PHOTOLUMINESCENCE AND RUTHERFORD BACKSCATTERING STUDY OF GE QUANTUM DOTS GROWN ON A SI(100) SURFACE COVERED WITH A THIN SILICON OXIDE LAYER

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Heteroepitaxial growth of Ge quantum dots (QDs) on Si substrates can be used to fabricate quantum devices for future opto- and microelectronic applications. The lattice parameter mismatch between Si and Ge (~4%) induces the well-known Stranski-Krastanow (SK) growth mode [1]. This is a way of growing uniform, small and coherent QDs (base diameter > 30 nm) with a density of $\sim 10^8$–$10^{10}/cm^2$ [2,3]. However, for optoelectronic applications, the quantum confinement has to be enhanced, so that the dots must be smaller (< 10 nm) and have still higher density. In order to solve this issue, a new method of Ge QDs growth on (111) and (001) silicon surfaces through an ultrathin interlayer of silicon oxide has recently been proposed [4,5]. Ge dots with a base diameter less than 10 nm and with a density of $\sim 10^{12}/cm^2$ can be obtained by this method [4–6]. These Ge dots are not connected among each other by a SiGe wetting layer (WL) as is it is the case in the SK growth mode. The structural and optical characteristics of dots grown by this technique are just starting to be studied [7,8].

In this work we study the Ge dots growth as a function of the thickness of the silicon oxide interlayer and the Ge deposition. Structural characterization was performed by Rutherford Backscattering/Channeling (RBS/C) of 2.0 MeV He^+ ions along the main crystal axes. Photoluminescence (PL) was performed on a Bruker IFS 66v FTIR spectrometer using the 488 nm line of an Ar^+ laser for excitation. Hydrogen passivation was done in order to enhance the PL intensity.

All samples were grown by MBE on (001) Si substrates. The SiO_2 interlayer was formed at 400ºC. Then Ge was deposited at 550ºC. Finally, a 100 nm thick Si capping layer was deposited at 500ºC. The thickness of the SiO_2 interlayer (d_{SiO2}) amounted to 0.5, 0.75 or 1 monolayer (ML) and that of the Ge film (d_{Ge}) was 0.3, 0.6 or 0.9 nm.

The PL spectra of the as-grown samples taken at helium temperatures contain: (i) several sharp peaks due to radiation-induced defects, e.g., those centered at 0.767 and 0.926 eV [9]; (ii) a broad emission at 0.8–0.9 eV; (iii) bound and free exciton-related emissions from the Si capping layer and substrate at energies higher than 1 eV [9]. For the smallest Ge deposition (0.3 nm) the broad emission essentially consists of the dislocation-related D1 band centered at 0.812 eV [10]. With increasing Ge thickness, a band centered at ~0.85 eV starts to grow, and is strongest for the maximum Ge deposition (0.9 nm). We attribute it to the Ge QD luminescence [11,12]. An influence of the SiO_2 thickness on the intensity of the PL broad band is observed, too (not shown). For the sample with 0.5 ML of SiO_2 the PL spectra exhibit only the D1 band. With increasing SiO_2 thickness, the band centered at ~0.85 eV starts to appear.

Fig. 1 shows a comparison between the PL spectra of as-grown and hydrogen passivated (100ºC for 15 min) samples. We clearly distinguish the D1 band from the 0.85 eV band attributed to the Ge QD emission.

The RBS spectra obtained in channeling and random directions for the sample with 1 ML of SiO_2 and 0.9 nm of Ge are shown in Fig. 2. The spectra clearly show a signal from the Ge layer.

The shift to lower energies for larger tilt angles (θ) is due to an increase of the path of the beam particles, $d = x/\cos\theta$ (x being the real thickness), inside the Si capping layer, which leads to a decrease of the energy of the backscattered particles. The aligned spectrum for the <110> axis (obtained at $\theta = 44.9^{o}$) shows a peak at channel 467 due to the presence of the non-crystalline SiO_2 interlayer. For the sample containing 0.5 ML of SiO_2 this signal is very weak.

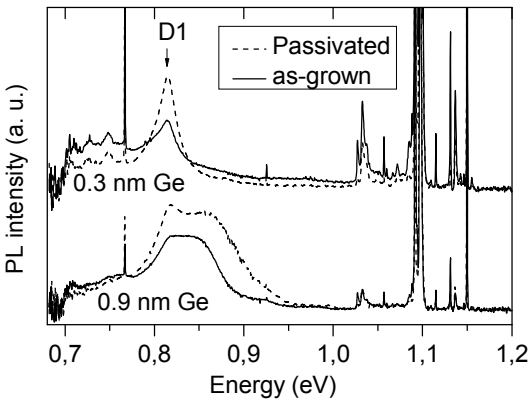

Figure 1. Comparison between the PL spectra of the as-grown and passivated samples with 1 ML of SiO_2 and with 0.3 nm and 0.9 nm of Ge. T_m = 5 K.

