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National Institute for Nano Engineering

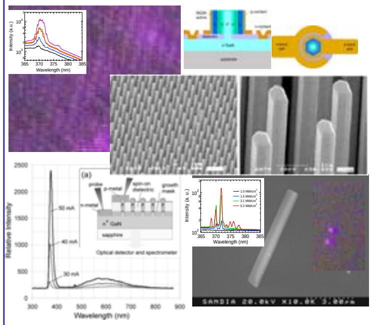
Nanomaterials for Electronics and Optoelectronics

A. Alec Talin, aatalin@sandia.gov

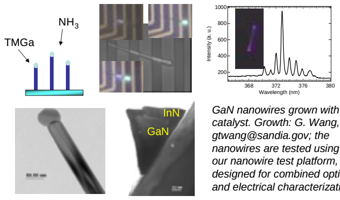
Single-crystal compound semiconductor nanowires

Single-crystal compound semiconductor nanowires can be grown on variety of substrates including Si. Direct bandgap and higher mobility make them attractive for applications such as chip-to-chip optical interconnects, head-mount displays, sensors, and flexible electronics. They are also excellent vehicles for understanding how reduced dimensions affect electrical and optical properties.

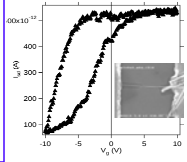
With our NINE partners at UNM (S. Hersee) we are exploring GaN nanorods grown by selective epitaxy as nanoscale vertical lasers with UV to VIS wavelengths. By incorporating Si (n) and Mg (p) dopants during growth, pn junction LEDs are formed, producing electroluminescence.



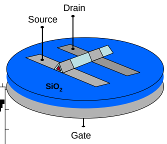
Group III-N, III-As, and III-P nanowires are also grown at SNL, using the VLS technique. These nanowires are tested individually as well as in vertically integrated ensembles

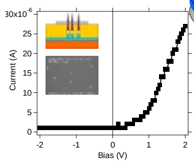


GaN nanowires grown with Ni catalyst. Growth: G. Wang, gtwang@sandia.gov; the nanowires are tested using our nanowire test platform, designed for combined optical and electrical characterization

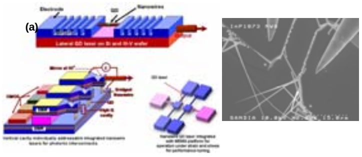


A 30 nm wide InAs nanowire tested by A. Katzenmeyer, a UC Davis NINE grad student (growth by J. Cederberg). The transistor characteristics reveal that the mobility is low, likely due to unpassivated surface states





InP PIN nanowires grown with Au catalyst by J. Cederberg, jcgeder@sandia.gov; Integration: J. Skinner, jlskinn@sandia.gov;



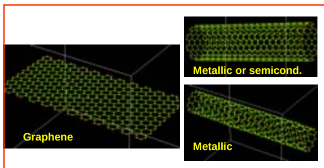
(a) Schematics of Nano-VCSELs in the form of nano-colonnades (b) an InP nanowire bridging Si electrodes (in collaboration with Prof. S. Islam, UC Davis)

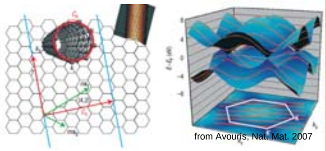
References

1. A. A. Talin, F. Leonard, B. S. Swartzentruber, X.Wang, S. D. Hersee, Unusually strong space-charge-limited currents in thin wires, Phys. Rev. Lett., in press
2. I. Arslan, A. A. Talin, G. T. Wang, Three-Dimensional Visualization of Surface Defects in Core-Shell Nanowires, J. Phys. Chem. C, in press
3. A. A. Talin, G. T. Wang, E. Lai, and R. J. Anderson, *Correlation of growth temperature, photoluminescence, and resistivity in GaN nanowires*, App. Phys. Lett. 92, 093105 (2008)

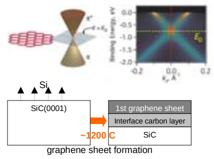
Carbon nanotubes are rolled up sheets of graphene

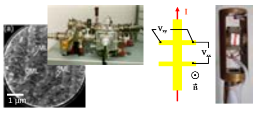
Carbon nanotubes are rolled up sheets of graphene, a one atom thick layer of sp^2 bonded carbon. Both nanotubes and graphene have unique and technologically attractive qualities, including high carrier mobility (2×10^5 cm^2/V-sec), high sustained current density (10^9 A/cm^2 vs. 10^6 A/cm^2 for Cu), and no surface dangling bonds, so many high-k dielectrics can be readily used as gate oxides.





