Development of the High-Efficiency Nanostructure - Based Solar Cells

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Alexander A. Balandin
Nano-Device Laboratory
Department of Electrical Engineering
University of California – Riverside
Riverside, CA 92521 USA

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Nano-Device Laboratory (NDL)
Department of Electrical Engineering
University of California – Riverside

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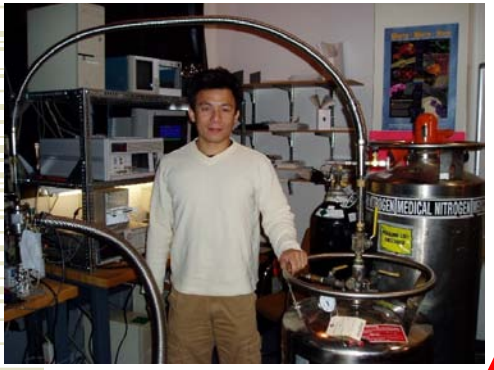
Profile: experimental and theoretical research in nano materials and devices

PI: A.A. Balandin

Research & Applications

Thermal and Electrical Characterization



Nanoscale Characterization

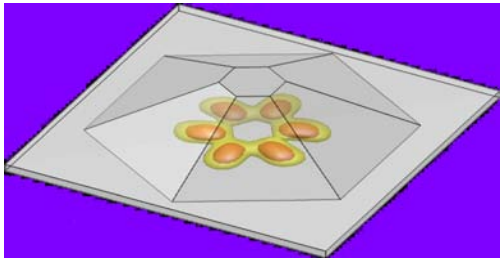
Electronic Devices and Circuits

Direct Energy Conversion

Optoelectronics

Bio-Nanotech

Theory and Modeling



Raman, Fluorescence and PL Spectroscopy

Device Design and Characterization

Research at NDL has been funded by NSF, ONR, SRC, DARPA, NASA, ARO, AFOSR, CRDF, as well as industry, including IBM, Raytheon and TRW

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Recent and Current Solar Projects

- High Efficiency Nanostructured III-V Photovoltaics for Solar Concentrators
  - *Collaboration: Rochester Institute of Technology*
  - *Funding: US Department of Energy (DOE)*
- Optimized Quantum Dot Superlattice Structures for Ultra-High Efficiency Photovoltaic Cells
  - *Collaboration: CFD Research Corporation, Huntsville, AL*
  - *Funding: US Air Force Office of Scientific Research (AFOSR)*
- Radiation-Hard Nanostructure Solar Cells
  - *Collaboration: CFD Research Corporation, Huntsville, AL*
  - *Funding: NASA*

University – Industry Cooperation and Technology Transfer

UCR

MBE grown samples

PV efficiency data

RPI

Characterization
stress/strain from Raman
electrical, optical and thermal
New design ideas

Theory and models
Material parameters

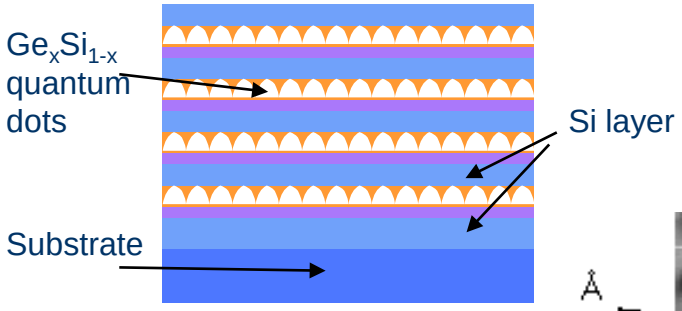
Physics-based modeling
software commercialization

Performance prediction

Quantum Dot Superlattices for PV Solar Cell Applications

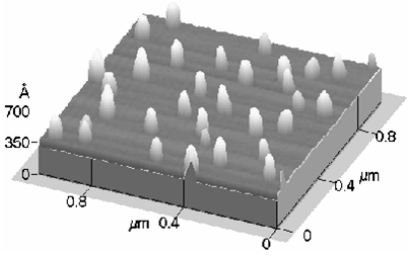
Electrons: Variation of the energy band gap and/or band offset

Phonons: Variation of the elastic constants and/or mass density

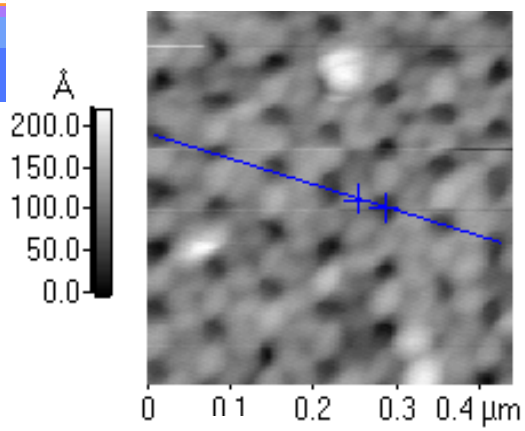


Schematic of Ge/Si QDS.

