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Characteristics of Boron Diffusion from BSG Film and the Formation of Ultra-Shallow, Low-Resistance Junctions

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Ultra-shallow (20-nm-deep), low-resistance (2.3 kΩ/sq.) boron-diffused layers in Si are successfully formed by using a solid-phase diffusion technique. This sheet resistance is 1/10 that of reported values at the same junction depth. The key to ultra-shallow, low-resistance junction formation is to control both the native oxide at the BSG/Si interface and the dopant concentration in the BSG film. However, the thermal budget should be reduced to maintain the desired profiles.

1. Introduction

As MOS device dimensions are scale down to around 0.1μm, ultra-shallow (< 30-nm deep), low-resistance (< 3 kΩ/sq.) extended parts of source/drain junctions (extension) are needed to suppress short-channel effects and reduce parasitic resistance. However, it is difficult to fabricate such junctions by implanting B or BF_2 because of ion scattering and channeling effects and the transient enhanced diffusion of boron. Solid-phase diffusion (SPD) from boro-silicate glass (BSG) film [1],[2] is a promising technique for fabricating shallow junctions with low resistance. However, the sheet resistance has recently been reported to be high (> 5 kΩ/sq. for 34-nm deep junctions [1]) because the surface concentration of boron is below the solid solubility [3]. In this paper, we clarify the boron diffusion mechanism from BSG film and we report on our ultra-shallow, low-resistance junctions achieved by controlling native oxide.

2. Experimental

The steps of SPD from BSG film are shown in Fig. 1. The substrates were n-type Si (100), 8-12 Ω cm wafers. Before BSG film deposition, the wafers were cleaned with conventional chemical solutions and were dipped in HF solution and deionized water to remove the native oxide. The BSG film was deposited at 420℃ by atmospheric-pressure CVD.

Rapid thermal annealing (RTA) at over 900℃ and furnace annealing at 800℃ were performed in N_2 gas. Depth profiles of boron atoms were obtained by secondary ion mass spectrometry (SIMS) with 1.5 keV O_2^+ ions at an incident angle of 60° . The sheet resistance of the boron-diffused layer was measured by using the four-point probe method.

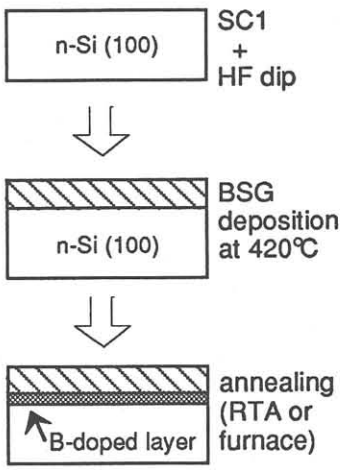

Fig. 1. Solid-phase diffusion of boron.

3. Results and discussion

The sheet resistance (ρs) of the boron-diffused layer as a function of annealing time is shown in Fig. 2(a, b, c). It decreases with increasing annealing time (t) for every sample and for all values of B_2O_3 mol%. It also decreases with increasing B_2O_3 mole concentrations at constant annealing time. On the other hand, the slope of the lines increases ($n > 0.5$) with decreasing annealing temperature for the 10 and 18 mol% samples, whereas it was 0.5 at all annealing temperatures for the 26 mol% samples. The dependence of the slope on the mol% of the B_2O_3 and the annealing temperature is shown in Fig. 2(d). The slope (n) approaches 0.5 with increasing mol%. The equation $\rho s \propto t^{-0.5}$ has been calculated for solid-phase diffusion when the surface concentration is assumed to be constant [4] as illustrated in Fig. 3(a). A slope higher than 0.5 suggests that the surface concentration is lower during the initial stage of annealing. This is probably because the native

oxide at the BSG/Si interface acts as a diffusion barrier for the boron, as illustrated in Fig. 3(b). The SIMS depth profiles of the boron diffused from 18 mol% BSG film are shown in Fig. 4. The surface boron concentration was constant at higher annealing temperature (1050℃) as shown in Fig. 4(a), but it increased with increasing annealing time as shown in Fig. 4(b). In the cases of the high-temperature-annealed samples and heavily boron-doped (26 mol%)-annealed samles for which the slope is 0.5, the melt-through effect [2], i. e., the mixing of BSG with native oxide, reduces the native oxide barrier.

