Extended Abstracts of the 1991 International Conference on Solid State Devices and Materials, Yokohama, 1991, pp. 41-43

B-1-2

Ion Flux Effect in Low Temperature Silicon Epitaxy by Low-Energy Ion Bombardment

Tohru YOSHIE, Masaki HIRAYAMA, and Tadahiro OHMI

Department of Electronics, Tohoku University

Sendai 980, Japan.

We have clarified the effect of ion flux in low temperature silicon epitaxy by low-energy ion bombardment. First, it is found that the impurity activation rate of the deposited film is reduced when the energy deposition to a growing film surface is performed under very large ion flux density. However, in order to enhance the carrier mobility, ion bombardment with large enough ion energy is needed. The precise control of the ion flux density as well as the ion bombardment energy is quite essential to growing high quality films. In addition, enhancement in the surface adatom migration by low-energy ion bombardment has been also experimentally verified.

1. Introduction

The low temperature processing is one of the most essential requirements for future ULSI device fabrication processes. We have established low temperature silicon epitaxy at temperatures as low as 250°C utilizing a low-energy ion bombardment process[1]. In this process, the epitaxial growth of silicon is promoted not only by substrate heating, but by concurrently bombarding the growing film surface by low energy ions. In short, a matter of paramount importance is the total energy deposited to the growing film surface by a flux of energetic ions, which is determined by the product of individual ion bombardment energy and ion flux density. Therefore, the essence of the process is to keep the ion flux density large enough for the crystal growth while controlling the individual ion bombardment energy to be low enough not to create any damages in the film. Although the effect of ion bombardment energy have been studied extensively[2], the role of the ion flux density has not been clarified at present. Then the purpose of this study is to investigate the effect of ion flux on the crystal growth at low temperatures.

2. Experimental

P-type(100) silicon wafers, 3-4Ωcm resistivity, were used as substrates. The rf-dc coupled mode bias sputtering system[3] was employed to grow silicon films on the substrate using phosphorus-doped Si wafer (1.5×10^{20}) as a target. The resistivity measurement, Hall measurement, and reflection electron diffraction(RED) analysis were carried out to evaluate crystallinity of deposited films. The plasma potential was measured using a Langmuire probe technique.

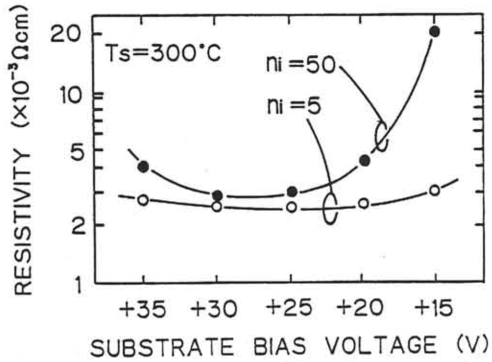

Fig.1 Resistivities of Si films deposited at 300°C as a function of the substrate bias voltage for two different ion flux densities(n_i): n_i=5(○);n_i=50(●).

3. Results and Discussion

Figure 1 shows the resistivity of a deposited Si film as a function of the substrate bias voltage(Vs) for two different values of the ion flux density(n_i). Here the normalized ion flux density n_i is defined as the number of Ar ions bombarding the film surface for a single deposited Si atom. At n_i=50, the resistivity is high as compared to that at n_i=5. And the resistivity changes in a wide range depending on Vs at n_i=50.

The relationship between the ion bombardment energy incident to the film surface and the substrate bias voltage Vs is shown in Fig. 2. At the condition of n_i=5, the ion bombardment energy is high as compared to that at n_i=50. Now the changes in the resistivity shown in Fig. 1 are

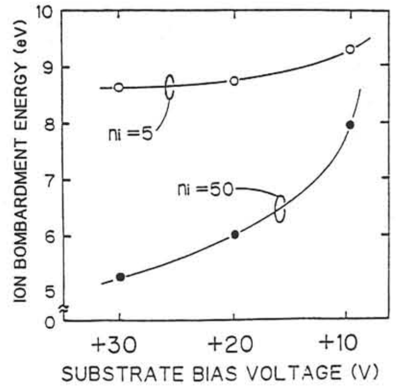

Fig.2 Ion bombardment energy incident to the growing film surface as a function of the substrate bias voltage for two different ion flux densities(n_i): n_i=5(○);n_i=50(●).

