BEAM TEST FASILITY AT KhIPT

The KhIPT Group

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1 Introduction

The impact of radiation on a semiconductor device is effected, mainly, via two mechanisms. The first mechanism of volume damage consists in damaging the crystal symmetry by displacing atoms out of lattice points. The second mechanism of surface action consists in changing the charge state of the Si/SiO_2 interface by ionizing the oxide [1, 2]. Owing to this, to simulate the radiation conditions for the inner tracking system (ITS) of the ALICE detector it is necessary to provide for an influence on ITS elements of a certain absorbed dose of ionizing radiation (~1600 Gy) and of neutron fluence [3]. Neutrons simulate the affect of high energy secondary particles on the bulk of detector material [4, 5].

Fast simulation of bulk damage for the development of detectors may also, probably, be carried out with sources of other particles. These particles would possess certain properties, such as high penetrating ability and high energy of shifted atoms in interaction.

This proposal considers the opportunities to apply KhIPT beam test facilities to study radiation resistance of microstrip detectors, read-out electronics and other devices according to the LHC heavy-ion program. There are considered test facilities based on electron linear accelerators.

2 Acclererators

Table 1 presents the parameters of KhIPT electron linear accelerators. Figures 1 and 2 show typical schemes of beam experimental devices for irradiating detectors with high energy electrons and photons.

3 Irradiation methods

To irradiate samples one applies beams of accelerated electrons as well as beams of gamma-bremsstrahlung. Depending on material and size of the device sample one chooses the particle energy in the range 5 to 1200 MeV sufficient to obtain the required uniformity of the absorbed dose over a sample volume.

Table 1: Beam parameters of KhIPT electron accelerators

No	Parameter	Units	LAE-10	LAE-40	KUT	EPOS	LAE-300	LAE-2000
1	Energy of accelerated electrons at spectrum maximum	MeV	8	30	10	20	250	1200
1,1	Control limits for the electrons energy	%	±25	+10 -50			+10 -40	+25 -50
1,2	Relative width of the energy spectrum (at the halfheight)	%	12	8			5	1,0
1,3	Relative instability of electrons energy	%	±5	±5			±5	±0.25
2	Current pulse duration of accelerated electrons	s$\cdot 10^{-6}$	0.5÷2.0	4÷10			2.0	1.0
3	Pulse sequence frequency of the beam current of electrons		6, 12, 25, 50, 100, 150, 300	3.125; 6.25; 12.5; 25; 50			1÷100	1÷50
4	Beam current of accelerated electrons							
4,1	Pulse	A	0.8÷1.2	0.1÷0.2			0.3	0.03
4,2	Average	mcA	50÷400	20	1000	500	60	1.5
4,3	Relative instability current	%	±10	±10			±5	±10

