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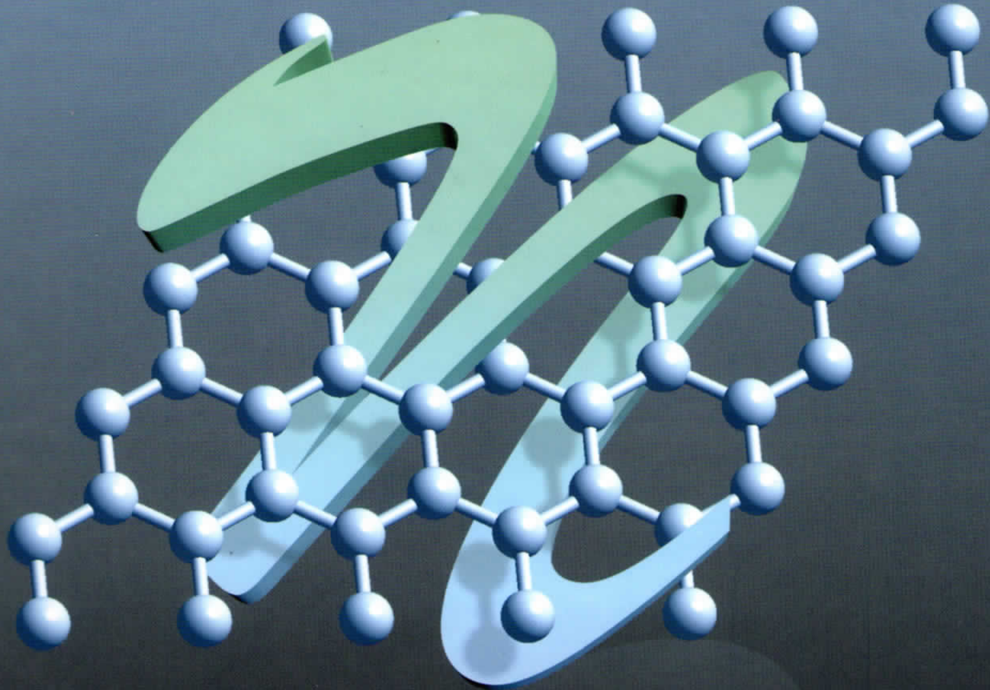

PROCEEDINGS OF INTERNATIONAL CONFERENCE
NANOMEETING - 2011

REVIEWS AND SHORT NOTES

PHYSICS, CHEMISTRY AND APPLICATIONS OF NANOSTRUCTURES

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REVIEWS AND SHORT NOTES

Minsk, Belarus, 24 – 27 May 2011

editors

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TEM CHARACTERIZATION OF GaAs NANOISLANDS ON Si

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A TEM study of GaAs nanoislands grown on (001) Si substrate by the droplet epitaxy technique is presented. The nanoislands turn out to be monocrystalline in perfect epitaxial relationship with Si. By X-ray microanalysis in the TEM it is also seen that the islands are stoichiometric. TEM images of the moiré fringes revealed the presence of dislocations at the nanoislands suggesting strain relaxation.

1. Introduction

Self-assembly of semiconductor nanostructures is the current approach for the production of devices exploiting quantum size effects. In this respect, considerable efforts are being dedicated to the integration of III-V semiconductor nanostructures on Si substrates [1-3]. For integration directly on Si-based integrated circuits a compatible growth procedure for the III-V compounds, *i.e.* a low thermal budget one, is necessary.

Droplet epitaxy (DE) fulfils such a requirement as it is a growth method based on molecular beam epitaxy (MBE) operating at 250-300 °C [4-5]. By DE the element(s) of the group III are first deposited onto the substrate leading to the formation of metallic droplets. The group III element flux is then stopped and the As flux is made on. Reaction of As with the metal droplets produces the desired III-V nanostructure. The vertical and lateral size as well as the density of the III-V nanoislands are determined by the deposition temperature and time and flux of the metal.

In this paper we present a transmission electron microscopy (TEM) study of GaAs nanoislands grown on Si substrates by DE. Such nanostructures are intended to work as local artificial substrates for the deposition of other III-V compounds, like InGaAs or AlGaAs, to build the active III-V nanostructure of the device [6-8].

