Measurement of Nonthermal Illumination-Enhanced Diffusion in Silicon

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INTRODUCTION

Formation of pn junctions in advanced Si-based transistors employs rapid thermal annealing (RTA) of ion-implanted regions in order to increase the activation of dopants. The need for ever-shallower junctions with low sheet resistances has driven a shift to “spike” RTA with exceptionally high heating rates near 400 °C/s. There has been suspicion that the strong lamp illumination required for this procedure may nonthermally influence the diffusion of dopants. Possible mechanisms include (a) photoenhanced formation of bulk vacancies and self-interstitials that mediate diffusion, and (b) photostimulated changes in the hopping mobility of existing interstitials. Both mechanisms involve changes in the average electrical charge state of the relevant species. Identification of such effects is difficult in conventional RTA geometries because lamps provide both heating and photostimulation, and because the interpretation of conventional dopant diffusion experiments is impeded by complex dopant-defect interactions and the presence of built-in electric fields in typical test structures. In this paper we present unambiguous experimental measurement of nonthermal illumination-enhanced diffusion in unimplanted silicon

EXPERIMENT

We used a novel experimental design employing a new heating configuration in which heating and illumination were largely decoupled. Experiments examined the decay of a step concentration profile of ^{30}Si tracer atoms in an epitaxial ^{28}Si matrix. Temperature uniformity on the illuminated and unilluminated sides was ensured through a structure consisting of two single-sided Si samples sandwiched together with Ta foil. Heating above 600 °C led to silicidation at the interfaces of Si/Ta/Si sandwich structure, thereby helping to ensure uniform temperature throughout. Optical view factors for the two sides were also matched. Experiments were performed in an ultrahigh vacuum chamber to minimize surface oxidation and corresponding OED effects. Illumination was accomplished with a He-Ne laser operating at 633 nm, and isotopic profiles on the light and dark sides were compared with SIMS after annealing.

RESULTS AND DISCUSSION

Profiles showed the exponential shapes characteristic of diffusing interstitial species. Illumination levels as low as 50 mW/cm^2 affected diffusion rates of these species by factors of two or more. Example results appear in Fig. 1. Illumination stimulated an increase in diffusion rate for n-doped material, and a decrease for p-type material. In this respect, the results mimic those obtained previously for illumination-influenced diffusion on Si(111) surfaces[1,2]. The illumination dependence of activation energy and pre-exponential factor will be presented in this paper along with dependence in illumination intensity.

1) R. Ditchfield, D. Llera-Rodriguez and E.G., Seebauer, *Phys. Rev. Lett.* **81** (1998) 1259.

2) R. Ditchfield, D. Llera-Rodriguez, E.G. Seebauer, *Phys. Rev. B* **61** (2000) 13710.

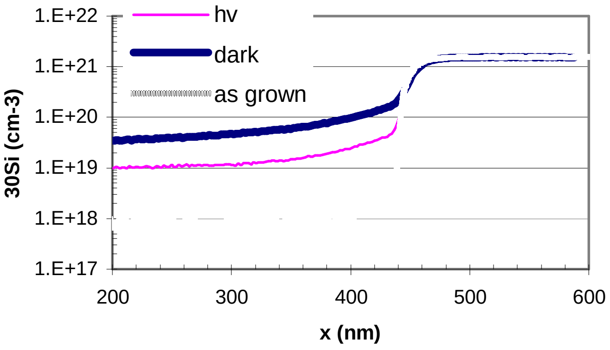

Fig. 1. Diffusion profiles of ^{30}Si in the presence and absence of 50 mW/cm^2 illumination. Material was B-doped to 10^{19} cm^{-3}. Anneal was 4 hr at 850°C.