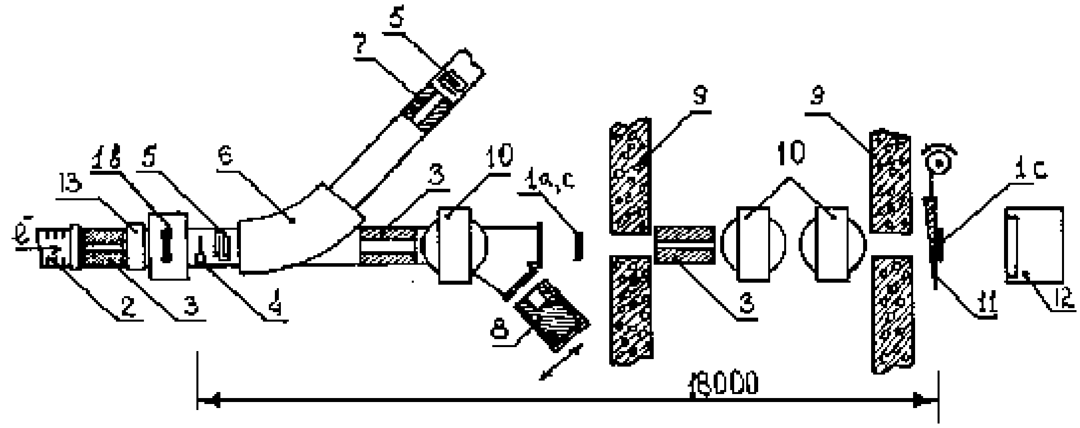

Figure 1: Scheme of irradiation with electrons and bremsstrahlung gamma-radiation at LEA-2000. 1a - is a sample irradiated with electrons; 1b - is a crystal target on a goniometer; 1c - is a sample irradiated with gamma-quanta; 2 - is the accelerating section; 3 - is the collimator; 4 - is an amorphous converter; 5 - is a secondary emission monitor; 6 - is a bending magnet; 7 - is a collimator-monochromator; 8 - is a Faraday box; 9 - is the protector; 10 - are purifying magnets; 11 - is the gamma-electron converter; 12 - is a quantometer; 13 - is a magnetic induction monitor.

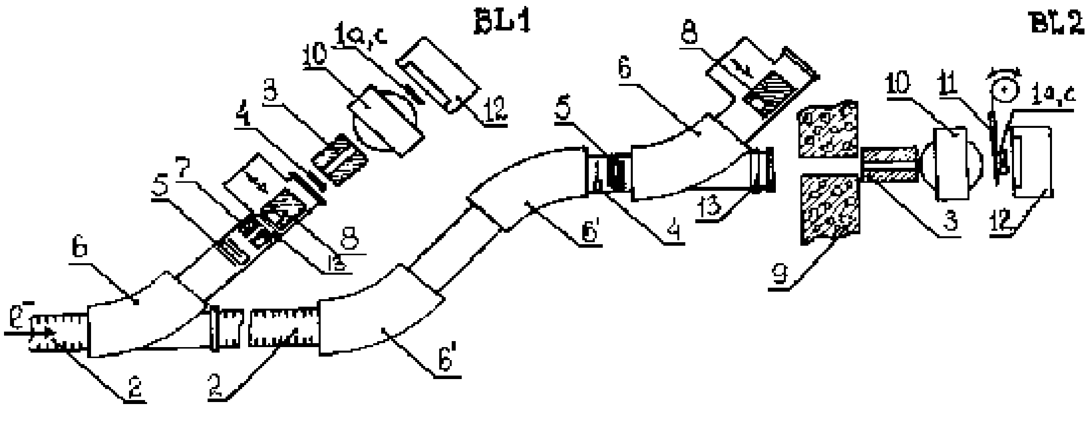

Figure 2: Scheme of irradiation with electrons and bremsstrahlung radiation at LEA-300. 1. Beam line for the 3 to 30 MeV energy range. 2. Beam line for the 60 to 300 MeV energy range. 6' are the bending magnets of parallel translation. The rest of notation are the same as in Fig. 1.

3.1 Irradiation with electrons

Fig. 1 shows the irradiation scheme and the diagnostics of electron beams. Electron beam current is measured with a Faraday box and with the secondary emission monitor. Stability of the beam current throughout the irradiation period is controlled with the magnetic induction monitors. Electron energy is measured with magnetic spectrometers. Amplitude and temporal characteristics of signals from technological and measuring systems are registered and processed by CAMAC electronics and computers.

The absorbed dose D (Gy) in the irradiated device sample is determined according to the well-known energy losses of electrons and measured integral electron flux densities F.

The absorbed dose and the distribution of the absorbed dose over the device sample volume are also measured with colour film dosimeters. Colour film dosimeters permit to perform measurements with the accuracy not more than 20% at constant ambient conditions and the temperature not exceeding 60 °C. The optic density of dosimeters is measured with the spectrophotometer SF-16 and the microphotometer IFO-451.

The dose absorbed by irradiated objects is one of the basic parameters characterizing the interaction between ionizing radiation and substance. However, it is not sufficient to measure only the absorbed dose if one irradiates samples with high energy particles. In this case the radiation effects are determined essentially by volume radiation defects of the structure arising due to displacements of substance atoms by particles of acting radiation.

Concentrations of displaced atoms in the tests are estimated on changes in the lifetimes of nonequilibrium charge carriers in small size semiconducting samples-witnesses.

The lifetime of nonequilibrium charge carriers is an electrophysical characteristic of a semiconductor material that is most sensitive to radiation. For example, if one irradiates samples with 10 MeV electrons the changes in the lifetime of nonequilibrium charge carriers can be measured for the integral flux density 10^{11} e^-/cm^2.

