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A technique for fabricating InGaAs/GaAs nanotubes of precisely controlled length

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Abstract. Single-crystal nanotubes of precisely controlled length were produced on a (110) cleaved facet of heterostructure. The selective MBE growth of a strained InGaAs/GaAs strip and its subsequent self-rolling were used. The proposed technique is capable of ensuring good reproducibility of all sizes and exact positioning of nanotubes.

Introduction

Achieving good reproducibility of sizes in nanotechnology, although being a problem of great significance, has not yet found a satisfactory solution. For instance, the electrical capacitance of a single-electron transistor Coulomb island, a key part of one of the most remarkable nonoelectronic devices, depends on the dimensions of this island and should be precisely controlled. In spite of a considerable number of advantageous properties of nanoobjects obtainable nowadays, the use of these objects in nanotechnology remains difficult. For instance, carbon nanotubes have poorly reproducible lengths, semiconductor mesostructures have rather irregular edges, etc. In this work we propose a technique which enables fabricating nanoobjects of precisely controllable dimensions. The method employs the possibility of self-rolling of a highly strained InGaAs/GaAs heterolayer in a tube-shaped scroll as the heterolayer detaches from substrate during selective etching of an AlAs sacrificial layer underlying it (Fig. 1). The diameter of the tube thus formed depends on the thickness of the heterolayer and on the mismatch of lattice parameters in it; hence, this diameter can be precisely controlled [1]. Recently, this possibility was used to obtain InGaAs/GaAs tubes with tube diameters as small as 2 nm and lengths as large as 1 mm. For successive use of such tubes in nanotechnology, it is required that their lengths be highly reproducible in the nanometer-size range. As evident from Fig. 1, in order the length L

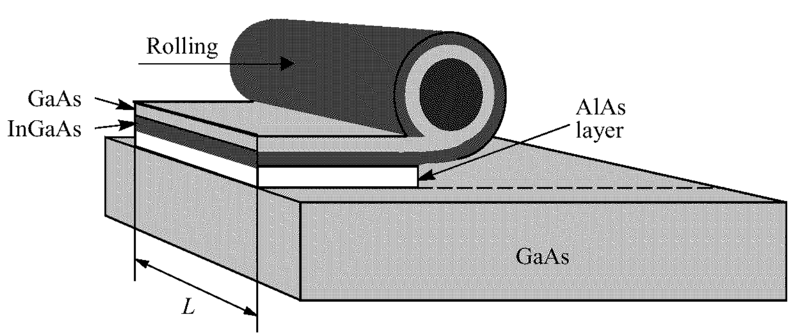

Fig. 1. A tube of length L is rolled from an InGaAs/GaAs heterolayer.

of an InGaAs/GaAs nanotube be controlled, it suffices that the nanotube be rolled from a plane InGaAs/GaAs bilayer of a precisely controlled width L.

Experemental

In this work, for the first time a InGaAs/GaAs bilayer of precise width to be rolled up in a tube was grown on a cleaved facet of a heterostructure using selective growth [2]. To grow such a bilayer, first, a heterostructure having a GaAs layer sandwiched between AlGaAs layers was cleaved to obtain a flat cleaved facet (see Fig. 2). The GaAs strip on the cleaved facet (edge of the GaAs layer in the initial heterostructure) has a precise preset width because the GaAs layer was grown by MBE (Fig. 2(a)). Second, an InGaAs/GaAs/AlAs heterolayer was selectively grown on that GaAs strip. No growth occurred on adjacent AlGaAs strips because they were oxidized. For preparetion of desired samples, the cleaved surface of the initial heterostructure was oxidized and then annealed at 620 °C to selectively remove oxide from the GaAs strip, the oxide on the AlGaAs strips remained intact (Fig. 2(b)).

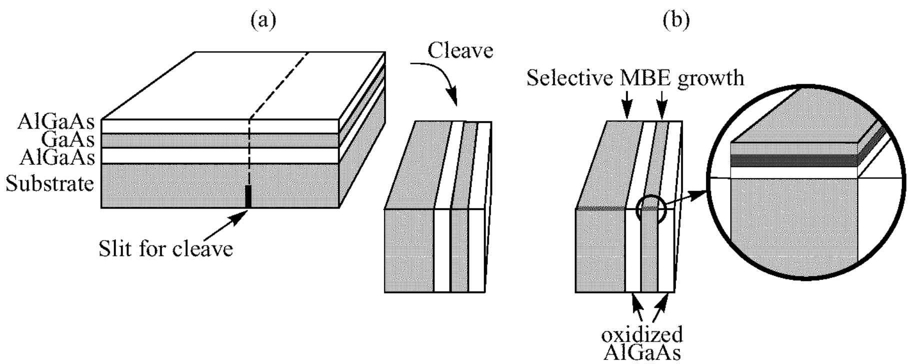

Fig. 2. (a) An initial herostructure has a GaAs layer sandwiched between two AlGaAs layers. The heterostructure is cleaved along a (110) cleavage plane, shown by the dashed line. (b) The cleaved facet thus obtained is subjected to oxidation followed by an anneal for evaporating oxide from the GaAs strip. Afterwords, a strained InGaAs/GaAs/AlAs heterolayer was selective grown on the GaAs strip.

Some experimental details are the following:

1. In order to obtain a desired facet of the heterostructure slits were prepared at desired places of the substrate with the help of optical lithography and liquid etching. Along these slits, cleavage was afterwards initiated.
2. To oxidize the cleaved facet it was exposed to atmospheric air or heated in wet nitrogen.
3. The heterostructures to be rolled were $In_{0.5}Ga_{0.5}As/GaAs$ heterolayer of various thicknesses were grown on the GaAs strip at 400 °C. The GaAs buffer layer of thickness 20 nm was grown before growth the sacrificial AlAs later.
4. The AlAs sacrificial layer was subjected to selective liquid etching in an HF-based solution. As a result of this etching, the InGaAs/GaAs heterolayer of a precise width rolled in a tube of precise length as shown in Fig. 1.

