Ultrashallow Junction Formation Using Low-Temperature Selective Si$_{1-x}$Ge$_x$ CVD

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The characteristics of in-situ B doping and selective epitaxy in Si$_{1-x}$Ge$_x$ CVD on Si at 550°C have been investigated to form high performance ultrashallow junctions. It was found that the incorporation rate of B increased proportionally with increasing B$_2$H$_6$ partial pressure and was larger for the film with a higher Ge fraction $x$. The 100nm-thick Si$_{0.5}$Ge$_{0.5}$ film was grown selectively using thermal SiO$_2$ film as a mask and the 150nm-thick film using PSG or BPSG. Using this low-temperature Si$_{1-x}$Ge$_x$ CVD, high performance self-aligned ultrashallow junction formation has been achieved with a low level reverse current density, the range of $10^{-10}$ A/cm$^2$ without heat-treatment.

1. INTRODUCTION

An ultrashallow junction formation is very important for the progress of ULSI's. The ion implantation method, widely employed in the ULSI fabrication, has disadvantages such as channeling effect and damage to the wafer, and as a result, it is not suitable for making a nm order shallow junction. A method was proposed where impurities were diffused from a molecular layer adsorbed on the surface to make a diffusion layer$^3$, but it is difficult to form the upper electrode with a good contact to the shallow diffusion layer. Diffusion from a doped poly-Si electrode leads to a nonuniformity in the distribution of the dopants caused by grain boundary diffusion in poly-Si$^2$. Although we achieved in-situ doped Si epitaxy at a very low temperature such as 650°C$^3$, selectivity was not so good for application to self-aligned electrode formation at such a low epitaxial temperature. However, we found that Ge alloying increases selectivity in low temperature epitaxy$^4$.

In the present work, in-situ B doping and selective epitaxy in Si$_{1-x}$Ge$_x$ CVD on n-type Si substrate at 550°C have been optimized for ultrashallow junction formation.

2. EXPERIMENTAL

The epitaxial growth of in-situ B doped Si$_{1-x}$Ge$_x$ films were deposited at 550°C in a SiH$_4$–GeH$_4$–B$_2$H$_6$–H$_2$ mixture using the ultraclean hot-wall low-pressure CVD system$^5$. With gate valves and a turbo molecular pump, the system is ultrahigh vacuum compatible. The deposition process sequence for high quality Si$_{1-x}$Ge$_x$ heteroepitaxial growth on Si using this system has been described in detail elsewhere$^5$$^7$.

In this study, the total pressure was about 29 Pa, and partial pressure ranges of SiH$_4$, GeH$_4$ and B$_2$H$_6$ were 1.65–6.0, 0.2–4.7 and 1.25x10$^{-3}$–6.0x10$^{-3}$ Pa, respectively. Before loading into the transfer chamber, wafers were cleaned in several cycles in a 4:1 solution of H$_2$SO$_4$ and H$_2$O$_2$, high-purity DI water, and 1% HF with a final rinse with DI water. The substrates used were n-type Si wafers of 3–5 ohm*cm with mirror polished (100) surfaces.

The Ge fraction $x$ of the thin Si$_{1-x}$Ge$_x$ film was estimated from the lattice constant of a thicker relaxed Si$_{1-x}$Ge$_x$ film deposited under the same conditions, determined by x-ray diffractometry. The B concentration in Si$_{1-x}$Ge$_x$ films was determined by secondary ion mass spectroscopy. The deposited thickness was measured by Tencor Alpha Step.

Fig.1. Cross-section of the $p^+n$ junction structure.

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A p+n junction diode shown in Fig.1 was fabricated by using selective Si1-xGex CVD on the sample patterned thermal SiO2 films on n-type Si substrates. The deposited thickness and B concentration of Si1-xGex epitaxial films optimized were about 40nm and 10^{20}cm^{-3}, respectively. The diode characteristics before and after heat-treatment were measured.

