obtain structures with specified physical characteristics by varying the parameters of laser treatment.

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