CHARACTERISTICS OF THE HETEROEPITAXIAL $Si_{1-x}Ge_x$ FILMS GROWN BY RTCVD METHOD

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ABSTRACT

The growth and the film characteristics of heteroepitaxial $Si_{1-x}Ge_x$ films grown by the Rapid Thermal Chemical Vapor Deposition (RTCVD) method are described. For the growth of $Si_{1-x}Ge_x$ heteroepitaxial layers, $SiH_4/GeH_4/H_2$ gas mixtures are used. The growth conditions are varied to investigate their effects on the Si/Ge composition ratios, the interface abruptness and crystalline properties. The Si/Ge composition ratios are analyzed with the RBS and the SIMS techniques, and the interface abruptness are deduced from these data. The crystalline properties are analyzed from TEM pictures. The experimental data shows that the crystalline perfection is excellent at the growth temperature of as low as 650℃, and the composition ratios change linearly with SiH_4/GeH_4 gas mixing ratios in our experimental ranges. Boron doping experiments are also performed using 200 ppm B_2H_6 source gas. The doping profiles are measured with SIMS technique. The SIMS data shows that the doping abruptness can be controlled within about 200Å/decade.

1. INTRODUCTION

$Si_{1-x}Ge_x$ heteroepitaxy provides a tool to bandgap engineered electronic devices and silicon based photonic devices. At first, to produce thin and device quality films of $Si_{1-x}Ge_x$ heteroepitaxial layer, MBE technology was used. Then, in the middle eighties, there was a pioneering studies at AT&T Bell laboratory, the IBM Thomas J. Watson Research Center. And now, many researchers are working on development of electronic and photonic devices on silicon substrates, like as HBT, SiGe BiCMOS, HEMT, pin avalanche and superlattice based photodiode.(1)

The technology for $Si_{1-x}Ge_x$ heteroepitaxial growth on the silicon wafer is to have cost effective silicon based heteroepitaxial material compare to the III-V compound material. Though there are various technologies to grow the $Si_{1-x}Ge_x$ heteroepitaxial layer, MBE UHV/CVD(2) and RTCVD(3) methods provide very useful techniques to control the thin layer and obtain the high crystallinity. In particular, RTCVD method provides manufacturing oriented, easy control compare to MBE method. The crystal quality grown by RTCVD method is competitive with the results from MBE and UHV/CVD.

RTCVD method is based on the combination of Rapid Thermal Processor and Chemical Vapor Deposition. An important requirement for any new ULSI processing technology is a method of minimizing thermal exposure, for dopant diffusion and interface broadening must be kept well below the thickness of individual layers. One possible solution is to employ low processing temperatures. But, in many cases, high temperatures are needed to obtain certain desirable materials and process characteristics. For example, the crystalline quality of CVD layers, the quality of Si/SiO_2 interfaces, high levels dopant incorporation, and high growth rates are all important goals which can be obtained using high temperatures. An optimum solution to this processing temperature dilema is a thermal cycle which minimizes the thermal exposure for any given temprature. This is achived by rapid thermal processing, an emerging technology which uses high intensity radiant energy to rapidly heat a thermally isolated semiconductor substrate.

In this letter, we report on the RTCVD method growing the $Si_{1-x}Ge_x$ heteroepitaxial films using the SiH_4/GeH_4 gas mixing ratios and B_2H_6 for *in-situ* doping. By SIMS and cross section TEM methods, the interface characteristics and crystal quality of $Si_{1-x}Ge_x$ heteroepitaxial layer is discussed. The Ge mole fraction is also measured by the RBS method and the Ge mole fraction dependence on source gas flowrate ratios is investigated.

2. RTCVD SYSTEM & EXPERIMENT

The schematic diagram of RTCVD system is shown in figure 1. The RTCVD system is composed of the followings : 1)gas delivery system 2)reactor 3)pressure controller 4)pumping system 5)toxic gas scrubber system.

