Coupled diffusion of impurity atoms and point defects in silicon crystals

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Table of Contents

Introduction

Thermal diffusion is a traditional method for doping semiconductors. Under conditions of thermal diffusion, the impurity transport at all stages of doping is carried out by intensive thermal movement of atomic particles at elevated temperatures. For the formation of $p-n$ junctions in silicon crystals they are doped with the impurities formed the local regions of different types of conductivity. The elements of group V (arsenic As, phosphorus P, antimony Sb) are used for forming the regions with the electron type of conductivity and impurity of the III group, namely, boron B, aluminium Al, and others, are used to form the regions with the hole type of conductivity. Usually, doping due to thermal diffusion includes two different stages: high-temperature introduction of impurity atoms into a semiconductor from a gas phase, liquid diffusant or deposited doped layer, and redistribution of injected impurity during subsequent thermal treatments. It is worth noting that the first semiconductor devices have been created by means of thermal diffusion. A great advantage of such doping process is the equilibrium state of the defect subsystem of a semiconductor crystal. On the other hand, thermal diffusion does not allow the formation of highly doped regions with submicron and nanometer dimensions. This is a great disadvantage from the point of view of the modern microelectronics. However, at the present find that thermal diffusion of impurity atoms in silicon is of interest both from the scientific point of view and due to the cheapness of the process. The low cost of thermal diffusion is very important for manufacturing of solar elements [1, 2, 3, 4, 5, 6, 7] and other semiconductor devices. Thermal diffusion is also used for the gettering of undesirable impurities such as iron [8, 9, 10].

It should be noted that the formation of different nanostructures in the volume or on the surface of a semiconductor or in the dielectric layer occurs very often due to the diffusion of impurity atoms and point defects [11, 12]. In this case, the elastic stresses generated in the nanostructures in the course of their formation [13, 14] can significantly influence the intensity and character of the diffusion of atomic particles. Below, we consider different aspects of the processes of transport and of quasichemical reactions of impurity atoms and point defects in crystalline silicon, including diffusion in a strong nonequilibrium state of the defect–impurity system. Such nonequilibrium conditions are realized, for example, in the cases of ion implantation, plasma processing, or on the formation of multilayered structures.

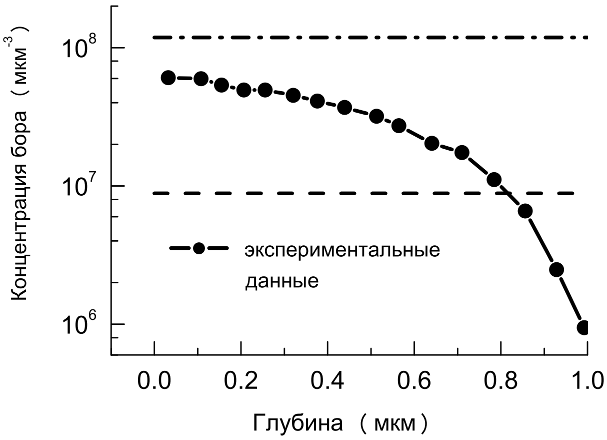

Figure 1: Distribution of the concentration of electrically active boron atoms for diffusion from a constant source. The temperature of diffusion 1000 °C, duration of thermal treatment 4 hours. Experimental data are taken from [15]. The dashed-dot line represents a limit of boron solubility in silicon C_{sol} [16], the dashed line is the concentration of intrinsic charge carriers n_i.

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