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### ► **To cite this version:**

Yidir Androussi, Tarik Benabbas, Slawomir Kret, Vincent Ferreiro, Alain Lefebvre. A Transmission Electron Microscopy study of composition in Si<sub>1-x</sub>Gex / Si (001) quantum dots. *Philosophical Magazine*, 2007, 87 (10), pp.1531-1543. <10.1080/14786430601055387>. <hal-00513799>

**HAL Id: hal-00513799**

**<https://hal.science/hal-00513799v1>**

Submitted on 1 Sep 2010

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**A Transmission Electron Microscopy study of composition in Si<sub>1-x</sub>Gex / Si (001) quantum dots**

Journal:	<i>Philosophical Magazine &amp; Philosophical Magazine Letters</i>
Manuscript ID:	TPHM-06-Jun-0217.R1
Journal Selection:	Philosophical Magazine
Date Submitted by the Author:	27-Sep-2006
Complete List of Authors:	Androussi, Yidir; CNRS, LSPES UMR 8008 Benabbas, Tarik; CNRS, LSPES UMR 8008 Kret, Slawomir; Institute of Physics, Polish Academy of Sciences Ferreiro, Vincent; CNRS, LSPES UMR 8008 Lefebvre, Alain; CNRS, LSPES UMR 8008
Keywords:	quantum dots, transmission electron microscopy
Keywords (user supplied):	chemical composition, displacement field



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3 **A Transmission Electron Microscopy study of composition in  $\text{Si}_{1-x}\text{Ge}_x$  / Si**  
4 **(001) quantum dots**

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21 A finite-element program has been developed to model strain relaxation in the  
22 case of epitaxial  $\text{Si}_{1-x}\text{Ge}_x$  / Si coherent quantum dots either with or without  
23 compositional inhomogeneities. The resulting elastic displacement fields are  
24 used to calculate the intensity of dynamical plan view TEM images of such  
25 quantum dots. Various types of linear or parabolic compositional  
26 inhomogeneities are studied. TEM images of quantum dots with such  
27 inhomogeneities are calculated as well as those of quantum dots with a  
28 homogeneous composition. They are then compared with experimental images.  
29 It is shown how the analysis of the main features of these experimental images  
30 (black/white lobes and moiré-like fringes) enables us to determine the conditions  
31 in which it is possible to distinguish quantum dots with a homogeneous  
32 composition from those with compositional inhomogeneity.  
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45 **Keywords:** Transmission electron microscopy; quantum dots; chemical  
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## 1. INTRODUCTION

Self-assembled quantum dots (QDs) in heteroepitaxial semiconductor systems have recently been an area of intense study because many electronic devices based on QDs have been theoretically proved to possess better electronic and optical properties than quantum-well devices. Knowing the structural parameters of QDs including the shape, size and chemical composition at different stages of QD island growth is thus important for understanding the structure-property relationship of the QDs as well as revealing information on QD growth mechanisms [1]. However, the accurate characterization of coherent islands is not trivial due to their small sizes and the coupling effects between composition and strain field. An additional complexity is that the island shape and composition are a function of substrate temperature (during growth), of coverage and of the type of crystal growth technique.

Ge/Si (001), in particular, has served as a model system because it is a simple two-component system and due to the hope of combining these QDs easily with existing Si technology. Morphology evolution of uncapped QDs has been extensively investigated and it is reasonably well understood [2-4], but despite its impact on optical and electronic properties, island composition evolution is still in debate. The determination of local composition can be carried out with techniques that average over many islands. These include high resolution x-ray diffraction [5], x-ray anomalous scattering [6,7] and x-ray absorption fine structure [8]. Selective etching coupled with atomic force microscopy [9] and electron-microscope-based methods make it possible to measure composition variations throughout individual islands. These methods are scanning tunneling microscopy [10] and transmission electron microscopy (TEM) techniques including high resolution imaging combined with finite element analysis [11], electron energy loss spectrometry (EELS) [12-14] and x-ray energy dispersive spectrometry (EDS) [15-16]. For each of the above TEM studies, very thin cross-section specimens are required. However, it is difficult to prepare cross-section TEM specimens, especially for samples with low QD densities, and even then the section might include any part of the QD. As a result, there is an advantage in using plan-view samples. Besides, plan-view samples have a larger sampling region that provides a superior statistical basis and contrary to cross-section samples, the surface relaxation effects are negligible in them. That is why plan-view specimens have been successfully used to extract alloying information in  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  QDs from diffraction contrast images [17].