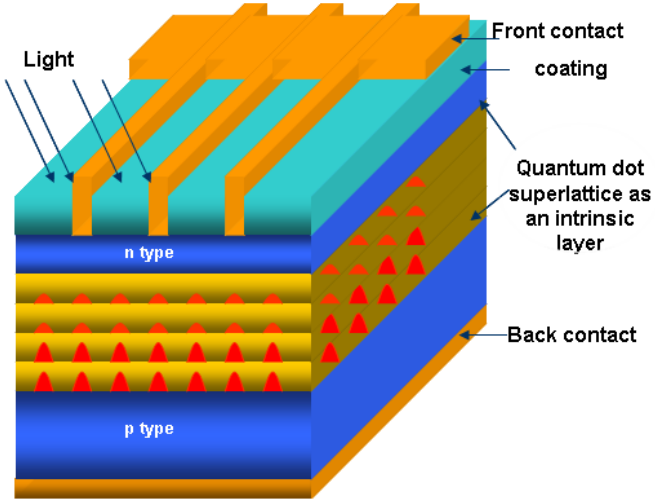
In-plane ordering of quantum dot is normally not implied by the term QDS. Periodicity of the layers along the growth direction is usually implied.



AFM of image of InAs quantum dots grown on Si (100) substrate. After K.L. Wang and A.A. Balandin, Quantum Dots: Physics and Applications (Wiley Inter-Science, 2001).



Regimented quantum dot array grown by electrochemistry. After A.A. Balandin, et al., *Appl. Phys. Lett.*, **76**, 137 (2000).



Why do We Need Quantum Dots in PV Solar Cells?

Tunable effective band-gap and multicolor / tandem designs for increased efficiency

$$\Delta E_g = \frac{h^2}{8d_{QD}^2}\left(\frac{1}{m_e^*} + \frac{1}{m_h^*}\right)$$

Intermediate band assisted absorption / three-level concept

A. Martí et al, “Novel semiconductor solar cell structures: The quantum dot intermediate band solar cell”, Thin Solid Films, 511-512 (2006) 638-644

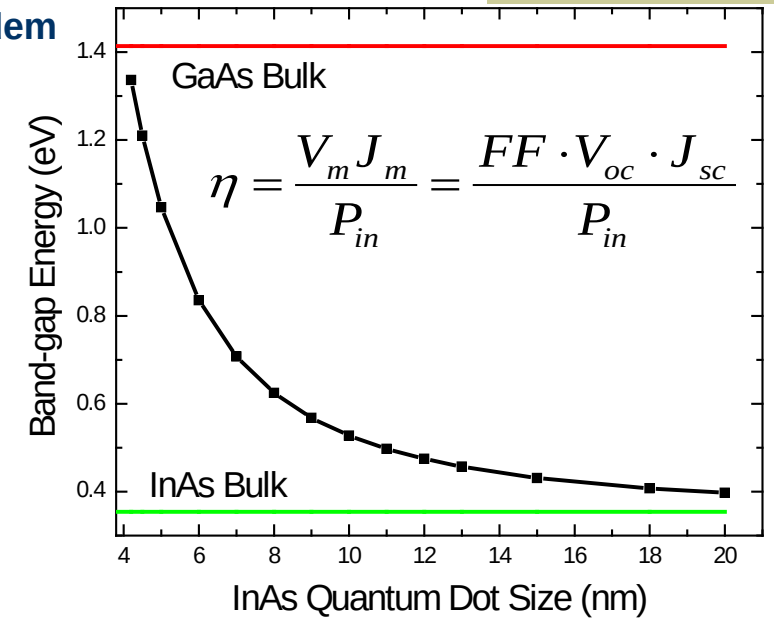
Improved radiation hardness

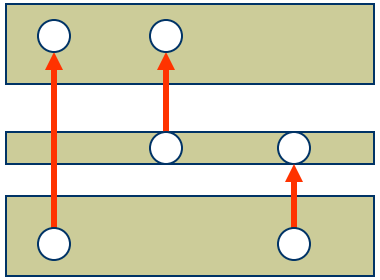
R. Leon et al., “Changes in luminescence emission induced by proton irradiation: InGaAs/GaAs quantum wells and superlattices,” App. Phys. Lett., 76, 2075 (2000).

