Nanotechnology, a scientific and technological discipline that takes advantage of new properties on the nanoscale, offers great promises for future applications. It explores unique properties of materials when their dimensions are comparable to the relevant correlation lengths, and requires innovative synthesis and fabrication methods.
We use rational synthesis of free-standing nanoscale objects like nanowires, nanocrystals, and nanotubes and combine spectroscopic techniques, transport measurements and advanced electron microscopy techniques to directly correlate structural and physical properties on the nanometer scale. Our interdisciplinary approach combines the following sub-programs:

- Growth of semiconductor nanowires and nanowire heterostructures with new structural, optical, magnetic, and electric properties.
- Development of new experimental tools for synthesis and nanoscale characterization of nanostructured materials.
- Applications in nanophotonics, nanoelectronics, and energy.

Experimental techniques and methodologies that are being developed as a part of our research endeavor are generally applicable to any material system where interplay between nanostructure, properties, and performance becomes significant.

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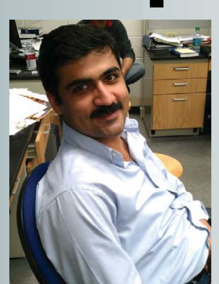
Ph.D. - Swiss Federal Institute of Technology (Lausanne)

Courses: 3.074/3.34 - Imaging of Materials
3.012 - Fundamentals of Materials Science

Group Members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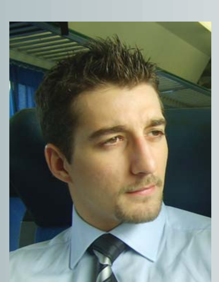
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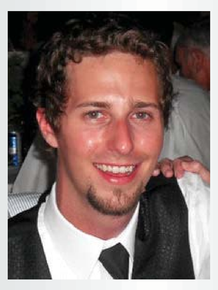
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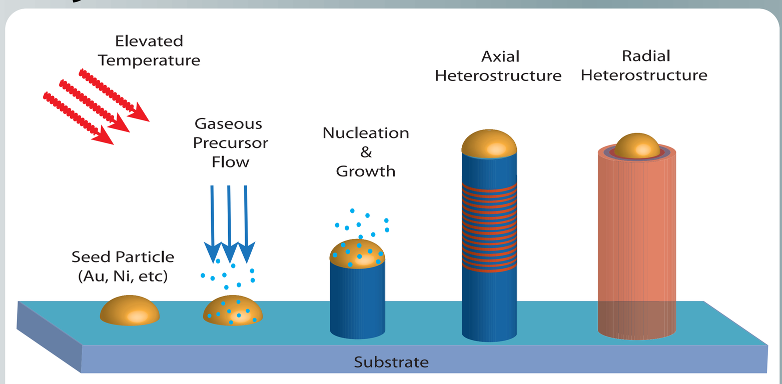
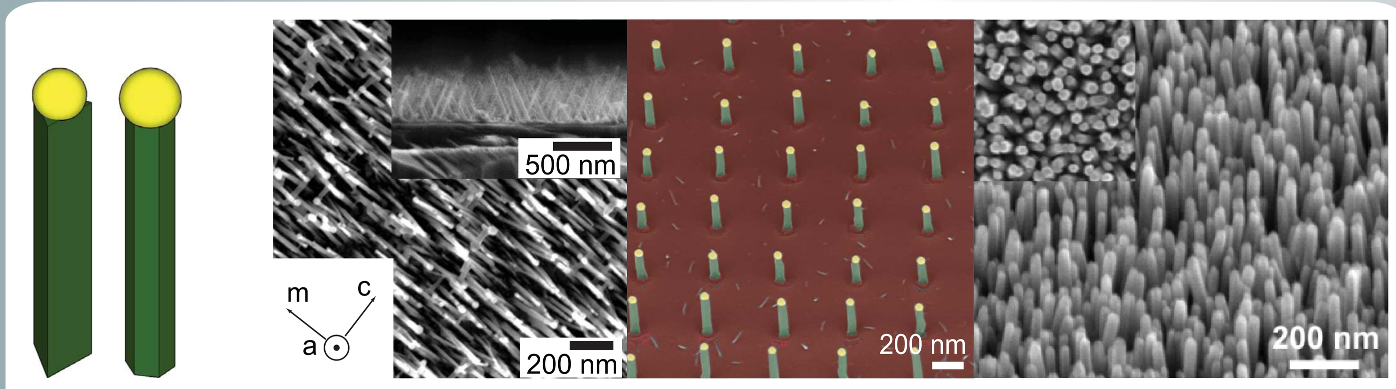
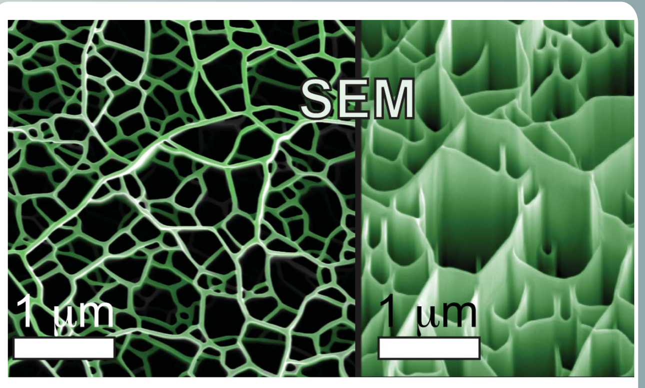
Synthesis of Nanostructured Materials