It has been recently shown that information on the chemical composition of coherently strained islands can also be obtained by TEM when fringes - which we have called "moiré-like fringes"- are observed in plan-view images of  $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$  QDs [18-20]. The same type of fringes has also been observed in  $\text{SiGe}/\text{Si}$  QDs [21-22]. This paper is aimed at showing that these moiré-like fringes can be used to study the chemical composition of such QDs. Finite-

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element (FE) calculations are performed in order to take account of various complex compositional variations. It is then shown how the resulting strain fields (and consequently the compositional inhomogeneities) can be studied via the dynamical contrast of TEM plan-view images of QDs.

## 2. EXPERIMENTAL PROCEDURE

The growth of the self-assembled islands is carried out in an ultra-vacuum chemical vapor deposition growth chamber with silane and germane diluted in hydrogen used as precursors [23]. Four monolayers of Ge are deposited at 600 or 700°C on Si (001). Atomic force microscopy (AFM) experiments are carried out in air using a Nanoscope III Multimode microscope from Digital Instruments operating in the tapping mode. Integrated silicon tips with a radius of curvature of about 10 nm and cantilevers (model TSEP) with a nominal spring constant 30 Nm<sup>-1</sup> are used. The (512 x 512 pixels) images are obtained with a 100 x 100 μm piezoelectric scanner and with a 0.4 Hz scanning frequency.

[Insert figure 1 about here]

The finite-element (FE) calculations are performed using a “home-made” program so as to calculate displacement fields  $\mathbf{R}$  taking account of possible compositional variations in Si<sub>1-x</sub>Ge<sub>x</sub>/Si QDs. They are carried out in the case of lens-shaped domes (Fig. 1) with values of  $b$  and  $h$  as indicated in table 1. The compositional variations are introduced by local variations of the elastic constants and for each finite element, a virtual thermal expansion coefficient is introduced so as to simulate a local lattice mismatch that will occur during the FE calculation by raising the temperature by 1K. The thermal expansion coefficient  $\alpha$  has thus to fulfill the relation  $a(x) = a(0) (1 + \alpha \Delta T)$  where  $a(x)$  is the bulk-material lattice parameter corresponding to the Si concentration  $x$  of the finite element.

[Insert table 1 about here]

Plan-view TEM thin foils are mechanically thinned from the substrate side by wedge polishing. TEM images are taken with a Philips CM30 microscope (operated at 300 kV) and directly captured with a cooled slow-scan charge-coupled device (CCD) Gatan camera.

The two-beam dynamical TEM contrast of QDs is simulated by solving the Howie and Whelan equations based on the so-called column approximation [24]. The displacement field  $\mathbf{R}$  is computed at equispaced points in the [001] direction by carrying out the Lagrange interpolation procedure on the data points provided by finite-element calculations. It should be noted that these calculations make it possible to readily vary the shape of the islands and their aspect ratio.

## 3. RESULTS

1  
2 A bimodal dot distribution with square-based pyramids and domes is observed  
3 by atomic force microscopy at 700°C (see for instance both types of islands in  
4 Fig. 2) whereas only domes are observed at 600°C. The average sizes of both  
5 types of islands are indicated in table 1 as a function of temperature. The aspect  
6 ratio  $\rho = 0.20 \pm 0.02$  was found to be constant for all the observed  $D_2$  islands.  
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9 [Insert figure 2 about here]  
10

11 The characteristics of plan-view dynamical TEM dark-field images of  
12 strained islands have been fully described in the case of coherently strained  
13  $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$  [19,25] or  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  islands [21,22]. They all exhibit a  
14 black/white contrast, as shown in Fig. 3 and 4 in the case of pyramids (P) grown  
15 at 700°C and in the case of domes grown at 600°C ( $D_1$ ) or 700°C ( $D_2$ ). When the  
16 islands display a sufficiently high aspect ratio ( $h/b > \sim 0.2$ ), moiré-like fringes  
17 are found to be superimposed to the black/white contrast (see  $D_2$  domes in Fig.  
18 4). This is fully consistent with what has been demonstrated in the case of  
19  $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$  islands [19]. These images were obtained for QDs on the  
20 electron entrance surface, with a diffraction vector  $\mathbf{g} = 220$  parallel to the  
21 interface and with  $w_g = s_g \xi_g = -1.10 \pm 0.05$  ( $s_g$  is the deviation parameter and  $\xi_g$   
22 the extinction distance). This negative value of  $w_g$  was used because it was found  
23 to give the highest contrasts and because it was consistent with the general rules  
24 established by Katerbau [26] for lattice defects near the specimen surfaces.  
25 Following these rules, the contrast of such defects depends on the imaging mode  
26 (bright or dark field), on the defect position (near the electron entrance or the  
27 electron exit surface of the specimen) and on the sign of  $w_g$ . The various cases  
28 are summarized in table 2 : for bright-field images, the contrast is reduced  
29 (enhanced) for  $w_g < 0$  ( $w_g > 0$ ) whatever the defect position. On the contrary, for  
30 dark-field images, the reduction (or enhancement) simultaneously depends on  
31 the sign of  $w_g$  and on the defect position. There is thus an advantage to take dark-  
32 field images (rather than bright-field images) either with QDs near the electron  
33 entrance (with  $w_g < 0$ ) or near the electron exit surface (with  $w_g > 0$ ): in both cases,  
34 the contrast is enhanced for QDs whereas it is reduced for defects resulting from  
35 the specimen thinning on the opposite surface.  
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40 [Insert figure 3 about here]