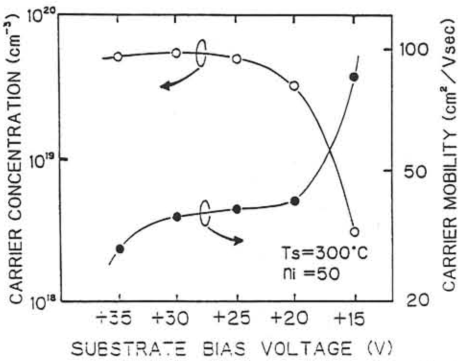

Fig.3 The carrier concentration and the carrier mobility as a function of the substrate bias voltage at n_i=50.

considered in terms of the ion bombardment energy given in Fig. 2. At n_i=5, the resistivity is overall low in spite of such high-energy ion bombardment, which, in the case of n_i=50, has increased the resistivity. In order to clarify the reason for this, we will first consider the case of n_i=50 in the following.

The ion bombardment energy at n_i=50 varies a lot depending on the substrate bias voltage. The resistivity increases according to the increase in the ion bombardment energy (for smaller Vs values). The resistivity also increases for smaller energies(large positive Vs values) as indicated in Fig. 1. The resistivity is determined by two factors, namely, the carrier concentration and the carrier mobility.

Then, the carrier concentration and the carrier mobility of the film deposited at n_i=50 are shown in Fig. 3 as a function of the substrate bias voltage. When the substrate bias voltage is high, i.e., the ion energy is low, the carrier concentration dose not change appreciably, and only the mobility becomes smaller. This indicates that the film quality becomes poor by the lack of total energy deposition to a growing film. When the substrate bias voltage is low, i.e., the ion energy is high, the carrier concentration decreases, resulting in the enhancement in the carrier mobility due to the decrease in the ionized impurity scattering. It is not clear whether the decrease in the carrier concentration at large ion energies is due to the lack of dopant incorporation to the film or the decrease in the dopant activation rate.

In order to know the reason, the films were annealed at 800°C for an hour and their resistivities were measured. Figure 4 shows the results. Large reduction in the resistivity is observed at high-energy ion bombardment. It was confirmed by Hall measurement that the resistivity reduction observed is due to the increase in the carrier concentration. Therefore, the decrease in the carrier concentration is due to the reduced dopant activation rate. It is known that a large energy deposition with large ion flux has a effect of decreasing dopant activation rate.

Figure 5 shows the carrier mobility normalized by the Irvin mobility[4] corresponding to the same carrier concentration as a function of the substrate bias voltage at n_i=50. The normalized mobility increases as the ion bombardment energy is increased. The data indicate that the increase in the individual ion energy in this range dose not induce crystalline defects, but rather enhance the crystallinity.

The results are summarized as in the following. There are two causes for the variation of the resistivity. One is the variation in the carrier activation rate, and

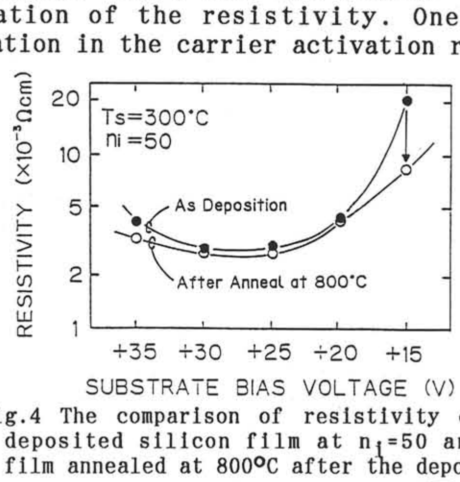

Fig.4 The comparison of resistivity of the deposited silicon film at n_i=50 and the film annealed at 800°C after the deposition.

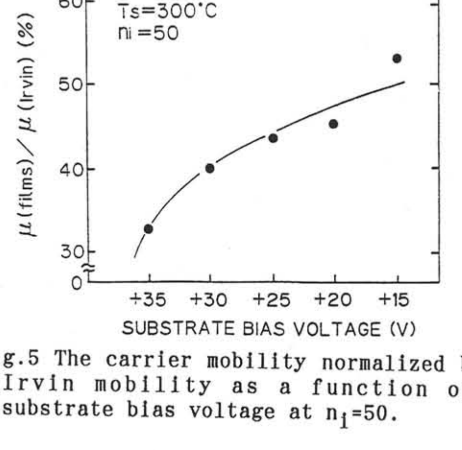

Fig.5 The carrier mobility normalized by the Irvin mobility as a function of the substrate bias voltage at n_i=50.