Results and discussion

In this manner, tubes with preset lengths ranging from 200 to 500 nm and with diameters ranging from 80 to 200 nm were obtained. Figure 3 shows an SEM photograph of an $In_{0.5}Ga_{0.5}As/GaAs$ (8 ML/4 ML) tube of length 400 nm and diameter 80 nm. Additional windows were preliminary made in the $In_{0.5}Ga_{0.5}As/GaAs$ heterolayer to open access for the etchant to the sacrificial layer. Therefore, this bilayer was rolling along to the longitudinal axis of the $In_{0.5}Ga_{0.5}As/GaAs$ strip.

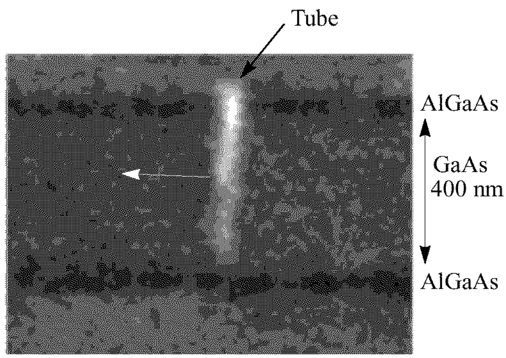

Fig. 3. An InGaAs/GaAs (8 ML/4 ML) tube of length 400 nm and diameter 80 nm prepared using the proposed technique.

In those cases in which no additional windows were made in the bilayer, this bilayer was rolling in the direction normal to its longitudinal axis. Figure 4 shows an SEM photograph of two such $In_{0.5}Ga_{0.5}As/GaAs$ tubes, 200 nm in diameter, occupying a final position of the center of the GaAs strip. As described above, these tubes were rolled up from different parts of a single 1 mm-wide InGaAs/GaAs heterolayer. As they were rolling during etching of the sacrificial layer, they moved one toward the other till they finally stopped. On their stoppage, the etch rate of the sacrificial layer beneath the tubes was drastically diminished because the access for the etchant to the AlAs layer was hampered. As a result, the tubes remained fixed to the GaAs cleaved edge approximately at its center. Thus, tubes prepared in this manner can be composed of a preset number of coils (one, in the case shown in Fig. 4), their final position being predetermined with good accuracy as well.

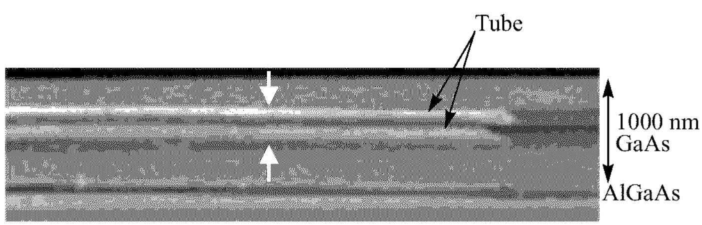

Fig. 4. Two coupled InGaAs/GaAs tubes 200 nm in diameter self-positioned in the center of the GaAs cleaved facet. White arrows show direction of the rolling.

If such nanotubes are composed of severals coils of a heterolayer, the surface atoms in adjacent coils appear to be in such a close proximity that they readily interact with one another. An HRTEM image shown in Fig. 5 shows that the wall of a two-coil tube prepared by rolling an $In_{0.5}Ga_{0.5}As/GaAs$ (10 ML/5 ML) heterolayer grown on an (110) cleaved facet of a heterostructure is indeed a single-crystal one. The coils have stuck together quite perfectly, and no oxide was observed at the interface between them. On the other hand, the photographs revealed dislocations at the interface between coils caused by slight misorientation between crystallographic directions in them (chirality).

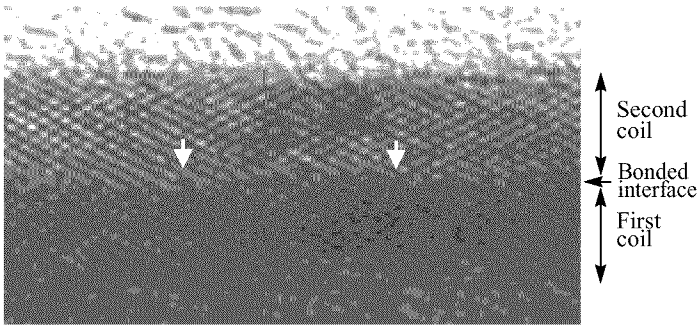

Fig. 5. An HRTEM cross-sectional image of the wall of a two-coil tube prepared by rolling an $In_{0.5}Ga_{0.5}As/GaAs$ (14 ML/5 ML) heterolayer grown on a (110) GaAs cleaved facet. The photograph confirms that the wall is indeed a single-crystal one. The coils stick together quite perfectly, no oxide being observed at the interface between them. The white arrows show dislocations at the bounded interface.

In conclusion, it may be argued that, using narrow GaAs strip, one can prepare even shorter nanotubes than those described in this work. Nanospirals and some other objects can be also obtained by selective growth of heterolayers on cleaved facets of other orientations, and also, for example, on the surfaces of V-shaped mesastructures.

Acknowledgements

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References

[1] V. Ya. Prinz,V. A. Seleznev, A. K. Gutakovsky, A. V. Chehovskiy, V. V. Preobrazenskii, M. A. Putyato and T. A. Gavrilova, *J. Phys. E* **6**, 829 (2000).

[2] M .Natomi, Y. Kadota and T. Tamamura, *Jpn. J. Appl. Phys.* **34**, 1451 (1995).