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Precise micro- and nanotubes formed by scrolling Langmuir–Blodgett/GaAs/InGaAs films

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Abstract. The paper is devoted to further development of previously advanced approach in nanostructuring. This approach is based on using few monolayer-thick bifilms for scrolling 3D heterostructures from them. In this work, initiallly flat strained GaAs/InGaAs bilayers with Langmuir-Blodgett films deposited onto them were rolled up in tube-shaped scrolls. It is shown that, giving local parts of the surface of the resulting tubes hydrophilic or hydro-phobic properties, one can fabricate a perfectly ordered array of free-standing nanotubes.

The present-day nanotechnologies develop along two entirely different lines. The first line is extension of well-established microstructuring methods to nanoscale-size region. The technological methods used here include conventional lithography, ion implantation, and, in some cases, even mechanical grinding. The processes employed here are usually described in terms of film deposition, patterning and etching steps, and often include a planarization procedure for preparing circuit wiring. However, this approach encounters many difficulties. For example, in lithographic processes, there is a limitation of fundamental character on the sizes of obtainable electronic components. In addition, fabrication of 3D nanostructures here is highly problematic.

The second approach in nanostructuring invokes procedures to be performed over individual atoms and molecules or over their highly ordered ensembles. In this case, transformation of initial objects into a more complex 3D structure is implied. This approach often employs various self-forming procedures. However, the possibility of easy assembling electronic components in a circuit here appears to be doubtful.

As initial object for preparation of 3D nanostuctures, we propose here to use semiconductor nanotubes with precisely controllable sizes. In addition to already proposed technological procedures, we describe here some new methods intended for fabrication of assembled arrays of 3D nanostructures.

Recently, self-formed semiconductor nanotubes have been fabricated, and the possibility of precise control over their parameters has been shown [1–3]. The fabrication process is based on using thin highly strained InGaAs/GaAs heterolayers that roll up in scrolls after being debonded from substrate (after selective etching of an underlying AlAs sacrificial layer). It has been shown that the layers in the resulting tube stick together forming a monocrystalline tube wall. Here, the tube diameter $D \approx d \cdot a/\Delta a$ is determined by the bilayer thickness d and by the mismatch of lattice parameters $\Delta a/a$. In this manner, InGaAs/GaAs tubes with tube diameters D ranging from 3 nm to 10 μm and lengths as large as 1 mm were fabricated.

In the present work, hybrid micro- and nanotubes scrolled from initially planar structures were fabricated for the first time which contain a strained InGaAs/GaAs bilayer with a thickness of several monolayers and a Langmuir–Blodgett (LB) film.

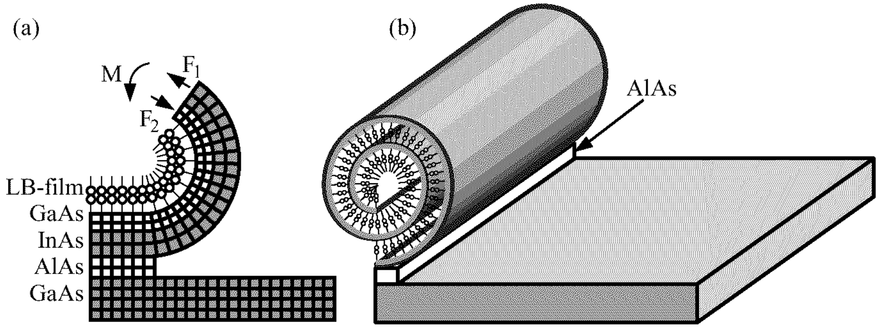

Fig. 1. Schematic representation of the proposed hybrid micro- and nanotube formation technology. (a) strain-induced bending of an initial LB/InAs/GaAs film after freeing it from bonding with substrate; (b) self-scrolling of the multilayer film after removing the AlAs sacrificial layer. The strained bifilm scrolls in a tube with the Landmuir–Blodgett film clamped between tube coils.

Figure 1 shows a schematic flow-chart representation of the procedure intended for production of hybrid micro- and nanotubes. The initial planar structure contains a strained InGaAs/GaAs bilayer with a thickness of several monolayers and an LB film also several monolayers in thickness (for instance, two). As the bifilm gets free of bonding with substrate, the interatomic forces in it start acting to increase the interatomic distance in the compressed InAs layer and to decrease it in the tensile-stressed GaAs layer (Fig. 1(a)). The elastic forces F_1 and F_2 are oppositely directed, and they give rise to a non-zero moment of forces M, which tends to bend the bilayer. Under the action of this moment, the initially planar bilayer scrolls in a tube with the LB film clamped between the tube turns.

In this way, we obtained multiturn tubes which can be considered as radial superlattices (see Fig. 1(b)). It should be noted that the tubes thus formed could be prepared fixed to a desired place of the substrate.

