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Low-Temperature SiGe(C) Epitaxial Growth by Ultraclean Hot-Wall Low-Pressure CVD

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1. Introduction

Low-temperature SiGe(C) epitaxial CVD technology has become indispensable for the fabrication of ultrasmall MOS devices and Si-based heterodevices, because high performance devices require atomic-order abrupt steps in the heterointerface and the doping profile. To perform low-temperature processing, not only a clean surface but also an ultraclean reaction environment is required. Improvements in the quality of gases and equipments have enabled ultraclean low-temperature epitaxial growth processing [1-4]. In this abstract, low-temperature SiGe(C) epitaxial growth process on Si(100) using SiH_4 and GeH_4 gases and impurity doping process using B_2H_6 or PH_3 or SiH_3CH_3 as a dopant gas by ultraclean low-pressure CVD are described and the industrial capabilities are discussed.

2. Ultraclean Processing

In order to keep a high-throughput even at low growth rate at low temperature, an ultraclean batch type hot-wall low-pressure CVD system is employed. The system was made ultrahigh vacuum compatible. But the molecular flow region is not employed as a mass-productive deposition condition, because long time maintenance should be inhibited. In order to prevent any contamination from the exhaust line, the wafers are transported through an N_2 purged transfer chamber into the reactor at a reactor temperature of about 100°C, and then heated-up to the surface cleaning or the growth temperature while purging with H_2 gas under a pressure of a few tens or hundreds Pa [3-5]. The typical pressure for the epitaxial growth is 30 Pa. The oxygen and carbon pileups at the interface between the epilayer and the Si substrate are drastically reduced below $5x10^{11}$ cm^{-2} by the thermal desorption and/or reduction due to Si source gas at 700-750 °C.

3. Low-Temperature Epitaxial Growth

A lower temperature during $Si_{1-x}Ge_x$ and Si capping layer depositions results in a smoother surface [3,5]. At a Ge fraction of around 0.2, atomically flat surfaces and interfaces can be obtained by depositing the $Si_{1-x}Ge_x$ and Si capping layers at 550 °C. For higher Ge fractions, however, much lower deposition temperatures are suitable, namely, 500 °C for a $Si_{0.5}Ge_{0.5}$ layer and 450 °C for a $Si_{0.3}Ge_{0.7}$ layer. These results clearly show that lowering the deposition temperature of the $Si_{1-x}Ge_x$ layers is necessary with increasing Ge fraction to prevent island growth of the heterostructure.

In surface-reaction limited regime obtained at low temperatures, the growth and doping characteristics are determined only by the temperature, reactant gas partial pressure and the surface material when the reactant gas consumption due to the reaction is neglected compared with the reactant gas flow amount, and the polymerization of source gases such as SiH_4 and GeH_4 scarcely occurs. In the case of the present system with 40 wafers of 1.25-in.-diameter per batch, the optimum $Si_{1-x}Ge_x$ growth temperature is below 550 °C (670 °C without GeH_4), the SiH_4 partial pressure below 25 Pa and the GeH_4 partial pressure below 6 Pa. Since the thickness and the Ge fraction have uniformities better than 5 % within a wafer and from wafer to wafer, and scarcely depend on the wafer spacing in the range 6-20 mm and the gas flow rate, the reaction rate is confirmed to be limited by the surface reaction. For such growth condition, loading effect can be suppressed. In order to increase the selectivity of the growth on Si surface and Si oxide surface, increase of Ge fraction or increase of growth temperature [4] or the use of the other reactant gas is necessary. Facet free selective growth can be performed under the higher reactant gas pressure [4,5], because surface migration is restricted due to adsorbed species.

In in-situ doped $Si_{1-x}Ge_x$ epitaxial growth on the (100) surface in a SiH_4-GeH_4-dopant (PH_3, or B_2H_6 or SiH_3CH_3)-H_2 gas mixture, the deposition rate, the Ge fraction and the dopant concentration are explained quantitatively assuming that the reactant gas adsorption/reaction depends on the surface site materials and that the dopant incorporation in the grown film is conducted by Henry's law [6].

Using the CVD system, self-limiting formation of 1-3 atomic layers of group IV or related atoms in the thermal adsorption and reaction of hydride gases (NH_3, PH_3, CH_4 and SiH_3CH_3) on Si(100) and Ge(100) are generalized based on the Langmuir-type model. Si epitaxial growth over the N and P layer already-formed on Si(100) surface is achieved [7]. It is found that higher level of electrical P atoms exist in such film, compared with doping under thermal equilibrium conditions. These results open the way to atomically controlled technology for ultralarge-scale integrations.

References

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