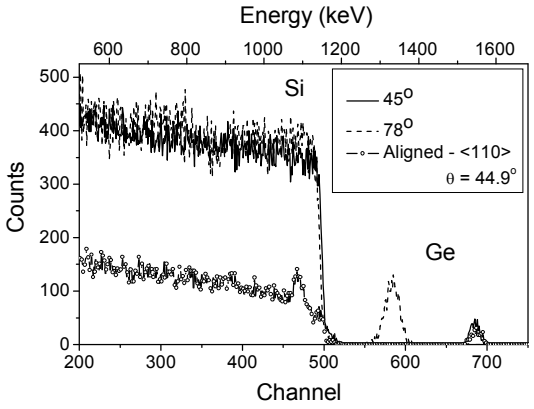

Figure 2. RBS spectra of the sample with 0.9 nm of Ge and 1 ML of SiO_2 for the channeling and random directions at two different tilt angles.

Angular scans along the main crystal axes (<100>, <110> and <111>) were performed for samples with 1 ML of SiO_2 and 0.3, 0.6 and 0.9 nm of Ge, and for samples with 0.9 nm of Ge and 0.5, 0.75 and 1 ML of SiO_2.

Table 1. χ_{min} and $\psi_{1/2}$ for samples with 1 ML of SiO_2 and 0.3, 0.6 and 0.9 nm of Ge, for the <110> direction.

		0.3 nm Ge	**0.6 nm Ge**	**0.9 nm Ge**
χ_{min}	Ge	5.9 %	32.0 %	48.6 %
	Si (surface)	2.5 %	9.6 %	17.6 %
$\psi_{1/2}$	Ge	0.81º	0.96º	1.26º
	Si (surface)	0.99º	0.96º	1.04º

In Table 1 we present the dechanneling yield (χ_{min}) of the RBS spectra and the width at half-minimum of ($\psi_{1/2}$) of angular scans related to the backscattering from Ge and Si for samples with 1 ML of SiO_2 and 0.3, 0.6 and 0.9 nm of Ge, for the <110> direction. For the sample with the thickest Ge-layer (0.9 nm) we observe that χ_{min} for the Ge curve is almost 50%, indicating a possible presence of strained Ge islands. This result also shows that as the Ge layer thickness increases, χ_{min} for the Ge-related curves is getting higher, indicating a crescent crystallographic disorder. This disorder can be interpreted as a way of releasing the strain energy accumulated in the Ge films due to the lattice mismatch between Si and Ge (~4%). An increase of the thickness of the Ge layer also induces a broadening of the Ge angular scan curve from 0.81º for d_{Ge} = 0.6 nm to

1.26º for $d_{Ge} = 0.6$ nm. The increase of the $\psi_{1/2}$ value also suggests the presence of Ge islands. However, the positions of the minima of both Si- and Ge-related curves are identical, which suggests that, despite having a lower crystalline quality, the Ge film is coherently aligned with the Si substrate.

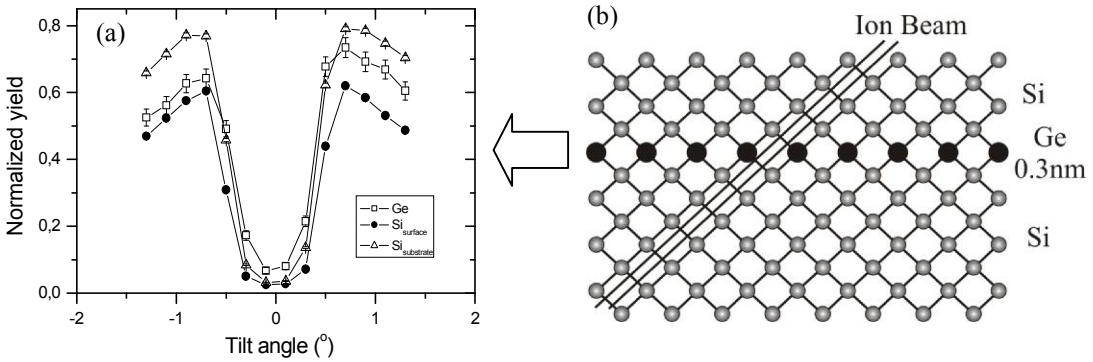

Figure 3. (a) Angular scan along <110> direction for sample with 1ML of SiO_2 and 0.3 nm of Ge; (b) Schematic diagram of the atomic structure of this sample.

For the sample with 1 ML of SiO_2 and 0.3 nm of Ge, the Ge-related scans and the Si-related ones are similar (see Fig. 3a). This is a clear indication that Ge atoms are incorporated substitutionally in the Si lattice, excluding the formation of Ge islands. In Fig. 3b we present a schematic drawing for a possible atomic structure of a sample with a thin Ge layer. Here, the Ge atoms are incorporated into the Si lattice.

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