Single Nanowire Lasers

Ezra Eibergen Literature Seminar October 20, 2005

Nanostructures have been under extensive study due to their unusual properties. The ability of such structures to confine photons, phonons, and electrons offers a unique opportunity to study fundamental electronic, thermal, mechanical, and optical properties. Studies of single nanowires and other nanostructures are paving the way to next generation nanodevices. As microelectronics approach bandwidth limits on silicon, much effort is being directed towards developing optoelectronic components. These photonic devices would use photons instead of electrons to perform logic operations, thus greatly increasing the speed. Studies of optically and electrically pumped nanowire lasers have led to the development of many photonic components at the nanoscale.

While conventional lasers and optics are well understood[1], much research has been put into understanding these devices on the nanoscale[2]. A variety of high band gap semiconductors have been used to create nanowires that undergo stimulated emission. ZnO[2-4], GaN[5,6], CdS[7,8], and ZnS[9] nanowires are under study using near-field and far-field imaging techniques. Photoluminescent properties[4] strongly show ultraviolet and visible two-dimensional confinement. This waveguiding behavior depends on the wavelength of the light and the geometry, size, and composition of the nanowire. These nanowires act as Fabry-Perot resonators showing mode spacing inversely related to nanowire length. Polarization studies have revealed these guided modes through which certain wavelengths of light are preferentially directed along the nanowire. Pumping the nanowire with pulsed laser light can promote the transition from spontaneous emission to stimulated emission. Studies of the end emission line width, line spacing, and polarization have lead to the characterization of longitudinal cavity modes and offer insight into their gain properties. The photoluminescence intensity increases linearly with excitation energy until the lasing threshold is met. At this point, a superlinear increase in gain is observed until the laser reaches saturation. Lasing thresholds as low as 70 nJ/cm^2 have been recorded at room temperature.

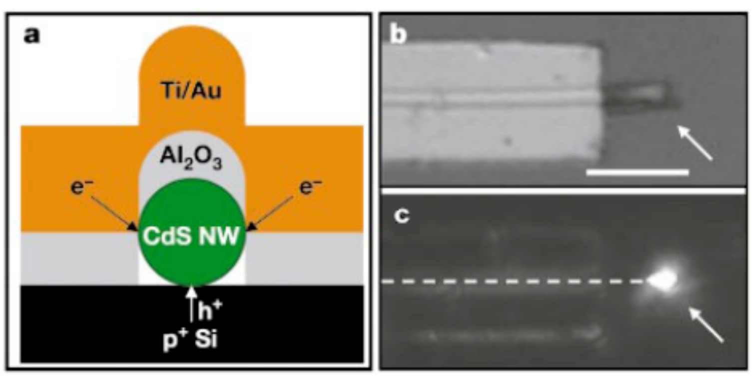

Figure 1: (a) Schematic of the cross section of an electrical injection nanowire laser, (b) an optical image of the device, and (c) an electroluminescence image of the device lasing.

Optical experiments establish single nanowires acting as Fabry-Perot resonators that exhibit lasing, yet without electrical pumping nanowire lasers would be of limited technological importance[9]. Optical and electronic measurements on crystalline CdS nanowires show similar results. Electroluminescence spectra from the nanowire end exhibit modulation corresponding to Fabry-Perot resonators, and the line widths similar to optical experiments. Electrically injected lasers made from semiconducting nanowires offer an approach for fabricating fully integrated photonic devices (Figure 1).

Another important step to creating nanowire photonics is the development of nanowire waveguides that can link individual components and form networks able to complete complex tasks such as logic operations[10-12]. High aspect ratio nanowires with diameters below the wavelength of light can act as efficient waveguides for their internally generated photoluminescence and also evanescently coupled ultraviolet and visible light (Figure 2). The robustness of these crystalline structures allows them to be manipulated on the surface to form various shapes and optical networks, such as nanowire emitter-waveguide-detector junctions. These semiconductor nanowires are able to extend subwavelength optical fibers beyond silica while simultaneous manipulation of photons and charge carriers between nanowires could open a myriad of possibilities for nanoscale devices.

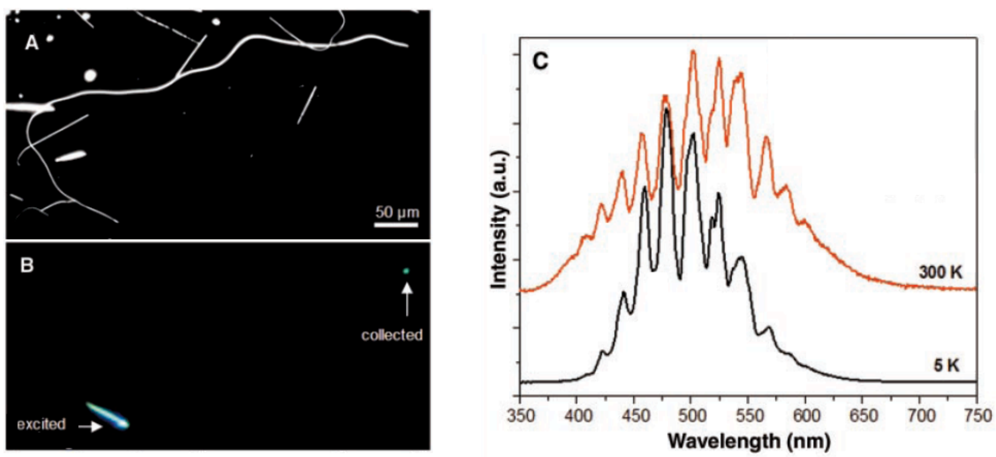

Figure 2: (a) Dark field image of SnO_2 nanoribbon (b) photoluminescence image of ribbon under
laser excitation illustrating the waveguiding properties (c) and emission spectra from the end of the waveguide at different temperatures showing guided modes.

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