2. Experimental

The GaAs nanoislands have been grown on (001) Si substrates in a conventional GEN II MBE machine. Ga droplets were formed at the deposition rate of

0.075 ML/sec and background pressure below 5×10^{-10} Torr. Three MLs of Ga were deposited. At this step two substrate temperatures have been used, either 600 °C or 250 °C. The temperature was then decreased to 150 °C and the Ga droplets were exposed to an As_4 flux at 5×10^{-5} Torr for 5 min thus getting complete crystallization of the Ga droplets. Crystallization was checked by *in-situ* RHEED (not shown here). TEM investigations were performed in a JEOL 2200FS instrument by the two beam diffraction contrast mode, selected area diffraction (SAD) and X-ray energy dispersive spectroscopy (EDS) attached to the TEM. The TEM specimens were prepared by standard Ar ion beam thinning after mechanical lapping.

3. Results and discussion

Fig. 1a is a typical plan view TEM image of the GaAs nanoislands. Their density was ~2.4×10^7 cm^{-2} and ~1.2×10^9 cm^{-2} for the sample grown at 600 and 250 °C, respectively. The average island size was 250 and 60 nm, respectively. The formation of crystalline GaAs was assessed by analysis of the moirè fringes [9] with diffraction vector [220] (Fig. 1b) and SAD (Fig. 2). The moirè fringes are better detectable in the 250 °C sample as the islands are smaller, while SAD patterns are more easily obtained from the bigger islands of the 600 °C sample. In Fig. 1b the measured average distance between the parallel moirè fringes is

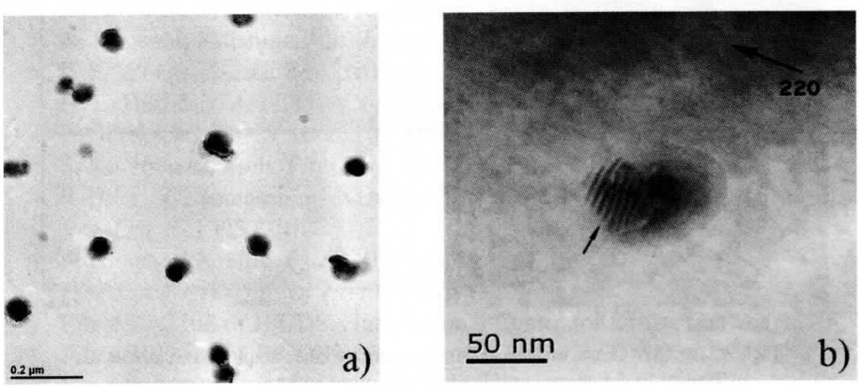

Figure 1. TEM images of GaAs/Si nanoislands in the sample grown at 250 °C: a) overview at low magnification, b) image of an island taken with diffraction vector [220] showing moirè fringes.

D = 4.75 nm in very good agreement with the expected value D_{th} of 4.80 nm for GaAs deposited on Si. In fact, D_{th} is given by $d_{Si}d_{GaAs}/(d_{GaAs} - d_{Si})$ where d is the (220) interplanar lattice distance of the respective bulk GaAs and Si materials

[9]. The moiré fringe not crossing the whole island indicated with an arrow in Fig. 1b is due to the presence of a dislocation [9] and thus suggests that the island could be fully relaxed.

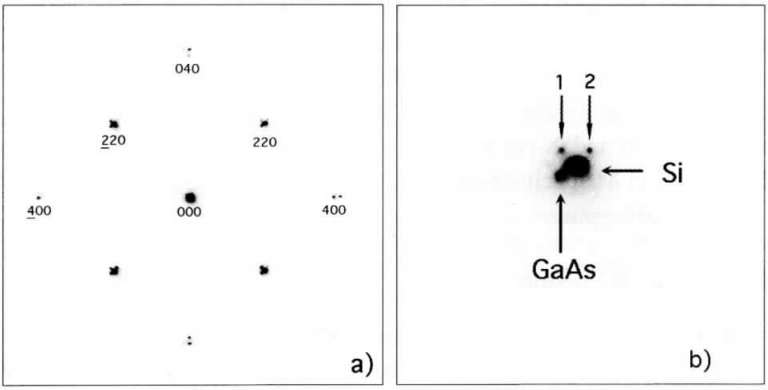

Figure 2. a) [001] zero order Laue zone SAD pattern (with inverted contrast) of a GaAs/Si nanoisland in the sample grown at 600 °C. b) Magnified image of the reciprocal space around the diffraction spot [220] of a). The diffraction spots of GaAs and Si are indicated. Spots 1 and 2 are due to double diffraction (see text).

