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SiGe Layers Heteroepitaxy on Si Substrate by RTP/VLP-CVD

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SiH_4 and GeH_4 Deposition of SiGe Layers by Rapid Thermal Process, Very Low Pressure Chemical Vapor Deposition (RTP/VLP-CVD) method have been studied in this paper. The Ge incorporation rate increases to a maximum value and then decreases as temperature increases, the deposition of SiGe has a maximum value of growth rate as Ge composition increases. Ge incorporation also enhances Si deposition rate in SiGe alloy.

1. INTRODUCTION

Heteroepitaxy of SiGe alloy on Si is very important for developing novel device structures, due to the possibility of tailing the band gap of heterostructures[1]. Many different methods exist for depositing strained SiGe layers on Si, including Molecular Beam Epitaxy (MBE)[2], Ultrahigh Vacuum Chemical Vapor Deposition (UHVCVD)[3,4], Rapid Thermal CVD (RTCVD)[5] and Very Low Pressure CVD (VLPCVD)[6] methods.

Of the processes proposed for SiGe epitaxial growth, CVD is of great interest since this technique appears to be compatible with manufacturing requirements such as high through, conformal coverage and low cost. High-quality heteroepitaxy SiGe alloy has been deposited on Si by several CVD methods and the relationship among the growth rate, Ge composition and substrate temperature have been reported. Some papers said that the growth rate of SiGe was found to monotonic decrease as Ge composition increased[6], but other found there is a maximum value in growth rate or monotonic increase as Ge composition increases[3,7]. It's observed that Ge composition only depend on SiH_4 and GeH_4 flow ratio and insensitive to growth temperature[4,5], but other found Ge composition in SiGe alloy would decrease as the temperature increases[6,8]. Ge incorporation to SiGe layer would also change the activation energy of growth rate[8,9].

In this paper, we provide detail data concerning the Ge incorporation, the growth rate of SiGe films, deposited by Rapid Thermal Process, Very Low Pressure Chemical Vapor Deposition (RTP/VLP-CVD) over temperature of 620^0C-780^0C. These results are similar to those on recent UHVCVD[10] and Atmosphere Pressure CVD (APCVD)[8,11], VLPCVD[7,9], RTCVD[5] growth of SiGe layer using the same reactant gases.

2. EXPERIMENT

The samples are grown by Rapid Thermal Process, Very Low Pressure CVD (RTP/VLP-CVD). After a standard procedure cleaning, a Si buffer layer of 100nm thick is grown on (100) Si substrate at first, then strained SiGe alloy and a Si caplayer are grown.

The growth substrate temperatures are from 620^0C to 780^0C. Changing the ratio of the reaction gases GeH_4/SiH_4 to get different Ge compositions, the growth pressure is about 10 mTorr. The samples are analyzed by Auger Electron Spectroscopy (PHI 550, ESCA/SAM), 1.5KV energy of Ar^+ sputtering at the angle of 50^0 was used to get the AES depth profile. Auger signals of Si(LVV, 92ev) and Ge (LMM, 1147ev) have been analyzed to determine Ge atom composition in the samples.

3. RESULTS AND DISCUSSION

Fig.1 is SiGe growth rate against Ge composition in SiGe layer. The growth rate of SiGe increases to a maximum value and then decreases as Ge composition increases at a constant SiH_4 flow rate.

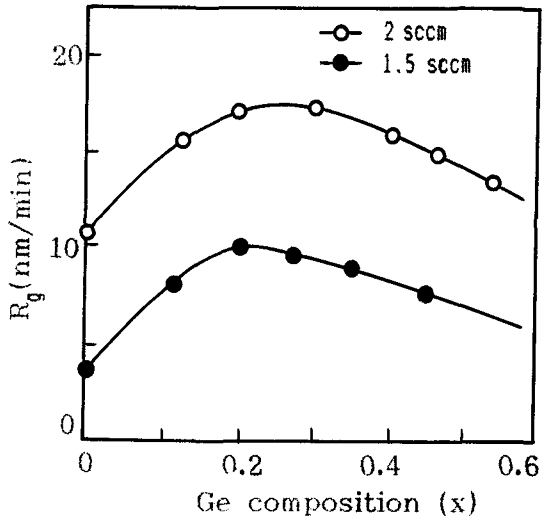

Fig.1 The SiGe growth rate as a function of Ge composition in SiGe alloy, SiH_4 flow rates are 1.5 sccm and 2.0 sccm respectively.

