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# Re-crystallization of Silicon during Rapid Thermal Treatment

***Abstract.*** *It is by means of the Auger-spectroscopy, spectral ellipsometry, X-ray diffraction that for the first time an opportunity was shown of applying the rapid thermal treatment for removal of the disrupted layer on the working surface of the silicon wafers after the chemical-mechanical polishing owing to its solid-phase re-crystallization.*

***Streszczenie.*** *Dzięki użyciu spektroskopii Augera, elipsometrii spektralnej oraz dyfrakcji rentgenowskiej po raz pierwszy przedstawiona została możliwość zastosowania szybkiego termicznego usuwania uszkodzonej warstwy na powierzchni roboczej wafli silikonowych, powstałych po chemiczno-mechanicznym polerowaniu, za pośrednictwem jego rekrystalizacji w fazie stałej.* ***(Rekrystalizacja krzemu podczas szybkiej obróbki termicznej)****.*

**Keywords:** disrupted layer, rapid thermal treatment, re-crystallization, silicon wafer.
**Słowa kluczowe:** uszkodzona warstwa, szybka obróbka termiczna, rekrystalizacja, wafel krzemowy.

## Introduction

The surface finish of the silicon wafers is one of the fundamental factors, determining quality and reliability of the integrated circuits. In view of this a great deal of attention is attributed to the issues of its preparation prior to the process of their formation. As a result of the mechanical grinding and polishing, a disrupted layer of the chippings, cracks, abrasive particles, dislocations, scratches, surface adsorbed organic and inorganic impurities forms on the wafer's surface.

One of the prospective ways of enhancing the surface properties of silicon may be its solid phase re-crystallization with application of the rapid thermal treatment with the second long pulses, ensuring the preheating of the wafer up to 1000ºC and above, which is usually used for re-crystallization of the amorphous layers of silicon, formed during the ion doping [1-4].

## Experimental

Influence of the rapid thermal treatment on the structure of the disrupted layer was under investigation with application of the methods of Auger-spectroscopy, electron microscopy, diffraction reflection curves, spectral ellipsometry. It was by means of the Auger-spectroscopy with the precision sputtering of the surface silicon layers and registration of the exit intensity of the Auger-electrons from the silicon surface, that the dependence was plotted of the quantity of the exiting electrons on the sputtering time duration with determination of the disrupted layer depth. The methods of the electron microscopy and the diffraction reflection curves were used to perform investigations of the surface structure of the silicon wafers prior and after the rapid thermal treatment. The optical characteristics of the wafers were studied by means of the method of the spectral ellipsometry. As samples, there were used silicon wafers with the diameter of 100 mm, grades – boron doped silicon with resistivity of 12 Ohm/cm and phosphorus doped silicon with resistivity of 4.5 Ohm/cm with orientation <100> after the chemical-mechanical polishing, subjected to the rapid thermal treatment for 7 s, which ensured their preheating up to 1100ºC and without it.

## Results and Discussion

Dependence analysis of the Auger-electrons exit on the silicon wafer sputtering time duration showed, that on the wafers without the rapid thermal treatment the exit on the mono-crystal silicon occurs after 1.75 min., which corresponds to the disrupted layer depth of 3.8 nm (Fig. 1a). After the rapid thermal treatment as a result of the solid body re-crystallization of the disrupted layer there occurs reduction of its depth, and its value constitutes less than 1.0 nm (Fig. 1b).

The electron-microscopic investigations of the surface of the given wafers prior and after the rapid thermal treatment made it possible to establish, that before the treatment it is characterized by the smooth micro-relief, practically without micro-irregularities (Fig. 2a). The diffraction picture "for reflection" (Fig. 2b) serves as an evidence about the predominant parallelism of the crystallographic planes of the deeper layers. After performance of the rapid thermal treatment the surface micro-relief of the silicon wafers does not undergo any changes and remains to be ideally smooth, as before the rapid thermal treatment.

