Nanowire Photonics I: FETs and LEDs

As information processing approaches the speed limits of silicon-based electronic devices, new technologies emerge which promise the high-speed signaling, low cost, and low power consumption necessary for future communication and logic computing. Photonics utilizes photons, instead of electrons, to carry out logic operations through the use of various optical components. One of the first challenges photonics scientist has been faced with is trapping photons in small volumes, similar to confining electrons in a transistor. Preferably this confinement would occur in volumes much smaller than the free space wavelength of the propagating light wave (i.e., in subwavelength structures). One-dimensional (1D) nanomaterials are promising candidates for photonics integration due to their intriguing optical and electronic properties. Typical cross-sectional dimensions can be tuned from a few nanometers to 500 nm, with lengths spanning hundreds of nanometers to millimeters (Fig.1). One-dimensional nanomaterials can be synthesized as specific functioning components (i.e., emitters, detectors) in an optical system. The assortment of 1D nanostructured optical and electronic devices includes nanowire transistors and logic gates, photodetectors, chemical and gas sensors, light emitting diodes and microcavity lasers.

Based on our early mechanism study of the vapor-liquid-solid (VLS) nanowire growth, one can now readily achieve controlled growth of nanowires at different levels. The diameter of nanowire is determined by the size of the alloy droplet, which is in turn determined by the original cluster size. By using monodispersed metal nanoclusters, nanowires with a narrow diameter distribution can be synthesized.

By applying the conventional epitaxial growth technique into this VLS process, it is possible to achieve precise orientation control during the nanowire growth. The technique, vapor-liquid-solid epitaxy (VLSE), is particularly powerful in controlled synthesis of high quality nanowire arrays. For example, ZnO prefers to grow along <001> direction and readily forms highly oriented array when epitaxially grown on a-plane (110) sapphire substrate (Fig.1). Similar level of growth control can be achieved for the GaN system (Fig.1). It is possible to use this VLSE technique for the growth of nanowire arrays with tight control over size (diameter < 20 nm) and uniformity (< ± 10%). This size-monodispersity control is crucial for many proposed applications, such as light emission and field-effect transistors.

Fig. 1 Scanning electron microscopy images of (a) ZnO nanowire arrays (b) GaN nanowire array

![Figure 1](Image)

Figure 2. Electronic and optical properties of a nanowire FET and p-n diode.

(a) Current-voltage of a ZnO nanowire FET. Inset: SEM image of the device. Scale bar = 1 µm.
(b) Transconductance of the device plotting source-drain current as a function of gate voltage. Inset: Logarithmic plot.
(c) Current-voltage plot of a GaN nanowire LED (Si-line: blue; GaN wire: red; p-n diode: green). Inset: SEM image of the GaN across multiple p-Si lines. Scale bar = 2 µm.
(d) Electroluminescence and photoluminescence spectra of the same GaN nanowire LED.

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![Figure 2](Image)

![Figure 3](Image)

Figure 3. Addressable GaN nanowire based UV LEDs. (a,b). GaN nanowire LEDs activated on line 2 and 4. (c) SEM of a 5x3 matrix of GaN nanowire LEDs.