This lifetime is connected with the integral flux density F of accelerated electron by the relation

$$1/\tau - 1/\tau_0 = K_\tau F, \tag{1}$$

where τ_0, τ are the lifetimes of nonequilibrium charge carriers in a semiconductor before and after irradiation; K_τ is the coefficient of radiation damage of a semiconductor obtained from the lifetime of nonequilibrium charge carriers.

The change of the inverse lifetime $1/\tau - 1/\tau_0$ satisfies the linear dependence in a broad range of integral flux densities F (fig. 3).

3.1.1 Development of electron-photon showers

The interaction of high energy electrons with matter possesses a feature permitting to apply electron beams for testing massive elements of a detector, e. g., an assembly comprising a scintillator and a semiconductor photodiode (fig. 4).

When a high energy electron is passing through matter an electron-photon shower is developing as a result of consequent radiation of gamma-quanta and their conversion into electron-positron pairs. The shower process changes the energy spectrum, composition, number and densities of particles of primary radiation. Electron-photon shower characteristics depend on the energy of primary electrons and the material of an irradiated sample.

The shower process at considerable penetration depths into matter may lead to the increase in the ionization degree of matter as well as in the concentration of atoms displaced by radiation. On irradiating massive samples one controls both these quantities.

Fig. 5 shows, as an example, changes in the radiation dose and the lifetime of nonequilibrium charge carriers in a semiconductor against the scintillator thickness for different energies of incident electrons and specific weight of the scintillator.

3.2 Irradiation with bremsstrahlung

To obtain the bremsstrahlung gamma-quanta the primary electron beam is converted on a tantalum amorphous target or on an aligned crystal target. With a crystal target one can obtain a spectrum of gamma-radiation enriched in the region of the gigantic resonance of photonuclear reactions [6, 7]. The silicon crystal target is positioned on a goniometer (with the accuracy of angle read-out $\sim 10-5$ radian).

The energy flux density of the bremsstrahlung radiation is measured with a thick-walled ionization chamber or a Wilson quantometer. The flux density distribution and the absorbed dose of the bremsstrahlung radiation are measured by a small-scale solid chamber and by film dosimeters.

Spectral characteristics of gamma-radiation are measured by threshold nuclear detectors or by "Grom" technique using Compton scattering of gamma-quanta [7, 8]. The energy spectra of scattered gamma-quanta are measured with scintillation or semiconductor detectors. Registration and processing of spectra are accomplished in the CAMAC standard and with the computer. The "Grom" technique provides for measuring actual spectra of gamma-radiation for practically all converter thicknesses and gamma-radiation intensities.

The broad range of electron energies provides for producing beams of gamma-quanta with different action on semiconducting materials. The gamma-quanta with E_γ^{max} (E_γ^{max} is the maximum energy in the bremsstrahlung spectrum) below the threshold of photonuclear reactions create mainly separate displacements. In this case the action is similar to one from ^{60}Co gamma-sources.

Recoil nuclei formed in photonuclear reactions are the main source of displaced atoms for the irradiation with high energy gamma-quanta. Fig. 6 shows the probability density of forming a displacement against the energy of the primarily knocked-out atom (recoil nucleus) [9, 10]. One sees that on irradiating with gamma quanta with energies E_γ^{max} above the threshold of photonuclear reactions the defects are formed mainly by high energy recoil nuclei.

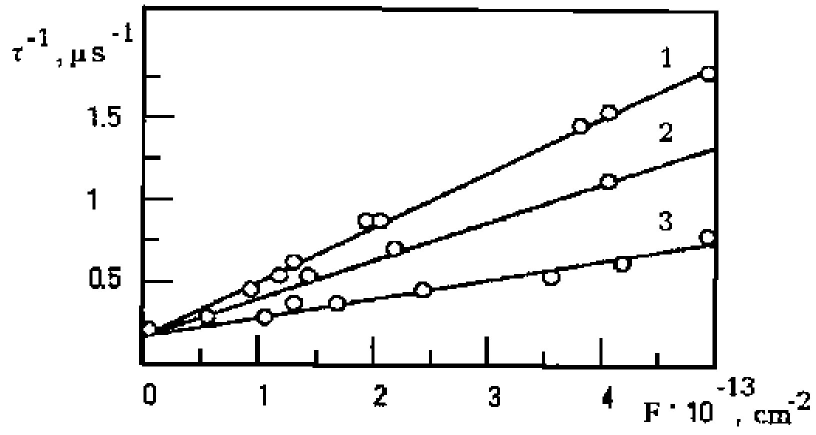

Figure 3: Inverse lifetime plotted against integral flux densities of electrons with energies: 1 - 5 MeV, 2 - 30 MeV, 3 - 120 MeV.

