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Epitaxial Growth of Heavily B-Doped Si and Ge Films on Si(100) by Low-Energy ECR Ar Plasma CVD without Substrate Heating

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1. Introduction

Ultrathin films with high carrier concentration is important for high-performance group IV semiconductor devices. Plasma CVD is useful to lower process temperature and to obtain heavily doped films out of thermal equilibrium for suppressed diffusion. In our previous work, by using electron-cyclotron-resonance (ECR) Ar plasma chemical vapor deposition (CVD), Si and Ge epitaxial growth on Si(100) [2] was achieved without substrate heating. In this work, we investigated epitaxial growth of B-doped Si and Ge films on Si(100) by low-energy ECR Ar plasma CVD, and recent progress will be presented.

2. Experimental

Si and Ge films on Si(100) were formed respectively by SiH_4 and GeH_4 reaction under low-energy Ar plasma irradiation with the microwave power of 100-200 W without substrate heating (**Fig. 1**) [3]. Ar partial pressure was 2.1 Pa. Substrate temperature was suppressed below 50 °C during plasma exposure even for a few hundred seconds. Substrates used were partially SiO_2 covered n-type Si(100) wafers, and were treated in a few % diluted HF solution to remove the native oxide and rinsed with deionized water just before loading into the reactor. To minimize air contamination into the reactor chamber, wafer loading and unloading were performed through a N_2 purged transfer chamber combined with a gate valve. B concentration was evaluated by X-ray photoelectron spectroscopy (XPS). Crystallinity, surface roughness, hydrogen incorporation and electrical resistivity of the films were evaluated by reflection high energy electron diffraction (RHEED), atomic force microscope (AFM), Fourier-Transform infrared spectroscopy (FTIR) and four-point probe method.

3. Results and discussion

In case of epitaxial growth of B-doped Si on Si(100), it is found that the B concentration increases with decreasing the microwave power and the B concentration increases up to $5.0x10^{21}$ cm^{-3} at 125 W. Here, it is also found that the deposition rate of B-doped Si (**Fig. 2)** tends to be enhanced at higher B_2H_6 partial pressure. Resistivity of B-doped Si film tends to increase with decreasing the microwave power, although the B concentration becomes higher. Referring Irvin curve [4], in the case of 200 W, the carrier concentration is at least about 10^{17} cm^{-3} at the B concentration of 10^{21} cm^{-3}. After heat treatment in N_2 atmosphere at 200 °C and 300 °C for 2 hours, the carrier concentration drastically increases up to around 10^{19} cm^{-3} at 300 °C. Because hydrogen concentration in the as deposited film was reduced by the heat treatment, hydrogen incorporation is considered as one of the causes of electrical deactivation of B atom.

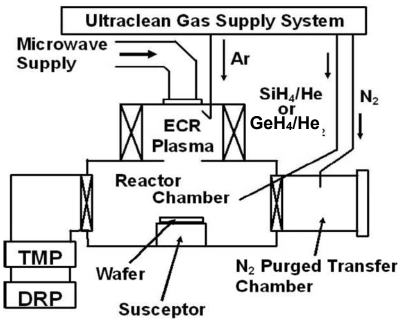

Fig. 1. Schematic of ECR Ar plasma CVD system.

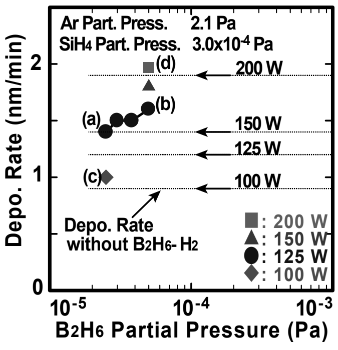

Fig. 2. Relationship between B_2H_6 partial pressure and deposition rate of B-doped Si for various microwave power.

In case of epitaxial growth of B-doped Ge on Si(100), it is found that the B concentration increases with decreasing the microwave power and B concentration as high as 2.2×10^{21} cm^{-3} can be observed at 150 W. Especially, in the case of direct deposition of B-doped Ge on Si(100), the deposited film tends to be amorphous. On the other hand, by introducing a 1 nm-thick undoped epitaxial Ge buffer layer, epitaxial growth of the B-doped Ge films with improved electrical resistivity (as low as around 10^{16} cm^{-3}) was observed without heat treatment.

From these experimental results, it is concluded that the heavily B-doped Si and Ge films can be grown epitaxially by using low-energy ECR Ar plasma CVD, and the high carrier concentration above 10^{18} cm^{-3} in Si can be obtained by low-temperature heat treatment at as low as 200-300 °C. Further investigations are still needed for B doping in Ge.

Acknowledgments

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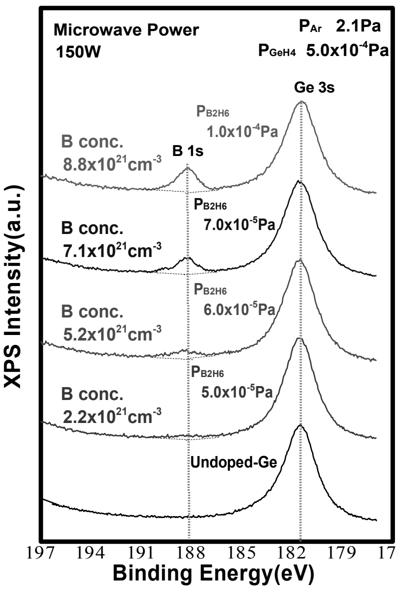

Fig. 3. XPS spectra of B 1s for undoped Ge, B-doped Ge deposited at various B_2H_6 partial pressure. Microwave power and GeH_4 partial pressure were 150 W and 4.0×10^{-4} Pa respectively.