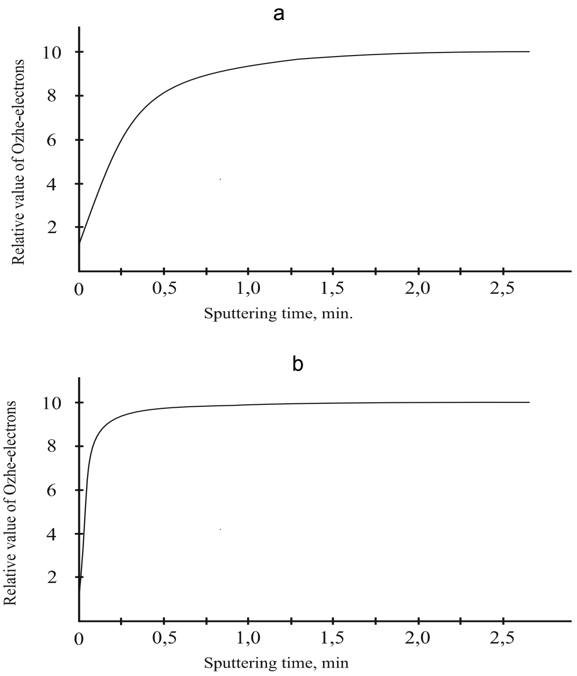

Fig.1. Dependence of the quantity of Auger-electrons on the sputtering time of the silicon wafer prior to (*a*) and after (*b*) the rapid thermal treatment.

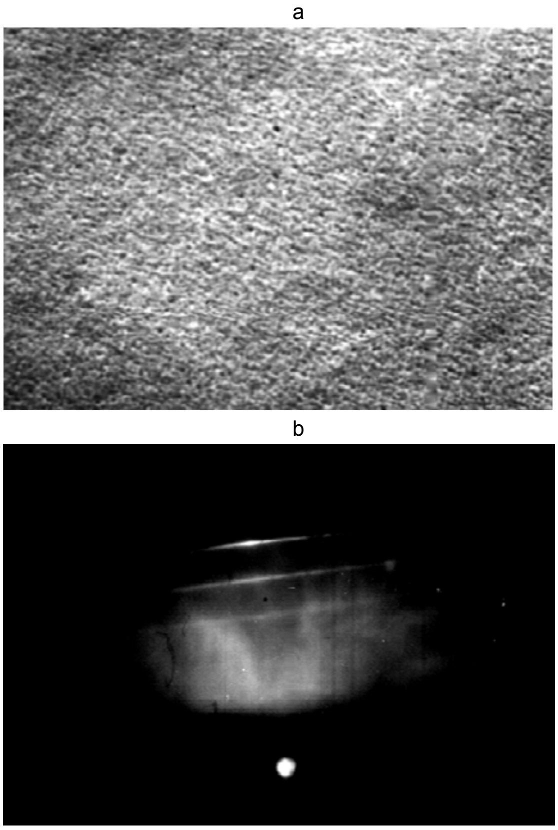

Fig.2 Morphology of the working surface of the silicon wafer and the picture of the secondary diffraction of electrons from it prior to the rapid thermal treatment: *a*) micro-relief of the surface, *b*) the electrons diffraction imaging

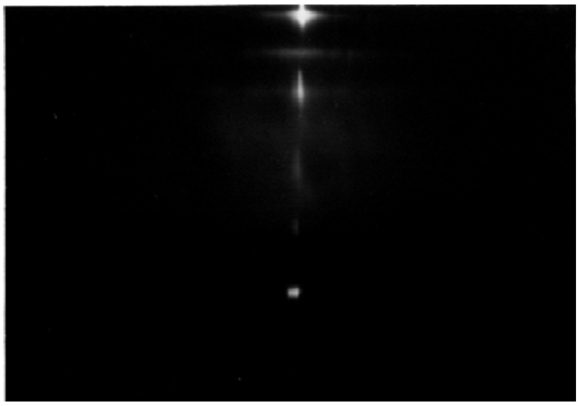

Fig.3. Picture of the electrons secondary diffraction from the silicon wafers surface after the rapid thermal treatment

However, the diffraction picture “for reflection” (Fig. 3) is an evidence of occurrence on it of the continuous vertical rods, being the result of the two-dimensional diffraction of electrons from the surface atomic layers and specifying the monatomic-flat surface.

The given results are entirely confirmed by the investigations, conducted by means of the method of the diffraction reflection curves (DRC). Comparison of DRC from the silicon surface prior and after the rapid thermal treatment revealed, that the expansion of the DRC base, peculiar to the disrupted layer, vanishes after treatment, and the curve approaches the standard one for the ideal surface (Fig. 4).

