

## Preface

The continuous increase in the complexity of problems of semiconductor electronics, as well as the development of new directions such as microwave electronics and optoelectronics have shown insufficient potential of the currently used technological processes of doping and have predetermined the inevitable search and development of new methods. One of the most promising techniques is radiation doping, i.e. the intentional, directional modification of the properties of semiconductors under the action of various types of radiation.

It is known that neutral particles, such as neutrons and  $\gamma$  quanta, find wide application to provides the uniform doping of semiconductor wafers and ingots. One of the most widely used method is the uniform doping of silicon with phosphorus by irradiation with slow neutrons (neutron-transmutation doping). Another would be the modification of the doping properties of silicon by radiation defects via the irradiation of wafers or finished devices with gamma quanta or electrons, with the purpose of changing material parameters such as the lifetime of the non-equilibrium charge carriers. However, modern semiconductor technology is based mainly on the creation of structures doped not quite uniformly in depth. Using radiation doping, non-uniform doping profiles can be obtained only by application of radiation, which can ensure effective modification of the properties of a semiconductor at predetermined depths. From this standpoint, the optimum method is the use of charged particles with a short range, such as accelerated ions, owing to the specific profile of their energy losses during stopping. In recent years, special attention has been paid on the use of the lightest ions, i.e. protons, for this purpose.

It was revealed in the 1960s that the use of charged particles leads to a doping of semiconductors. It was then that the first attempts to modify  $p$ - $n$  junctions in Si with the help of proton and  $\alpha$ -particles irradiation were carried out. Nevertheless till the middle of the 1970s all information on doping was obtained only in the form of  $p$ - $n$  junction depth. Investigations of the distribution profiles of the doping impurities throughout the depth of the crystal, which are the

physical basis of the any non-uniform doping method of semiconductors, were yet to be conducted. It was not possible to use irradiation of the crystals with charged particles for crystal doping because of the limited data of the experiments and the absence of the physical models which could describe adequately the regularities observed. Significant progress has been achieved for the past decade in the understanding of a number of important processes which occur during radiation doping of semiconductors with the charged particles. Along with the practical importance of these investigations, a set of the experiments was found to be very topical from the scientific point of view. This being that it has extended the information on the generation of radiation defects, their properties and their interaction with the impurities in the semiconductors, essential for the development of radiation physics of the solid state. Investigations performed during the last 20 years have established the most prospective kind of the charged particles that were the lightest ions — the protons. Thus a new method of radiation, doping–modification with proton beams, was formed. At present review papers devoted to modification of micro hardness, transmutation doping of selected semiconductors, and the irradiation-induced defects in semiconductor devices have been most widely represented in scientific publications. Nevertheless till now there is no review-papers on the radiation defect engineering in semiconductor technology in the world literature.

In this paper the basic principles of the interaction of the protons with single crystal semiconductors are considered and all the types of the proton modification of the materials known presently are analyzed in detail.

*Radiation Defect Engineering* will be useful to all scientists, technicians, and students interested in semiconductor electronics and radiation physics of the solid state. More than 400 references are cited in the paper.

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