Chemical vapor depostion (CVD) based growth of nanowires via the vapor-liquid-solid (VLS) growth mechanism: homogenous nanowires as well as axial and radial heterostructures.

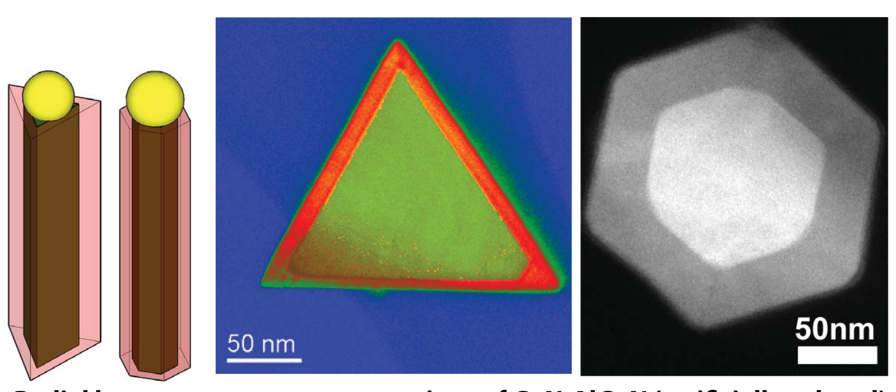


Homogenous nanowires: SEM images of GaN nanowires on the left (gray-scale), vertically-grown GaAs nanowires with patterning of the seed-particles using galvanic displacement in the middle (artificially colored), and ZnO nanowires grown on graphene on the right.



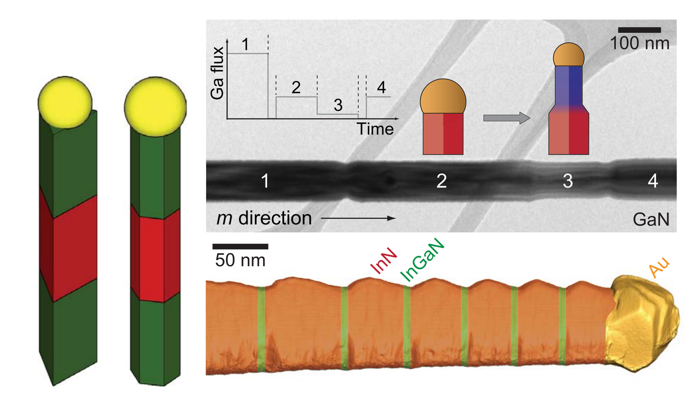
SEM images (top) of ZnO nano-walls, with top-down (top left) and tilted (top right) views and panchromatic cathodoluminescence emission image.

Core-shell nanowires



Radial heterostructures: cross-sections of GaN-AlGaN (artificially colored) and GaAs-AlGaAs (grayscale) core-shell structures, imaged with scanning transmission electron microscopy (STEM).

Axial heterostructures



Axial heterostructures: Demonstration of diameter control in pure GaN (top) and InN/InGaN (bottom) heterostructures.