One of the crucial parameters of the initial silicon wafers, information significant about the surface condition of the silicon wafer is manifested in its optical characteristics, specifically, the refraction and absorption ratios. As related to the disrupted layer, the most sensitive to its presence is the absorption ratio, which may be determined with the high accuracy by means of the method of the spectral ellipsometry. The given method also makes it possible to determine the influence of various factors on the dispersion of optical parameters in the wide spectral range. Analysis of the spectral dependence of the refraction ratio and the absorption ratio of silicon showed, that it possesses the vivid variation in the absorption ratio in the region of 3.43 eV (Fig. 5). Such a growth of the silicon absorption ratio in the given spectrum area can be related to the fact, that the absorption under observation corresponds to the direct singularity transitions of Van Howe of the conducting band. In silicon the G-spot of the conducting band is deem a singularity point of Van Howe, whose energy constitutes 3.43 eV [5, 6].

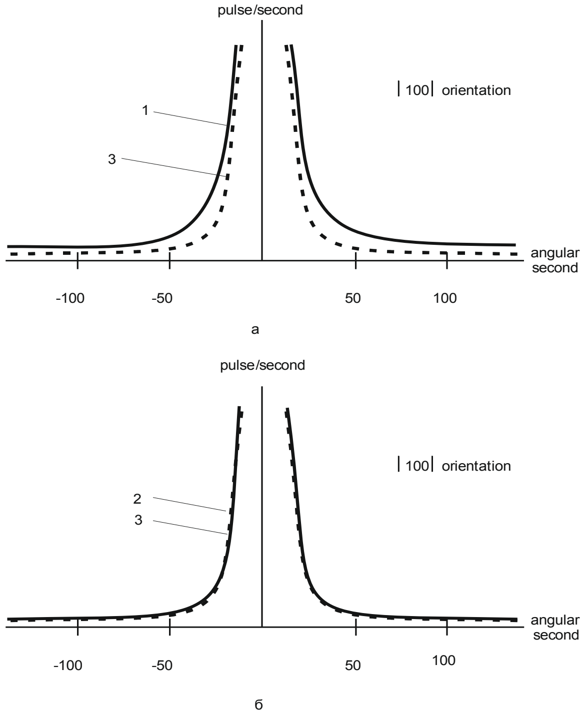

Fig.4 The diffraction reflection curves from the silicon wafers surface after the mechanical polishing (*a*) and the subsequent rapid thermal treatment (*b*): *1* – prior to treatment; *2* – after treatment; *3* – of the standard surface

Investigation of the samples after the rapid thermal treatment by means of this method showed, that in the absorption are, corresponding to the G-spot of the conducting band there took place growth of the absorption ratio (Fig. 6) as compared with its value prior to the treatment. Such a behavior, it appears, is related to the following causes. As silicon possesses the face - centered cubic lattice, its reverse lattice is body – centered with the first Brillouin zone in the shape of the truncated octahendron. In such a structure the G-spot possesses a complete symmetry of the cube and, consequently, any distortions of the crystal lattice will ensue disruptions of such symmetry. This means, that the deformation presence of the silicon crystal lattice from the working side of the wafer will result in the appropriate variation in the silicon absorption in the spectral range close to 3.43 eV. In our case the absorption increase in the given area signifies, that the rapid thermal treatment results in the structural improvement of the surface layer from the working side of the wafer owing to reduction of the internal stresses, and, consequently, of deformation of the crystal lattice. Meanwhile, the given result does not depend on the polarity of conductivity of the investigated silicon wafers.

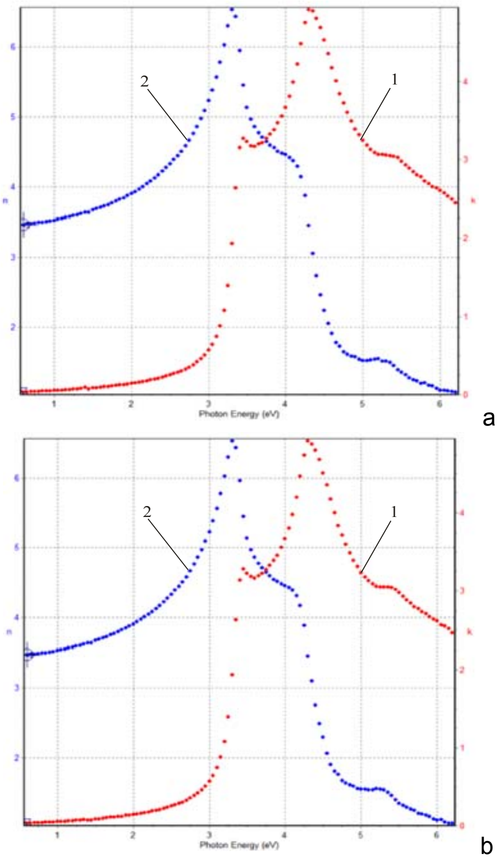

Fig.5. Spectral dependence of the extinction ratio (*1*) and the refraction ratio (*2*) of the initial silicon: *a*) phosphorus doped silicon with resistivity of 4.5 Ohm/cm, *b*) boron doped silicon with resistivity of 12 Ohm/cm

