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Rapid Vapor-Phase Direct Doping; Ultra-Shallow Junction Formation Method for High-Speed Bipolar and Highly-Integrated DRAM LSIs

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A novel doping method called Rapid Vapor-phase Direct Doping (RVD) has been developed to form ultra-shallow junctions. In this method, the impurity atoms directly diffuse from the vapor-phase into silicon by a rapid thermal process in a hydrogen atmosphere. By varying the gas flow rates, diffusion time, and temperature, ultra-shallow junctions below 50 nm with controlled surface concentrations were successfully formed. This method was applied to the base region of a bipolar transistor and an ultra-narrow base of 25 nm was obtained.

1. Introduction

With recent advances in Si LSI technology, there has been a growing interest in developing a process to form a shallow junction.[1)2)] The ion implantation method, which is widely used to form p-n junctions, has disadvantages such as the channeling effect of ions and damage to the wafers. Hence, it is difficult to make a junction shallower than 100 nm. For high-speed npn bipolar transistors, it is indispensable to form a narrow p-type base region. Some processes for this purpose have been reported.[3)4)] With advanced MOS transistors, shallow source and drain regions must be doped with high concentration. Ion implantation is not able to make such a doped layer. In this paper, we propose a novel doping method called Rapid Vapor-phase Direct Doping (RVD), which is a kind of vapor phase diffusion method.[5)] This method is suitable for making a shallow junction with a controlled surface concentration due to the following features; (1) The impurity atoms directly diffuse from the vapor phase into silicon in a hydrogen atmosphere after native oxide is removed. (2) The impurity concentration of the doped layer can be controlled over a wide range by changing the flow rate of the source gas. (3) The doping time can be shortened to a few minutes. Additionally, unlike the ion implantation, this method does not induce any defects in the silicon.

2. RVD Process

The experimental setup is shown in Fig. 1. This setup is a vertical CVD reactor consisting of a reaction chamber and a gas supply system and is operated at atmospheric pressure. The wafers on a graphite susceptor coated by SiC are heated using an RF induction coil. The carrier gas is pure hydrogen and the doping gas is hydrogen-diluted (0.1%) B_2H_6. The hydrogen flow rate was maintained at 50 l/min, and the B_2H_6 flow rate was varied from 10 ml/min to 100 ml/min. After the wafers were loaded, the atmosphere in the chamber was changed from nitrogen to hydrogen, and this was followed by H_2 cleaning at 1050°C to remove the native oxide. Then the substrates were cooled to the doping temperature, and B_2H_6 gas was injected into the chamber. The doping time was varied from 1 min to 30 min. Subsequently, the B_2H_6 gas supply was stopped and post-annealing was carried out for 2 min while purging the chamber of doping gas.