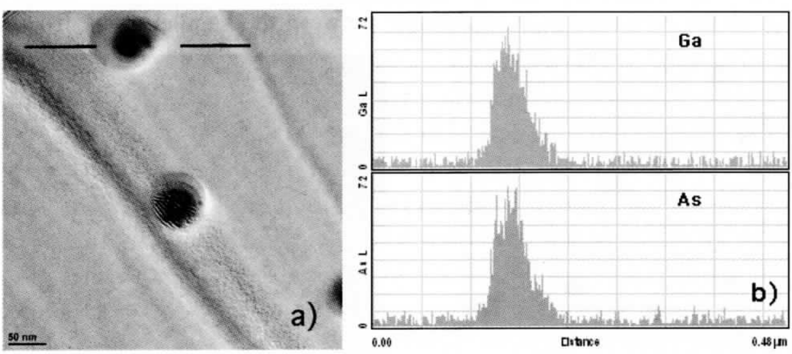

Figure 3. a) TEM image of 2 GaAs/Si nanoislands in the sample grown at 250 °C. b) Typical EDS intensity profile of the GaL (top) and AsL (bottom) signals across the top island in a) along the dash line.

Fig. 2 is the plan view [001] SAD pattern from a nanoisland that confirms the formation of single crystalline GaAs as well as the correct epitaxial relationship to the Si substrate. The measured interplanar distances of the brightest outer diffraction spots of the square pattern are those of Si [10] while those of the medium bright inner spots are due to GaAs [11]. The less intense spots around the Si and GaAs ones are due to double diffraction (DD) of the beams diffracted by the GaAs island (located at the top entrance surface with respect to the TEM primary beam direction) by the Si substrate. The invisibility of some expected DD spots is likely due to their very low intensity.

The compositional homogeneity was checked by EDS microanalysis (Fig. 3b). The Ga and As signals have the same intensity as well as the same spatial distribution across the measured island suggesting that the GaAs nanoislands are stoichiometric.

Acknowledgments

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References

1. S. F. Fang, K. Adomi, S. Lyer, H. Morkoç, H. Zabel, C. Choi, N. Otsuke, *J. Appl. Phys.* **68**, R31 (1990).
2. O. Kwon, J. Boeckl, M. L. Lee A. J. Pitera, E. A. Fitzgerald, S. A. Ringel, *J. Appl. Phys.* **97**, 034504 (2005).
3. Z. Zhao, Z. Hao, K. Yadavalli, K. L. Wang, A. P. Jacob, *Appl. Phys. Lett.* **92**, 083111 (2008).
4. N. Koguchi, S. Takahashi, T. Chikyow, *J. Cryst. Growth* **111**, 688 (1991).
5. N. Koguchi, K. Ishige, *Jpn. J. Appl. Phys.* **32**, 2052 (1993).
6. P. S. Wong, G. Balakrishnan, N. Nuntawong, J. Tatebayashi, D. L. Huffaker, *Appl. Phys. Lett.* **90**, 183103 (2007).
7. C. Somaschini, S. Bietti, N. Koguchi, F. Montalenti, C. Frigeri, S. Sanguinetti, *Appl. Phys. Lett.* **97**, 053101 (2010).
8. S. Bietti, C. Somaschini, N. Koguchi, C. Frigeri, S. Sanguinetti, *Nanoscale Res. Lett.* **5**, 1905 (2010)
9. P. Hirsch, A. Howie, R. B. Nicholson, D. W. Pashley, M. J. Whelan, *Electron Microscopy of Thin Crystals* (Krieger, New York, 1977).
10. File # 77-2108 of JPCDS - International Centre for Diffraction Data.
11. File # 80-0016 of JPCDS - International Centre for Diffraction Data.