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Nanomaterials Synthesis, Photonics and Solar Energy

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One-dimensional (1D) semiconductor nanowires (NWs) present a cylindrical cross-section confined to the nanoscale (<10 to ~1000 nm) with an axial dimension extended to a much larger length scale (~100 nm to ~1 mm). This distinct NW geometry gives rise to a variety of unique quantum-electronic, nano-optical, and transport properties, and in the past decades, NWs have emerged as an ideal platform for creating ultra-small nanodevices for technologies including nanoelectronics, photonics, and solar energy conversion by virtue of the excellent crystal quality, precise doping control, and wide access to various materials.

The Kim group is interested in synthesizing semiconductor NWs through vapor-liquid-solid (VLS) growth with various materials compositions, doping profiles, and geometric shapes, as well as investigating their fundamental electronic and nanophotonic properties. We are currently developing our innovative metal-organic chemical vapor deposition (MOCVD) system that will be equipped with precise gas regulation apparatus capable of flowing gas-phase precursors of various materials at a wide range of pressure and temperature. Optimized growth is expected to produce NWs with clean surfaces, uniform diameters and a true nanoscale spatial resolution at the near-atomic level (Top-left, Figure 1). Moreover, a rapid switching of precursors and/or dopants creates abrupt heterojunctions within individual NWs, which, when repeated, can produce periodically modulated NW superlattices (Top-right, Figure 1). We also combine epitaxial, vertical growth of these NWs with lithographic patterning to prepare large-area ordered arrays (Bottom, Figure 1). These 2D NW arrays find a number of applications as tunable photonic lattices, metasurfaces, NW solar cells, and photonic topological insulators.

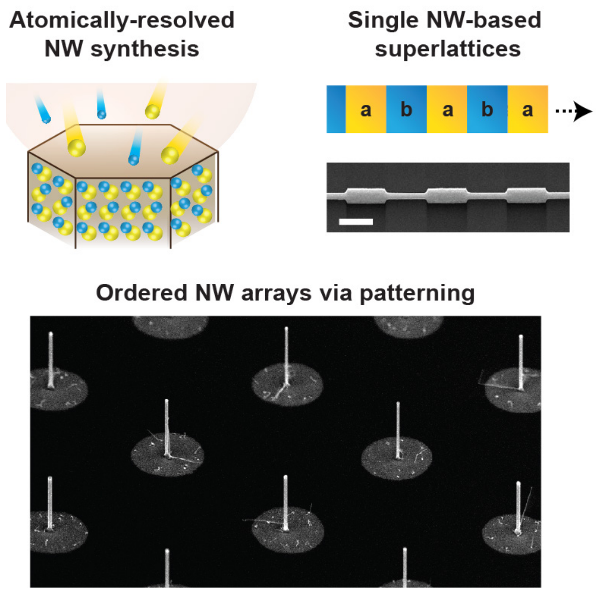

Figure 1. VLS growth of NWs, design of NW superlattices, and image of ordered NW arrays.

Another primary research area of the Kim group is to study novel photonic/meta-optical properties of NW superlattices using finite-element numerical modeling and precision spectroscopy. Figure 2a shows a simple example of the design of an index-modulated NW superlattice that can exhibit photonic guided resonances as shown in Figure 2b. Precisely tailored NW superlattices present unique photonic properties that no other single nanostructures can easily possess such as optical bound states in the continuum (BICs, Figure 2c). These optical resonances and states are the unique ways of confining light waves inside the NWs with quality factors (or photon lifetimes) much higher than what has been observed with nanostructures, which enables highly enhanced performances in photocurrent generation, luminescence, and nonlinear processes. We use numerical modeling to find the design parameters for the NW synthesis, fabricate NW devices using our MOCVD, and experimentally demonstrate the predicted properties through spectroscopy.

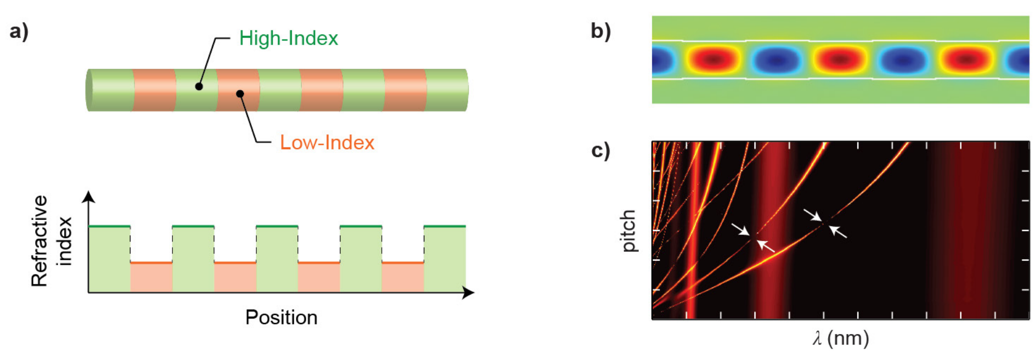

Figure 2. (a) Design of an index-modulated NW superlattice, (b) mode pattern of a guided resonance, and (c) a confined-energy heatmap showing optical BICs.

Selected Publications

Mie-Resonant Three-Dimensional Metacrystals, S. Kim *et al.*, *Nano Letters* **2020**, *20(11)*, 8096–8101.

Geometric Nanophotonics: Light Management in Single Nanowires through Morphology, S. Kim, J.F. Cahoon, *Accounts of Chemical Research* **2019**, *52(12)*, 3511-3520.

Photonics of Sub-Wavelength Nanowire Superlattices, S. Kim, *MRS Advances* **2019**, *4(51-52)*, 2759-2769.

Optical Bound States in the Continuum with Nanowire Geometric Superlattices, S. Kim, K.-H. Kim, J.F. Cahoon, *Physical Review Letters* **2019**, *122*, 187402.

Mie-Coupled Bound Guided States in Nanowire Geometric Superlattices, S. Kim *et al.*, *Nature Communications* **2018**, *9*, 2781.

Self-Catalyzed Vapor-Liquid-Solid Growth of Lead Halide Nanowires and Conversion to Hybrid Perovskites, J.K. Meyers, S. Kim *et al.*, *Nano Letters* **2017**, *17(12)*, 7561–7568.

Designing Morphology in Epitaxial Silicon Nanowires: The Role of Gold, Surface Chemistry, and Phosphorus Doping, S. Kim *et al.*, *ACS Nano* **2017**, *11(5)*, 4453–4462.