Spectroscopic Ellipsometry of Si/graded-$Si_{1-x}Ge_x$/Si Heterostructure Films Grown by Reduced Pressure Chemical Vapor Deposition

J.J. Seo, S.S. Choi, H.D. Yang, J.Y. Kim, J.W. Yang, T.H. Han*, D.H.Cho*, K.H. Shim
Department of Semiconductor Science and Technology, Semiconductor Physics Research Center
Chonbuk National University, 664-14 Deokjinjdong, Deokjinku, Jeonju, 561-756 Korea
*R&D Center, Tachyonics, Seoul, Korea

Abstract : We have investigated optical properties of Si/graded-$Si_{1-x}Ge_x$/Si heterostructures grown by reduced pressure chemical vapor deposition. Compared to standard condition using Si(100) substrate and growth temperature of 650℃, Si(111) resulted in low growth rate and high Ge mole fraction. Also samples grown at higher temperatures exhibited increased growth rate and reduced Ge mole fraction. The features regarding both substrate temperature and crystal orientation, representing high incorporation of silicon supplied from gas stream played as a key parameter, illustrate that reaction control were prevailed in this process growth condition. Using secondary ion mass spectroscopy and spectroscopic ellipsometry, microscopic changes in atomic components could be analyzed for Si/graded-$Si_{1-x}Ge_x$/Si heterostructures.

Key Words : SiGe, SE, RPCVD, Epitaxy

I. Introduction

In a way of analyzing SiGe films grown with complicated structures, conventional technologies such as XRD, RBS, SIMS have been prevailed. But disadvantages of destructive analysis leave them not able to become in-line tools[1]. SE(Spectroscopic Ellipsometry), since it uses light reflecting from sample surface that is illuminated to the surface with a broad range of spectrum can analyze multi-layer transparent films for easy and non-destructive method. As an in situ monitoring of composition, thickness, and uniformity of growing films of multi-layer compound semiconductors, SE used to reveal its availability[2,3].

This work has been performed to understand the effects of crystal orientation and of substrate temperature on SiGe multi-layer film growth. Depth profiles of atomic composition measured from SIMS were compared with SE spectra. If properly controlled by in-line monitoring, the repeatability and uniformity of RPCVD epitaxial growth will be able to elevate throughput and yield in production line.

II. Experiments

Shown in Fig. 1. shows the cross section view of Si/graded-$Si_{1-x}Ge_x$/Si heterostructure films used in this experiment. Films were grown with Si-cap (40nm), graded-SiGe (30nm), SiGe plateau (10nm), Si-seed (10nm), and boron atoms are in situ doped in the Si-seed and middle of graded-SiGe layers.

Depth profile of atomic composition and elliptical spectra were measured using Secondary ion mass spectroscopy(SIMS) and spectroscopic ellipsometry(SE). SE measurements of tan(Ψ) and cos(Δ) were performed using Nanoview system, automatic spectroscopic ellipsometry model MG-1000, in the range of 1.5~5.2eV with a 70° angle of incidence. Thickness and composition in Si/graded-$Si_{1-x}Ge_x$/Si films obtained using software program were compared with those from depth profile of SIMS.

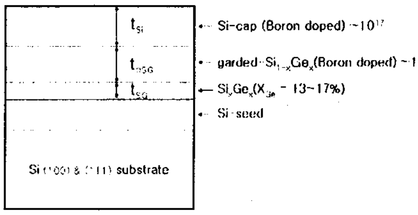

Fig.1. Si/graded-$Si_{1-x}Ge_x$/$Si_{1-x}Ge_x$/Si heterostructure

III. Results and Discussion

Fig. 2.(a) and (b) represent the depth profile of Ge for different substrate orientation and growth temperatures varying in the range of 5℃ above and below of standard growth temperature 650℃. The thickness of silicon cap layer is measured as 40nm and 30nm respectively on Si(100) and Si(111)

substrates. Also the mole fraction of germanium peak varies from -5% to +5% as the substrate temperature was 645℃ and 655℃ respectively.

