Bandgap engineering in a nanowire: self-assembled 0, 1 and 2D quantum structures

Jordi Arbiol[1,2,*], Maria de la Mata[1], Martin Eickhoff[3] and Anna Fontcuberta i Morral[4,*]

[1] Institut de Ciència de Materials de Barcelona, ICMAB-CSIC, Campus de la UAB, E-08193 Bellaterra, CAT, Spain
[2] Institució Catalana de Recerca i Estudis Avançats (ICREA), E-08010 Barcelona, CAT, Spain
[3] I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Heinrich-Buff-Ring 16, DE-35392 Gießen, Germany
[4] Laboratoire des Matériaux Semiconducteurs, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

Inherent to the nanowire morphology is the exciting possibility of fabricating materials organized at the nanoscale in three dimensions. Composition and structure can be varied along and across the nanowire, as well as within coaxial shells. This opens up a manifold of possibilities in nanoscale materials science and engineering which is only possible with a nanowire as a starting structure. As the variation in composition and structure is accompanied by a change in the band structure, it is possible to confine carriers within the nanowire. Interestingly, this results in the formation of local two, one and zero-dimensional structures from an electronic point of view within the nanowire. This novel palette of nanostructures paves the way toward novel applications in many engineering domains such as lasers, high-mobility transistors, quantum information and energy harvesting. In the present review we summarize and give an overview on recent achievements in the design and growth of advanced quantum structures starting from nanowire templates. The quantum structures presented have been grown by molecular beam epitaxy and correspond to different confinement approaches: quantum wells (2D), quantum wires (1D) and quantum dots (0D).

Introduction

The latest developments in nanoscale self-assembly and in particular in the area of nanowire growth have opened up many possibilities in materials science and engineering. In particular, the control that scientists have gained in achieving the required composition, shape and structure of nanowires [1–5] and also on the variation in the three dimensions of space at the nanoscale level is notable. Change in composition and structure is always related to variations in the electronic structure. In this way, a 3D variation in composition and crystal phase at the nanoscale leads necessarily to the formation of low dimensional confinement potentials within the nanowire. This results in the possibility of designing new advanced applications in the area of electronics [6,7] optoelectronic devices [8–10], energy harvesting [11–14,102], energy transport [15], light emission [16,17] or light absorption [18–20]. In the case of energy harvesting, for example, tandem solar cells based on semiconductor heterostructures in a nanowire [21], allow a better utilization of the solar spectrum and thereby result in an increase in the efficiency of the cells by absorbing a wider range of light wavelengths [22]. Furthermore, improved thermoelectric efficiencies can be also obtained by using core-shell nanomaterials with a previous band energy selection [23–25]. High mobility field-effect transistors can also be designed by selecting the appropriate heterostructures allowing higher gain and carrier mobilities [15,26]. Among all the nanostructures used as templates for bandgap engineering, semiconductor nanowires are one of the most promising. Because of their one-dimensional (1D) morphology, with smaller cross-section compared to their length, they can be easily integrated in circuits and devices, allowing higher performance of operation [27,28]. In addition, when positioned vertically on a substrate, they show a more efficient coupling with light when compared to planar structures, meaning that they can become better emitters or

*Corresponding authors:. Arbiol, J. (arbiol@icrea.cat), Morral, A.F.i. (anna.fontcuberta-morral@epfl.ch)

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