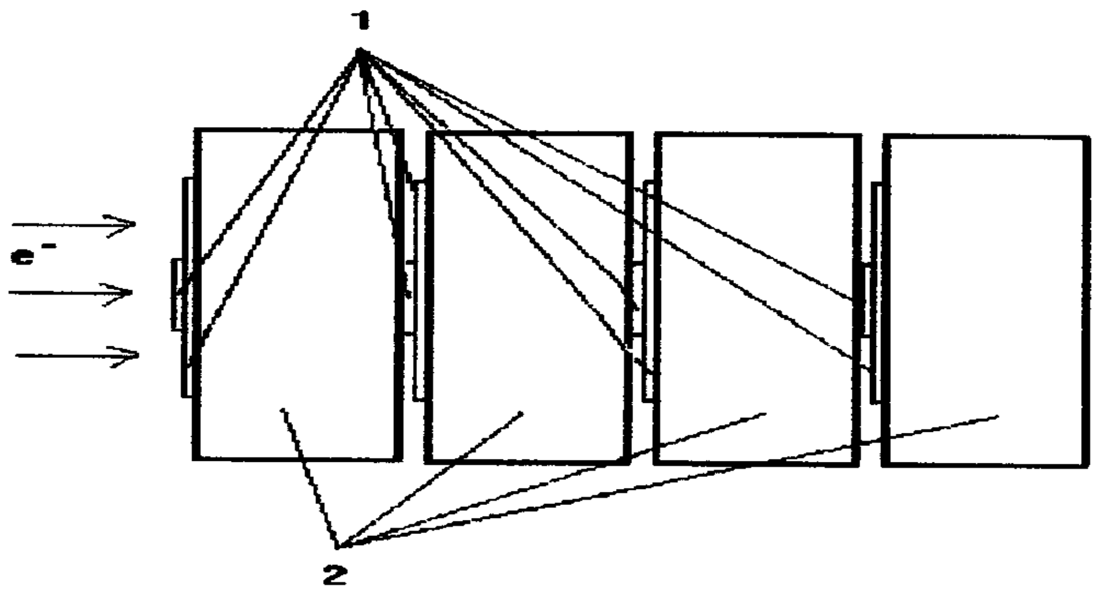

Figure 4: Studies of radiation resistance of massive elements of a detector using beams of high energy electrons. 1 - are semiconductor samples and film dosimeters; 2 - are plates of a scintillator or a metal.