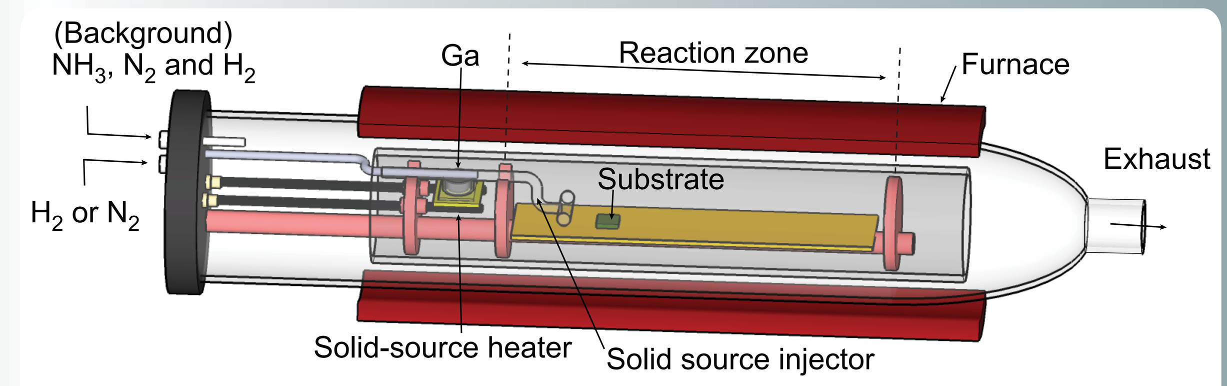
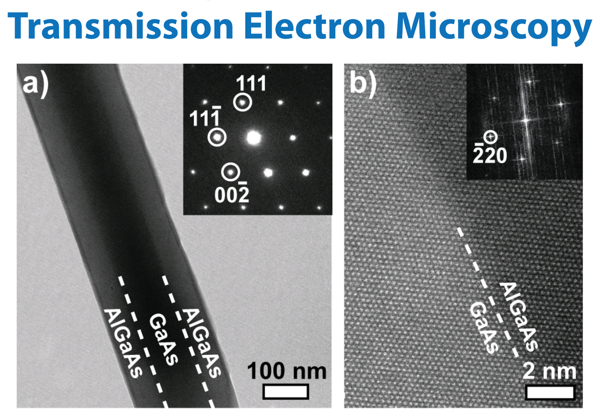


Illustration of the (metal-organic) chemical vapor deposition (MO)CVD. The precursors are delivered through the injector, using a carrier gas such as N2, to the reaction zone, which is held at an elevated temperature to promote the formation of GaN.

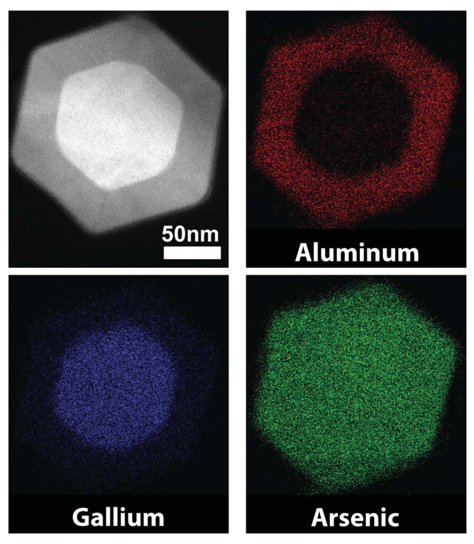
Advanced Characterization Techniques and Modeling