Light trapping and absorption of normally incident light / quasi-direct band gap

M.A. Green, “Prospects for photovoltaic efficiency enhancement using low-dimensional structures,” nanotechnology, 11, 401 (2000).

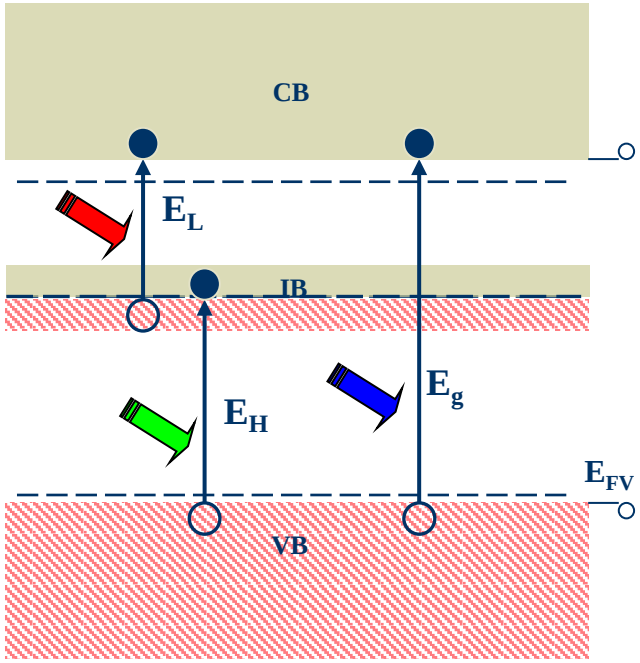
Hot-carrier solar cells and extended thermalization times

