Modeling of nuclear radiation detection with MEMS

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Abstract

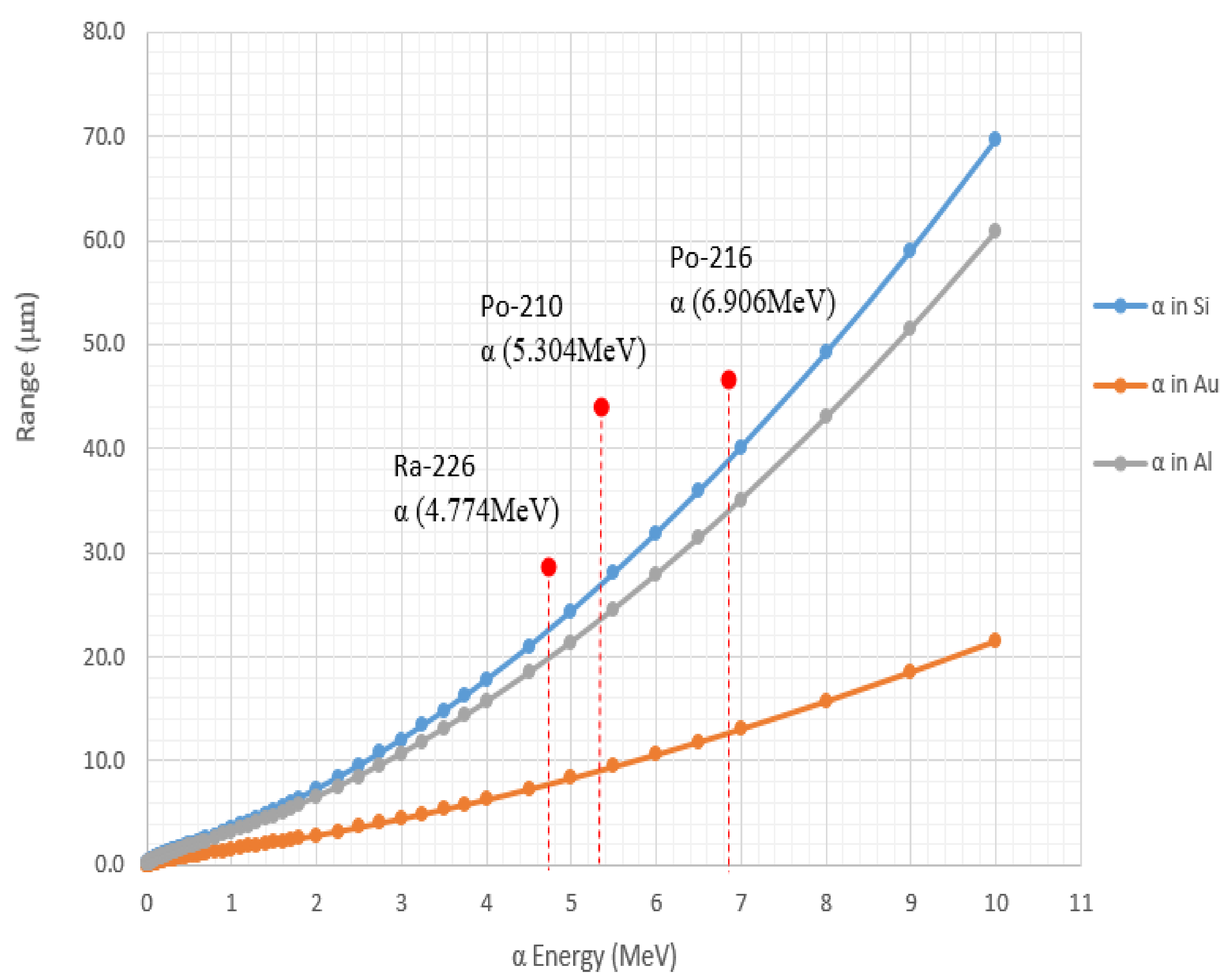
In this paper we aim to analyze the possibility of detecting nuclear radiation with a microdetector MEMS based. A part of our work is related to modeling the response of some materials like silicon to the interaction with nuclear radiation in particular with alpha radiation. Changing of mechanical, thermal, electrical properties of materials can be used for the development of small and little expensive detectors. As a second aspect we investigate the measurable effects of nuclear radiation on electronic devices in particular to a PIN diode.

