CHANGE IN CHARGING STATE OF INSULATORS IRRADIATED BY CHARGED PARTICLES OF LOW AND MEDIUM ENERGY

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Introduction

Study of charging of dielectric materials under electron and ion irradiation is not only of scientific, but also of great practical importance, for example in methods of surface analysis using ion and electron beams, scanning electron microscopy and focused ion beam microscopy, in lithography and space technology.

Electron irradiation

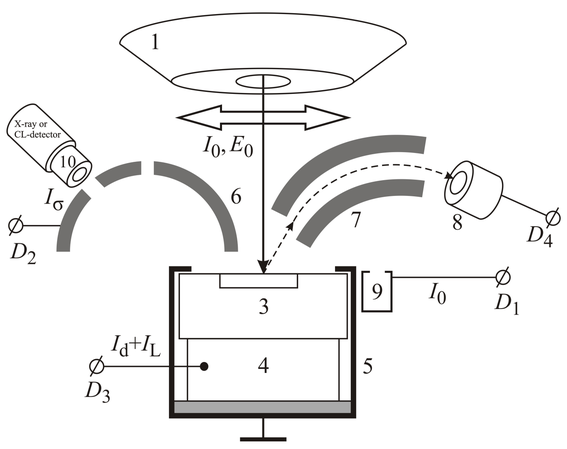
It was found experimentally [1, 2] that the charged surface potential of some dielectric samples (for example, crystalline sapphire) begins to grow not immediately after electron irradiation switching on, but only after a certain critical irradiation fluence F_{cr}.

In present research the kinetics of charged surface potential V_S and intensity of cathodoluminescence signal I_{CL} was measured simultaneously.

Materials and Methods

Samples (100) SiO_2 and (0001) Al_2O_3 single crystals

Experimental setup



1 – objective lens
2 – electron beam
3 – dielectric sample
4 – conductive substrate
5 – grounded metal grid
6 – hemispherical electron collector
7 – electrostatic toroidal spectrometer
10 – cathodoluminescence signal detector
D_1, D_4, D_2, D_3 – signal detectors

Parameters of electron beam

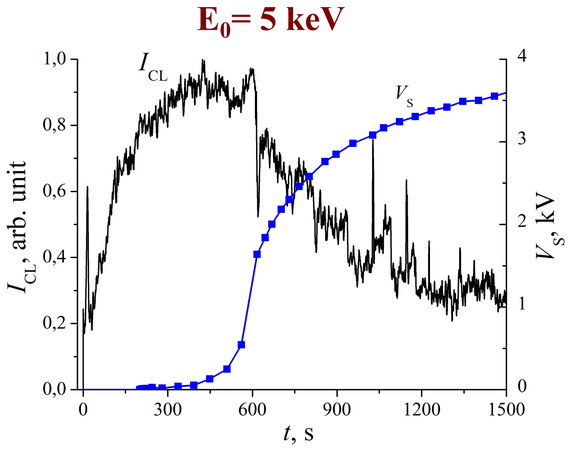
- electron beam energies E_0= 5 and E_0=15 keV
- electron beam current density $j_0 = 10^{-5}$ A/cm^2
- irradiated area S = 100×100 μm^2

Experimental results

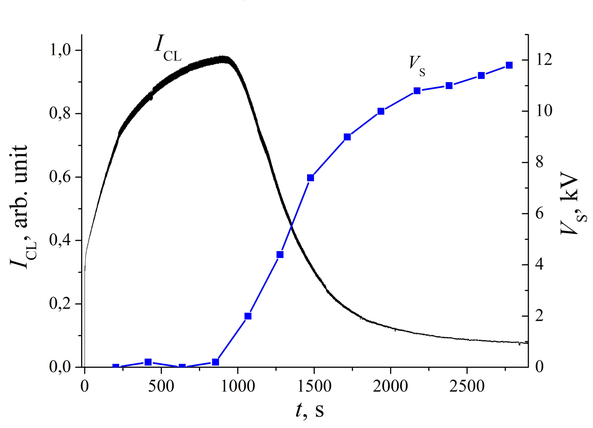
Cathodoluminescence intensity I_{CL} and surface potential -V_S of Al_2O_3 crystal as a function of electron irradiation time t

