GROWTH OF SiGe NANOPARTICLES BY LOW PRESSURE CHEMICAL VAPOUR DEPOSITION FOR NANOELECTRONIC DEVICES

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SiGe nanoparticles embedded in SiO_2 have potential applications for room temperature operation of single-electron transistor memories, non-volatile memory devices and optoelectronic devices [1]. The deposition of SiGe nanoparticles was carried out in a commercial low pressure vapour deposition (LPCVD) reactor in batch mode using germane (GeH_4) and disilane (Si_2H_6) as precursor gases. An O_2 injector also allows to deposit SiO_2 at low temperature (LTO). SiGe nanoparticles were deposited on a SiO_2 layer on top of a Si (001) substrate and covered with a SiO_2 LTO layer deposited in the same run at 390 ºC. The four samples presented here include SiGe nanoparticles prepared using a germane to disilane flow ratio of 0.82 and a total pressure in the chamber of 50 mTorr. The deposition times were 60, 25, 12.5 and 6 minutes for samples labelled A, B, C and D respectively. The samples were characterized by cross-sectional Transmission Electron Microscopy (TEM) equipped with EDX and Z-contrast imaging in STEM mode, X-ray Reflectometry (XRR), and Rutherford Backscattering Spectrometry (RBS). TEM studies show that the layer deposited between the two SiO_2 layers in sample A is amorphous and almost continuous (figure 1), while a line of amorphous nanoparticles of decreasing thickness and lateral size is observed in the samples B and C (see figure 2). For samples D no contrast is observed in the TEM images due to the small size of the nanoparticles, but Z-contrast STEM images (not shown) indicate that the morphology of the sample is the same than in sample C with a smaller size of the nanoparticles. Nanoparticles in samples C and D are spherical. EDX spectra indicate that the atomic Ge fraction of sample A was ≈ 0.3, and that the nanoparticles of samples B, C and D are SiGe, but their Ge fraction could not be estimated due to their small size. An estimation of the average number of nanoparticles per cm^2 in sample C is 1.2×10^{12}. The bottom SiO_2 / nanoparticles interface in all the samples is very sharp and quasi-parallel to the Si substrate. In sample A the lateral uniformity and interface sharpness of the agglomerates are poor, and the top oxide layer presents undulations associated to the roughness of the SiGe layer close to 2 nm. The measured thickness of the SiO_2 layers and the size of the nanoparticles are summarized in Table I. XRR measurements were performed, using Cu $K_{\alpha1}$ line in a θ-2θ knife geometry. XRR measurements were performed using Cu $K_{\alpha1}$ line in a θ-2θ knife geometry. Figure 3 shows the X-ray reflectivity spectra and their fits for the A, B, C and D samples. Individual layer thickness as well as roughness have been determined from the fits. In the case of a pseudo-layer composed of embedded nanoparticles, supposedly spherical, the average particle height can be estimated by adding in quadrature the fitted average thickness of the SiGe layers with the thickness distribution given by the fitted roughness. The measured thickness of the SiO_2 layers and the diameter of the nanoparticles are summarized in Table I. RBS in grazing incidence conditions (tilt angle of 78 º in Cornell geometry) was used to determine the amount and composition of the SiGe as well as the thickness of the SiO_2 layers. Figure 4 shows the RBS spectra of the A, B, C and D samples. The analysis using the RUMP code [2] shows that the SiGe films had to be treated as discontinuous to obtain a fit to the experimental data, while the SiO_2 layers were continuous. Furthermore, the existence of a SiGe alloy had to be assumed in order to calculate the correct heights for the Si and Ge

signals in the regions of the spectra corresponding to the SiGe layer. Equivalent thickness for the SiGe layers, i.e. thickness assuming continuous layers with Ge fraction 0.3, were derived from the measured Ge contents. The measured thickness of the SiO_2 layers and the equivalent thickness of the SiGe layers are also summarized in Table I. In conclusion, it is possible to deposit in a controllable way SiGe nanoparticles with almost uniform diameters in the 1 - 5 nm range, embedded in a SiO_2 matrix and located in the same horizontal plane, using a conventional hot wall LPCVD reactor operating in a single run.

