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**PHYSICS
OF SEMICONDUCTOR DEVICES**

Shallow *p–n* Junctions Formed in Silicon Using Pulsed Photon Annealing

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Abstract—Shallow and ultrashallow *p–n* junctions were formed in Si by stimulated diffusion of P from phosphosilicate glass and B from borosilicate glass under pulsed photon annealing. Electrical, photoelectric, and optical properties of these junctions were investigated. Special features of stimulated diffusion of P and B in surface layers of Si under pulsed photon annealing were revealed. The obtained results are discussed in terms of *kick-out*, pair vacancy–interstitial, and dissociative diffusion mechanisms. The features of the dopant concentration profiles are explained in terms of the vacancy–interstitial mechanism and the stimulated diffusion model with allowance made for the time dependence of the dopant surface concentration and the concentration dependence of the diffusivity. *© 2002 MAIK “Nauka/Interperiodica”.*

1. INTRODUCTION

There is much interest in using shallow and ultrashallow p^+–*n* and n^+–*p* junctions in Si to increase the integration scale, operating speed, and reliability of integrated circuits (ICs), microelectronic devices, and self-assembled microstructures and nanostructures of different types [1–3]. This is especially urgent now, considering that very large-scale integrated circuits (VLSICs) with a device dimension of 0.18 μm are presently manufactured, and future reduction of the device dimension is expected: to 0.13 μm in 2004, 0.10 μm in 2007, and 0.07 μm in 2010. In addition to this, as shown in [1], ultrashallow diffusion *p–n* junctions can be successfully used to form superlattices of different types, self-assembled microresonators and quantum wells, one-electron memory cells, and other nanoelectronic devices.

A number of methods are used to form ultrashallow *p–n* junctions: planar diffusion via fluxes of excess vacancies or self-interstitials generated at the Si–SiO_2 interface [4, 5], low-energy B implantation [6], dual implantation of B^+ and Si^+, amorphization of Si by BF_2 implantation [7], proton implantation [8], and ion implantation through a thin silicide film [9]. Preamorphization of Si is most often used. However, when using this technique, it is very difficult to optimize the conditions of postimplantation annealing, which is necessary to activate dopant atoms, remove radiation defects, and retard the diffusion. Thus, alternative techniques should be looked for.

There is much interest in diffusion stimulated by laser annealing [10], different types of radiation (e^-, α, β, γ) [11], combined radiation and electric field [12], and combined radiation, implantation, and photon annealing [2, 13]. However, more and more interest is being shown in doping Si with the use of diffusion caused by pulsed photon annealing (PPA) or rapid thermal annealing (RTA) (which is widely used for thermal treatment of ion-implanted semiconductors [2–5, 14–16]) as an alternative technique for forming ultrashallow *p–n* junctions. Commonly, diffusion of either B from borosilicate glass (BSG) or P from phosphosilicate glass (PSG) is used. As shown in [2–5, 14, 15], this technique makes it possible to form ultrashallow (10–30 nm) *p–n* junctions in Si with higher concentration gradients of B and P, compared with *p–n* junctions formed by ion implantation. With the use of secondary-ion mass spectrometry (SIMS) and relevant calculations, it was shown [14] that the diffusivity of B in a BSG–SiO_2–Si system subjected to RTA exceeds the conventional diffusivity by a factor of 9–10.

Different stimulating effects can be used in this technology. These include fluxes of excess nonequilibrium vacancies and interstitials generated at the Si–SiO_2 interface; excitation of the electron subsystem and charge exchange between dopant atoms, caused by PPA; and other effects related to the nonequilibrium stimulated diffusion. However, to date, many of these effects have not been adequately investigated and opinions differ as to the mechanism and model of the stimulated diffusion of B and P in Si [17]. Thus, additional basic and applied research is necessary for widespread implementation of this technology.

In this paper, we report the results of the investigations of shallow and ultrashallow *p–n* junctions formed in Si by stimulated diffusion of P from PSG and B from BSG using PPA. We measured the depth of n^+–*p* and p^+–*n* junctions, the sheet resistance of diffusion layers, the current–voltage characteristics of junctions, and we