自己形成法を用いた、ナノメートル領域のボトムアップ法とマイクロメートル領域のトップダウン法との架橋技術の構築

Bridging the gap between the nanometer-scale bottom-up and micrometer-scale top-down approaches through a self-assembly process

章　国強 [1,2*]、滝口雅人 [1,2]、舘野功太 [1,2]、後藤秀樹 [1]
°Guoqiang Zhang[1*], Masato Takiguchi, Kouta Tateno[1], and Hideki Gotoh[1]
[1]NTT 物性科学基礎研究所, [2]NTT ナノフォトニクスセンタ, 神奈川県厚木市森の里若宮 3-1, 243-0198
*E-mail: zhang.guoqiang@lab.ntt.co.jp

The field of microelectronics has been at grips with the issue of miniaturization for decades as demand for ever-smaller products pressures manufacturers to make smaller components [1]. Photolithography, a top-down method, is limited by the diffraction limit of light. This issue has opened the door to the development of other methods for fabricating devices. Another competing method, self-assembly [2], is to rely on a bottom-up process driven energetically as the total system reaches a lower energy state.

III-V compound semiconductor nanowires (NW) are successful example of the bottom-up approach. Site-defined growth of III-V NWs, whereby NWs are grown in pre-determined areas on a substrate, is a common method. For many methods previously demonstrated, the diameter of the NWs is the same as the width of the window [3], therefore to achieve NWs with a uniform nanometer-scale diameter top-down techniques like photolithography are not feasible. This work presents a method that bridges the gap between the nanometer-scale bottom-up and micrometer-scale top-down approaches for site-defined NWs, which has long been a significant challenge for applications that require low-cost and high-throughput manufacturing processes.

We synthesized the InP/InAs NWs in a metalorganic vapor phase epitaxy (MOVPE) system in the self-catalyzed (or self-assisted) vapor-liquid-solid (VLS) [4]. Indium particles were formed on InP substrate by introducing trimethylindium (TMIn) source material through a self-assembly process (Fig. 1a). The InP substrates with circular open windows defined by SiO_2 masking film were fabricated by the photolithography technique (Fig. 1b).

We realized the bridging by controlling the seed indium nanoparticle position inside the open window. This was achieved by optimizing the temperature and the window spacing (Fig. 1c). Site-defined InP NWs were then grown from the indium-nanoparticle array (Fig. 1d). We demonstrated that the developed method can be used to grow a uniform InP/InAs axial-heterostructure NW array (Fig. 2a). The ability to form a heterostructure NW array with this method makes it possible to tune the emission wavelength over a wide range by employing the quantum confinement effect (Figs. 2b and 2c) and thus expand the application of this technology to optoelectronic devices. Successful combination of a controllable bottom-up growth technique with a top-down substrate preparation technique greatly improves the potential for the mass-production and widespread adoption of this technology.

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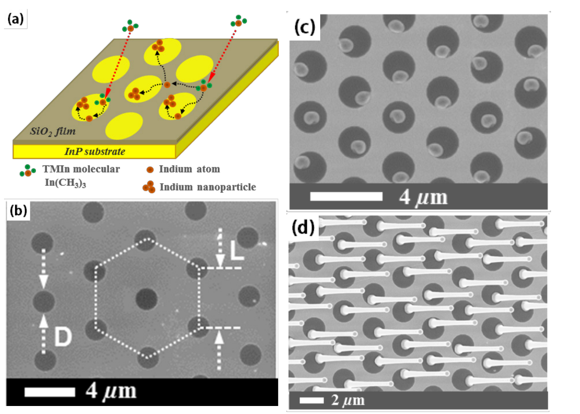

Figure 1. (a) Schematic diagram of absorption and decomposition of source materials, surface diffusion and accumulation of indium adatoms on the surface. (b) SEM image of InP (211)B with open windows of exposed InP area. The diameter of the circular open window, D, is 2 μm. The window spacing (L) is 5μm in the image. (c) SEM image of indium particles deposited at 500 °C on InP (211)B with an L of 3 μm. (d) SEM image of InP NWs grown from the indium particles.

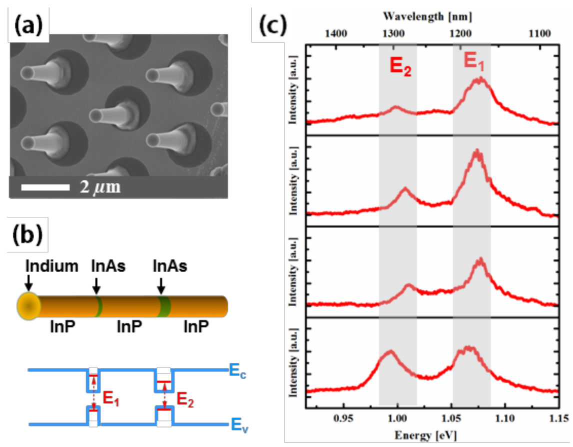

Figure 2. (a) SEM image (top view) of InP NWs with two InAs quantum disks grown on InP (211)B. The NWs are inclined to the substrate because of the <111> direction. (b) Schematic diagram of the NW structure in (a) and the band structure diagram. (c) Spectroscopy of 4 single NWs. The excitation laser power is 1 μW with a laser spot diameter of 2 μm. Two peaks (E_1 and E_2) are originated from the two InAs quantum disks, as indicated in (b).