***Graphene** sheets can be produced by attaching a graphite microcrystal to an AFM tip and scratching it over a Si wafer. Although sufficient for basic research this method is not readily adapted to large scale device fabrication. At SNL we are making graphene layers by heating SiC to ~1200C, while monitoring this process using Low Energy Electron Microscopy*



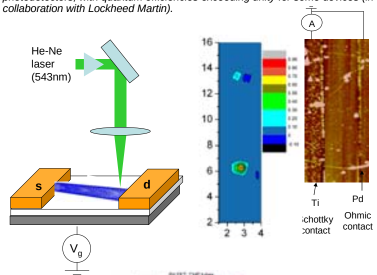


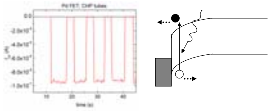
Low energy electron microscopy allows real-time monitoring of graphene formation on nanometer scale

Low temperature magneto-transport

Contact: Taisuke Ohta (Surface & Interface Sciences Dept.

***Carbon nanotubes** are attractive for IR photodetector applications because of their high carrier mobility and high efficiency for converting light to electrons. Using Pd as the contact metal we make simple photoconductors; with two different metal contacts, a Schottky diode is formed. Both make promising photodetectors, with quantum efficiencies exceeding unity for some devices (in collaboration with Lockheed Martin).*





Contact: F. Leonard, fleonar@sandia.gov

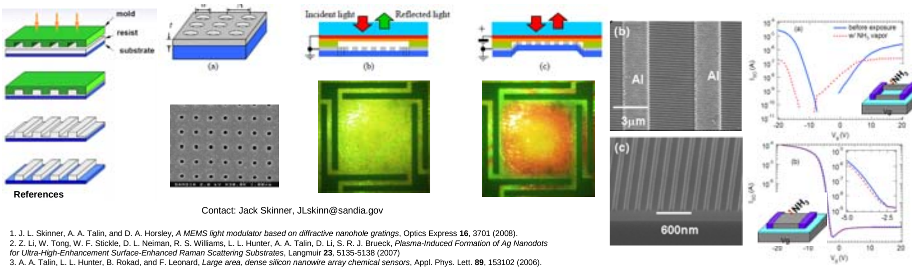
References

1. F. Leonard and A. A. Talin, *Size-dependent effects on electrical contacts to nanotubes and nanowires*, Phys. Rev. Lett. **97**, 026804 (2006).
2. D.A. Stewart and F. Léonard, "Energy conversion efficiency in nanotube opto-electronics", Nanoletters **5**, 219 (2005).

Nano and micro patterned structures

Nano and micro patterned structures in 2- and 3-D can render unique optical and sensing characteristics, such as photonic band gap crystals, resonant plasmonic and subwavelength gratings, substrates for high-gain surface enhanced Raman spectroscopy, and large area nanowire arrays chemical sensors.

***Nanoimprint lithography (NIL)** is a quick way to nano-pattern a surface, well suited for large area repeating geometries such as lines and dots, as well as stand alone nanostructures such as nanogap electrodes. A 2D plasmonic grating is formed by imprinting nanoholes into PMMA and evaporating a thin metal layer over the pattern. By making this pattern on a thin actuator, we demonstrated an optical switch (in collaboration with UC Davis, Prof. D. Horsley). A grating pattern of 200 nm pitch was used to make Si 'nanowire' with <70 nm diameter and 100 cm length, which served as excellent chemical sensors.*