Introduction

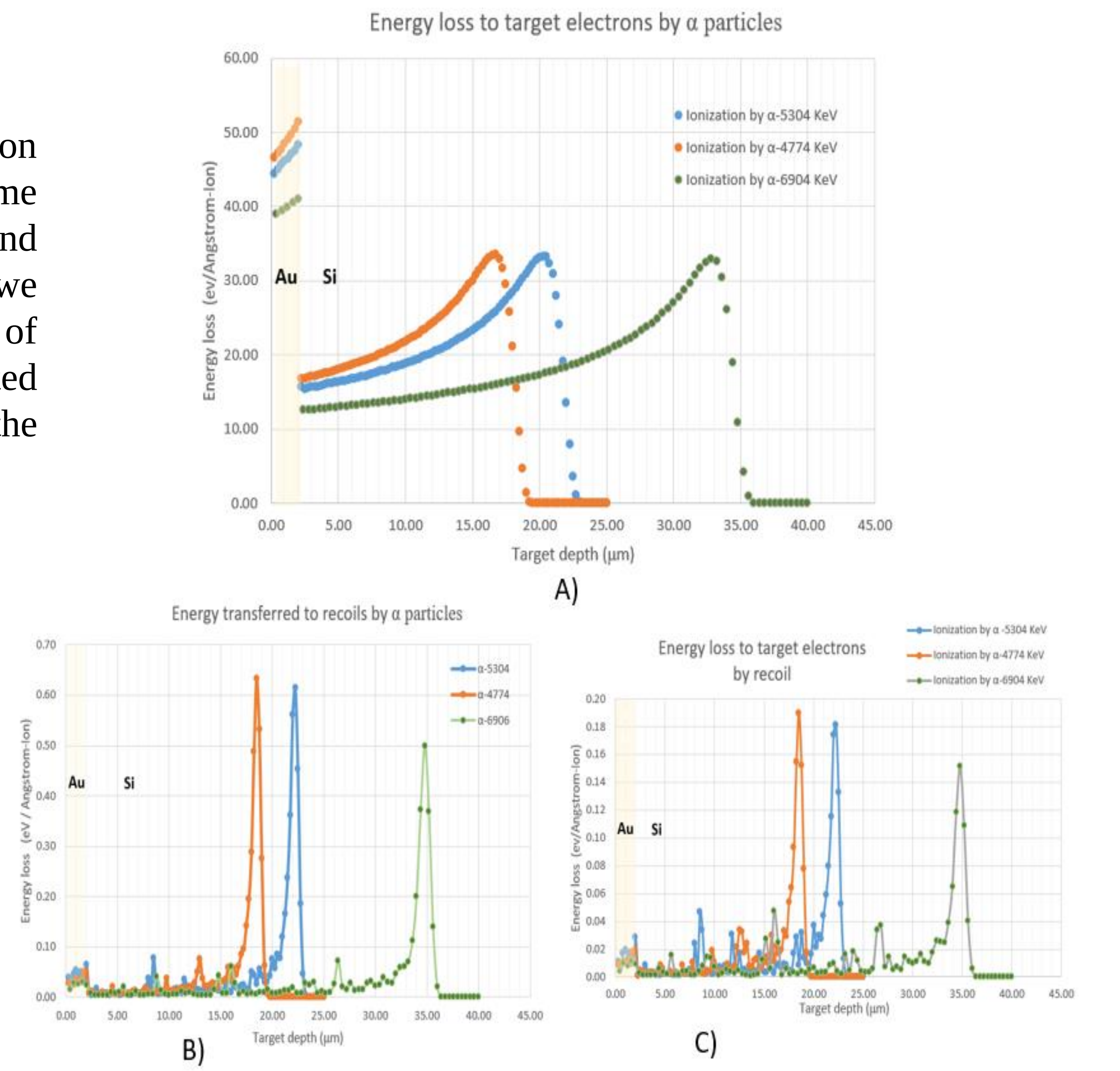
Nuclear radiation consists of high energies particles like electrons, positrons, alpha particles and high frequency gamma radiation produced by the decay of an atomic nuclei or by nuclear fission or fusion. Our work is a preliminary study for the particular case of alpha particles emitted by ordinary radioactive sources in 4-7 MeV energy range. In the first part we investigate the mechanisms of energy transfer from alpha particles to some specific materials. In the second part, using the finite element method, it is shown that the influence of ionization process on a small PIN diode leads to measurable changes of the electric field that can be used to design small MEMS based detectors.