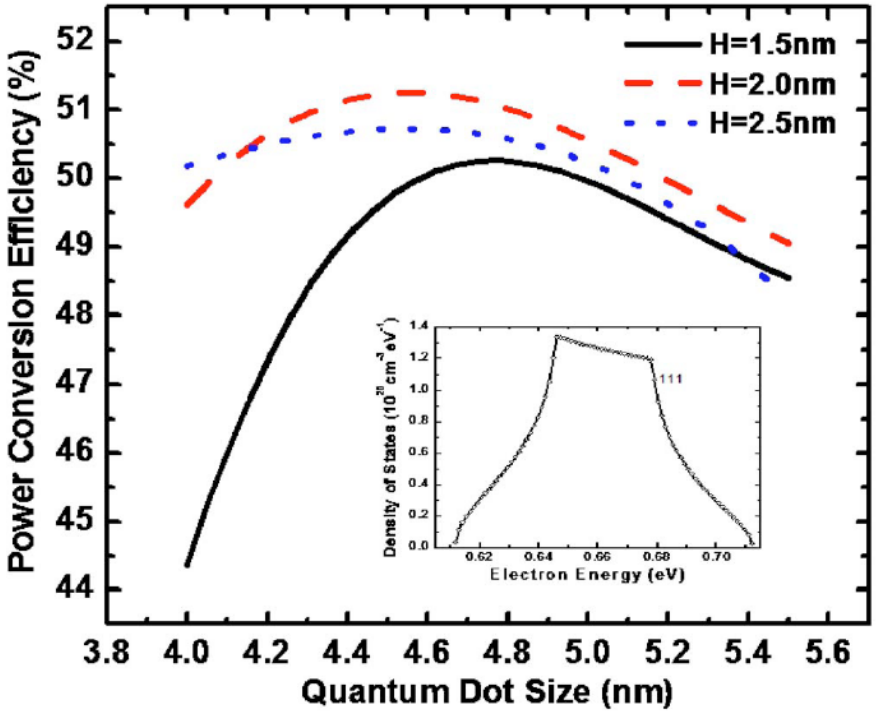




three-level concept

Implementation of IB Solar Cells with Quantum Dots

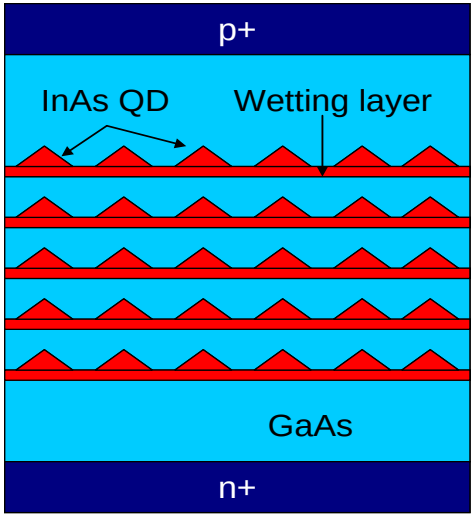




Q. Shao, A.A. Balandin, A.I. Fedoseyev and M. Turowski, "Intermediate-band solar cells based on quantum dot supra-crystals," *Applied Physics Letters*, **91**, 163503 (2007)

QDS with negligible valence band offset: $InAs_{0.9}N_{0.1}/GaAs_{0.98}Sb_{0.02}$

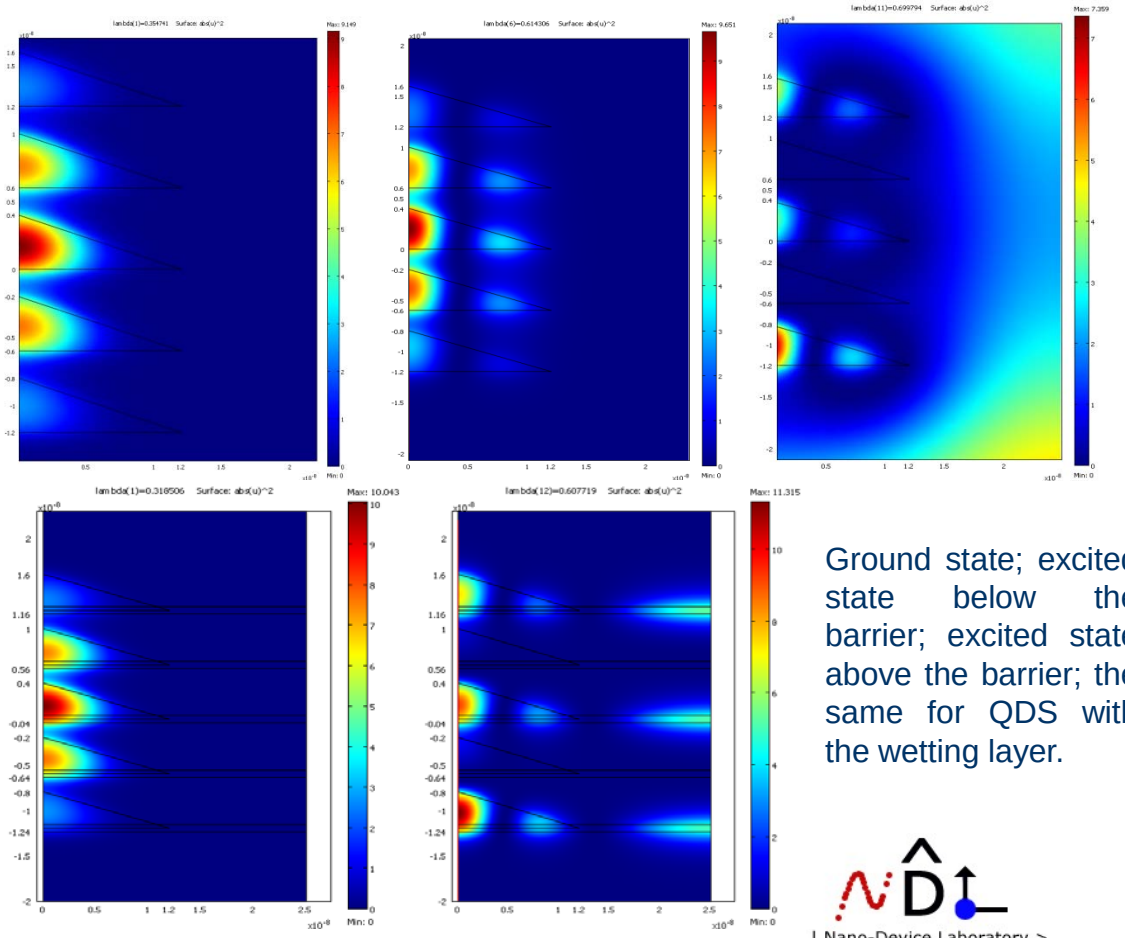
Modeling of the Photogenerated Carriers in QDS Structures



schematic of InAs/GaAs quantum dot superlattices structure

Conical Quantum Dots

height: 4 nm; base diameter: 24 nm;
wetting layer thickness: 0.8 nm;
inter-dot spacing along growth direction: 2 nm;
effective mass (GaAs): 0.067m;
effective mass (InAs): 0.023m;
barrier height for electron: 0.697eV;
dielectric constant (GaAs): 12.9;
dielectric constant (InAs): 15.15.



