Enhancement of Oxide Break-Up by Implantation of Fluorine in Poly-Si Emitter Contacted p^+-n Shallow Junction Formation

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Abstract— **In this study, it is demonstrated that the incorporation of fluorine can enhance poly-Si/Si interfacial oxide break-up in the poly-Si emitter contacted p^+-n shallow junction formation. The annealing temperature for breaking up the poly-Si/Si interfacial oxide has been found to be as low as 900°C. As a result, the junction depth of the BF_2-implanted device is much larger than that of the boron-implanted device.**

I. INTRODUCTION

FORMATION of an ultra-shallow p^+-n junction is important for future ULSI application [1]. The BF_2 implantation is typically used to form a p^+-n shallow junction, since it exhibits less channeling tail [2]. However, the BF_2 implantation would create much larger damages near the Si surface and subsequently result in a larger junction leakage as compared with the B implantation [3].

Recently, the highly B-doped poly-Si has been used as a diffusion source to form an ultra-shallow p^+-n junction for BiCMOS applications [4], [5]. Although some researchers had been devoted to studying the physics and the metallurgical structures of the boron-doped poly-Si contacted devices, the exact nature of the poly-Si/Si interface has not been fully understood [6]–[8]. It is well known that there exists an unintentional oxide layer at the poly-Si/Si interface [7]. This interfacial oxide layer acts not only as a diffusion barrier of dopant but also as an electrical barrier for the transport of both minority and majority carriers and will significantly increase the emitter resistance [8]. This interfacial oxide layer can be broken-up only under a high doping level ($N \geq 1 \times 10^{20}$ cm^{-3}) and a high temperature anneal ($T_a \geq 950°C$) [7]. Recently, William *et al.* found that at a higher temperature annealing ($\geq$ 1100°C), the sheet resistance of the BF_2-implanted poly-Si layer was slightly less than that of the B-implanted poly-Si layer and suggested that the incorporation of fluorine into the poly-Si could accelerate the break-up of the interfacial oxide during the early part of the emitter diffusion [9].

In this study, we first use the transmission electron microscopy (TEM) to demonstrate that with the incorporation of fluorine into the poly-Si layer, the poly-Si/Si interfacial oxide layer can be easily broken up. The annealing temperature for breaking up the poly-Si/Si interfacial oxide of the BF_2-implanted poly-Si emitter contacted $p^+ - n$ shallow junction diode has been found to be as low as 900°C, while that of the B-implanted device must be larger than 950°C.

II. EXPERIMENTAL PROCEDURES

The diodes were fabricated on n-type 8–12 Ω-cm (100) Si wafers. Prior to the poly-Si deposition, all wafers were dipped in a $HF{:}H_2O$ (1:50) to remove the surface native oxide. Then, the poly-Si film of about 2500-Å-thick was deposited at 625°C followed by a boron or BF_2 implantation with a dose of $1 \times 10^{16} cm^{-2}$. To obtain the same average depth of the implanted ions, i.e., the projected range (R_p), the implantation energy of boron and BF_2 were 27 keV and 120 keV, respectively. After implantation, all wafers were annealed at 800°C and 30 min in an N_2 ambient followed by driving in at 900°C for 25, 40, 60 min or at 950°C for 20 min all in an N_2 ambient. The impurity profiles were measured with a VG Ionex SIMS tool using an O_2^+ beam for the boron and fluorine. The high resolution TEM (HRTEM) with a JEOL 4000EX TEM system operating at 400 kV was used to delineate the structural morphologies of the poly-Si/Si interface.

III. RESULTS AND DISCUSSIONS

Figs. 1(a) and (b) show the cross-sectional TEM micrographs for the BF_2-implanted and boron-implanted diodes, which were subjected for annealing at 900°C for 25 min after the implantation. For the BF_2-implanted sample, the interfacial oxide had been fully broken and the maximum epitaxial thickness of about 500 Å had grown, while for the boron-implanted sample the interface was still uniform and continuous. The latter was consistent with the result of Probst et al. [7]. Fig. 2(a) shows the SIMS profiles for two sets of BF_2-and boron-implanted diodes annealed at 900°C and 950°C, respectively. It is well known that, with the same R_p, the junction depth after annealing of the boron-implanted (100)

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(a) (b)

Fig. 1. The TEM micrographs of the poly-Si/Si interfacial morphologies of (a) the BF_2-implanted diode and (b) the B-implanted diode. The diodes were annealed at 900°C for 25 min.

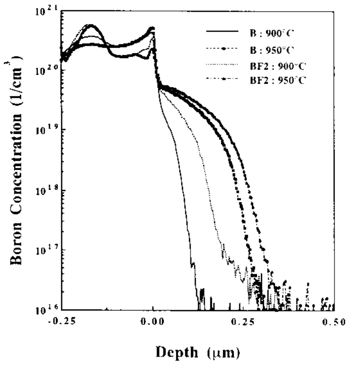

Fig. 2(a). The SIMS profiles of boron distribution of the BF_2-implanted and boron-implanted poly-Si emitter contacted p^+-n shallow junction diodes annealed at 900°C for 25 min and at 950°C for 20 min, respectively.

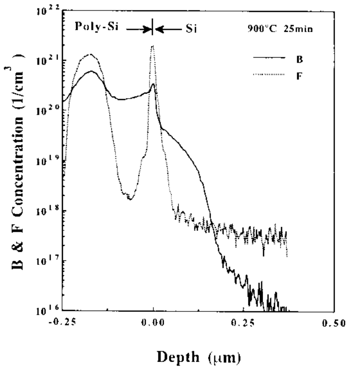

Fig. 2(b). The SIMS profiles of the implanted boron and fluorine of the 900°C annealing BF_2-implanted poly-Si emitter contacted p^+-n shallow junction diode.

Si is much deeper than that of the BF_2-implanted (100) Si due to the ion channeling effect [1]–[3]. However, in Fig. 2(a), the junction depths of the boron-implanted diodes are much shallower than that of the corresponding BF_2-implanted diodes. For example, the junction depth of the 900°C annealing boron-implanted diode is about 0.1 μm shallower than that of the 900°C annealing BF_2-implanted diode.

The above phenomena had not been reported previously. They are believed to be caused by the fluorine effect [9]–[11]. Fig. 2(b) shows the SIMS profile of fluorine along with boron for a 900°C annealing BF_2-implanted diode. It is seen that a large amount of fluorine segregates at the poly-Si/Si interface. It has been reported that the incorporation of fluorine into oxide could degrade the oxide by breaking Si-O bonds and forming Si-F bonds and subsequently resulting in a volatile SiF_x product [10]. It has also been reported that the incorporation of fluorine into the boron-doped poly-Si gate would significantly enhance the diffusion of boron through the grain boundaries of poly-Si [11]. Hence, for the BF_2-implanted samples, the poly-Si/Si interfacial oxide can be easily broken up at a lower temperature and subsequently it causes a deeper junction than the boron-implanted samples.

IV. CONCLUSION

In this letter, we report that the poly-Si/Si interfacial oxide of the poly-Si emitter contacted devices can be easily broken up by introducing the fluorine into the poly-Si layer, e.g., by using the BF_2 ion implantation. The annealing temperature to completely break up the interfacial oxide layer can be as low as 900°C. As a result, the junction depth of the BF_2-implanted poly-Si emitter contacted p^+-n junction diode will be much deeper than that of the B-implanted device due to the breakup of the poly-Si/Si interfacial oxide.

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