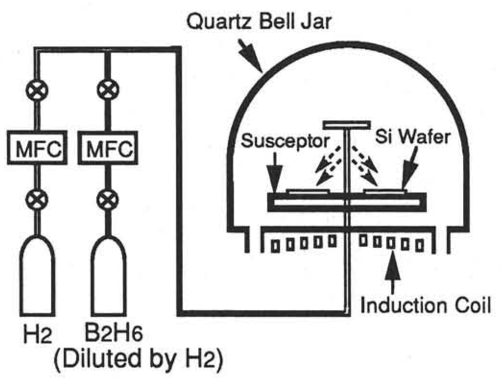

Fig.1 Experimental setup

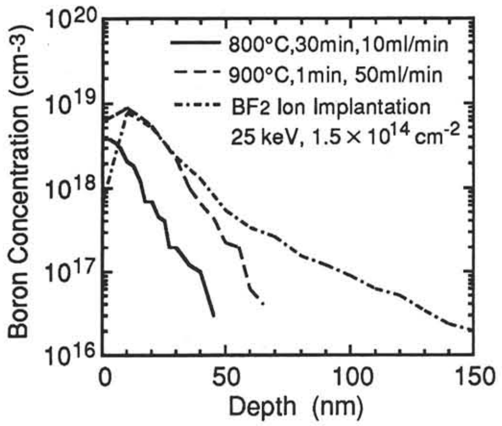

Fig.2 SIMS profiles

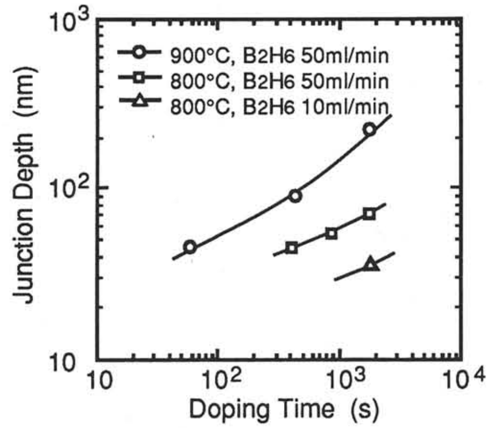

Fig.4 Junction depth as a function of doping time

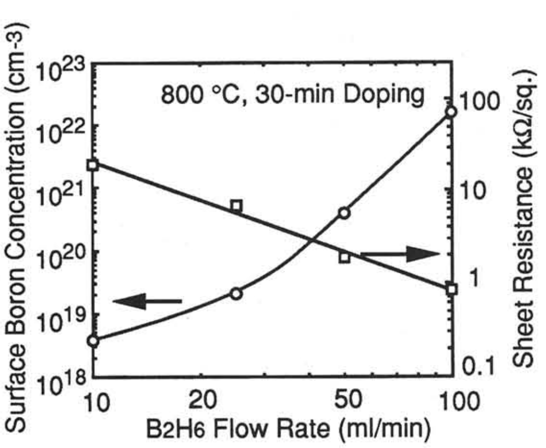

Fig.3 Surface concentration and sheet resistance as a function of B2H6 flow rate

3. Experimental Results

Figure 2 shows the impurity profile of the boron doped layer measured by secondary ion mass spectrometry (SIMS). Two typical conditions were chosen for this measurement, a low-temperature, long-time process, and a high-temperature, rapid thermal process. For comparison, the profile of a sample implanted with BF2 after activation annealing at 900°C for 10 minutes is also shown. This differs from a conventional vapor source diffusion in that the diffusion time can be shortened to a few minutes using RVD. The RVD profiles show no channeling tails and give junctions shallower than 50 nm.

The surface boron concentration and the sheet resistance were measured by SIMS and the four-probe method, and are shown in Fig.3. The doping conditions are 800°C for 30 min. By varying the B2H6 gas flow rate, the surface boron concentration and can be changed from 4×10^{18} cm^{-3} to 1.6×10^{22} cm^{-3} and the sheet resistance from 18 kΩ/sq. to 800 Ω/sq. The variation in the sheet resistance was a few percent over the wafer. When the B2H6 flow rate is above 100 ml/min, the surface boron concentrations exceeds the solid solubility and the activation ratio is fairly low. These excess boron atoms may degrade the device characteristics. At lower B2H6 flow rates, almost all boron atoms were activated.

To make a shallower junction, a rapid doping process was also investigated. The junction depth is shown in Fig.4 as a function of the doping time. The junction depth means the point where the boron concentration is at 1×10^{17} cm^{-3}. A lower temperature and a shorter diffusion time give shallower junctions. We believe that by using a lower temperature process and a lower B2H6 flow rates, an ultra-shallow junctions below 20 nm can be obtained.

4. Application to Devices

This method was applied to the intrinsic base region of a bipolar transistor. The device structure was the conventional walled emitter type. The base was doped with a B2H6 flow rate of 30 ml/min at 800°C for 30 min. After the base region was formed, phosphorus-doped poly silicon was deposited as the emitter, followed by annealing at 850°C for 1 min and at 900°C for 30 s. The device characteristics are summarized in Table 1 and the Ic-Vce curve is shown in Fig. 5. The current gain is 100. The Gummel plot of the transistor with the emitter size of 1.2×3 μm^2 is shown in Fig.6. Both Ic and IB have almost ideal