Fig.2 is Si and Ge deposition rate of SiGe alloy against Ge composition. Si deposition rate reaches a maximum value at lower Ge composition (x=0.15), but Ge deposition rate increases and then saturates as Ge composition increases.

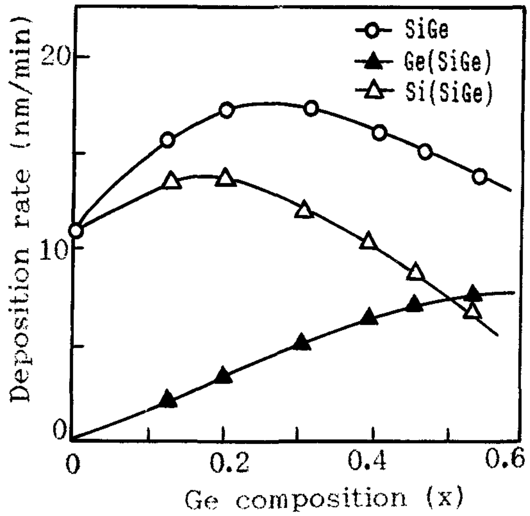

Fig.2 The Si and Ge deposition rate as a function of Ge composition, SiH_4 flow rate is 2.0 sccm.

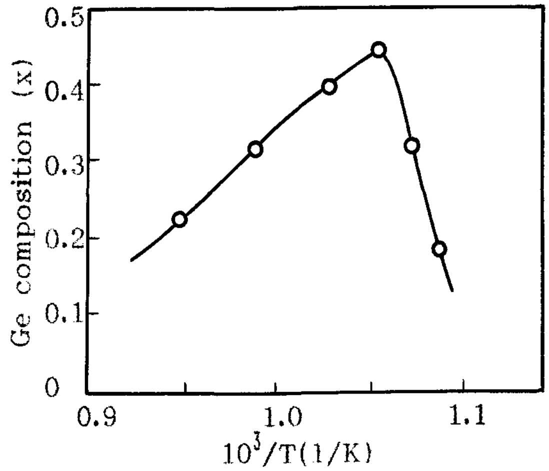

Fig.3 The Ge composition of SiGe alloy as a function of substrate temperature, SiH_4 and GeH_4 flow rates are 1.5 sccm and 0.21 sccm.

The incorporation of Ge atom in SiGe alloy as a function of temperature is shown in Fig.3. A maximum value of Ge composition is found at a certain temperature, Ge composition increases to a maximum value and then decreases as temperature increases.

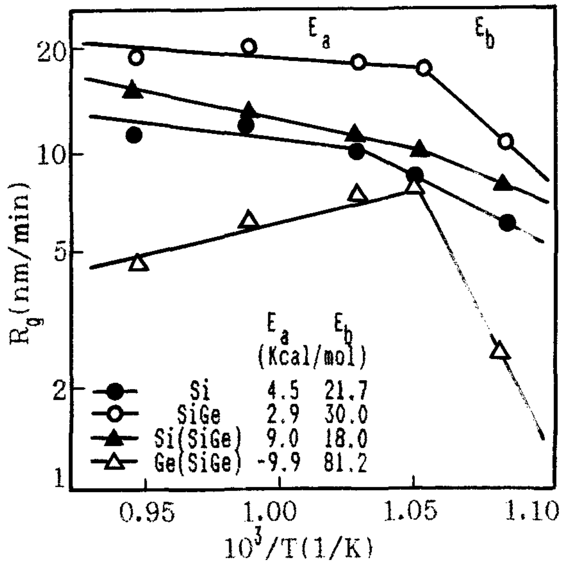

Fig.4 The Si and SiGe growth rate and also the Si and Ge deposition rate of SiGe alloy as a function of substrate temperature, SiH_4 and GeH_4 flow rates are 1.5 sccm and 0.21 sccm respectively.

