Microstructure of rolled-up InGaAs/GaAs and AlN tubes

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Over the last years, strain driven nano- and micro architectures by the deterministic release and rearrangement of thin films and nanomembranes have been created. This technology includes rolled-up nanotubes used to produce various types of hybrid radial superlattices based on strained semiconductor layers [1]. The structure of these novel superlattices compromising a quasi radial geometry has been studied in some detail [2], and are promising for optical, magnetic and thermoelectrical applications [1-2].

Here, the structure of two classical semiconductor based thin rolled-up layers is studied by transmission electron microscopy. Special attention is paid towards the crystal structure of the rolled-up thin layers as well as the resulting interfaces. The first system is the well-established InGaAs/GaAs zincblend semiconductor, where inherently strained bilayers are deposited on top of an AlAs sacrificial layer by epitaxial growth. The layers are released by epitaxial lift-off removing the AlAs layer. Strain release results in rolled-up InGaAs/GaAs nanotubes forming a radial superlattice as depicted in Fig. 1. Figure 1(a) shows a top-view TEM image of such a rolled-up nanotube as well as the electron diffraction pattern obtained from the structure. The overview image already indicates that the single crystal structure of the epitaxial film stays basically intact but a new non-crystalline phase develops. Detailed studies of the wall structure – as seen in Fig. 1(b) and 1(c) – reveals the development of an interface region. In contrast, Fig. 2 shows TEM images and the diffraction pattern of a rolledup AlN nanomembrane. The nanomembrane was deposited by epitaxial means on top of a Si (111) substrate and has a wurzite crystal structure. Resulting from the growth of AlN [3], we observe a structure of the rolled-up membrane (Fig. 2(a) and (b)), where interconnected grains form a porous network. Surprisingly, the observed electron diffraction pattern of the rolled-up membrane nearly exclusively comprise only reflexes of the <001>-zone axis (Fig. 2(c)). Furthermore, the pattern shows only twice as many reflexes as expected from the sixfolded symmetry of the zone axis and not a random distribution as expected for a polycrystalline material. This indicates a strong texture of the material as well as a crystal correlation of neighboring grains. In contrast to the InGaAs/GaAs system no special interface region of succeeding windings is observed (Fig. 2(b)).

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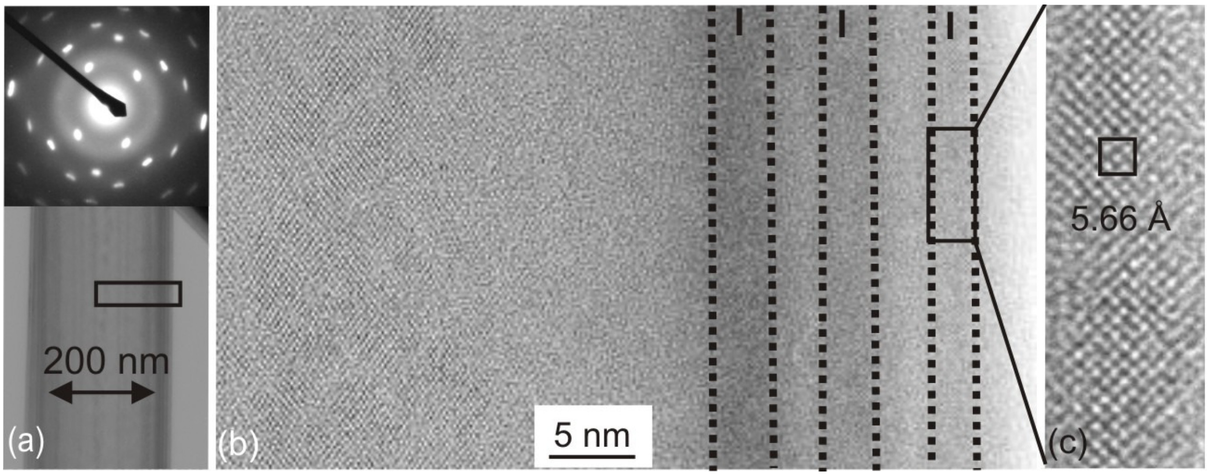

Figure 1. (a) Top view projective TEM image of a rolled-up InAs/GaAs nanotube. The inset shows the obtained selected area electron diffraction pattern. (b) TEM image of the wall of the nanotube. Beside crystalline areas non-crystalline areas are also identified. Such a wall is the prototype of an RSL obtainable by roll-up nanotech. (c) HRTEM image of the crystalline areas of (b). The zincblend lattice of the InGaAs/GaAs heterostructure can clearly be identified.

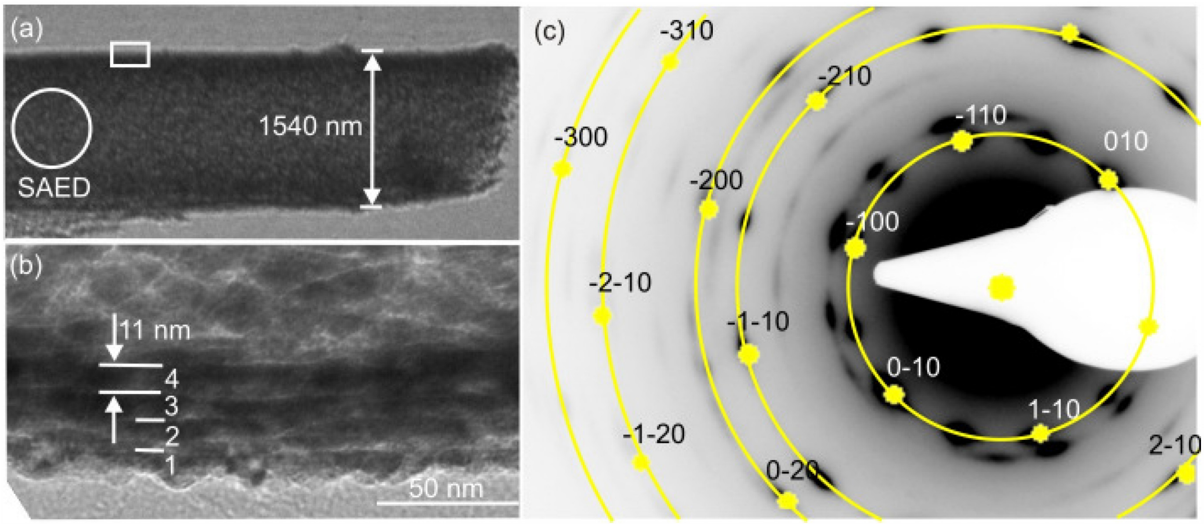

Figure 2. (a) Top view image of a rolled-up AlN membrane with a diameter of 1.5 µm. Areas where electron diffraction pattern were obtained from and HR-TEM were taken are marked. (b) Higher magnified TEM image of the wall of the rolled-up AlN tube. In contrast to the InGaAs/GaAs tube no explicit interface region of succeeding windings is observed. (c) Electron diffraction pattern of the rolled-up AlN membrane indexed for the <001>-zone axis.

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