41 [Insert figure 4 about here]

42 [Insert table 2 about here]  
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44

45 Uncapped  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  islands grown either by molecular beam epitaxy or by  
46 chemical vapor deposition generally display aspect ratios inferior to  $\sim 0.3$  and  
47 two types of compositional heterogeneities. In the first type, a diffuse interface  
48 with Si/Ge mixing is observed, the island composition is homogeneous away  
49 from the intermixed interface and a laterally constant composition is maintained  
50 in the  $r$  direction [7,13]. In the second type, the islands contain a Si-rich core  
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covered with a Ge-rich shell and the composition is not laterally constant [6,17]. It should be noted that a uniform composition has been found in low mismatch  $\text{Si}_{0.8}\text{Ge}_{0.2}/\text{Si}$  QDs [27]. Islands grown by liquid phase epitaxy are not taken into account in our study because they display higher aspect ratios ( $\sim 0.5$ ) [28]. We have thus calculated dark-field (220) TEM images of  $\text{D}_2$  domes for homogeneous compositions and for two types of composition variations. In the first type, a laterally constant composition is maintained in the  $r$  direction (Fig. 5a) whereas compositional gradients are introduced in the  $z$  direction either with a linear (“linear/linear” model) or S-shaped profile (“linear/S” model). In the second type, various models have been tested with parabolic contour lines in the  $(r,z)$  plane and linear dependence on the  $z$  axis (“parabolic/linear” model) (Fig. 5b). The linear (S) dependence of indium composition  $x$  as a function of  $z$  is indicated in Fig. 5c (d).

[Insert figure 5 about here]

Fig. 6 shows calculated dark-field (220) TEM images of  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  domes with the same geometrical characteristics as  $\text{D}_2$  domes and either with a homogeneous composition (with various values of germanium content  $x$ ) (Fig. 6a) or with the models of compositional inhomogeneities defined in Fig. 5 (Fig. 6b-d). All the images have the same characteristics (i.e. black/white contrast and superimposed moiré-like fringes). L is defined as the distance between the centers of white and black lobes, and  $\sigma$  is defined as the mean periodicity of moiré-like fringes (the periodicity of these fringes is not constant within any experimental or calculated images and that is why  $\sigma$  has been defined as a mean periodicity). A  $(\sigma, L/b)$  diagram can be established for various homogeneous or heterogeneous compositions, and with the following parameters in the case of Fig.7: aspect ratio  $\rho = 0.20$ , thin foil thickness  $t = 349$  nm,  $A_{220} = 0.0315$  (the anomalous absorption coefficient),  $\xi_{220}^e = 62.7$  nm (the effective extinction distance of  $\text{Si}_{0.5}\text{Ge}_{0.5}$ , calculated using the Vegard’s law),  $w_{220} = -1,10$ . It should be noted that moiré-like fringes are not found for low values of  $x$  ( $x < \sim 0.4$  for homogenous composition and  $x_1$  or  $x_s < \sim 0.6$  for heterogeneous compositions). The main result in this figure is that islands with a homogeneous composition can be theoretically unambiguously distinguished from islands with compositional inhomogeneity. However the experimental uncertainties on the measured values of  $\sigma$  and  $L/b$  (spread out in the rectangle in Fig.7) make it difficult to distinguish between islands with an homogeneous composition  $x = 0.4$  and islands with a “parabolic/linear” heterogeneous composition.

