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DETERMINATION OF THE Si-PIN DETECTOR ACTIVE ZONE THICKNESS USING ANALYTICAL LINE INTENSITY WAVELENGTH DEPENDENCE OF THE SINGLE-COMPONENT STANDARDS

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The simple procedure of the detector active zone thickness determination is proposed, in which the fluxes of fluorescent radiation analytical lines from single-component samples excited by monochromatic radiation of a secondary radiator are used as the known fluxes. The superposition of experimental and calculated curves of the analytical line intensity versus the wavelength allows determination of the active zone thickness $d = 170$ *μm with an accuracy of* $\pm$ 10 *μm.*

Keywords: *X-RAY FLUORESCENT RADIATION, ANALYTICAL LINES, DETECTOR, ACTIVE ZONE, SECONDARY RADIATOR.*

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1. STATEMENT OF THE PROBLEM

Si-based solid-state X-ray detectors have found a wide application in physics of nanoscale objects due to the high sensitivity and determination rate of the chemical composition [1]. Low efficiency in the measurements of the hard X-ray radiation with the wavelength $\lambda < 1.0$ Å because of the weak absorption of this radiation in the detector active zone material is their main constraint. The value of the active zone, as a rule, is substantially less than the thickness of the silicon detector wafer and is determined by the doping area depth and operating conditions. To perform correct quantitative measurements in a wide wavelength range, it is necessary to know the value of the active zone and introduce the corresponding corrections to the measured intensities. The active zone thickness can be experimentally determined by measuring the known fluxes of monochromatic radiation. This work is laborious, since it requires the reconstruction of the spectrometer X-ray optical scheme.

In the present work we propose the simple procedure of determination of the active zone thickness, at which fluxes of fluorescent radiation analytical lines from single-component samples excited by monochromatic radiation of a secondary radiator are used as the known fluxes.

2. EXPERIMENTAL TECHNIQUE

Fluorescent radiation of the single-component targets with atomic numbers from $Z = 27$(Co) to $Z = 42$(Mo) was excited by the radiation of a secondary radiator made of superfine silver. The secondary radiator was illuminated by the X-ray tube BS-22 spectrum with a silver shoot-through anode at the voltage $U = 35$ kV. Recording of the target fluorescent radiation was realized by Si-pin detector X-123 ("Amptek", USA) with the thickness of detector silicon 300 μm. Incidence angles φ and angles ψ of the radiation departure to the sample surface, respectively, were equal to 52° and 70°. Integral input of the detector during measurements did not exceed 6000 pulses/sec.

3. RESULTS AND DISCUSSION

Fluorescence intensity of the single-component target under excitation by monochromatic radiation I_0 on the analogy with [2] will be written as

$$I_i = \frac{S}{4\pi r^2} \cdot I_0 \cdot \left(1 - \frac{1}{S_{q_i}}\right) \cdot \omega_i \cdot p_i \cdot \sin\varphi \cdot \frac{1}{\left[1 + K\left(\mu_{ii}/\mu_{0i}\right)\right]} = \frac{S}{4\pi r^2} \cdot I_0 \cdot R_i, \quad (1)$$

where $S/4\pi r^2$ is the solid angle of sample illumination; S_{q_i} , ω_i and p_i are the values of absorption jump, fluorescence yield, and fraction of the i-th line intensity in spectral series, respectively; μ_{0i} and μ_{ii} are the mass attenuation factors of monochromatic radiation of the reradiator and fluorescent radiation outgoing from target; $K = \sin\varphi/\sin\psi$. Detector efficiency is determined by the expression [1]

$$F_i = 1 - \exp\left(-\mu_{iSi} \cdot \rho_{Si} \cdot t\right), \quad (2)$$

where μ_{iSi} defines attenuation of the i-th analytical line in the detector active zone material (Si); ρ_{Si} = 2,3 g/cm^3 is the silicon density.

