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IT-4-P-1829 Determination of the second critical energy of primary electrons in relation to dielectric thickness and angle of incidence

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At the second crossover energy E_{2C} of incident electrons the equilibrium is maintained between the electron probe currents I_0, the second electron emission (SEE) currents $I_0\delta$, the backscattered electron (BSE) currents $I_0\eta$, as well as the leakage currents I_L and the displacement currents I_d that are responsible for the accumulated charge Q. At the equilibrium state the equality $I_0=I_0(\delta+\eta)+I_L+I_d$ is fulfilled, while for the target remaining uncharged the condition $\delta+\eta=1$, $V_s=0$ is valid, where δ and η are the emission coefficients of SE and BSE.

Experimental results for dielectrics, in the case when incident electrons impinge on the sample surface at the angle α, can be described by the following semi-empirical expression: $E_{2C}=E_{2C}(0)\exp[(\ln(R_{2C}/2\lambda))(1-\cos\alpha)]$, (1)

where λ is the effective emission depth of SE, $R_{2C}=76E_0^{1,67}$ ρ is the depth of penetration of primary electrons with the energy E_0, ρ is the specific density of the dielectric material. As an example, fig.1(a) shows the experimental dependence and the dependence calculated by formula (1) of the second critical electron energy $E_0=E_{2C}$ on the angle of incidence α, for the target potential $V_s=0$, i.e. when the target remains uncharged. Fig.1(b) shows the dependence of the energy E_{2C} on the angle of incidence α for ungrounded metals.

Consider the dependences of the V_s of PMMA films with the thickness d on a silicon substrate at the electron energy E_0.

The experimental results are in qualitative agreement with the calculated results as shown in fig.2(a), presenting the dependences $V_s(d)$ for MICA plates 2 to 30 µm thick and for PMMA films 0.4, 1.4, 2.7, 4 µm thick on the Si-substrate.

At the radiation energies E_0 in the range of 0.5–1.0 keV the negative charging begins (note that according to previous views, positive charging was expected because $E_0<E_{2C}$). At this energy the sign polarity of V_s changes, i.e. at the point where $V_s=0$ V. For PMMA this value lies in the range $E_0=0.4$–0.6 keV, with the thicknesses of the layers of positive and negative charges and the values of these charges are approximately equal ($\lambda\approx R_0$, $Q_+=Q_-$), which is responsible for the total absence of charging. In the region of 1 keV $<E_0<E_{cr2}$ one can clearly observe negative charging, and the greater d, the higher the value of $-V_s$. This range corresponds to the condition $\lambda<R_0<d$. The value of $-V_s$ at first increases and reaches the maximum, then as E_0 and R_0 grow, it starts decreasing slowly in the absolute value and reaches zero at the points of E_{cr2}, that are different for each film thickness d. These points can be used in high-voltage lithography, because it is at these values of $R_0\geq 2d$ that the conduction current I_T is generated and it carries excessive negative charges (electrons) onto the substrate, hence $V_s=0$ V.

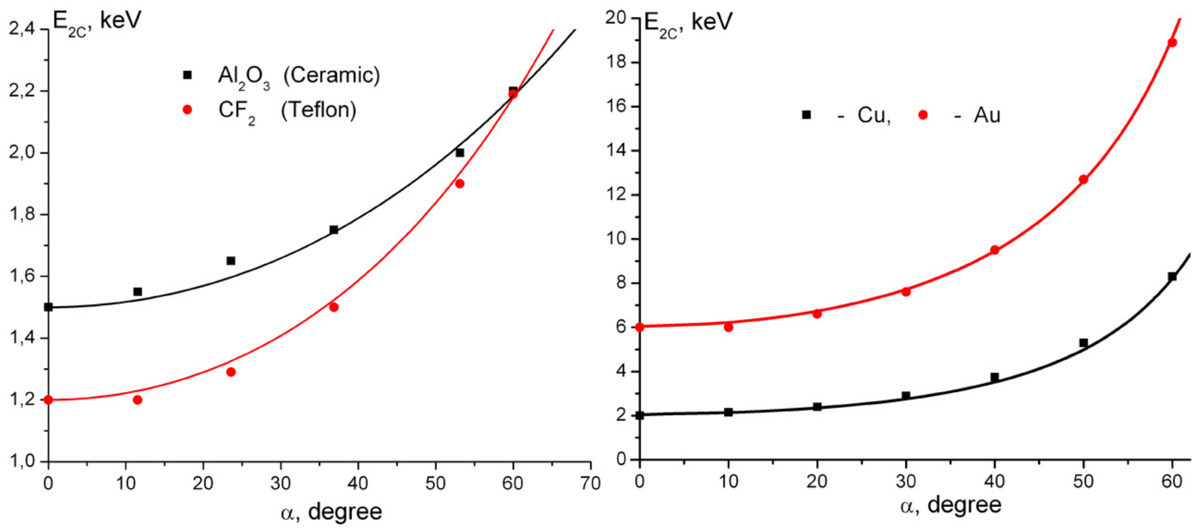

Fig. 1: Characteristics of the value of the second critical electron energy E_{2c} as a function of angle of incidence α for dielectrics (a) and ungrounded metals (b).

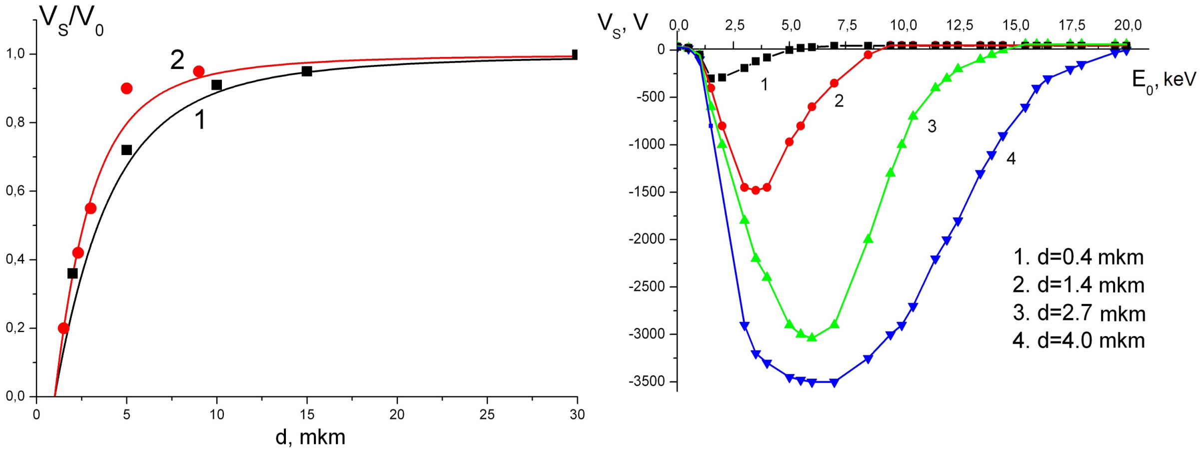

Fig. 2: (a) - Dependence of surface potential of dielectric films on their thicknesses: (1) $V_s(d)$ for mica (plot 1) and for PMMA (plot 2). (b) - Dependences of surface potential V_s on incident electron energy E_0 for PMMA films of different thickness d on Si-substrate.