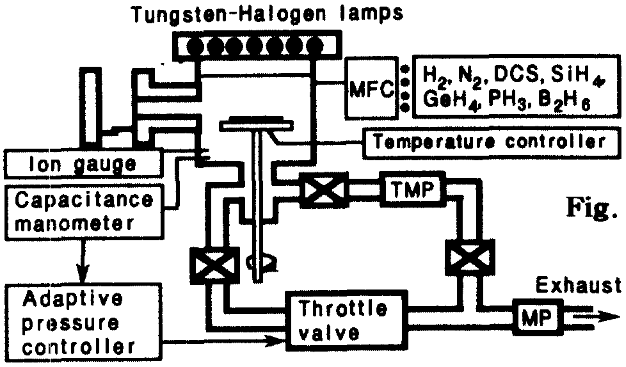

Fig. 1 The schematic diagram of RTCVD system

In the gas delivery system, silane and germane gases are used for $Si_{1-x}Ge_x$ hetero epitaxy, and dibolane diluted in hydrogen gas is used for *in-situ* doping. All the process gas flows are controlled by mass flow controllers. The reactor is made of water cooled stainless steel vacuum chamber, susceptor made of quartz and tungsten halogen lamp arrays installed. The wafer temperature is monitored during the epitaxial growth by an optical pyrometer, and is very quickly heat up on the ramp up speed of 150℃/second. Chamber pressure is monitired by a capacitance manometer and an ion gauge, and is controlled with a throttle valve. The base pressure that can be achived with a turbo molecular pump is on the order of $5x10^{-5}$ torr. The toxic gas scrubber system of burner type is also installed. Figure 2 is the process profile of an RTCVD heat cycle for the growth of $Si_{1-x}Ge_x$ heteroepitaxial layers. It is composed of the H_2 prebake step and the epitaxy step. At the first heat cycle, on the purpose of removing the native oxide, the silicon wafer is heattreated at 900 ℃ for 2 minutes in hydrogen gas ambient. The second heat cycle is for $Si_{1-x}Ge_x$ heteroepitaxy at the 650℃ or 800℃.

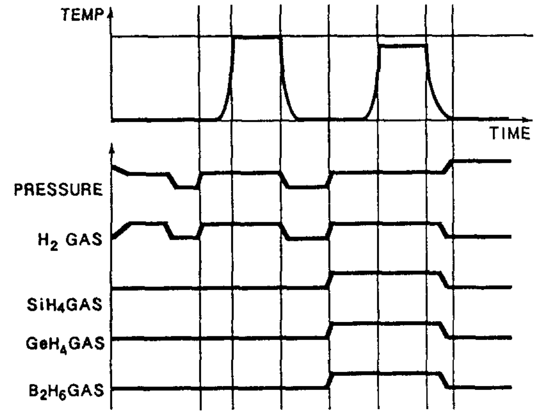

Fig.2 The process profile of an RTCVD heat cycle

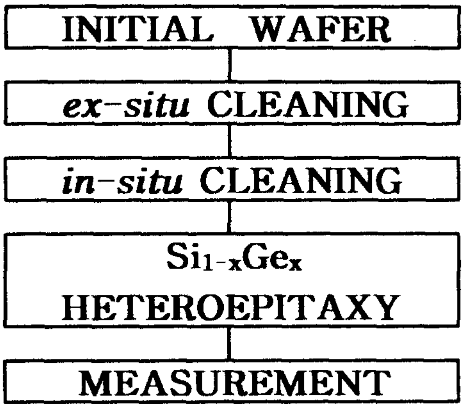

Fig.3 The flowchart of our experiment

Figure 3 is the flowchart of our experiment. Experimental procedure is as follows. Epitaxial films were deposited on 4 inch (100) silicon substrates. Substrate resistivities is used 8-12 ohm cm boron doped substrates. Preparation of the substrate surface prior to growth plays a critical role in epitaxial growth technique. In our experiments, *ex-situ* cleaning is not carried out and initial silicon wafer directly from the maker's product box is prebaked at 900℃ for two minutes in hydrogen gas ambient. Total gas flow rate and process pressure are around 1 lpm and 5 torr, respectively. In $Si_{1-x}Ge_x$ heteroepitaxial growth step, $SiH_4/GeH_4/H_2$ gas mixtures are used. The growth conditions are varied to investigate their effects on the film properties. The crystalline properties are analyzed from cross section TEM pictures. The Si/Ge composition ratios and the interface abruptness are measured with RBS and SIMS techniques.

3. RESULTS & DISCUSSION

Figure 4 is the SIMS depthprofile of an epilayer grown after H_2 prebake process at 900℃, 70 seconds without *ex-situ* cleaning. As indicated SIMS data, under the previous H_2 prebake process condition, native oxide in the growing interface is remarkably removed but carbon contamination is observed at large amount. And except for the carbon contamination in the interface, contamination free epitaxial layer is successfully growned. The contamination of carbon in the interface is believed at cleanroom environment, HF diluted *ex-situ* wet cleaning, in chamber wall during the heat treatment or rotary pump oil mist. That contamination is expected to be severely decreased as the blocking the oil mist backstreamed from the rotary pump and installation of the load lock chamber.