3. RESULTS AND DISCUSSION

3.1. In-situ B doping

Figure 2 shows the dependence of B concentration in in-situ Si1-xGex films on the B2H6 partial pressure. It is found that the B concentration increases proportionally with the B2H6 partial pressure, and doping control in the range 3x10^{17}-2x10^{20} cm^{-3} is achieved. The dependence of B incorporation rate, given by the product of the B concentration Cb and the deposition rate R, on the B2H6 partial pressure is obtained as shown in Fig.3. It is found that the incorporation of B increased proportionally with increasing B2H6 partial pressure and was larger for the film with a higher Ge fraction x.

On the Si1-xGex deposition in the SiH4-GeH4 gas mixture, it was reported that SiH4 is dominantly adsorbed at the adsorption site based on Langmuir's adsorption isotherm under the same deposition conditions as the present experiment. However, at the GeH4/SiH4 partial ratio of 1/30, the incorporation of B into Si1-xGex films was independent on SiH4 partial pressure in the SiH4 partial pressure range 3.0-11.2Pa. Therefore, it is proposed that B-hydride adsorption occurs regardless of Si-hydride surface adsorption, and as a result, the B concentration in Si1-xGex films is determined by the balance between the surface adsorption rate of B-hydride and deposition rate. Based on this model, it is concluded that the increase of B incorporation rate with increasing Ge fraction is caused by the larger surface adsorption rate of B-hydride on Ge atoms than on Si atoms.

3.2. Selective epitaxy

The deposition time dependence of undoped and B doped Si0.5Ge0.5 film thickness on Si for various mask film materials is shown in Fig.4. It is found that the 40nm-, 100nm- and 150nm-thick Si1-x Gex film is grown selectively using Si3N4, thermal SiO2 as the mask.
and PSG or BPSG and that the degradation of selectivity by in-situ B doping is scarcely observed. From SEM micrographs, the dependence of incubation period of nucleation on mask film materials was the same as above-mentioned. It is considered that the adsorption site densities on the PSG and BPSG surfaces are lower than those on the thermal SiO₂ and Si₃N₄ surfaces. It was reported that the incubation period was independent of the GeH₄ partial pressure, i.e., the Ge fraction. Since the higher GeH₄ partial pressure causes the larger deposition rate, the higher selectivity is obtained by the higher Ge fraction. Although a higher Ge fraction results in a rougher surface of Si₁₋ₓGeₓ layer by island growth, the interface between the 40–100nm-thick Si₀.₅Ge₀.₅ layer and the Si substrate was flat.

3.3. Ultrashallow junction characteristics

A p⁺n junction diode was fabricated under an optimized condition. The dependence of the reverse current density on the bias voltage for various Ge fractions in Si₁₋ₓGeₓ films and for various heat-treatment temperatures are shown in Figs.5 and 6, respectively. The level of the reverse current density is as low as 10⁻¹⁰ A/cm², which is about two order lower than the reported value. The reverse current density is large at the Ge fraction of 0.8 compared with that at the lower Ge fractions. This may mean that the heterojunction is degraded by island growth. Although the reverse current density tends to be improved with increasing heat-treatment temperature, excellent junction characteristics is obtained even without heat-treatment. Estimated from the diffusion coefficient in Si extrapolated to 550°C, the B diffusion length into the Si substrate is nm or lower for the sample without heat-treatment, thus the junction should be ultrashallow. The diode ideality factor n value was in the range of 1.00–1.05, which was independent of the Ge fraction. Consequently, in-situ B doped Si₁₋ₓGeₓ epitaxy on Si is suitable for a self-aligned ultrashallow junction formation method.

4. CONCLUSIONS

The in-situ B doping control of Si₁₋ₓGeₓ layer was achieved in the range of 3x10¹⁷–2x10²⁰ cm⁻³, and the 100nm- and 150nm-thick Si₀.₅Ge₀.₅ film is grown selectively using thermal SiO₂ and PSG or BPSG film as a mask. Using this low-temperature selective Si₁₋ₓGeₓ CVD, high performance ultrashallow junction formation was achieved with a low level reverse current density, the range of 10⁻¹⁰ A/cm².

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