[Insert figure 6 about here]

We have then considered the influence of the uncertainties with which the above parameters ( $t$ ,  $A_{220}$ ,  $\xi_{220}^e$ ,  $w_{220}$  and  $\rho$ ) can be determined. It is thereafter

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Deleted: Defining L as the distance between the centres of the white and black lobes, and  $\sigma$  the periodicity of moiré-like fringes for every calculated image, a

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2 illustrated in the case of the  $(\sigma, L/b)_{\text{hom}}$  points corresponding to homogeneous  
3 compositions.  
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6 [Insert figure 7 about here]  
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9 The anomalous absorption coefficients were respectively taken to be  $A_{220} =$   
10  $0.0144$  for Si and  $A_{220} = 0.0485$  for Ge: these values were obtained from those  
11 calculated at 100 kV [29] or 120 kV [30] by extrapolating to 300 kV, using the  
12 analysis by Metherell and Whelan [31]. Vegard's law was used in the case of  
13  $\text{Si}_x\text{Ge}_{1-x}$  alloys.  
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16 [Insert figure 8 about here]  
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18 As an example, Fig. 8 shows the variations of  $(\sigma, L/b)_{\text{hom}}$  points as a function  
19 of  $A_{220}$  varying in the range 0.0144 (Si) - 0.0485 (Ge): inspecting this figure  
20 shows that for any  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  alloy, the positions of these points are rather  
21 insensitive to the uncertainties with which  $A_{220}$  can be calculated.

22 The influence of  $w_{220}$  is depicted in Fig. 9. This figure shows that the  
23 experimental error in this parameter ( $\pm 0.05$ ) has little influence on the  
24  $(\sigma, L/b)_{\text{hom}}$  points, mainly through variations in L.  
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27 [Insert figure 9 about here]  
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29 The effective extinction distances were respectively taken to be  $\xi_{220}^e = 74.8 \pm$   
30  $0.02$  nm for Si and  $\xi_{220}^e = 50.7 \pm 0.11$  nm for Ge in keeping with the calculations  
31 of Doyle and Turner [32] or Lu et al [33]. The Vegard's law was used in the case  
32 of  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  alloys. Calculations show that the positions of  $(\sigma, L/b)_{\text{hom}}$  points  
33 are insensitive to the uncertainties with which  $\xi_{220}^e$  can be calculated.  
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36 [Insert figure 10 about here]

37 [Insert figure 11 about here]  
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39 Calculated dark-field (220) TEM contrasts were found to be very dependent  
40 on foil thickness  $t$ . Defining the moiré-like fringe contrast  $C$  as  $I_2 - I_1 / I_2 + I_1$   
41 where  $I_{2(1)}$  is the intensity of the first dark (bright) fringe in the dark lobe, Fig. 10  
42 shows, for instance in the Si case, that the variation of  $C$  as a function of  $t$  is  
43 periodic and with an approximate  $\xi_{220}^e$  period. Only experimental images with  
44 the highest contrasts ( $> \sim 0.50$ ) leading to precise measurements of  $\sigma$  and L,  
45 were considered, i.e. images corresponding to the range 330-360 nm for the 300-  
46 380 nm period. **The specimen thickness was measured in the vicinity of every**  
47 **studied QD and the location of the corresponding electron microprobe was**  
48 **subsequently checked with the resulting contamination spot.** As an example, for  $t$   
49  $= 349$  nm situated in this range, Fig. 11 shows the variations of  $(\sigma, L/b)_{\text{hom}}$ .  
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2 points corresponding to the uncertainty  $\pm 4$  nm with which  $t$  can be measured  
3 using conventional CBED analysis[34,35]. The influence of this uncertainty on  
4  $(\sigma, L/b)_{\text{hom}}$  points is found to be negligible.  
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7 [Insert figure 12 about here]  
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9 Fig. 12 shows the variations of  $(\sigma, L/b)_{\text{hom}}$  points as a function of aspect ratio  
10  $(0.15 < \rho < 0.30)$ . Examining this figure shows that for a homogeneous  $x = 0.4$   
11 composition, moiré-like fringes are not found with  $\rho = 0.15$ , which is consistent  
12 with the fact that moiré-like fringes are never observed in the case of  $D_1$  domes.  
13 It should be noted that for any given composition  $x$ ,  $\sigma$  is very sensitive to the  
14 variations of  $\rho$  and that it is thus important to determine the aspect ratio as  
15 accurately as possible. In the case of  $D_2$  domes, the effect of the uncertainty  $\pm$   
16  $0.02$  on the determination of  $\rho$  is illustrated in Fig.12.  
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#### 19 4. DISCUSSION AND CONCLUSION 20