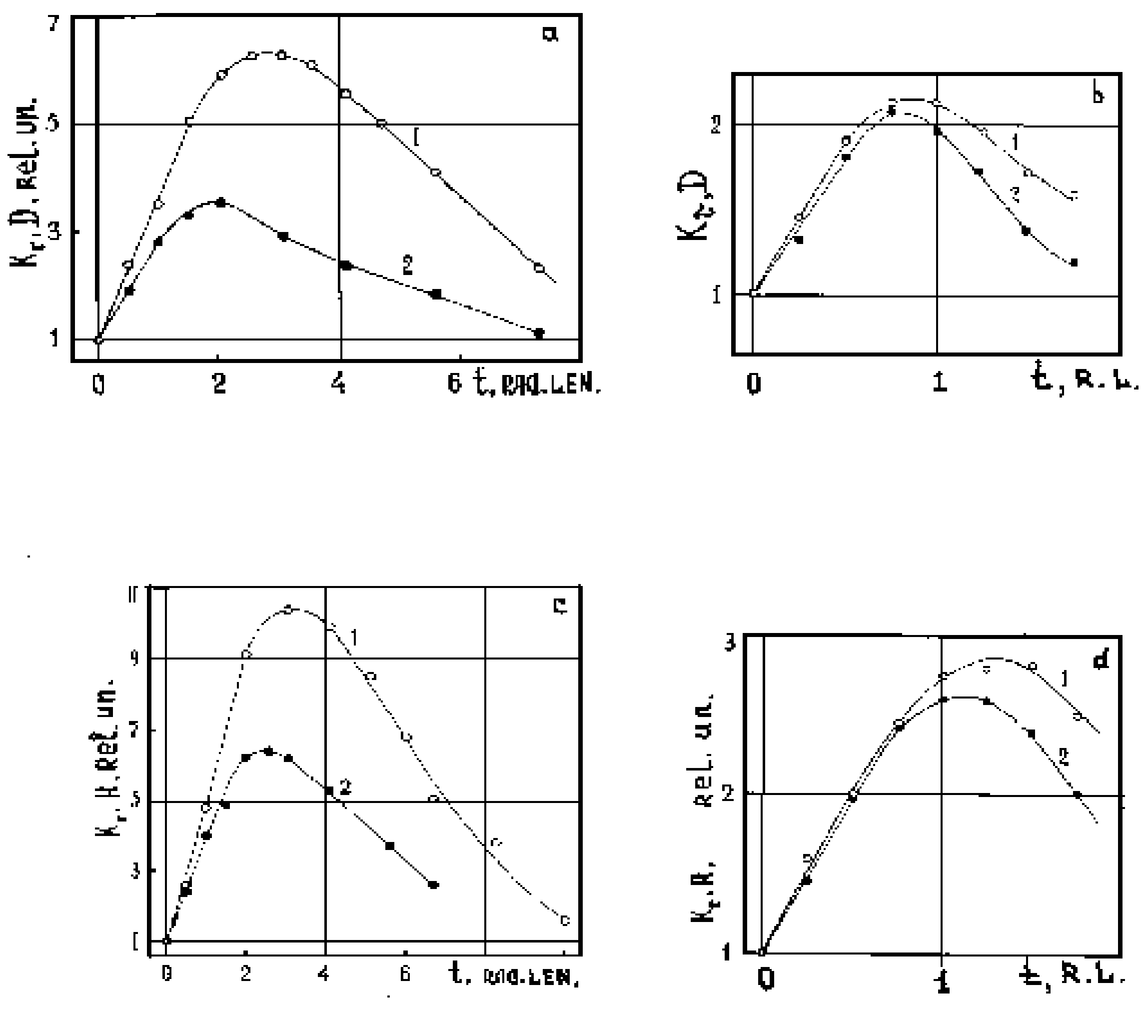

Figure 5: Absorbed dose D (1) and damage of silicon K_τ (2) against the scintillator thickness t. Primary electron energies 500 MeV (a, b) and 1000 MeV (c, d). Specific densities of scintillators ∼3 (b, d) and ∼11 g/cm (a, c).

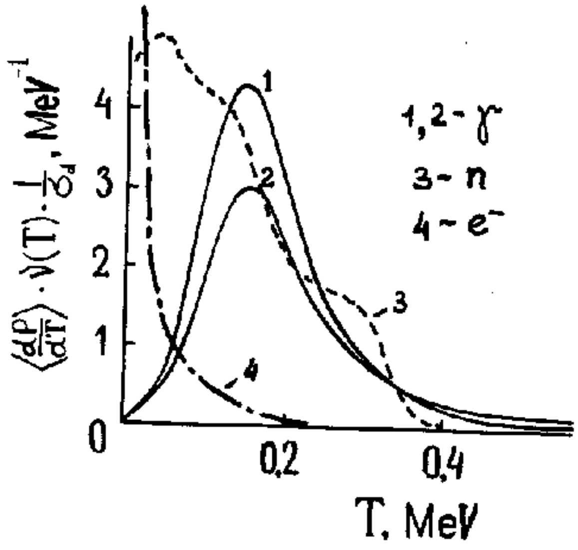

Figure 6: Probability density for displacement (Frenkel pair) formation by a primarily knocked-out atom against its energy T. Bremsstrahlung with the energy E_{γ}^{max} 30 (1) and 150 (2) MeV.

Fig. 6 also shows the probability densities for displacement formation on irradiating with neutrons from a heat and fast reactors. The dependences for fast neutrons and gamma-quanta are similar. Displacements are made mainly by high energy recoil nuclei for neutron as well as gamma-quanta irradiation. This fact permits to hope that one can simulate processes occurring in LHC detectors with gamma-radiation. Conventionally, these processes are simulated with neutron irradiation.

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