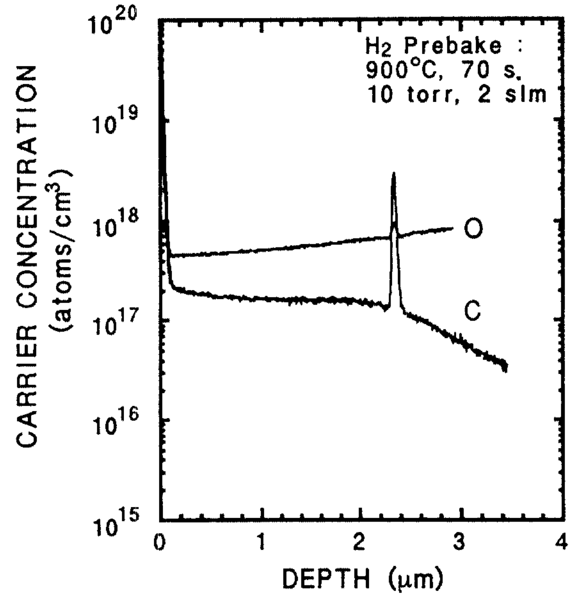

Fig.4 the SIMS depthprofile of an epilayer grown after H_2 prebake process at 900℃, 70 seconds without *ex-situ* cleaning

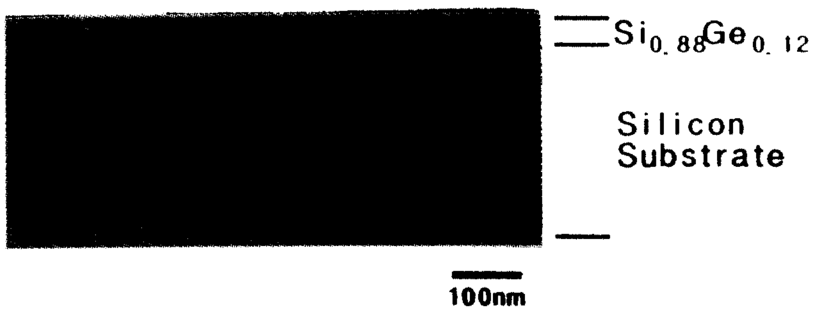

Fig.5 the cross section TEM micrograph of $Si_{0.88}Ge_{0.12}$ heteroepitaxial layer grown at 650 ℃ for 30 seconds

Figure 5 is the cross section TEM micrograph of $Si_{0.88}Ge_{0.12}$ heteroepitaxial layer grown at 650 ℃ for 30 seconds. At the total gas flowrate of 2 slm, the process pressure is chosen at the 5 torr. The Ge mole fraction was measured by RBS technique. On this cross section TEM result, any misfit threading dislocation in $Si_{0.88}Ge_{0.12}$ heteroepitaxial layer is not found. Thickness of $Si_{0.88}Ge_{0.12}$ heteroepitaxial layer is about 400Å. In spite of the carbon contamination in the interface, there was not induced other defects in the single crystal layer. It is believed that above contamination level is not severe to grow the epitaxial film. And transitional abruptness of Ge atom in the interface is limited and heteroepitaxial layer planarity is excellent. It shows that the SiGe heteroepitaxial layer grown at 650℃ has the high crystallinity and also good controllability in thin film growing.

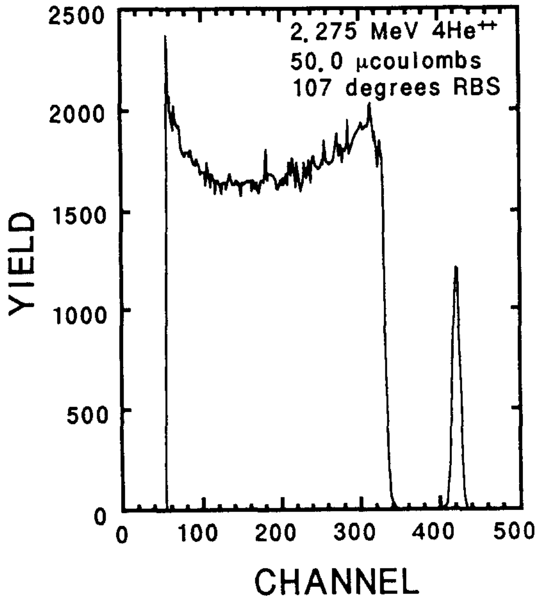

Fig.6 the RBS energy spectra of $Si_{0.88}Ge_{0.12}$ heteroepitaxial layer grown at 650℃