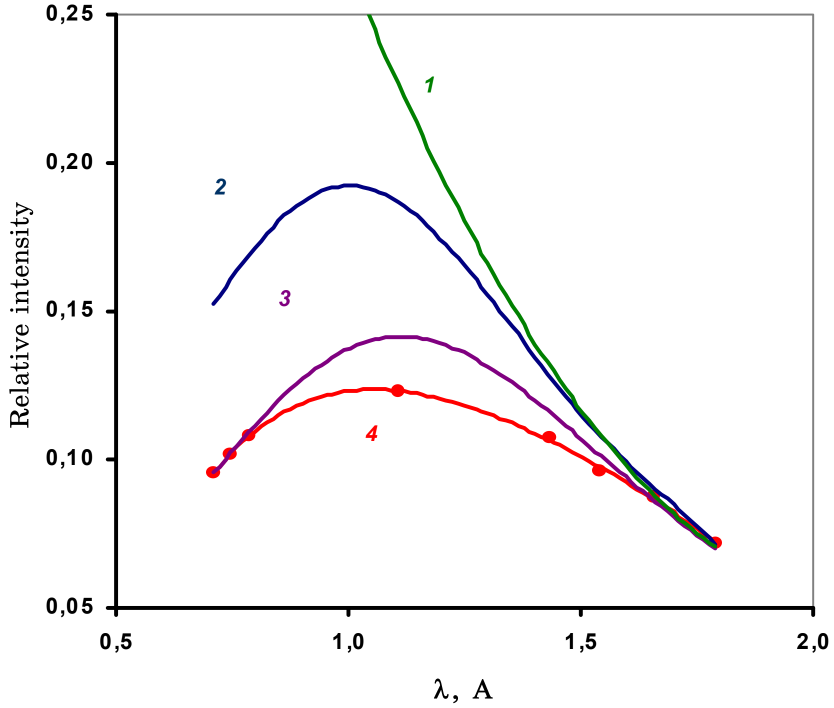

Fig. 1 *– Intensity of the analytical line Kα of single-component samples depending on the wavelength for different thickness d of the Si-pin detector active zone. Theoretical curves: (1) d → ∞; (2) d = 300 μm; (3) d = 170 μm; (4) – experimental curve. Detector X-123 ("Amptek", USA)*

At full detector efficiency, in accordance with formula (1), dependence of the analytical line intensity of chemical elements should decrease monotonically with the increase in the wavelength (Fig. 1, curve 1). However, on the experimental dependence (Fig. 1, curve 4) one can observe non-monotony with maximum near $\lambda \approx 1.15$ Å, which is conditioned by the hard radiation passage through the detector active zone without absorption and the current pulse formation [3] there. If the detector active zone stretched for the whole its thickness 300 μm, the recorded intensity of analytical lines of pure Mo ($\lambda = 0.71$ Å), Nb ($\lambda = 0.74$ Å), and Zr ($\lambda = 0.78$ Å) would be two times more than the line intensity of Cu ($\lambda = 1.54$ Å) and Ni ($\lambda = 1.65$ Å) (Fig. 1, curve 2). Maximum of the curve would be on $\lambda = 1.0$ Å. Decrease in the active zone thickness, in accordance with (1), leads to the decrease in the mentioned correlation and shift of the curve maximum towards longer wavelengths (Fig. 1, curve 3). Superposition of the experimental (curve 4) and calculated (curve 3) curves allows to determine the active zone thickness $d = 170$ μm with an accuracy of ± 10 μm. Parameters for the calculation of the analytical line intensity of the single-component standards by formulas (1)-(2) and experimental values of the integral intensity I_{exp} are represented in Table 1.

Table 1 *– Calculation parameters for the analytical line intensities of the single-component standards using formulas (1)-(2) and experimental values of the integral intensity* I_{exp}

Line	λ, Å	ω	S_q	μ_{Si}, cm^2/g	R	$R{\cdot}F$ $d = 0{,}017$	I_{exp}, pulses
Mo-K_α	0.709	0.764	6.48	7.12	0.3877	0.0953	312981
Nb-K_α	0.746	0.748	6.55	8.2	0.3889	0.1023	333521
Zr-K_α	0.786	0.730	6.63	9.48	0.3490	0.1093	354530
Se-K_α	1.105	0.596	7.18	24.5	0.2272	0.1410	403770
Ge-K_α	1.254	0.554	7.41	34.9	0.1814	0.1358	–
Zn-K_α	1.435	0.479	7.67	58.0	0.1308	0.1177	352230
Cu-K_α	1.541	0.443	7.82	62.1	0.1076	0.0984	315002
Ni-K_α	1.656	0.414	7.98	76.1	0.0277	0.0881	286879
Co-K_α	1.789	0.366	8.13	94.1	0.0712	0.0695	236706

4. CONCLUSIONS

Thus, at the thickness of 300 μm of Si wafer of the X-123 detector its active zone is 170 μm. Analysis by the curve $I(\lambda)$ at monochromatic fluorescence excitation of single-component samples allows to sufficiently quickly define one of the key detector characteristics.

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