21  
22 The above analysis shows that all the parameters ( $t$ ,  $A_{220}$ ,  $\xi_{220}^e$ ,  $w_{220}$  and  $\rho$ )  
23 influencing the contrast of moiré-like fringes can be measured or calculated with  
24 a sufficient precision and have thus little influence on the *calculated* values of  $\sigma$   
25 and  $L/b$ . However, the experimental uncertainties on the *measured* values of  $\sigma$   
26 and  $L/b$  (spread out in the rectangle in Fig.7-9 and 11-12) make it difficult to  
27 distinguish between islands with a homogeneous  $x = 0.4$  composition and islands  
28 with a “parabolic/linear” heterogeneous composition. That is why an additional  
29 x-ray energy dispersive spectrometry investigation has been performed [36] and  
30 it has shown that  $D_2$  domes have an approximately homogeneous  $x = 0.4$   
31 composition.  
32

33 This result is consistent with those of Schüllli et al [7] who have studied the  
34 influence of growth temperature on interdiffusion in uncapped SiGe/Si islands  
35 grown by molecular beam epitaxy: the aspect ratio is found to be constant (0.22)  
36 between 620 et 750°C and the maximum Ge content rapidly decreases from  
37 about 70 to 22% for growth temperatures between 620 and 800°C and is  
38 approximately 45% at 700°C.  
39

40 Our geometrical approach shows how it is possible to distinguish quantum dots  
41 with a homogeneous composition from those with compositional inhomogeneity.  
42 However this does not make it possible to choose between various compositional  
43 variations and precise determination of these variations should take account of  
44 the relative intensities of black/white lobes and of moiré-like fringes.  
45

#### 46 ACKNOWLEDGEMENTS 47

48 This work was partially supported by the French “Région Nord-Pas de Calais”,  
49 by the European FEDER (“Fonds Européen de Développement Régional”) and  
50 the “Action Concertée Nanosciences/Nanotechnologies”. Many thanks are due to  
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2 Drs D. Bouchier and L.H. Nguyen (Institut d'Electronique Fondamentale, Orsay,  
3 France) for providing the SiGe/Si samples.  
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Growth temperature (°C)	b (nm)	h (nm)
600	100 (D <sub>1</sub> )	15 (D <sub>1</sub> )
700	110 (D <sub>2</sub> ) 100 (P)	22 (D <sub>2</sub> ) 12 (P)

Table 1: Average sizes of domes (D<sub>1</sub> and D<sub>2</sub>) and pyramidal islands (P) for various growth temperatures ; b=base, h= height.

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	Electron entrance surface	Electron exit surface
Bright field		
$w > 0$	+	+
$w < 0$	-	-
Dark field		
$w > 0$	-	+
$w < 0$	+	-

Table 2: Enhancement (+) or reduction (-) of dynamical TEM contrast for lattice defects near the specimen surfaces.

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Figure 1: Schematic view of the dome-shaped islands used for the FE calculations and for the TEM contrast simulations.

Figure 2: Tapping mode ( $1.2 \mu\text{m} \times 1.2 \mu\text{m}$ ) image of  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  QDs grown at  $700^\circ\text{C}$ . A few pyramidal (dome-shaped) QDs are indicated with black (white) arrows.

Figure 3: Experimental dark-field (220) TEM image of  $D_1$  dome-shaped  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  QDs grown at  $600^\circ\text{C}$ ;  $w_{220} = -1.10$ .

Figure 4: Experimental dark-field (220) TEM image of  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  QDs grown at  $700^\circ\text{C}$ ;  $w_{220} = -1.10$ ,  $t = 349 \text{ nm}$ . (a): a pyramid (P) and two domes ( $D_2$  and  $D'_2$ ). Only the domes display moiré-like fringes. (b): enlargement of the  $D_2$  dome.

Figure 5: Various models of compositional inhomogeneity. (a): linear variation in the  $(r,z)$  plane. (b): parabolic variation in the  $(r,z)$  plane. (c): linear dependence of germanium composition  $x$  as a function of  $z$  and for  $r = 0$ . (d): S dependence of germanium composition  $x$  as a function of  $z$  and for  $r = 0$ .