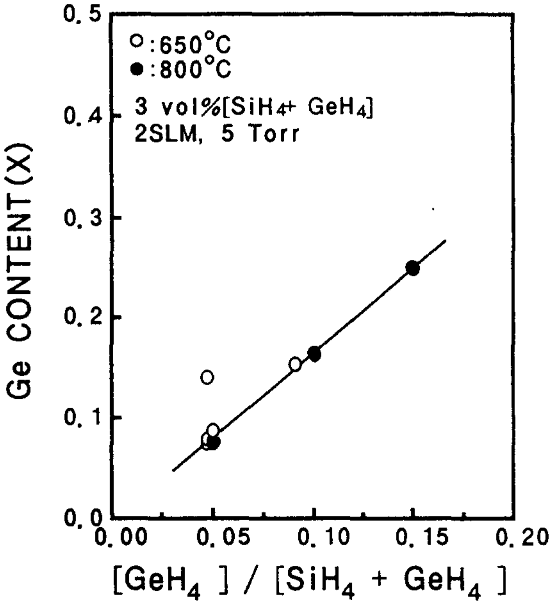

Fig.7 The Ge mole fraction dependence on source gas flowrate ratio $[GeH_4]/[SiH_4+GeH_4]$

Figure 6 shows the RBS energy spectra of the $Si_{0.88}Ge_{0.12}$ heteroepitaxial layer grown at 650℃. The RBS spectra is acquired at backscattering angle of 110 degrees with respect to the incident ion beam. The 110 degrees, grazing angle detector spectra allow detailed information about the composition in the surface silicon germanium layer. It shows that the mole fraction of Ge atom is 12 percent. Figure 7 shows the Ge mole fraction dependence on source gas flow rate ratio, germane gas flowrate over total source gas flowrate of silane gas plus germane gas. The germane mole fraction has linearly dependence with the source gas flowrate ratio. The slope is about 1.6. Those trends are independent on growing temperature if the samples are grown at 650 ℃ and 800℃. Therefore the germane mole fraction is dependent on gas flowrate ratio, and independent on growing temperature although the dessociative energy from the source gas is different each other, silane and germane gas. Figure 8 is the SIMS depth profile of *in-situ* Boron doped silicon germanium hetero epitaxial layer using the 200 ppm B_2H_6 source gas. The SIMS data shows that the abruptness of the doping profile can be controlled within about 200Å/decade and Ge compositional abruptness is also excellent.

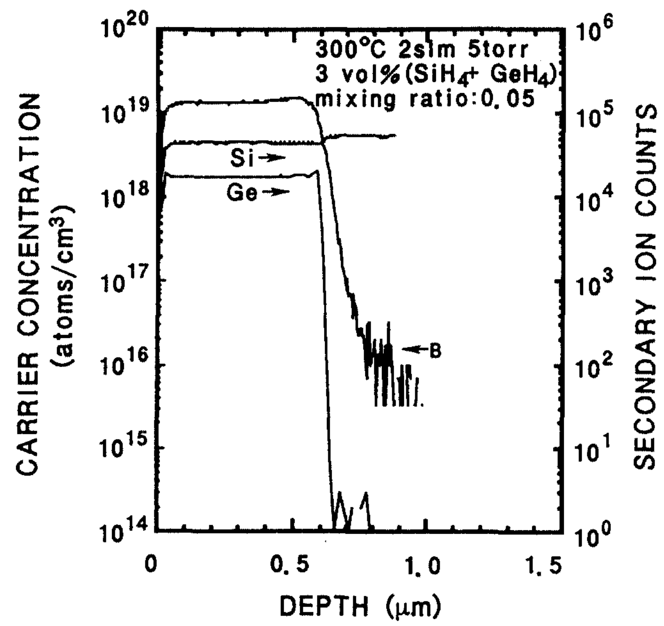

Fig.8 The SIMS depth profile of *in-situ* Boron doped silicon germanium heteroepitaxial layer using the 200 ppm B_2H_6 source gas

4. CONCLUSIONS

From these results, the following conclusions can be drawn:

1) $Si_{1-x}Ge_x$ heteroepitaxial films has been successfully growned by the RTCVD method.
2) The excellent crystalline ferfection of the silicon germanium layer is obtained at the growth temperature at 650℃.
3) On the growth of silicon germanium epitaxial films, the transition width of doping profile and Ge composition is easily controlled less than about 200Å/decade.

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