High Resolution Transmission Electron Microscopy



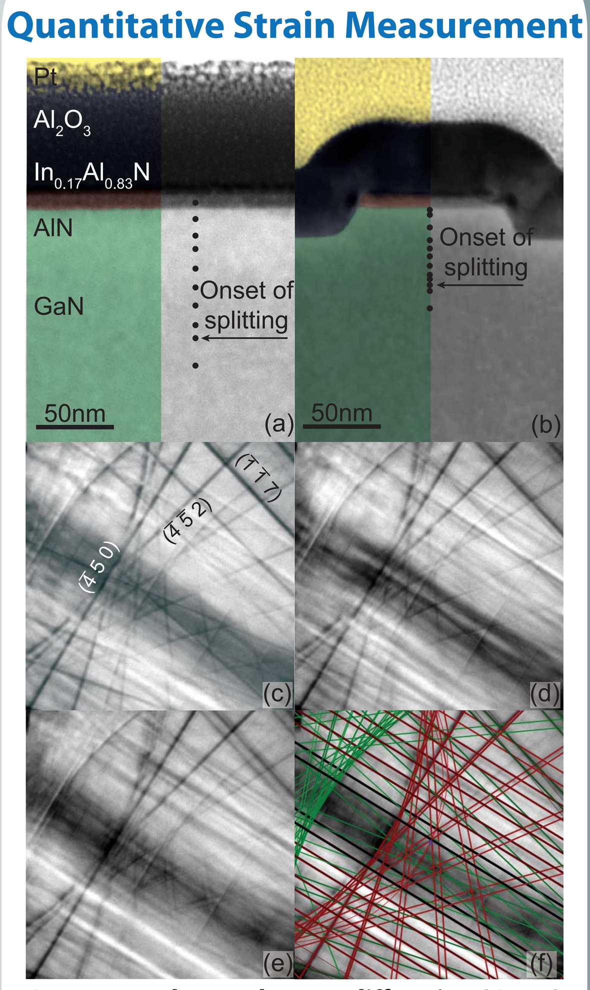
Lattice resolved TEM and diffraction pattern of GaAs/AlGaAs nanowire heterostructure (a). Atomically abrupt AlGaAs/GaAs interface (b).

Chemical mapping with Energy Dispersive Energy X-Ray Spectroscopy (EDS)



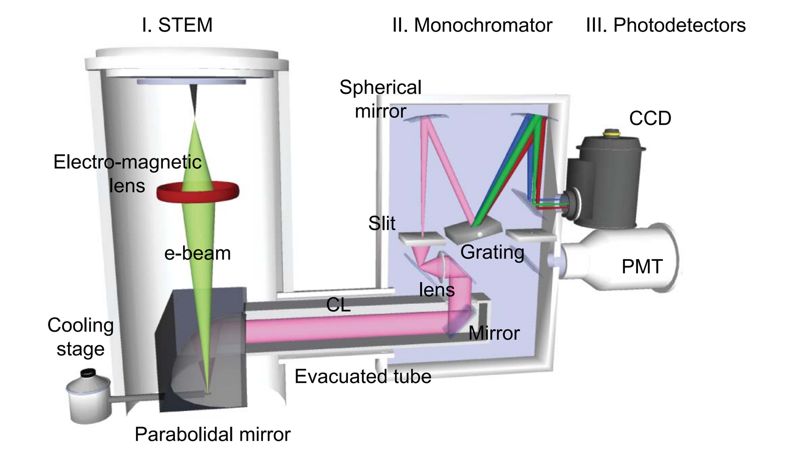
HAADF STEM image and corresponding EDX chemical maps of GaAs/AlGaAs core-shell nanowire heterostructure cross section.

Quantitative Strain Measurement

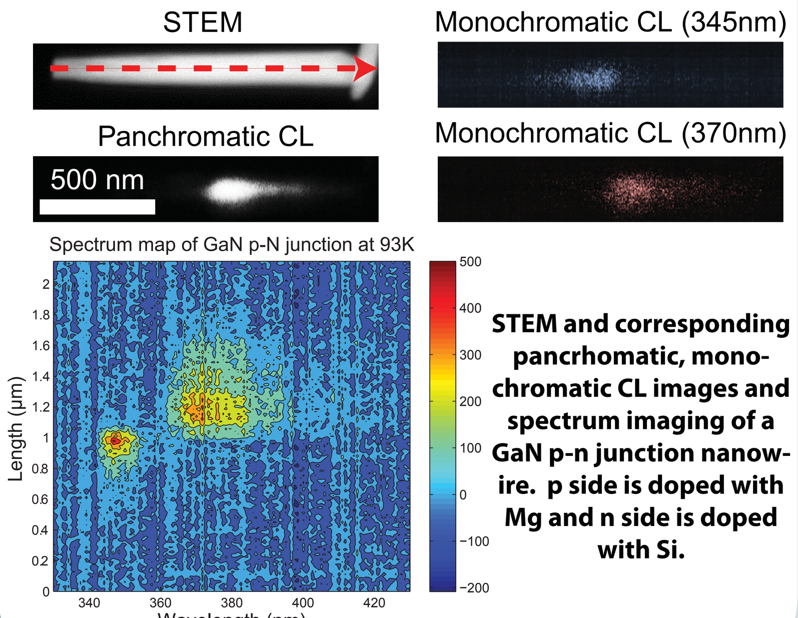


Convergent beam electron diffraction (CBED) to quantitatively measure the strain based on the splitting of HOLZ lines.

