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Transient processes in semiconductors after heavy particle irradiation and consequences for detection

The studies of interactions of particles in crystalline semiconductors are motivated by the scientific and technological relevance of the subject, with applications to new materials and detectors or to devices with improved parameters to radiation for particle and astroparticle experiments. The energy transferred by the heavy particle to the crystalline semiconductor is found in the electronic subsystem as ionisation and in the nuclear subsystem as atomic displacements and phonons. In more cases, the partition of the imparted energy between ionisation, displacements and phononic excitations is performed treating the processes as unconnected. In the last years, better approximations are obtained taking into consideration the spatial and energetic coupling between the two subsystems. This hypothesis is also used in this contribution, where the time and spatial evolution of the electronic and nuclear systems is obtained as solution of coupled differential equations with two term sources for ionisation and production of defects. The peculiarities of the processes are investigated for incident ions versus weakly interacting massive particles, at room and cryogenic temperatures. In the modelling of defect production, locally, for short times, high temperatures are obtained and defect kinetics could be different from that corresponding to environmental temperatures. The possible effects due these temperatures on defect annealing are discussed.

Summary (Additional text describing your work. Can be pasted here or give an URL to a PDF document):

Damage effects created by heavy particle irradiation in crystalline semiconductors depend on the competition between energy transfer to atomic electrons, energy spent in defect formation and energy stored in lattice excitations. Various approximations are introduced for solving the integral equations describing these processes, usually supposing them unconnected events, and correlated only by energy conservation [1].
The energy imparted by the incoming particle to atomic electrons is quickly shared among the electrons by electron –electron interactions and is also transferred to the atoms by electron –phonon interactions; in the same time, a fraction of the energy of the projectile is transferred to the lattice by direct projectile –lattice atom collision, with the production of cascades of atomic displacements. These two systems are transiently characterised by different temperatures and different spatial extensions of the excited regions, and do interact; their evolution continues up to the realisation of the thermal equilibrium. In the modelling the of the transient processes in the semiconductor, we started from the theory of the temperature spike developed by Seitz and Kohler, which supposes the electron gas and the atomic lattice as continuous media, between which the heat flows according to Fick's law [2], and considered in addition to the energy generated due to the slowing down of the ions in the electronic stopping power regime [3 –6], the energy in the atomic subsystem. So, ionisation [7] and lattice excitations could also represent a possible source of structural defects.
In the transient temperature regime, different time scales are obtained, depending on the particle, on its initial energy and on the temperature of the material. The higher temperatures locally obtained suggest the possibility of a different evolution of the primary radiation defects, in the interaction between themselves and with the impurities and defects present in the material [8, 9] than that considered in current investigations where annealing processes are supposed to take place at environmental temperatures. The first consequence is the lower effective number of primary defects. Defect kinetics is discussed in the frame of the theory of diffusion limited reactions.
The numerical analysis in the frame of coupled differential equations puts in evidence the peculiarities of the phenomena for light and heavy particle interactions in semiconductors and differences in behaviour for exotic projectiles as WIMPs (weakly interacting massive particles), analysed for cryogenic and room temperatures.
In the concrete calculations, experimental data on temperature dependencies of lattice specific heat and of lattice conductivity are fitted monotonically in order to extrapolate them to cryogenic temperatures.
The primary defects in silicon are considered in agreement with Ref. [10] and defect kinetics at higher temperatures considers the possible processes in agreement with Ref. [9].

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