Ultra-Shallow Junction Formation by AsH3 Adsorption Method

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1. Introduction
Table 1 shows the technical comparison for the recent N-type doping methods. Even though the technical originality of several doping methods, process feasibility and controllability are still questionable in sub 0.1 μm MOSFET fabrication. In particular, low energy and new implantation method cannot avoid a thermal annealing to cure the implantation damage. AsH3 adsorption in GSMBE provides ultra-shallow junction with wide temperature margin which means good controllability, and no extra annealing and simple integration which mean good process feasibility in sub 0.1μm MOSFET fabrication.

2. Experimental
A GSMBE apparatus is shown schematically in Fig.1. The base pressure of the main chamber was less than 3 × 10−10 Torr. AsH3 gas diluted to 10% concentration by H2 gas was used as the N-type doping gas for junction formation. The standard process sequence was carried out as shown in Fig.2. After thermal cleaning, 10SCCM AsH3 gas was injected into main chamber at the variable temperatures and adsorption times for the arsenic doping.

3. Results and discussion
Fig.3 shows the typical arsenic SIMS depth profile for AsH3 adsorption. Very shallow (Xj; 300 Å) and heavy doping (Cp; above 1 × 1020 cm−3) profile was obtained at 850°C, 5 min doping condition. Fig.4 shows the temperature effect of AsH3 adsorption. The As peak concentrations and junction depths (≥ 1018 cm−3) showed the saturation trend at above 550°C. The stable junction characteristics can be achieved at the temperature range from 700°C to 950°C as shown in Fig.4. These experimental results were quite well matched to arsenic coverage simulation data of Fig.5-(1) [1]. Fig.6 shows the change of arsenic concentration at the increasing adsorption times. It was found that arsenic concentrations reached to some maximum values and then went to decrease with increasing doping time. Initial stage of increasing concentration can be explained from the simulation data of adsorption time dependence(Fig.5-(2)) but the second stage of decreasing concentration cannot be well understood. This mechanism will be verified from the further experiments. The higher Cp (peak concentration) and longer peak time for one of 850°C compared with 700°C can be attributed to higher surface desorption and diffusivity. Fig.7 shows in-situ annealing effect at 850°C. As shown in Fig.7, increasing annealing time gave negative effect for the sheet resistance, which means that extra annealing is not necessary for junction formation. Finally, Fig.8 shows the strong correlation between arsenic concentrations and junction depths.

4. Conclusion
From the results of junction characteristics, it is suggested that AsH3 adsorption method is very effective for N-type ultra-shallow junction formation.

References
method | controllability | process and scaling feasibility | simple integration | damage and defect free
---|---|---|---|---
SPD | bad | good | good | most area
ion implant | good | good | very good | most area
doped epil | good | bad | fair | most area
delta doping | fair | bad | fair | most area
inversion ST | fair | very bad | fair | most area
AsH₃ doping | good | good | very good | skip area

Table 1. N-type doping technology comparison.
SPD means solid phase diffusion method.

Fig. 1. Schematic diagram of gas source MBE.

Fig. 2. Standard process sequence for AsH₃ adsorption.

Fig. 3. SIMS depth profile of AsH₃ adsorption.
Arsenic ion implantation for the comparison was done.

Fig. 4. Temperature dependence of junction characteristics. The only 5min adsorption without extra annealing was done.

Fig. 5. Arsenic coverage simulation data using a model with Langmuir adsorption and first-order desorption reaction, curve(a) is temperature dependence at adsorption time 300s, (b) is adsorption time dependence at the variable temperature.

Fig. 6. AsH₃ adsorption time dependence of arsenic concentration at temperatures of 850 and 700°C.

Fig. 7. Annealing effect at 850°C. Adsorption time was 5 min.

Fig. 8. Correlation result for C0 vs Xj.
It showed good exponential relation with R.F of 0.92.