OPTICAL PROPERTIES OF SiO_2/Si STRUCTURE FORMED BY YAG:Nd LASER RADIATION

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Abstract

The change of optical properties of SiO_2 layer on Si single crystal exposed to YAG:Nd laser radiation has been found experimentally. Before irradiation the SiO_2 layer with thickness 0.70 μm had red color in reflecting light due to the interference. After irradiation by the laser it has changed red color to yellow one. However, samples with thickness 0.21 μm did not change color after irradiation.

Dielectric permittivity (K) of SiO_2 layer is decreased more then 40% after irradiation. We suppose that after irradiation of the SiO_2 layer decrease of K takes place due to the formation of nanopores in SiO_2 or/and generation of the charged point defect at the interface of Si-SiO_2. Particularly it is in agreement with measurements of micro hardness and capillary effect.

Keywords: SiO_2 layer, laser radiation, dielectric permittivity, low-K, Si single crystal

Introduction

Change of optical and electrical properties of SiO_2 glass is a very important task for solid state physics and applications in optoelectronics and microelectronics. An example is a reduction of dielectric permittivity (K) – leading to "low-K" of dielectrics [1]. Low-K dielectrics have a reduced parasitic capacitance in integrated circuits (ICs). One of the ways to reduce K is to use porous low-K dielectrics [2, 3]. However, materials with micrometric size of pores at the surface become brittle, and can absorb a photoresist contaminating it. Another potential way is to use Fluorinated Silicate Glass [4] instead of Silicon Dioxide. It means that impurities in the SiO_2 can change of optical properties of SiO_2 glass. In paper [5] the possibility to reduce light absorption near the absorption edge is shown for SiO_2 doped by fluorine and irradiated by F_2 laser. This fact is explained by photolysis of interstitial O by F_2 laser irradiation. This work assumed that results of interaction of strongly absorbed laser radiation (LR) with SiO_2 leads to growth of the peroxy radicals $\equiv$ Si-O-$O^{\bullet}$ and decrease of the concentration of dangling oxygen bonds $\equiv$ Si-$O^{\bullet}$.

It is known that if an absorption factor (α) is changed, then a reflection factor (n) will be changed simultaneously, but $n = \sqrt{K}$, K is the real part of dielectric permittivity. We can conclude that K could change due to both formation of pores or/and generation of new defects. Of course, change of defects concentration leads to gradual change of optical parameters of material.

An oxygen vacancy can generate two kinds of defects, depending on its electric charge: E' and B_2 centres. The E' ($O{\equiv}Si^{\bullet}$) and B_2 ($O{\equiv}Si\text{-}S{\equiv}O$) centres are responsible for the well-known absorption bands at 214 and 248 nm, respectively. Photoluminescence studies show that an emission band at 400 nm is associated with B_2 centres.

Another defect, which can be generated is a nonbridging oxygen hole centre (NBOHC: $O{\equiv}Si\text{-}O^{\bullet}$) responsible for a PL band at 650 nm. Finally, as a result of an oxygen displacement, certain regions of the implanted sample have an excess of oxygen, that can lead to creation of peroxy radical defects (POR:$O{\equiv}Si\text{-}O\text{-}O^{\bullet}$). These defects are less studied than the E' and B_2 centres or NBOHC defects [7].

The aim of this study is experimental instigation optical properties changes of SiO_2 on Si effected by YAG:Nd laser radiation.

Experimental part

Si p- and n-type with SiO_2 top layer used in our experiments. SiO_2 was grown by thermal oxidation method. The thickness of SiO_2 layers were 0.7 μm and 0.21 μm. The SiO_2 layer with the 0.7 μm thickness (thick samples) had red colour in reflecting light due to the interference. The SiO_2 layer was irradiated by YAG:Nd LR (wavelength λ = 532 nm, pulse duration τ= 10 ns). The intensities of LR were from 3.5 MW/cm^2 till 20 MW/cm^2. Optical microscope, atomic force microscope, method of capacity–voltage characteristics, microhardness measurements, X-ray luminescence were used in the experiments. The experiments were carried out at room temperature and atmospheric pressure.

Results and discussion

The SiO_2 layer is transparent for second harmonic of YAG:Nd laser radiation, but Si is strongly absorbed. The SiO_2 layer with thickness 0.7 μm had red color in reflecting light due to the interference. After irradiation by the laser with intensity I= 20 MW/cm^2 the SiO_2 layer has changed the red color to the yellow one. It could be explained by change of optical path (see Fig. 1 profiler measurement). However, samples with thickness 0.21 μm did not change color after irradiation.