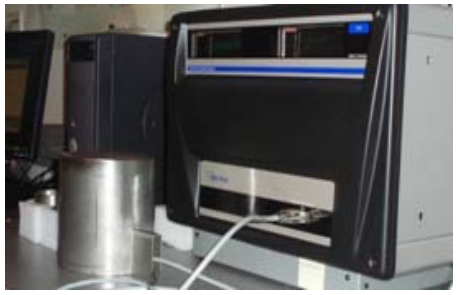
Ground state; excited state below the barrier; excited state above the barrier; the same for QDS with the wetting layer.

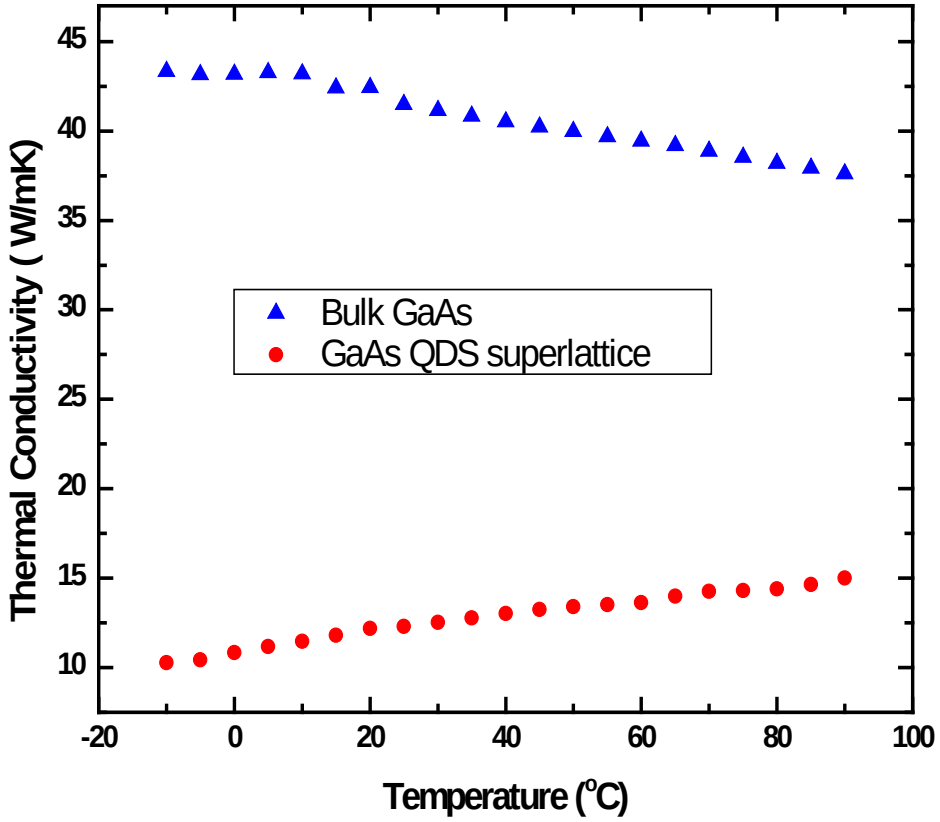
Thermal Management of Nanostructure Solar Cells

Thermal management has been an important issue for both one-sun flat-plate and concentration system applications.

System output power, or efficiency, decreases with the increasing temperature of the cell due to a decrease in open-circuit voltage as a function of increasing temperature.