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Figure 6: Calculated dark-field (220) TEM images of dome-shaped  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  QDs with a homogeneous composition (a), or with various compositional inhomogeneities: linear/linear model (b), linear/S model (c), parabolic/linear



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2 model (d). Aspect ratio  $\rho = 0.20$ ,  $t = 349$  nm,  $A_{220} = 0.0315$ ,  $\xi_{220}^e = 62.7$  nm,  
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5  $w_{220} = -1,10$ .  
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9 Figure 7: Calculated  $(\sigma, L/b)$  diagram for dome-shaped  $\text{Si}_{1-x}\text{Ge}_x/\text{Si}$  QDs, either  
10 with homogeneous compositions and various  $x$  silicon contents ( $\blacklozenge$ ) or with  
11 compositional inhomogeneities: ( $\blacksquare$ ) = linear/linear model; ( $\blacktriangle$ ) = linear/S model;  
12 ( $\square$ ) = parabolic/linear model. Aspect ratio  $\rho = 0.20$ ,  $t = 349$  nm,  $A_{220} = 0.0315$ ,  
13  $\xi_{220}^e = 62.7$  nm,  $w_{220} = -1,10$ . Experimental points corresponding to the measured  
14 values  $\sigma$  and  $L/b$  are spread out into the rectangle located in the upper part of the  
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27 Figure 8: Variations of  $(\sigma, L/b)_{\text{hom}}$  points as a function of  $A_{220}$ . Aspect ratio  $\rho =$   
28  $0.20$ ,  $t = 349$  nm,  $\xi_{220}^e = 62.7$  nm,  $w_{220} = -1,10$ . The rectangle located in the  
29 upper part is the same as in Fig.7.  
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36 Figure 9: Variations of  $(\sigma, L/b)_{\text{hom}}$  points for various values of  $w_{220}$   
37 corresponding to the experimental uncertainties. Aspect ratio  $\rho = 0.20$ ,  $t = 349$   
38 nm,  $A_{220} = 0.0315$ ,  $\xi_{220}^e = 62.7$  nm. The rectangle located in the upper part is the  
39 same as in Fig.7.  
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2 Figure 10: Moiré-like fringe contrast  $C$  as a function of the foil thickness  $t$ .

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4 Aspect ratio  $\rho = 0.20$ ,  $A_{220} = 0.0315$ ,  $\xi_{220}^e = 62.7$  nm,  $w_{220} = -1,10$ .

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9 Figure 11: Variations of  $(\sigma, L/b)_{\text{hom.}}$  points for various values of  $t$  ranging from

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11 345 to 353 nm. Aspect ratio  $\rho = 0.20$ ,  $A_{220} = 0.0315$ ,  $\xi_{220}^e = 62.7$  nm,  $w_{220} = -$   
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13 1,10. The rectangle located in the upper part is the same as in Fig.7.

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18 Figure 12: Variations of  $(\sigma, L/b)_{\text{hom.}}$  points for various values of  $\rho$  ranging from

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20 0.15 to 0.30: ( $\blacklozenge$ )  $\rho = 0.15$ ; ( $\blacksquare$ )  $\rho = 0.20$ ; ( $\blacktriangle$ )  $\rho = 0.25$ ; ( $\bullet$ )  $\rho = 0.30$ .  $A_{220} =$   
21  
22 0.0315,  $\xi_{220}^e = 62.7$  nm,  $w_{220} = -1,10$ ,  $t = 349$  nm. The rectangle located in the  
23  
24 upper part is the same as in Fig.7. The effect of the uncertainty  $\pm 0.02$  with  
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26 which  $\rho = 0.20$  can be measured is illustrated with dotted rectangles.  
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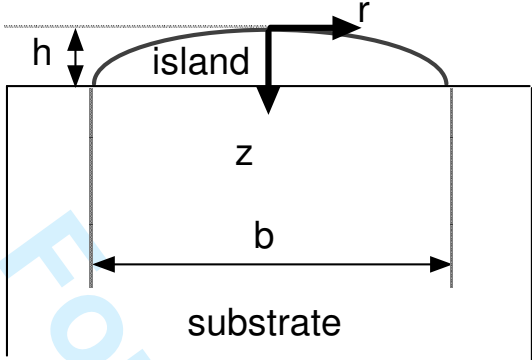