Cathodoluminescence with TEM

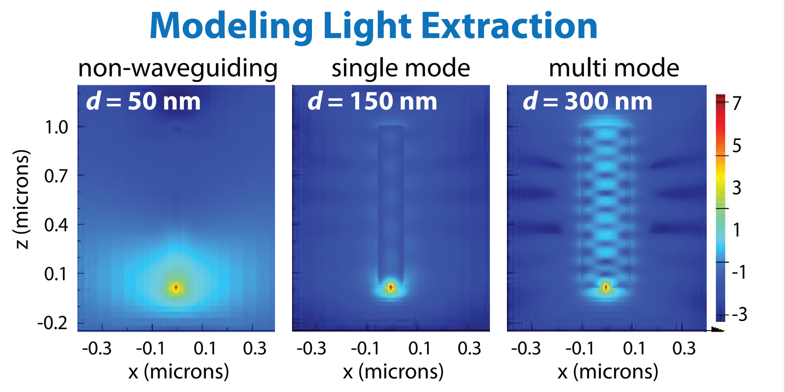


Schematic of cathodoluminescence (CL) integrated with TEM.



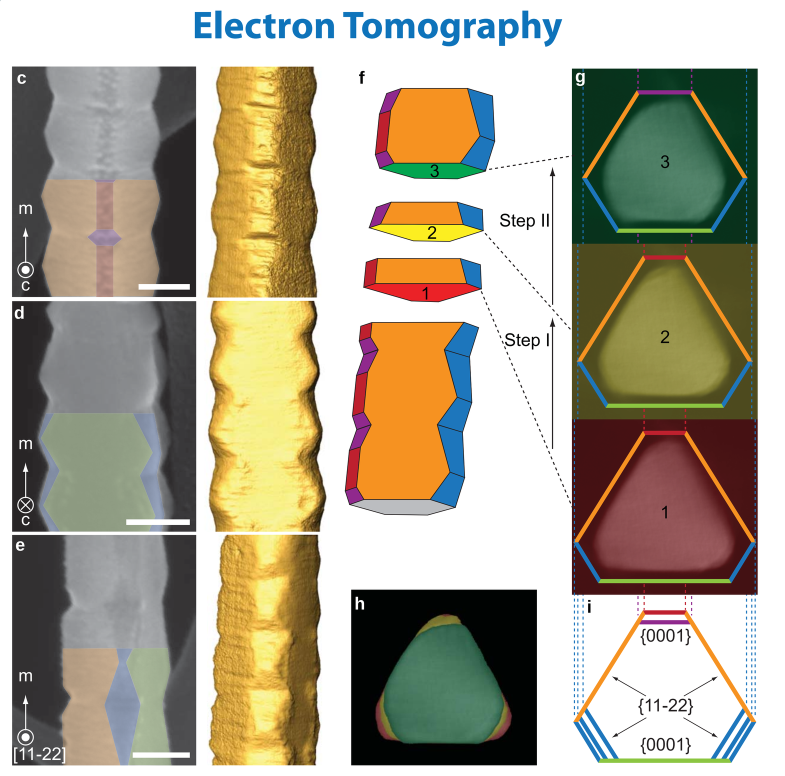
STEM and corresponding panchromatic, monochromatic CL images and spectrum imaging of a GaN p-n junction nanowire. p side is doped with Mg and n side is doped with Si.

Modeling Light Extraction



FDTD simulations of light extraction in nanowires. Waveguiding along the nanowire depends on the nanowire diameter, *d*.

Electron Tomography


Electron tomography: SEM images from different perspectives of an InN/InGaN axial nanowire heterostructure and corresponding electron tomography reconstruction (c-e), which is used to reconstruct the nanowire morphology a specific facets, as illustrated (f-i).