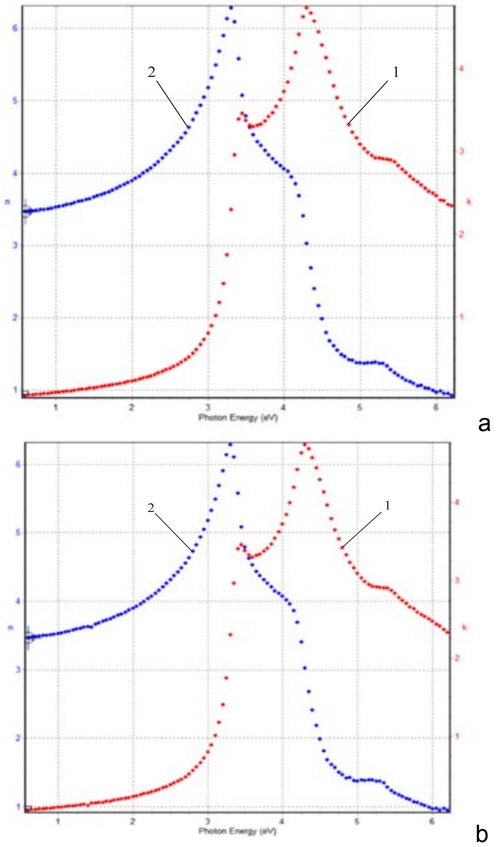

Fig.6 Spectral dependence of the extinction (*1*) and refraction (*2*) ratios of silicon after the rapid thermal treatment: *a)* phosphorus doped silicon with resistivity 4.5 Ohm/cm, *b*) boron doped silicon with resistivity 12 Ohm/cm

Investigations of the absorption ratio value at the wave length of 632.8 nm showed, that in the result of the rapid thermal annealing of the silicon wafers (boron doped silicon with resistivity 12 Ohm/cm) with the second long pulses the absorption ration went down for 1.55 times – from 0.014 to 0.009, for the silicon wafers (phosphorus doped silicon with resistivity 4.5 Ohm/cm) – from 0.012 to 0.011. This signifies, that in the process of such treatment the silicon surface was purified from the various impurities and its microstructure was reset.

## Conclusion

Thus, the rapid thermal treatment of the initial silicon wafers results in enhancing the structural perfection of their working surface owing to reduction of the disrupted layer depth, securing provision of the monatomic-flat surface. It is for the first time, that by means of the spectral ellipsometry method the Van Howe singularity presence was confirmed at the G-spot of the conducting band at 3.43 eV with demonstration of the deformation influence of the crystal lattice under force of the stresses, active in the disrupted layer, on the silicon absorption ratio in the given region of the spectrum.

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## REFERENCES

[1] Q.-Y.Tong, M. Gosel, Wafer bonding fnd layer splitting for Microsystems, Adv. Mater. 11 (17), (1999), 1409-1425.
[2] G.Ya. Krasnikov, N.A. Zaitsev, Physical-Technological Fundamentals of Ensuring Quality of VLSIs M. "Micron-print". 1999.
[3] Yu.A. Kontsevoy, Yu.M. Litvinov, E.A. Fattakhov, Plasticity and Strength of the Semiconductor Materials and Structures M.: Radio and Communications, 1982.
[4] V.A. Pilipenko, V.A. Gorushko, V.N. Ponomar, Cleaning the Surface of the Silicon Structures in the VLSI Technology, IFZh, 76 (5), 2003, 103.
[5] V.I. Gavrilenko, A.M. Grekhov, D.V. Korbutyak, V.G. Litovchenko, Optical Properties of Semiconductors Reference Book, Kiev: Navukova dumka, 1987, p. 608.
[6] I.S. Pankratov, R.P. Seysyan, A.A. Shorokhov, Investigation of the Direct Optical transitions in the Silicon Monocrystals as per the Transmission Spectra, Letters to ZhTF 38 (13), (2012), 1-7.