As shown in Fig. 4(b) (sample A), the surface concentration ($6x10^{19}$ cm^{-3}), which has almost the same value of the solubility at this annealing temperature, is higher than the reported value ($2x10^{19}$ cm^{-3}) [1]. This shows that the diffusion barrier is lower. As a result, we obtained a low-resistance (2.3 kΩ/sq.), ultra-shallow (20-nm deep; junction depth X_j defined at $1x10^{18}$ cm^{-3}) boron-diffused layer, whose sheet resistance is 1/10 that of reported values at the same junction depth, as shown in Fig. 5.

Fig. 6 shows junction depth as a function of annealing temperature. The available thermal budget for 30-nm-deep junctions is typically 8 s at 950℃.

4. Summary

In summary, ultra-shallow (20-nm deep), low-resistance (2.3 kΩ/sq.) boron-diffused layers were successfully formed using a solid-phase diffusion technique. The key to ultra-shallow, low-resistance junction formation is to control the BSG/Si interface conditions. However, the thermal budget should be reduced to maintain the desired profiles.

Acknowledgments

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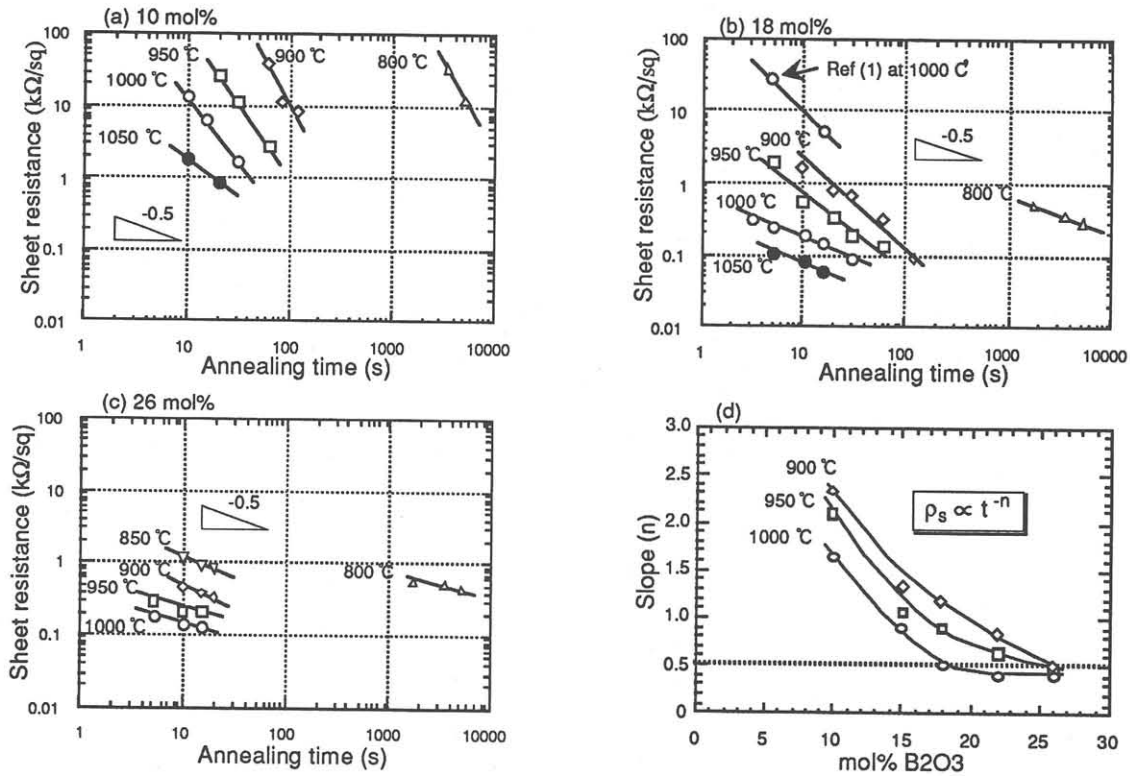

Fig. 2. (a, b, c) Sheet resistance as a function of annealing time and (d) dependence of slope on B2O3 mole concentration .

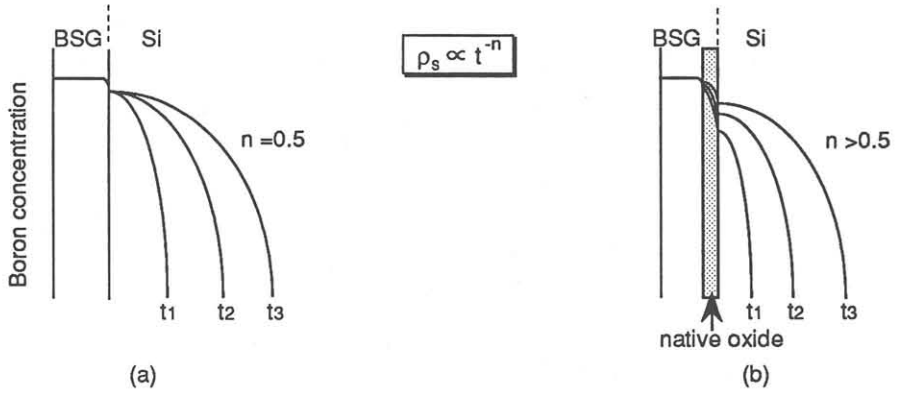

Fig. 3. Dependence of sheet resistance on annealing time:
(a) without native oxide, (b) with native oxide.