Applications

Hybrid Photovoltaics

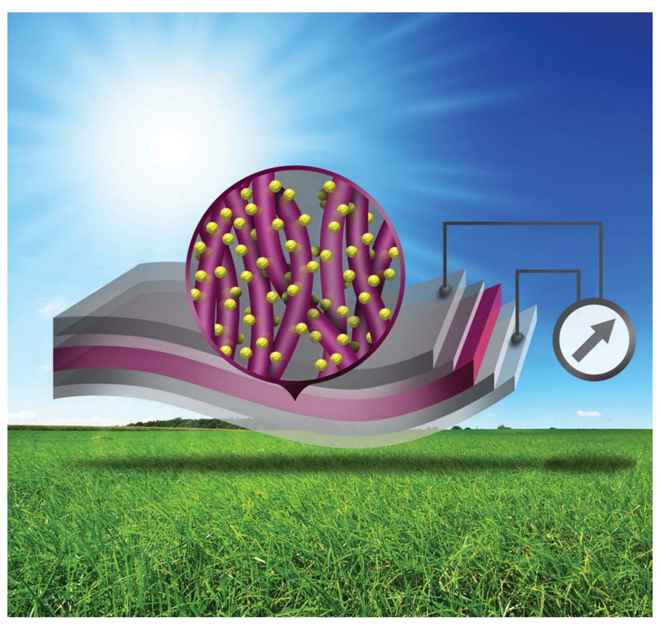
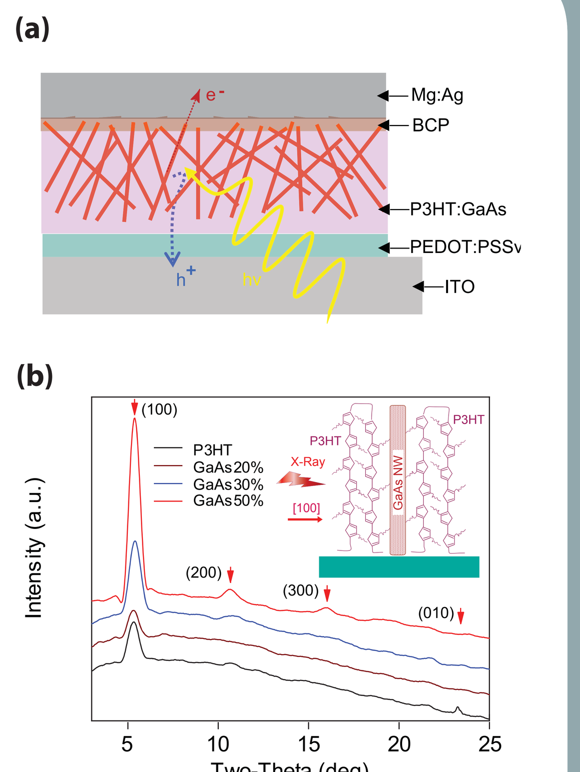
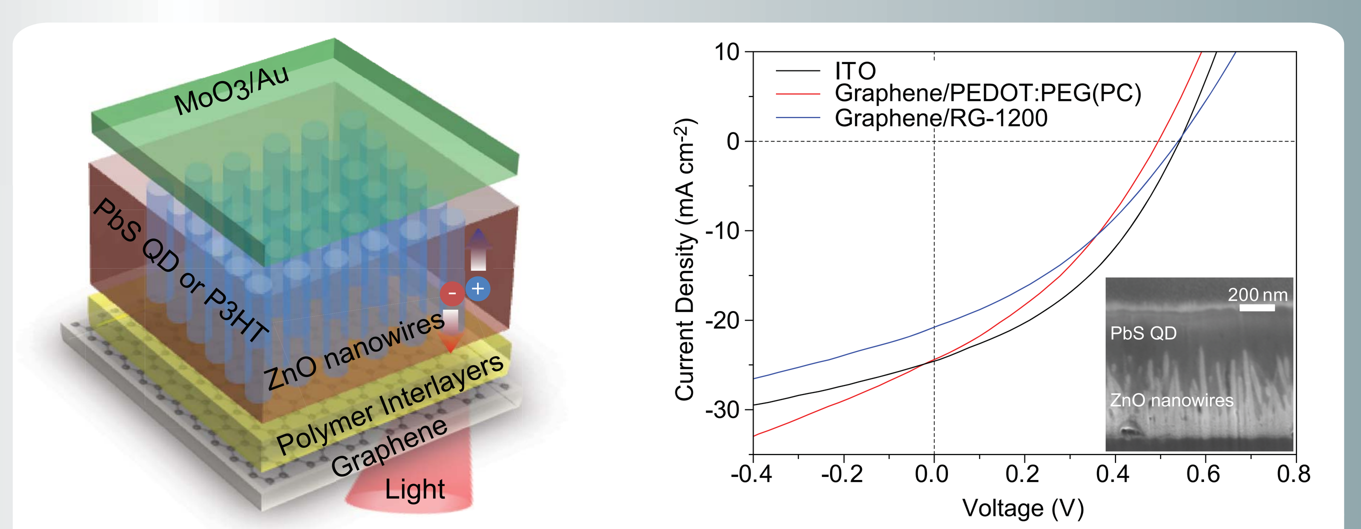


