Gallium Nitride Nanowire Devices – Assembly, Fabrication, and Applications.

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Gallium nitride (GaN) nanowires are excellent candidates for realizing high-performance transistors, light-emitting diodes, and chemical/biological sensors. They have unique material properties like wide direct-bandgaps, radiation hardness, and mechanical/chemical stability. Large-scale batch fabrication methods that are compatible with existing silicon processes are needed for commercially realizing these nanosystems.

Dielectrophoresis (motion of neutral particles in non-uniform electric fields) is a potential candidate for post-growth large-scale assembly of any kind of nanowires. The primary advantages are that this technique is independent of nanowire material and assembly substrate, and it is capable of assembly in layers for hierarchical systems. The GaN nanowires used for this study were grown by direct reaction of Ga and NH_3 and had diameters ranging from 100 nm to 250 nm and lengths up to 200 µm. Nanowires were dielectrophoretically aligned on pre-patterned substrates to achieve large number of reliable devices. (see Fig. 1) The effect of various parameters (e.g. solvent types, nanowire dimensions) on the alignment yield was studied. In general below 1kHz the difference in conductivity between the nanowire and the solvent was important while above 1kHz the difference in permittivity was the dominant factor in determining the aligning force. Electrostatic simulation was used to understand the effect of alignment pad designs on the alignment yield. Implementing the design modification in the assembly process resulted in increased precision and yields of the placement of the nanowires.

Robust nanowire devices were fabricated using standard photolithography, metal and oxide deposition, and wet-etching. We will discuss the various effects of the processing parameters (passivation, metal-nanowire contact annealing) on the device performance. We have realized different device geometries essential for studying applications and fundamental transport properties of these nanowires. GaN nanowire field-effect transistors (FETs), light-emitting diodes (LEDs), and four-terminal structures (4T) will be discussed. Nanowire FETs with silicon substrate as a backgate showed field-effect electron mobility values in excess of 300 $cm^2\ V^{-1}\ s^{-1}$ for the 200 nm diameter nanowires. Beyond the simple back-gated FET designs, we will discuss improved FET geometries like omega-gate FETs, (see Fig. 2) and its effects on the device performance. Temperature dependent field-effect electron mobility and resistivity measurements revealed that the impurity scattering is the dominant mechanism in transport in these nanowires. GaN nanowire LEDs were realized by assembling n-type nanowires on p-GaN substrate using the dielectrophoretic alignment technique. The resulting p-n homojunctions exhibited electroluminescence with a peak wavelength of 365 nm and full width half maximum of 25 nm at 300 K, without any parasitic emissions. (see Fig. 3). These types of nanowire LEDs are cheap to produce and offer a key wavelength range for biological detection. We will also discuss the gas sensing properties of these nanowires.

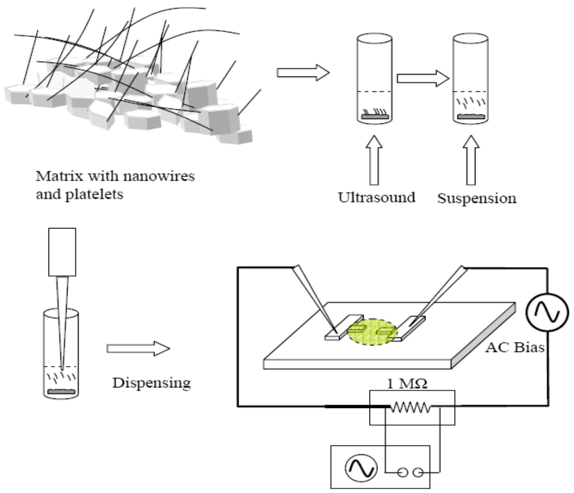

Fig. 1 Dielectrophoretic alignment of GaN nanowires.

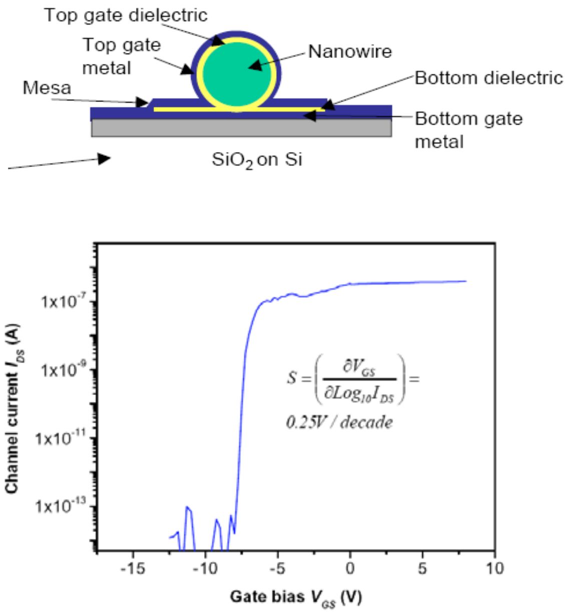

Fig. 2 Omega gate GaN nanowire structure.and the channel current vs. gatye voltage showing the high on/off ratio and subthreshold slope.

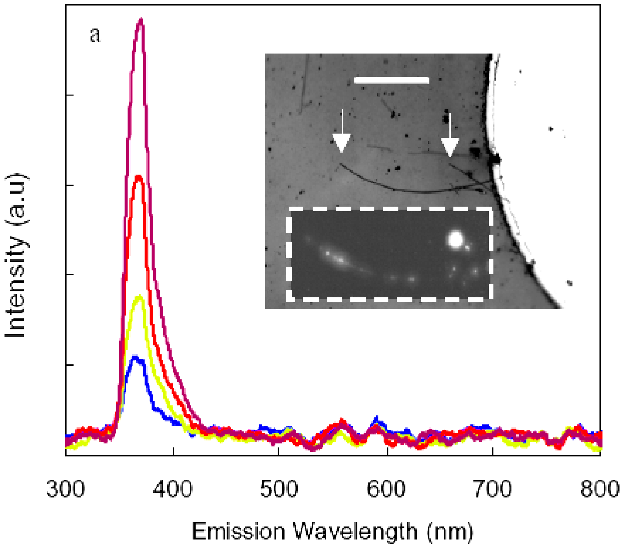

Fig. 3 Electroluminescence from a GaN nanowire LED at room temperature at different bias voltages (inset shows the optical image of nanowire under bias emitting.