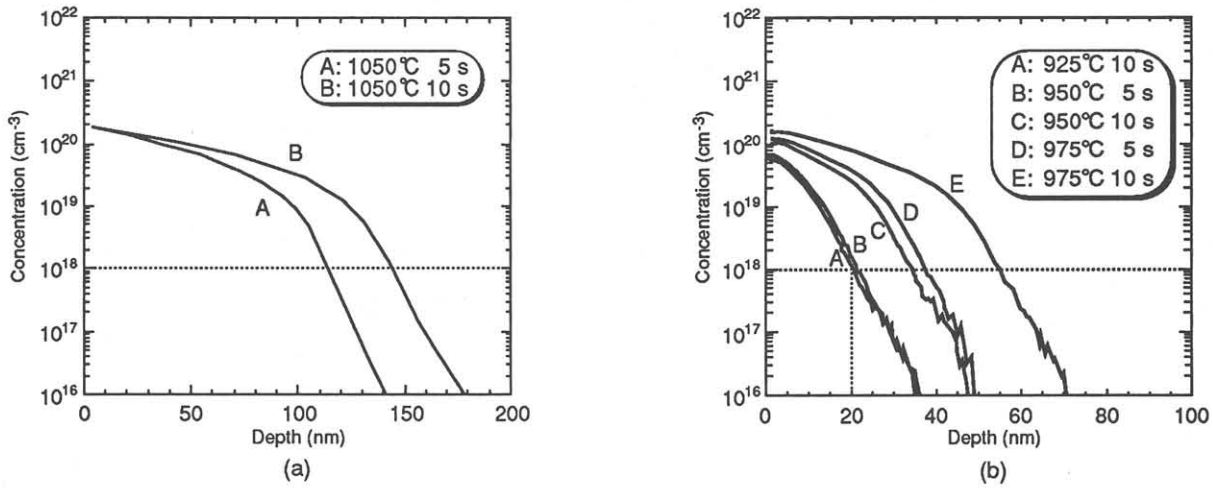

Fig. 4. SIMS depth profiles of boron.
(a) surface concentration is constant during annealing,
(b) surface concentration is not constant during annealing.

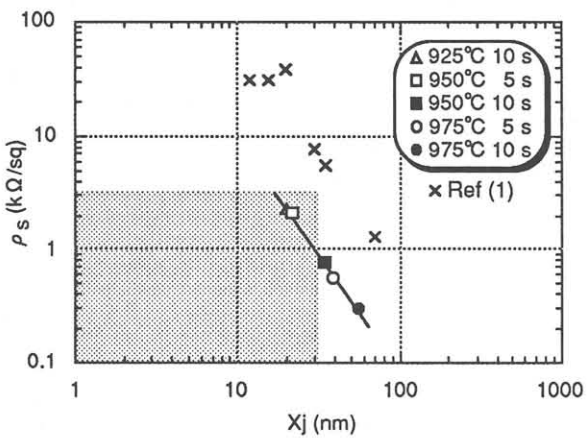

Fig. 5. Correlation between sheet resistance and junction depth.

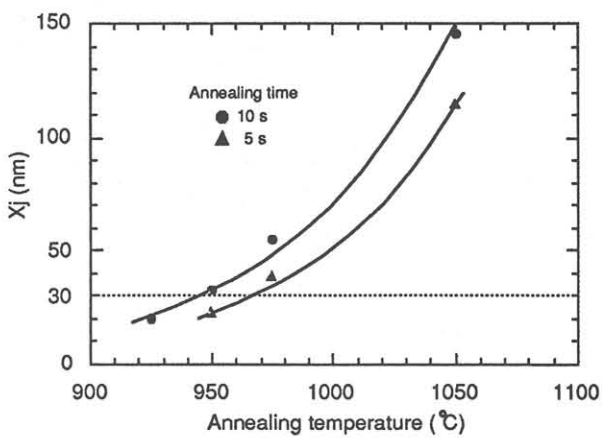

Fig. 6. Junction depth as a function of annealing temperature.