The impact of temperature on Si and SiGe growth rate have been shown in Fig.4. Ge incorporation increases SiGe growth rate at all temperature regimes and the activation energy of growth rate at low temperature regime (E_b), the activation energy of growth rate at high temperature regime (E_a) decreases as Ge incorporates into SiGe layer. It's also found the exist of Ge atoms increase Si deposition rate at all temperature regimes, but Ge deposition rate increases to a maximum value and then decreases as temperature increases.

The VLPCVD reaction is the surface controlled reaction including SiH_4 and GeH_4 adsorption and the desorption of hydrogen on the surface limited reaction. Higher temperature or higher Ge composition will lead the adsorption rate constants to decrease but the desorption rate constant of hydrogen to increase, so a competition exists between an increasing desorption rate of hydrogen adatoms and a decreasing dissociative adsorption from the reactive hydrides. The first factor dominates at low temperatures and low x values, and the second at higher Ge composition or high temperatures.

Higher temperature will lead the reduction of SiH_4 and GeH_4 adsorption rate, but the adsorption rates of SiH_4 and GeH_4 don't change in the same degree. Since the activation energy of SiH_4 adsorption rate is larger than that of GeH_4 adsorption rate, SiH_4 and GeH_4 adsorption rate have a different dependence on substrate temperature. It's believed that at proper high temperature, the GeH_4 adsorption rate will reduce more and so Ge incorporation rate thus Ge composition in SiGe alloy may decrease as temperature increases as shown in Fig.3.

At higher temperature, the decreasing of dissociative adsorption from the reactive hydrides result to the reduction of SiH_4 and GeH_4 reaction rates and thus lead to the decreasing of SiGe growth rate. But the decreasing of Ge composition as temperature increases would lead to the increasing of SiGe growth rate. The competition between the reduction of SiH_4 and GeH_4 reaction rates and the increasing of SiGe growth rate by the reduction of Ge composition at a proper higher temperature will lead to the increasing of SiGe growth rate according to Fig.1 and the increasing of Si deposition rate as in Fig.4. Certainly, at a proper condition, This Si-growth rate enhancement, caused by the addition of GeH_4 to the gas flow at low temperature may turn into growth-rate inhibition at higher temperature or high Ge composition as shown in Ref.9.

The reaction parameters involved in the growth rate at higher x can be overcome to a certain degree by increasing SiH_4 and GeH_4 flow rates. As shown in Fig.1, changing the flow rate of SiH_4 from 1.5 sccm to 2.0 sccm, the maximum value of Ge composition increases from 0.2 to 0.25. The reduction in growth rate at higher Ge composition by increasing Ge is associated with the reduction of SiH_4 and GeH_4 adsorption by Ge composition increases, the growth rate may not be limited by hydrogen desorption but the reduction of SiH_4 reaction rate as Ge composition increases.

Based on Langmuir adsorption isotherm, it should be understood that the decrease in SiH_4 reaction rate at higher GeH_4 flow rate is caused by suppression of Si-hydride adsorption, for the GeH_4 reaction rate saturates at higher GeH_4 flow rate. The saturate reaction rate with respect to the GeH_4 flow rate results to high coverage of Ge-hydrides and reduces the SiH_4 deposition rate as shown in Fig.2.

4. SUMMARY

In the process of SiGe deposition, a competition exists between an increasing desorption rate of hydrogen adatoms and a decreasing dissociative adsorption from the reactive hydrides. The Ge incorporation rate increases to a maximum value and then decreases as temperature increases, the deposition of SiGe has a maximum value of growth rate as Ge composition increases. Ge incorporation also enhances Si deposition rate in SiGe alloy. These results have been explained by increasing the rate of hydrogen desorption at low temperature and low value of x and the reduction in the probability from dissociative adsorption of reactive hydride at high temperature and higher value of x.

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