1. ENERGY LOSS OF ALPHA PARTICLES IN SILICON

Our purpose is to analyze how alpha particles emitted in common radioactive decay in 4-7 MeV energy range interact with some materials, in particular with silicon and some metals like gold and aluminum. We choose 3 alpha emitting isotopes (see below) and we answer at the following problems: the range of particles, the types of mechanisms through which the energy of alpha particles is deposited in matter. The target model consists of Au (2μm)+Si(100μm) with the alpha particles coming at normal angle of incidence.



With SRIM code we investigate how the energy of incident alpha particles is distributed in the target material. If we analyze by comparison the electronic and the nuclear stopping energy loss for the same α particles and materials we see that the dominant mechanism is by ionization and excitation of target electrons, the contribution of the particle-nucleus interaction is much smaller. In our model about 99.7% returns in direct ionization, about 0.25% generate recoils of atoms and about 0.025% generate phonons.



.A) Energy transferred from α particles to target by ionization. B) Energy absorbed from α particles by Au and Si atoms of target which goes into recoils cascades. C) Energy from recoils which can cause ionizations.

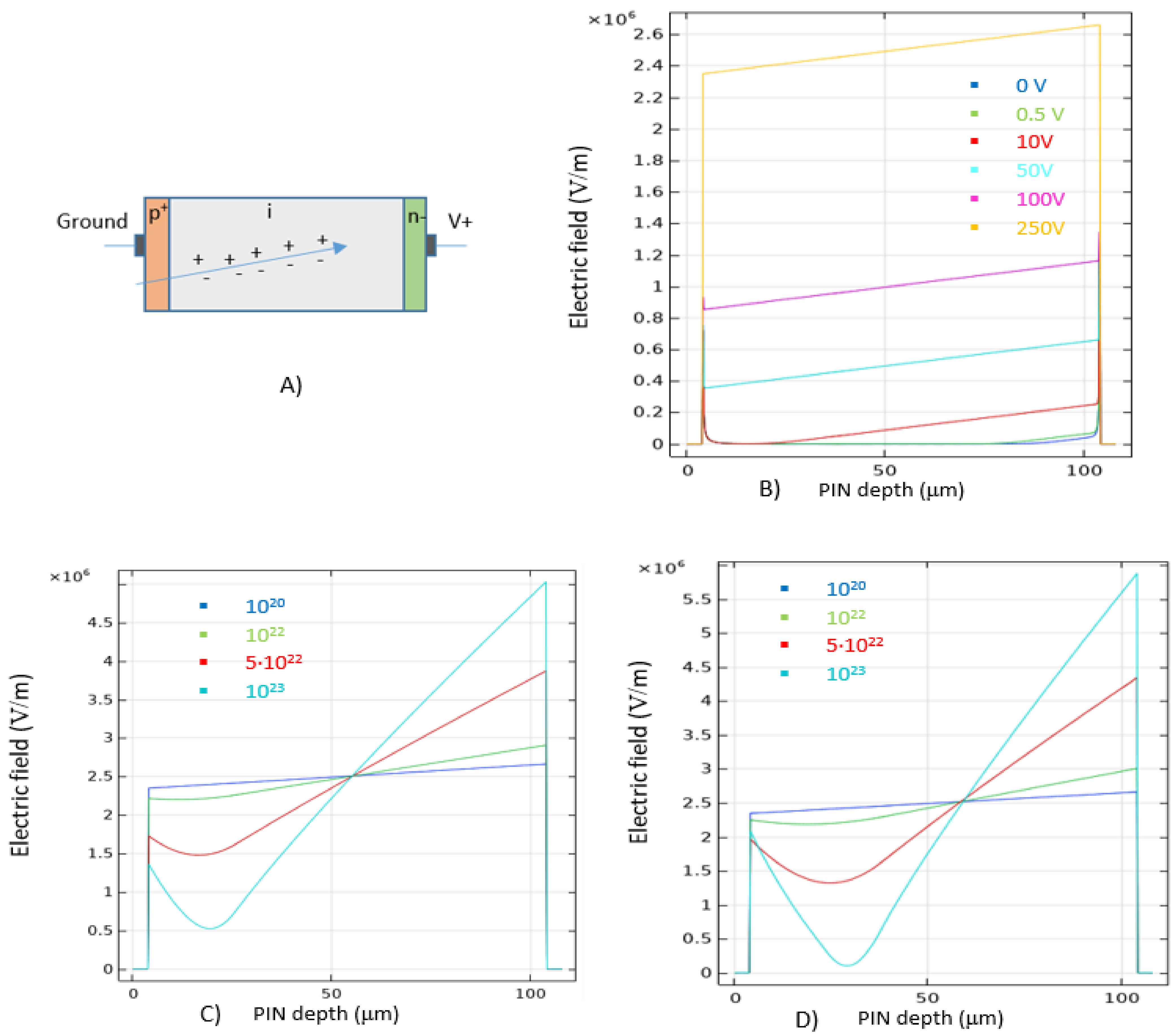
2. MEMS DETECTOR MODELING

The purpose of this study is to model a basic microdetector that can detect alpha particles in 4-5 MeV energy range using a silicon crystal. The basic structure is that of a PIN diode (Fig.5A).The PIN diode consist of p and n region strongly doped separated by a large intrinsic or very low doped region (this is a bulk medium). To suppress the leakage current due to thermally generated charge carriers in the bulk medium under equilibrium condition the PIN diode is operated with a reversed bias at sufficient voltage to fully deplete the thickness of intrinsic region. This volume is use to collect alpha particles. In our model in order to detect alpha particles between

4-5 MeV energy the thickness of p and n regions was taken as 4μm and the intrinsic region as 100μm. The acceptor dopant in p region has a concentration of 10^{18} ($1/cm^3$), the donor dopant in n region 10^{20} ($1/cm^3$). The intrinsic region has a small concentration of acceptor dopant of 10^{12} ($1/cm^3$).