Transient Plane Source (TPS) Technique





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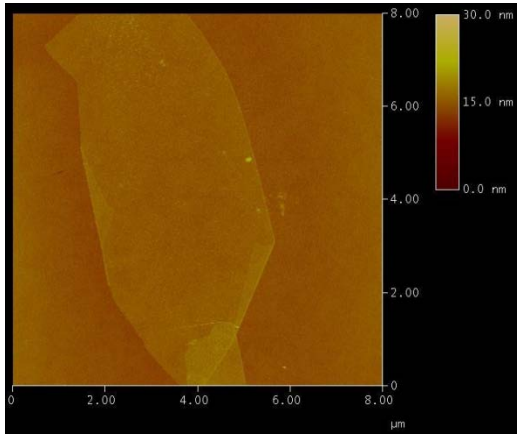
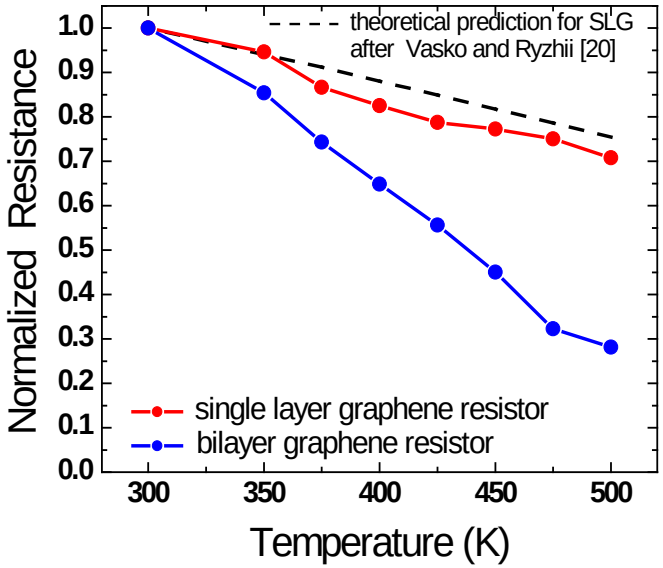
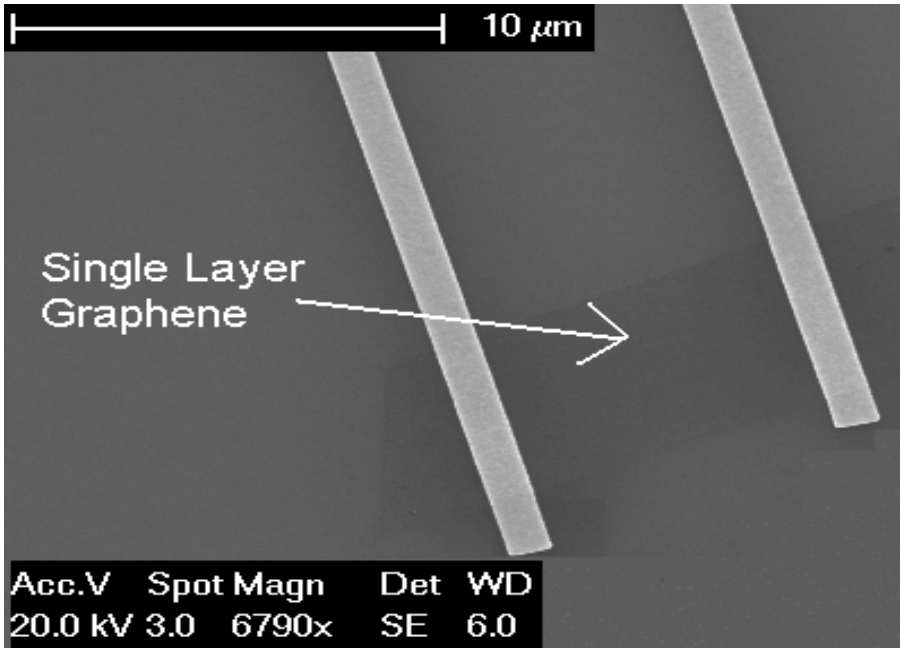
Graphene Layers as Transparent Electrodes







Q. Shao, G. Liu, D. Teweldebrhan and A.A. Balandin, "High-temperature quenching of electrical resistance in graphene interconnects," *Applied Physics Letters*, **92**: 202108 (2008)

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Acknowledgements

Photo: Nano-Device Laboratory (NDL) group members at University of California – Riverside, November 2006. From left to right: Qinghui Shao (GSR), Dr. Vladimir Fonoberov (PGR), Manu Shamsa (GSR), Professor Alexander A. Balandin (Group Leader and PI), Suma Raj (GSR), Sivashankar Krishnakumar (USR), Farough Parvizi (USR) Alejandro Echeverria (USR) Suchismita Ghosh (GSR), and Irene Calizo (GSR).