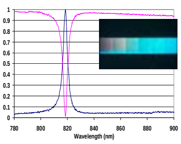


Contact: Jack Skinner, JLskinn@sandia.gov

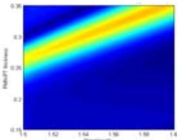
References

1. J. L. Skinner, A. A. Talin, and D. A. Horsley, *A MEMS light modulator based on diffractive nanohole gratings*, Optics Express **16**, 3701 (2008).
2. Z. Li, W. Tong, W. F. Stickle, D. L. Neiman, R. S. Williams, L. L. Hunter, A. A. Talin, D. Li, S. R. J. Brueck, *Plasma-Induced Formation of Ag Nanodots for Ultra-High-Enhancement Surface-Enhanced Raman Scattering Substrates*, Langmuir **23**, 5135-5138 (2007)
3. A. A. Talin, L. L. Hunter, B. Rokad, and F. Leonard, *Large area, dense silicon nanowire array chemical sensors*, Appl. Phys. Lett. **89**, 153102 (2006).

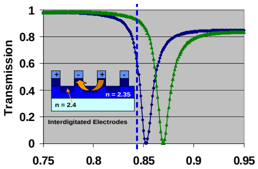
***A high speed, active sub-wavelength resonant grating** is realized when a thin film of PLZT on sapphire, $Pb_{1-3y/2}La_y(Ti_{1-z}Zr_z)O_3$, is patterned with a 400 nm period Au interdigitated electrode array. Application of 40 V bias leads to a field strength of $3X10^7$ V/m, which translates to an increase in the refractive index of 0.05 for 90% contrast in absorption peak. The resulting change in spectral transmission and reflectance can be used for fast spectroscopy and multi-color imaging and offers a compact 'on-pixel' optical solution with no moving parts.*



Reflectance and transmission spectral data for a passive sub-wavelength resonant grating designed for operating wavelengths around 820nm. (Ref. 1)



Rigorous coupled wave analysis (RCWA) modeling showing the change in transmitted power as a function of electrooptic film thickness (in this case PMN-PT) and wavelength. Simulations like this one allow for more precise device design.



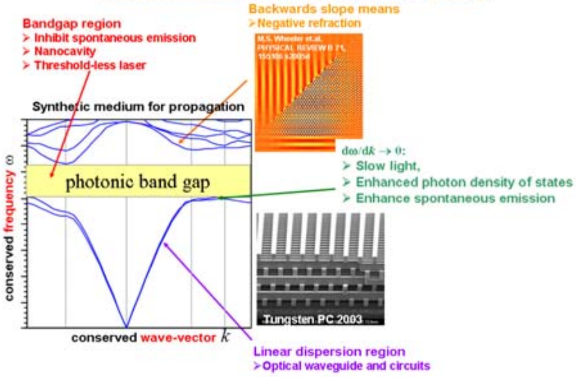
Results from rigorous coupled wave analysis (RCWA) models demonstrating the spectral shift in the transmission due to electrostatic bias on the interdigitated electrode array.

A fabricated resonant subwavelength grating device on PLZT thin film. Optical testing of similar active RSG devices is now underway.

Contact: Aaron Gin 1725 (Photonic Microsystems Technologies)

Photonic crystal band structure anatomy and applications

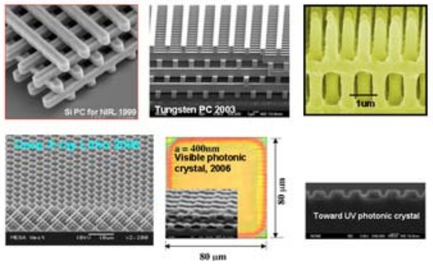
T.S. Luk, Sandia National Laboratories, 505-844-8931, tsluk@sandia.gov



Photonic Crystal Fabrication at SNL

T.S. Luk, Sandia National Laboratories, 505-844-8931, tsluk@sandia.gov

- Enabling fabrication technologies - Low temperature, low stress CMOS compatible and large volume fabrication.
- Other fabrication techniques: proximity field lithography, DXRL, EBL.
- Band edge span from IR to visible wavelengths.



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