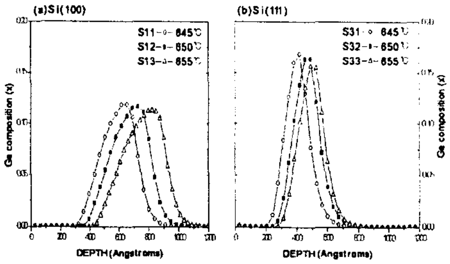

Fig.2. Depth profile of Ge measured from Si/graded-Si$_{1-x}$Ge$_x$/Si$_{1-x}$Ge$_x$/Si grown on Si (a) (100) and (b) (111) substrate

Fig. 3.(a) and (b) reveal SE spectra measured from Si/graded-Si$_{1-x}$Ge$_x$/Si$_{1-x}$Ge$_x$/Si heterostructures grown on Si(100), substrate for three different temperature of 645, 650, 655℃, where Ψ and Δ are ellipsometry angles. The spectra show a smooth progression with the E1 peak moving toward up and down energies for high and low temperature growth. From correlating the results between SE and SIMS, best fit lines for Ψ and Δ correspond very well to symbol, and excellent match has been found with the SIMS profile.

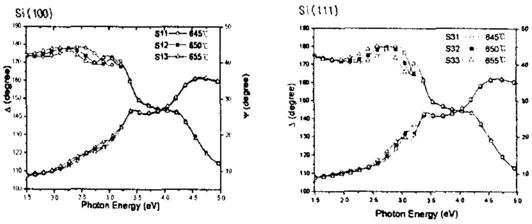

Fig.3. SE spectra measured from Si/graded-Si$_{1-x}$Ge$_x$/Si$_{1-x}$Ge$_x$/Si structures grown on (a) Si(100) and (b) Si(111) substrates

Both Ψ and Δ values in the Fig. 3. clearly show spectrum depending on the substrate temperature. Compared to the spectrum of 650℃, the sample grown at 645℃ low shifted to low energy side and the sample grown at 655℃ high shifted to the higher side. Likewise, SE spectrum measured from sample grown on Si(111) substrate represented same properties as observed from samples grown on Si(100).

Table 1. is thicknesses and Ge mole fraction of Si/graded-Si$_{1-x}$Ge$_x$/Si$_{1-x}$Ge$_x$/Si heterostructures. There constants were obtained from depth profile of SIMS and fitting parameters of SE spectra are presented for comparison. Although fitting using semi-automatic optimization process could have errors, the date from SIMS and SE matching quite well illustrate their accuracy presents in acceptable ranges.

Table 1. Thicknesses and germanium mole fraction of Si/graded-Si$_{1-x}$Ge$_x$/Si$_{1-x}$Ge$_x$/Si heterostructures

SIMS (Secondary ion mass spectroscopy)				
sample	t_{SG}	t_{gSG}	t_{Si}	x_{Ge}
S11	323	252	75	0.121
S12	358	292	75	0.117
S13	420	343	87	0.115
SE (Spectroscopic ellipsometry)				< t_{ox} ~ 13 Å >
sample	t_{SG}	t_{gSG}	t_{S}	x_{Ge}
S11	312.12	267.38	64.72	0.149
S12	359.79	278.89	64.36	0.153
S13	409.77	292.83	70.00	0.134

Therefore, by the virtue of in-situ monitoring capability, SE looks practical and useful in establishing repeatability in process line of Si/graded-Si$_{1-x}$Ge$_x$/Si$_{1-x}$Ge$_x$/Si heterostructures designed with sophisticated structures.

Ⅳ. Conclusion

Si/graded-Si$_{1-x}$G$_x$/Si$_{1-x}$G$_x$/Si heterostructure were grown by RPCVD at different substrate temperatures and on Si(100) & (111) substrates, and their structural properties were investigated using SIMS and SE. Compared to Si(100), the growth on Si(111) resulted in low growth rate and high germanium mole fraction in graded-Si$_{1-x}$Ge$_x$ layer. Growth at high temperature exhibited increase in growth rate and reduction in Ge mole fraction compared to those grown at low temperature. Such behaviors could be understood to happen due to the rate of silicon incorporation.

Acknowledgement

"This work was supported by the Korean Ministry of Industry, Energy, and Commerce(Grant: 10016968)."

References

[1] C. M. Scheirer, R. F. Jones, P. Nguyen, H. Pois, S. Zangooie, Applied Surface Science, **75**, 214, 2003.

[2] F. Ferrieu, P. Ribot, J. L. Regolini, Thin Soild Films, **221**, 373, 2000.

[3] C. Piockering, Thin Solid Films, **406**, 313-314, 1998.