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A New Technique for Low Concentration Diffusion of Boron into Silicon

Ginjiro Kambara, Susumu Koike, Toshio Matsuda, and Morio Inoue

Research Laboratory, Matsushita Electronics Corporation

Takatsuki, Osaka, Japan

The commonly employed method for the low concentration diffusion of boron into silicon from a doped-oxide source[1-3] has a difficulty in reproducibility of the result, which strongly depends on the low level source deposition. To obtain a surface concentration of 10^{16} cm^{-3}, for instance, the B_2O_3 source in the CVD glass film should be doped to such a low concentration as 0.01 mole %. Moreover, some redistribution of boron in silicon due to the out-diffusion does occur during the drive-in step in the oxygen ambient.

The present paper proposes a new technique for doped-oxide diffusion of boron into silicon, which provides a controlled surface concentration over a wide range of 10^{15} to 10^{20} cm^{-3}. The principle is based on our finding that if the deposited borosilicate film is heat-treated in an NH_3 gas ambient prior to the drive-in step the transfer of boron into silicon is greatly suppressed. The effect of the NH_3 heat-treatment on the concentration of diffused boron in silicon is well controlled by both the temperature and the time of the heat-treatment. In addition, an undoped SiO_2 film overdeposited on the source film functions as a mask against the NH_3 ambient so that local diffusions of boron to high and low concentrations can be simultaneously performed from a single source film. Figure 1 schematically shows the new process, where a part of the undoped SiO_2 film overdeposited is windowed to exposure the SiO_2-B_2O_3 film to the NH_3 ambient.

The doped-oxide films were deposited on n-type silicon wafers of (111) orientation from the vapor phase of SiH_4, B_2H_6, and O_2 at a temperature of 400°C. The thickness and B_2O_3 concentration of the film were about 0.1 μm and 1 - 12 mole %, respectively. The NH_3 heat-treatment was

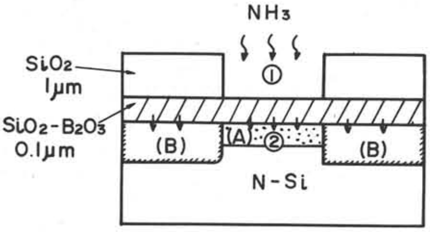

Fig. 1 Schematic illustration of the new boron diffusion technique.

① NH_3-treatment step.

② drive-in step.

By the local NH_3-treatment, low (A) and high (B) concentration regions are formed from a single source film.

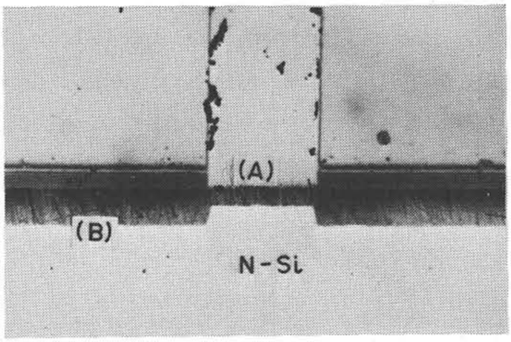

Fig. 2 Cross-sectional view of an n-type silicon wafer diffused with boron from a locally NH_3-treated borosilicate source film.

(A) surface concentration : $3x10^{17}cm^{-3}$
junction depth : 1.0μm

(B) surface concentration : $2x10^{20}cm^{-3}$
junction depth : 2.3μm

carried out at a temperature between 700 and $1000^{\circ}C$ for 30 - 60 min, and the drive-in step at 1000 - $1200^{\circ}C$ in N_2 was followed. Figure 2 is an experimental result of high and low concentration diffusion of boron into silicon from an NH_3 treated borosilicate glass film which was locally covered with an undoped SiO_2 film as in Fig. 1. The cross-sectional view of the diffused region explicity reveals the difference in depth and concentration of diffused boron between the covered and uncovered regions. In Fig. 3 is shown the surface concentration of diffused boron in silicon as a function of the concentration of B_2O_3 in the source borosilicate glass for different NH_3 heat-treatments. The NH_3 heat-treatment remarkably suppresses the boron concentration in silicon which can be controlled by the time and temperature of the treatment. For the surface concentrations below $10^{16}cm^{-3}$, the source oxide film doped with 1.1 mole % of B_2O_3 were subjected to prolonged high-temperature NH_3 treatments.

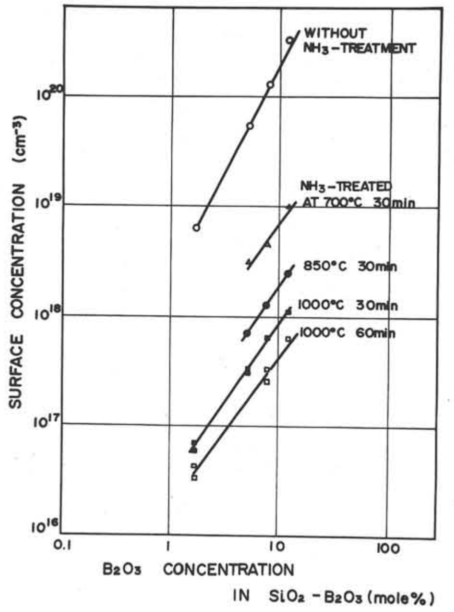

Fig. 3 The surface concentration of diffused boron in silicon as a function of the concentration of B_2O_3 in the SiO_2-B_2O_3 film for different NH_3-treatments. The drive-in was performed at $1150^{\circ}C$ for 30 min.

The profiles of the diffused boron concentration in silicon, which were observed by the SIMS technique, were found to be in good agreement with the complementary error functions, suggesting no redistribution of boron in silicon due to the out-diffusion during the drive-in step. As is seen in Fig. 3, the dependence of the diffused boron concentration in silicon on the B_2O_3 concentration in the source oxide is weakened by the NH_3 heat-treatment. This fact provides an advantage over the conventional doped-oxide diffusion technique, that fluctuation of the B_2O_3 concentration in the source glass has little effect on the uniformity and reproducibility of the resulting boron concentration in silicon. The transfer of boron through the interface between doped oxide and silicon may be the rate-determining process for the suppressed diffusion in the drive-in step.

The potential application of the new technique for the boron diffusion will be found in the integrated circuit process, especially by the use of simultaneous formation of high and low resistivity regions.

1) A.W. Fisher, J.A. Amick, H. Hyman and J.H. Scott, Jr., RCA Review, 29, 533, (1968).

2) A.W. Fisher, J.A. Amick, RCA Review, 29, 549, (1968).

3) D.M. Brown, P.R. Kennicott, J. Electrochem. Soc., 118, 1147, (1971).