In order to estimate the electric field distribution after the interaction between alpha particle and the silicon detector we used Comsol Multiphysics Modeling Software. The distribution of carriers, the electric potential and the electric field distribution in semiconductor can be found by solving the continuity equation for holes and electrons (1), the Poisson equation (2), and the drift-diffusion equations (3) with boundary condition determined by the PIN diode contacts (in our case imposing the corresponding potential values).

Considering the maximum depth for the energy loss of alpha particles with energies between 4-7 MeV discussed in previous section we performed simulations for two lengths affected by radiations that can generate electron-hole pairs respectively 26μm and 38μm. The G_n and G_p generation rates for electrons and holes have been defined for a very short time interval 0.5ns. We considered the case of uniform rates, 10^{20} ($1/cm^3s$) correspond to Polonium-210 radioactive source (1g has $16.6 \cdot 10^{13}$ Bq activity which generate on average about 60000 electron-hole pairs per μm estimated with SRIM code). Solving numerically equations (1)(2)(3) in the new conditions, the distribution of electric field inside the PIN diode is illustrated in Fig.5 C) and D). When the generation rate increase above 10^{20}($1/m^3s$) (meaning the dose of radiation increase) the distribution of electric field inside the PIN diode is detectably modified.



A) The structure of the PIN diode. B) Electric field distribution inside the PIN diode for several reverse bias voltage applied, no radiation. C)-D) Electric field distribution inside the PIN diode for different extrinsic generation rates (expressed in $1/cm^3s$) when the length that produced electron-hole pairs by radiation is 26μm (C) and 38μm (D) (simulation with Comsol Multiphysics).

CONCLUSIONS

Our preliminary study answers the questions regarding the energy loss of alpha particles in silicon and the electron-hole pairs generation as a results of ionization of silicon atoms. The investigation take into account the particular case of alpha particles in 4-7 MeV energy range. Based on Comsol Multiphysics simulations for the one-dimensional case we can say that spatial charges induced by radiation alter the distribution of electric field inside of a PIN diode and can be detected. The goal is to build a MEMS microsensor, with minimal cost, for detection of ionizing radiation produced by alpha particles. There are off course questions concerning the limitation of the model, in our next investigation we will consider a more detailed analysis on a 3-dimensional model.

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