Measurement of capacity (C) after irradiation of Al/SiO_2/Si/Al structure with layer thickness 0.21 μm by capacity – voltage (CV) characteristics method, has shown decrease of C to more than 40%. It is possible if dielectric permittivity K decreases or thickness of the SiO_2 layer increases. Atomic force microscope measurements did not show any change of the SiO_2 layer thickness. It means that after irradiation of the SiO_2 layer decrease of K - low-K dielectrics [1] takes place. We suppose that such change of K-factor occurs due to the formation of nanopores in SiO_2 or that generation of new defect at the interface of Si-SiO_2 takes place. Particularly this is in agreement with measurements of microhardness, using a precision microhardness tester at small test loadings. Microhardness test was performed using a microhardness tester PMT-3 with original self-adjusting loading device, allowing to carry out precision microhardness measurements at very small test loading (starting from 1.5mN) [8]. The indentor used was a Vicker's diamond pyramid and relaxation time was 15s. After irradiation both microhardness and brittleness of SiO_2 decreases, that could be connected with the relaxation of internal stresses due to the nanopores. At the same time, near the interface microhardness increases, that could be explained by the formation of defects at the Si-SiO_2 interface after irradiation. An evidence of the pores formation in SiO_2 layer is the presence of capillary effect which was observed at chemical treatment of SiO_2/Si in HF acid. A measurement of **n** from ellipsometry is in agreement with our hypothesis. Measurement of X-ray luminescence at room temperature has shown presence of spectral band with maximum at 2.3eV which corresponds to self-trapped exiton in glass SiO_2 [6].

After irradiation by the laser this band intensity arises 2 times and does not depend on intensity of LR. Influence of the interference on the luminescence spectrum has been taken in to consideration for interpretation of luminescence from multilayer structure [9].

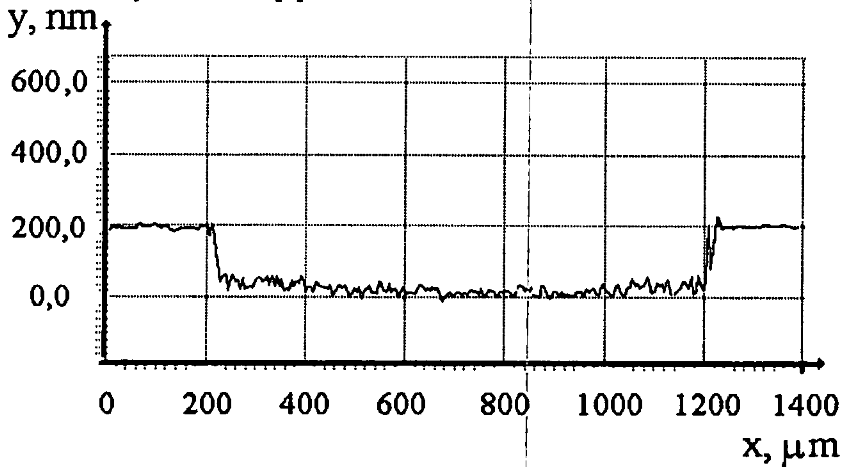

Fig. 2 Profile of SiO_2/Si thick sample after laser radiation measured by DEKTAK 6M BENCH-TOP STYLUS PROFILER. The size of SiO_2 is decreased by 180 nm.

From point of view of solid state physics it is very important to study the gradual decrease of K in materials where luminescence takes place through exiton recombination [6]. Decrease of K leads to increase of an exiton radius at the same Coulomb force of interaction between an electron and a hole in an exiton. It may be possible to observe a transition localized exiton - free exiton (delocalised). And lastly, decrease of K could lead to blue shift of an exiton Photoluminescence (PL) spectrum at the same radius of exiton.

Conclusions

1) The decrease of dielectric permittivity of SiO_2 layer after irradiation by YAG:Nd laser is explained by formation of nanopores in SiO_2 and possibly by formation of the charged point defects at the Si-SiO2 interface.
2) The colour change of SiO_2 layer (for the 0.7 μm samples) can be explained by decrease of the SiO_2 layer thickness due to sublimation of SiO_2 and formation of nanopores at the Si-SiO_2 interface.

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