The LB films used in this study was cadmium beganate ($[\mathrm{CH_3(CH_2)_{20}}]_2\mathrm{Cd}$) films prepared by covering the free surface of a $4 \cdot 10^{-4}$ mole/liter cadmium chloride aqueous solution with a behenic acid solution in hexane. The prepared monolayer covering was transported from the liquid surface onto an InGaAs/GaAs heterostructure under a surface tension of 30 mN/m at $T = 23 \pm 1\,^{\circ}\mathrm{C}$. The transport velocity was 1.5 cm/s [4]. The surface of the GaAs layer onto which the LB film was transported was hydrophobic, as well as the surface of the detached InAs layer. An important point is that the LB technique permits preparation of ordered multilayers of organic molecules with a definite number of layers. To bond the LB film to the surfaces of the scrolled layers, we used films composed of even numbers of monolayers (namely, 2, 4, 6, and 20 monolayers). The thickness of each monolayer in the LB film was 30.4 ± 0.4 Å. The inside diameter of the produced tubes is dependent on the characteristics of the InGaAs/GaAs layer used [1, 2]. In this study, tubes with inside diameters ranging from 80 nm to 8 μm were fabricated. A simplest example of application of the described technology is shown in Fig. 2.

On complete removal of the sacrificial layer, we obtain a free-standing tube. The following important property of such tubes is noteworthy: being placed onto a water surface, they float freely on it and, if necessary, can be arranged in ordered arrays (of the LB film type).

The surface of a free-standing tube can be made either hydrophobic or hydrophilic, or be given spatially alternating hydrophobic/hydrophilic properties, which can, in turn, be used for exerting precise control over the geometry of nanoobject ensembles prepared as

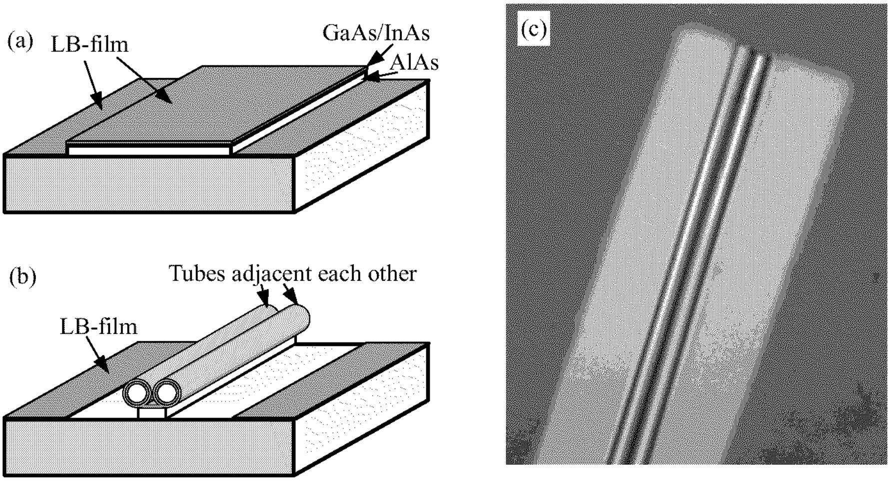

Fig. 2. Simplest example of application of the proposed technology for fabrication of hybrid micro- and nanotubes. (a) transport of the LB film on a mesa-structure; (b) selective wet etching of the AlAs sacrificial layer and self-scrolling of the strained bilayer into a double tube fixed to the AlAs bar; (c) the example of obtained hybrid microtubes. The thickness of the self-scrolled bifilm: 60 nm LB film + 45 nm GaAs + 10 nm $In_xGa_{1-x}As$ ($x = 0.25$). The diameter of the tubes is 8 μm.

described above.

For example, if a tube is prepared in such a manner that one its part has a hydrophilic and other a hydrophobic surface, then, on a water surface, it will float half-submerged into water. An ensemble of such tubes freely floating on a water surface can be used to prepare LB-like films of more intricate geometries.

In conclusion, it is shown that the LB technique can be used for fabrication of intricate 3D structures which cannot be prepared by any other technology.

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References

[1] V. Ya. Prinz, V. A. Seleznev and A. K. Gutakovsky, *World Scientific* 1998 ISBN: 981-02-4030-9 (CD).

[2] V. Ya. Prinz, V. A. Seleznev, A. K. Gutakovsky, A. V. Chehovskiy, V. V. Preobrazenskii, M. A. Putyato and T. A. Gavrilova, *Physica E* **6**, 828-831 (2000).

[3] V. Ya. Prinz, S. V. Golod and V. I. Mashanov *Proc. 7th Int. Symp. Nanostructures: physics and technology, St. Peterburg, Russia, June 14-18* p 536, 1999.

[4] S. M. Repinsky, L. L. Sveshnikova and J. I. Hapov, *Zh. Fiz. Khim.* **72** 825 (1998).