References

[1] D. - W. Kim *et al*. J. Electrochem. Soc. **150**, G240-243 (2003).
[2] L. R. Doolittle. Nucl. Instr. Meth. **B9**, 344-351 (1985); http://www.genplot.com.

Figures

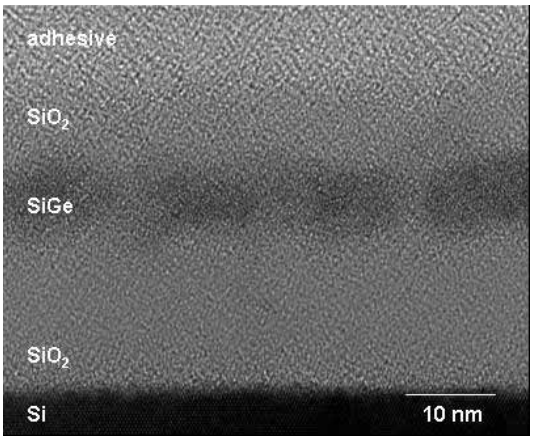

Figure 1. Cross-sectional bright field TEM image of sample A.

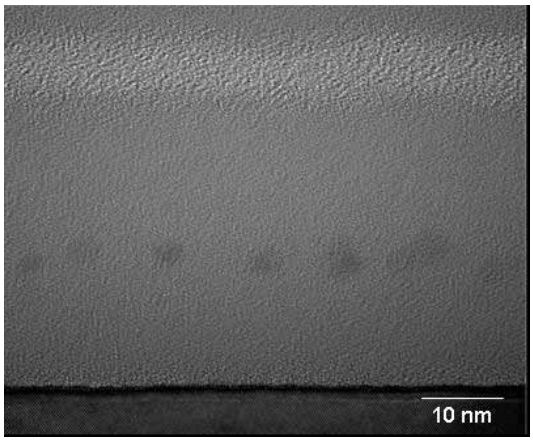

Figure 2. Cross-sectional bright field TEM image of sample C.

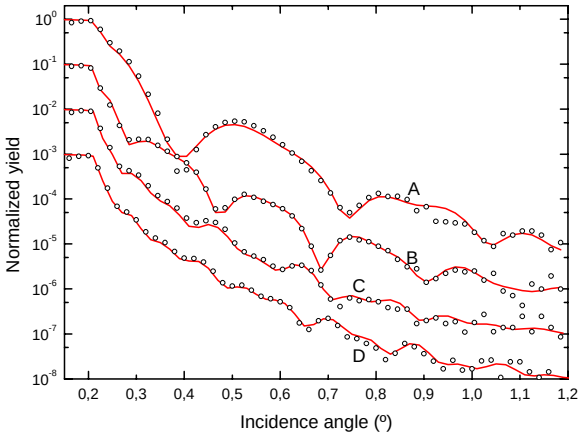

Figure 3. XRR spectra and their fit for the 4 samples.

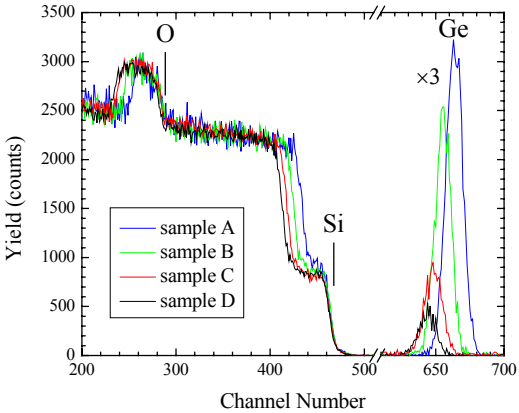

Figure 4. RBS spectra of the 4 samples.

	BOTTOM SiO_2 (nm)			SiGe (nm)			TOP SiO_2 (nm)		
SAMPLE	TEM	RBS	XRR	TEM	RBS	XRR	TEM	RBS	XRR
A	12.7	10	15.5	4-6	4.6	4.7-5.1	6.7-11	10	8.5
B	13.7	18	17.3	3-6	1.5	2.5-3.9	13	19	18.6
C	17	18	18.3	2.1-4	0.45	1.7-3.1	24	26	24.6
D	18.3	18	20.3	< 2	0.26	1.0-1.8	21.9	29	26

Table I. Thickness of the oxide layers and size of the SiGe nanoparticles as determined by the three techniques.