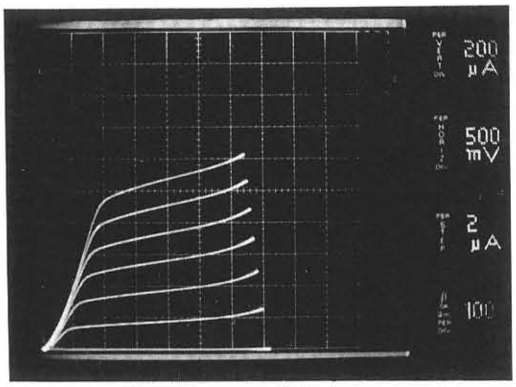

Fig. 5 Ic-Vce characteristics of the transistor

Table 1. Device Characteristics

Emitter size	$1.2 \times 3\ \mu m^2$
Thickness of epitaxial layer	600 nm
Current gain	100
C-E breakdown voltage	5.5 V
C-B breakdown voltage	10.3 V
E-B breakdown voltage	8.9 V

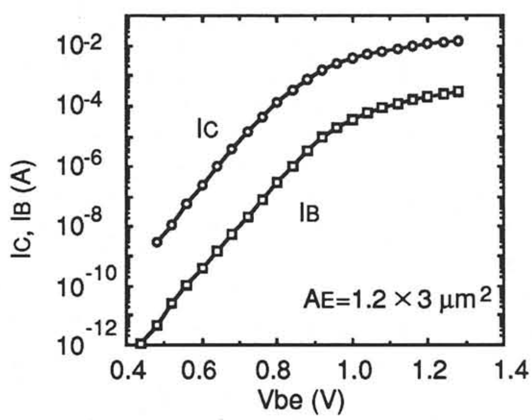

Fig.6 Gummel plot of the transistor

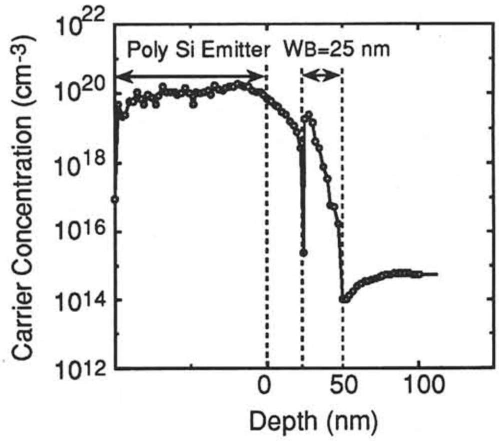

Fig.7 Carrier profile of emitter and base

current-voltage characteristics. Since there is no recombination current in IB, it is clear that the RVD-doped layer does not have any defects that degrade the device characteristics. The emitter and base profile after emitter annealing was measured using a spreading resistance profiler (SRP), and is shown in Fig. 7. An ultra-narrow base width of 25 nm was obtained. Such a narrow base will be necessary for future high-speed bipolar LSIs. RVD has other applications such as forming the shallow source and drain of MOS transistors, and sidewall-doped trench capacitors for DRAMs.

5. Conclusion

A novel doping method called Rapid Vapor-phase Direct Doping (RVD) has been developed to form shallow junctions. Ultra-shallow doped layers below 50 nm with controlled surface concentrations were successfully formed by varying the doping time, temperature, and B_2H_6 flow rate. This method was applied to a bipolar transistor and it was found that the RVD-doped layer had good electrical properties. An ultra-narrow base width of 25 nm was obtained. This method is suitable for making junctions shallower than 50 nm for future high-speed bipolar and highly-integrated MOS LSIs.

References

1) J. Nishizawa et al., Appl. Phys. Lett., 56, 1334 (1990)

2) A. Bousetta et al., Appl. Phys. Lett., 58, 1626 (1991)

3) T. Yamazaki et al., Tech. Digest of IEDM p.309 (1990)

4) G. L. Patton et al., Symp. on VLSI Tech., p. 49 (1990)

5) T. Inada et al., Appl. Phys. Lett., 58, 1748 (1991)