Illustration of our flexible hybrid organic/inorganic solar cell using CdS quantum dots and P3HT nanowires.



Schematic of hybrid PV device (a) shows how GaAs nanowires incorporate into the P3HT active layer. Device performance improves as nanowires act as a template for crystallization, as shown by XRD (b).



(Left) Hybrid solar cell structure. Active layer consists of ZnO nanowires and PbS Quantum dots (or P3HT polymer). Nanowires are grown on graphene layer, by utilizing polymer interlayers. (Right) J-V characteristics of ZnO/PbS QD hybrid PV device. Devices based on graphene shows comparable power conversion efficiencies to that of an ITO based device.

Selected Publications

1. S. K. Lim, S. Crawford, G. Haberfehlner, S. Gradečak, "Controlled modulation of diameter and composition along individual III-V nitride nanowires", Nano Letters **13**, 331-336 (2013). Cover Page article.

2. S. Crawford, S. K. Lim, S. Gradečak, "Opportunities and limitations for modulating nanowire diameter via particle-mediated growth", Nano Letters **13**, 226-232 (2013).

3. H. Park, S. Chang, J. Jean, J. J. Cheng, P. T. Araujo, M. Wang, M. Bawendi, M. S. Dresselhaus, V. Bulovic, J. Kong, S. Gradečak, "Graphene cathode-based ZnO nanowire hybrid solar cells", Nano Letters **13**, 233-239 (2013).

4. J. Chesin, X. Zhou, S. Gradečak, "Light extraction in individual GaN nanowires on Si for LEDs", Proceeding of SPIE **8467**, 846703 (2012).

5. E. J. Jones, M. Azize, M. J. Smith, T. Palacios, Silvija Gradečak, "Correlating stress generation and sheet resistance in InAlN/GaN nanoribbon high electron mobility transistors", Applied Physics Letters **101**, 113101 (2012).

6. X. Zhou, J. Chesin, S. Crawford, S. Gradečak, "Using seed particle composition to control structural and optical properties of GaN nanowires", Nanotechnology **23**, 285603 (2012). Featured as the Publisher's pick, Lab Talk Article on nanotechweb.org for June 2012, and in the Highlights of 2012.

7. M. Brewster, X. Zhou, M. Y. Lu, and S. Gradečak, "The interplay of structure and optical properties in individual ZnO nanostructures", invited review article, Nanoscale **4**, 1455 - 1462 (2012).

8. S. Ren, N. Zhao, S. C. Crawford, M. J. Tambe, V. Bulovic, and S. Gradečak, "Heterojunction photovoltaics using GaAs nanowires and conjugated polymers," Nano Letters **11**, 408-413 (2011).

9. S. K. Lim, S. C. Crawford, and S. Gradečak, "Growth mechanism of GaN nanowires: preferred nucleation site and effect of hydrogen," Nanotechnology **21**, 345604 (2010).

10. M. J. Tambe, L. F. Allard, and S. Gradečak, "Characterization of core-shell GaAs/AlGaAs nanowire heterostructures using advanced electron microscopy," Journal of Physics: Conference Series **209**, 012033 (2010).

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