Figure 1

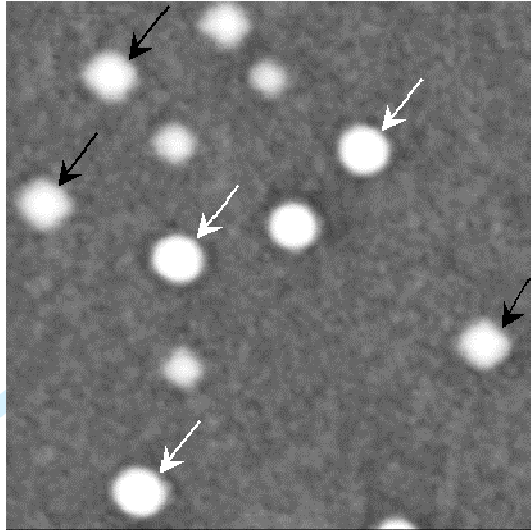


Figure 2

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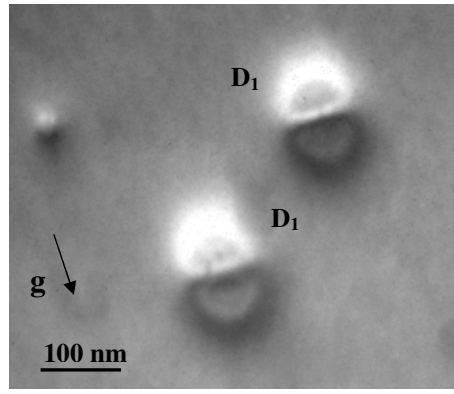
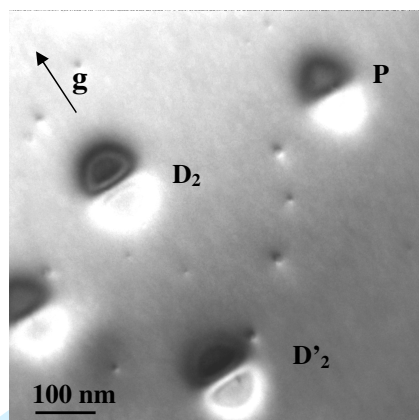
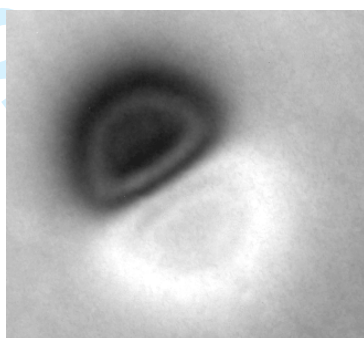


Figure 3

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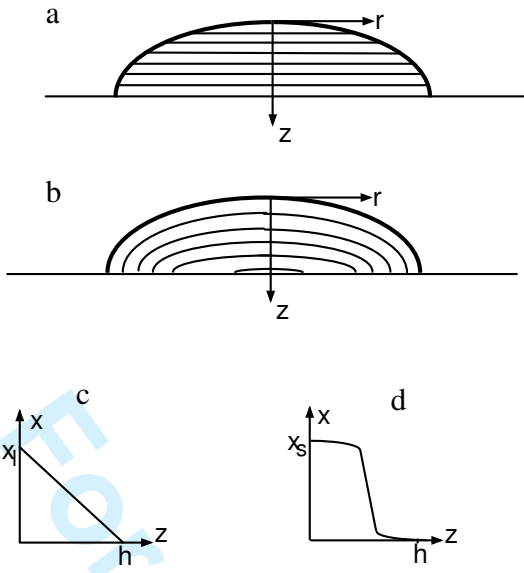
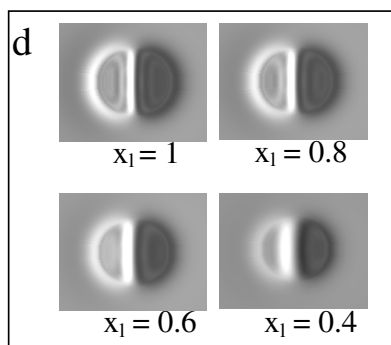
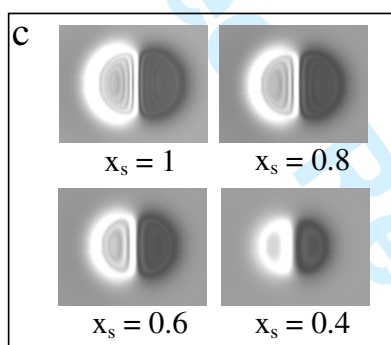
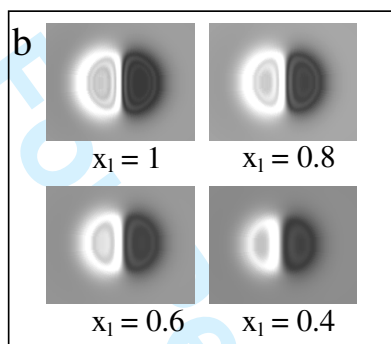
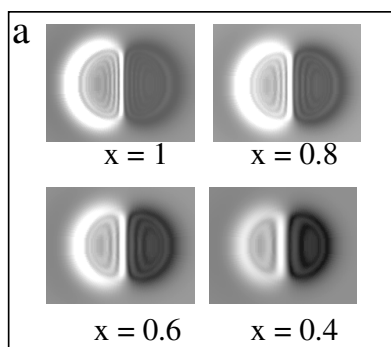