pristine Al_2O_3 crystal

E_0= 5 keV

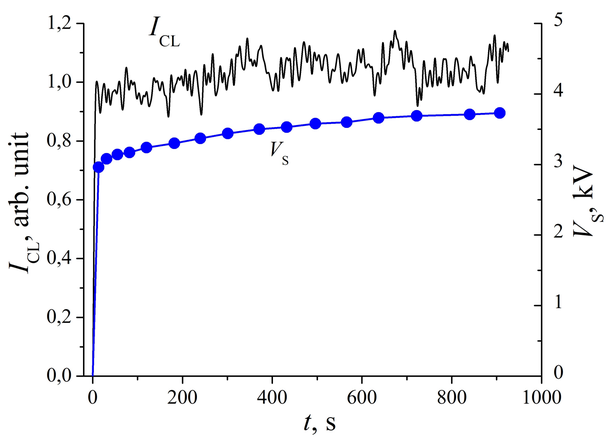


E_0= 15 keV

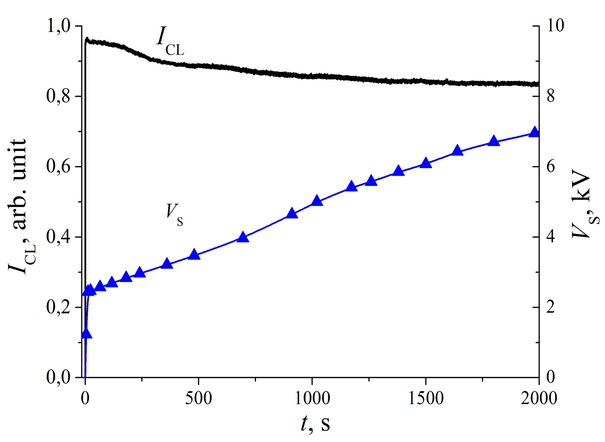


Al_2O_3 crystal pre-irradiated by electrons energy 1 keV, fluence 2 ×10^{20} cm^{-2}

E_0= 5 keV



E_0= 15 keV

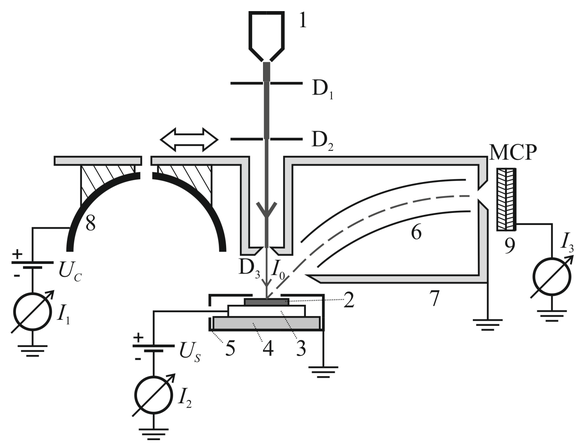


Ion irradiation

Previous experiments [3] showed that under positive Ar^+ ion bombardment the surface of insulators is charged to a very high positive potential. It was also observed a significant increase in the yield of positive ions emitted from the surface. The purpose of recent study was to investigate the reasons for such an ion emission enhancement under medium energy ion irradiation of insulators charged to high potentials.

Materials and Methods

Experimental setup



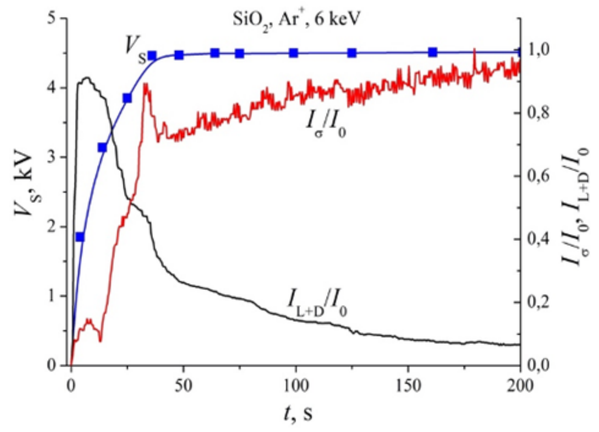
1 - ion gun
2 - dielectric target
3 - metal substrate
4 – insulator
5 - shielding chamber for samples
6 - toroidal sector energy analyzer
7 - energy analyzer spectrometer
8 - hemispherical ion collector
9 - microchannel plate detector (MCP)
D_1, D_2, D_3 - collimating diaphragms.

Parameters of ion beam

- ion beam energy E_0= 6 keV
- ion beam current I_0 =500 pA

Experimental results

Time evolution of charging characteristics of pristine SiO_2 crystal under Ar^+ ion irradiation



I_0 – incident ion current
I_σ–emission current
I_{L+D}– displacement current
V_S – surface potential

Conclusions

- It has been found a non-monotonic dependence of cathodoluminescence intensity from pristine Al_2O_3 crystal on the electron irradiation time.
- For the pristine sapphire crystal, there is a critical fluence of electron irradiation at which the charging potential starts to grow. The onset of charging coincides in time with the onset of the decay of the cathodoluminescence signal.
- The critical fluence at which the charging of the sapphire crystal begins is inversely proportional to the electron irradiation energy due to the inverse proportionality of the inelastic interaction cross section to electron energy.
- For sapphire pre-irradiated by electrons with high fluence of 2×10^{20} cm^{-2}, charging begins immediately after electron irradiation switching on and a monotonic dependence of cathodoluminescence signal is observed.
- These experimental results can be explained by a generation of radiation-induced defects which are the luminescence centers in crystal. At high electron fluence the radiation defect concentration reaches the great magnitude and defects start to form aggregates which are the deeper traps for electrons. It leads to the decay of the cathodoluminescence signal and the onset of charging.
- The observed enhancement of ion-ion emission from insulators charged to high potentials can be explained by a decrease in probability of primary ion neutralization and a reduction of the chemical bond energy due to appearance of a hole at the O atom in the lattice.

References

[1] E.I. Rau, A.A. Tatarintsev, E.Yu. Zykova. *NIMB* 460 141, 2019.
[2] E.I.Rau, A.A.Tatarintsev, E.Yu.Zykova, et al., *Phys. Solid State* 59 1526, 2017.
[3] E. Rau, A. Tatarintsev, E. Zykova, et al., *Vacuum* 177 109373, 2020.