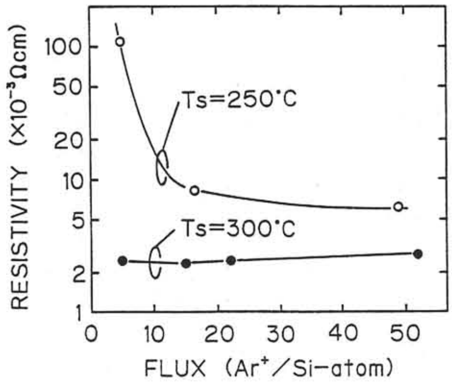

Fig.6 Film resistivity as a function of ion flux density under the condition of optimum ion bombardment energy. Films were deposited at two different temperatures: 250 C(○); 300 C(●).

the other is that in the carrier mobility. At the condition of n_i=5, the resistivity shows always small values in spite of its higher ion energy as compared to those of n_i=50. The Hall measurements performed on the samples of n_i=5 showed both mobility and carrier concentration are larger than those of n_i=50 samples. The larger mobility would be due to the large ion bombardment energy as it is expected from the data shown in Fig. 5. Supplying sufficient amount of energy by relatively large individual ion energy under smaller flux density would be the reason for the larger activation rate, because large flux density tends to decrease the activation rate at the condition of high-energy ion bombardment.

Other effect of ion flux density are discussed in the following. Figure 6 shows the relationship between the resistivity and the ion flux density under the optimum condition of individual ion bombardment energy. At 300°C, the resistivity slightly increases with the increase in the ion flux. In this case, this is interpreted in that too much energy given to the film causes the dopant (phosphorus) evaporation during the film growth. This was confirmed by the annealing experiment and Hall measurement. However, at 250°C, the increase in the ion flux density contributes to the substantial reduction in the film resistivity. Figure 7 demonstrates reflection electron diffraction

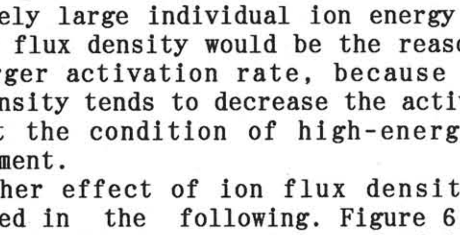

Fig.7 Reflection electron diffraction patterns from silicon films deposited at 250°C, with two different ion flux densities: n_i=8(left);n_i=18(right)

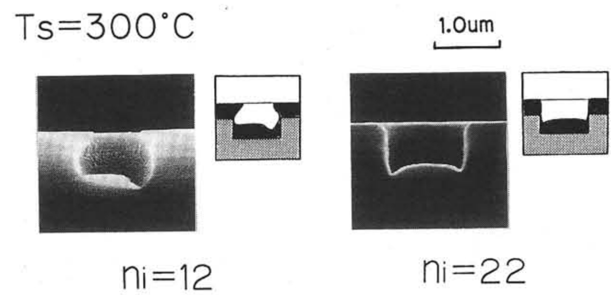

Fig.8 Cross-sectional views of silicon films deposited at holes with two different ion flux densities.

patterns from Si films deposited at 250°C. When the ion flux density is low, the deposited film is amorphous, while single crystal is formed at high ion flux density. Epitaxial growth obtained at 250°C with n_i=18 is due to the surface migration enhancement caused by the ion bombardment with sufficient amount of ion flux. Experimental verification of such surface migration enhancement by the ion bombardment is demonstrated in Fig. 8. The closs-sectional views of the Si films deposited at holes were observed by a scanning electron microscope. With the increase in the ion flux density, the silicon film coverage at the edge of the hole etched on the silicon surface becomes smoother, indicating the enhanced migration of Si atoms.

4.Conclusion

We have clarified the effect of ion flux which is the key parameter in low temperature silicon epitaxy by low-energy ion bombardment. First, it is found that the ion flux density has a profound effect on the three parameters, the impurity concentration, the impurity activation rate, and carrier mobility, which determine the film resistivity. Therefore, the precise control of ion flux is quite essential to achieve high quality Si films by low temperature epitaxy.

Acknowledgment

The majority of this work was carried out at the SuperClean Room of the Laboratory for Microelectronics, Research Institute of Electrical Communication, Tohoku University.

References

1. T. Ohmi, K. Hashimoto, M. Morita, and T. Shibata, J. Appl. Phys. 69 (1991) 2062.
2. T. Ohmi, T. Ichikawa, T. Shibata, K. Matudo, and H. Iwabuchi, Appl. Phys. Lett. 53 (1988) 346.
3. T. Ohmi, H. Kuwabara, S. Saitoh, and T. Shibata, J. Electrochem. Soc. 137 (1990) 1008.
4. J. C. Irvin, Bell System Tech. J. 41 (1962) 387.