Figure 5



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**100 nm**

Figure 6



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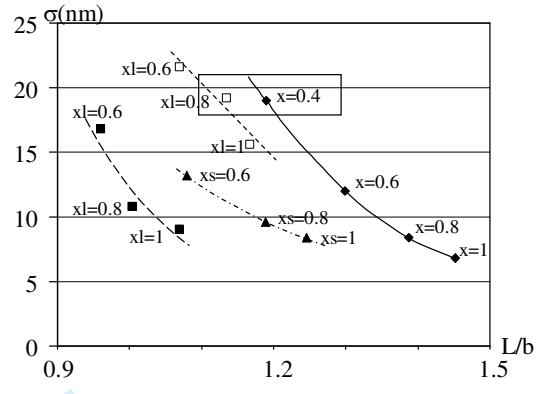


Figure 7

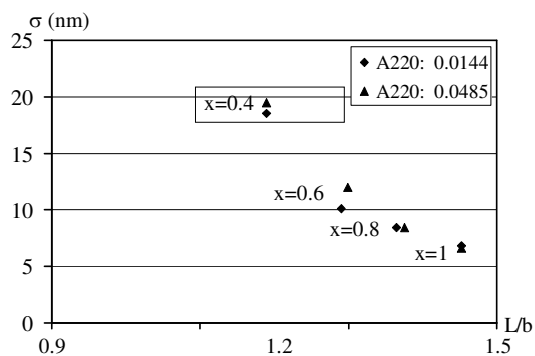


Figure 8

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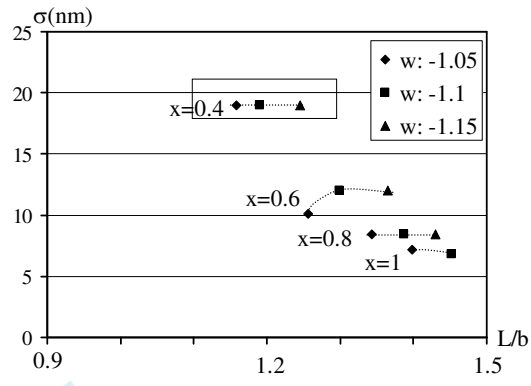


Figure 9

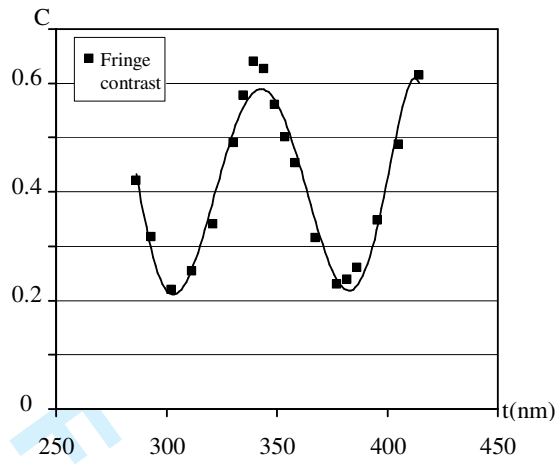


Figure 10

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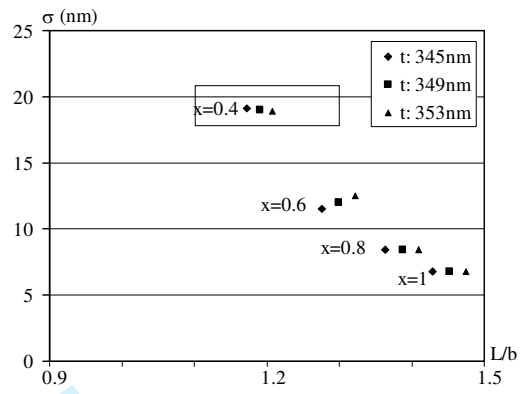


Figure 11

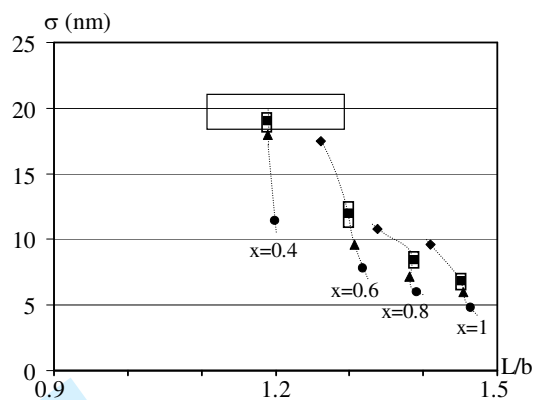


Figure 12

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