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GENERATION OF SURFACE STATES ON THE Si — SiO_2 INTERFACE UNDER THE INFLUENCE OF SYNCHROTRON RADIATION

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НОВОСИБИРСК

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Having extraordinary properties such as continuous spectrum, high spectral brightness in all the spectrum, high natural collimation degree, temporal stability of characteristics, synchrotron radiation (SR) becomes a powerful tool in submicron technology and analytical studies [1].

However, due to the fact that the SR beam has so high value of spectral brightness (2-4 orders of magnitude more than that of the most powerful conventional *X*-ray tube with a rotating anode [2]) there is a danger of the appearence of some radiation damages in samples to be investigated using a SR beam. It can destroy unpredictably silicon wafers in the process of their production. In our early work (see Ref. [3]) when topographic exposures of Gadollinium Gallium Garnet crystals were made we observed the appearance of some color centers after the experiment. In [4], investigating the influence of the SR beam on the electric parameters of the $Si-SiO_2$ interface we have shown that the surface states density on the $Si-SiO_2$ interface increases with increasing the exposure time. However, such a dependence is not universal and belongs to a particular SR source used in the experiment. Our aim was to analyze the dependence of the surface states density on the exposure dose absorbed in the $Si-SiO_2$ interface of Metal-Oxide-Silicon (MOS) structures.

So we have calculated the exposure dose absorbed by a sample. Following [5], first of all, we have found the spectral illuminance $A(\lambda)$ of the source at the distance L with the help of the formula

$$A(\lambda)\left[\frac{\mathrm{W}}{\mathrm{mm}^2\cdot\text{Å}}\right]=\frac{59E^2[\mathrm{GeV}]\,I[\mathrm{A}]}{\lambda[\text{Å}]\,L^2[\mathrm{m}]}\,\eta\left(\frac{\lambda}{\lambda_c}\right)\,\nu^{-1}\left(\frac{\lambda}{\lambda_c}\right)\,\frac{\Delta\lambda}{\lambda}, \qquad (1)$$

where E is the electron beam energy, I is the electron beam current, λ_c is the critical wavelength, $\eta(\lambda/\lambda_c)$ and $\nu(\lambda/\lambda_c)$ are the average spectral and angular distribution functions, respectively, for radiation from the bending magnet of the SR source. Then we have obtained the spectral illuminance absorbed by a spacimen using the values of the total mass absorption coefficients for beryllium, $\mu_{\mathrm{Be}}(\lambda)$, and for air, $\mu_{\mathrm{A}}(\lambda)$, and also the real absorption coefficients of silicon, $\mu_{\mathrm{Si}}(\lambda)$:

$$C(\lambda)=A(\lambda)\exp\{-(\mu_{\mathrm{Be}}t_{\mathrm{Be}}+\mu_{\mathrm{A}}t_{\mathrm{A}})\}(1-\exp\{-\mu_{\mathrm{Si}}t_{\mathrm{Si}}\}), \qquad (2)$$

where t_{Be}, t_{A}, t_{Si} are the thicknesses of beryllium foils, the air gap between the exit beryllium foil and a sample, and a silicon specimen, respectively. Integrating formula (2) over all wavelengths, we have got the exposure dose, D, absorbed by the sample:

$$D[\mathrm{Rad}]=C_{\Sigma}\left[\frac{\mathrm{W}}{\mathrm{kg}}\right]T[\mathrm{s}], \qquad (3)$$

where C_{Σ} is the integrated illuminance absorbed by the sample, T is the exposure time.

Experiments were conducted using the VEPP-4 storage ring. Its parameters were: $E=5.5$ GeV, $\lambda_c=0.83$ Å, $I=0.01$ A, $L=23.5$ m. Five beryllium foils (total thickness was 1 mm) were installed on the beam line of the facility. The air gap thickness was 10 cm. The samples were prepared as it was described in [6]. The methods of measuring the surface states density are described in [4]. The total thickness of the MOS-structures was 380 μm.

The dependences of the illuminance of the SR source and that absorbed by the samples, calculated by means of formulae (1) and (2), are depicted in Fig. 1a (curves *1* and *2*, respectively). The increment of the surface states density dependence, ΔN_{SS}, on the exposure dose, calculated by using formula (3), is depicted in Fig. 1b (curve *1*). It appears that the surface states density generated on the $\mathrm{Si-SiO_2}$ interface by the SR beam increases as the exposure dose increases and can be approximated by the ratio function:

$$N_{\mathrm{SS1}}=N_{\mathrm{SS0}}(1+QD^{B}), \qquad (4)$$

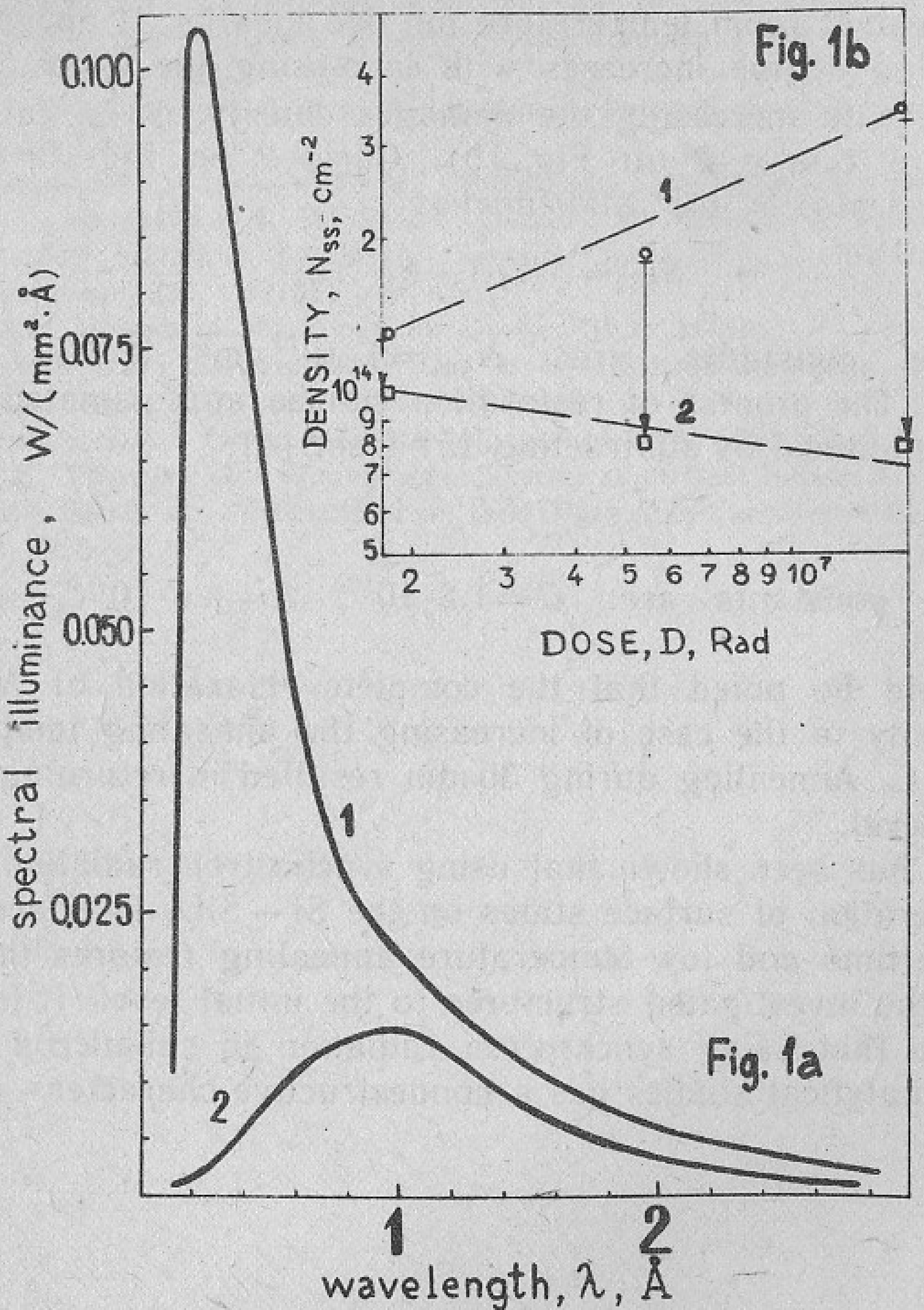

Fig. 1a. The spectral dependence of the illuminance of the SR source (*1*) and that absorbed by the sample (*2*).

Fig. 1b. Dose dependence of the increment of the surface states density ΔN_{SS} measured after exposure (*1*) and after keeping at room temperature for two months.

where the constants are $N_{SS0}=1\cdot10^{12}\,\text{cm}^{-2}$, $Q=5.6\cdot10^{-2}$, $B=0.46$. The surface states density decreases gradually after the samples had been kept at room temperature for two months. It appears that the relaxation degree increases with increasing the exposure dose and, hence, with increasing the damages density, ΔN_{SS}, caused by the exposure (curve *2* on Fig. 1b). Curve *2* on Fig. 1b can be approximated also by the ratio function

$$N_{SS2}=N_{SS0}(1+RD^{K})\,, \tag{5}$$

where the constants are: $N_{SS0}=1\cdot10^{12}\,\text{cm}^{-2}$, $R=1.15\cdot10^{3}$, $K=-0.15$. The process of restoration can be approximated by the expression obtained by subtracting (5) from (4):

$$\Delta N_{SS}=G(SD^{\varkappa}-1)\,D^{\xi}\,, \tag{6}$$

where the constants are: $G=1.2\cdot10^{15}$, $S=4.6\cdot10^{-5}$, $\varkappa=0.60$, $\xi=0.15$.

It should be noted that the complete relaxation of N_{SS} was observed only in the case of increasing the annealing temperature up to 150° C. Annealing during 30 min resulted in returning N_{SS} at the initial level.

Thus it has been shown that using synchrotron radiation results in the generation of surface states on the $Si-SiO_2$ interface. However, short time and low-temperature annealing restores the parameters of the investigated structures to the initial level. It has been shown also that using synchrotron radiation in submicron technology and analytical studies has a nondestructive character.

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Генерация поверхностных состояний на границе раздела Si — SiO_2 под воздействием синхротронного излучения

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