SAND2013-7628C

Exceptional service in the national interest

Sandia National Laboratories

An Overview of Sandia National Laboratories

and research in solar microsystems

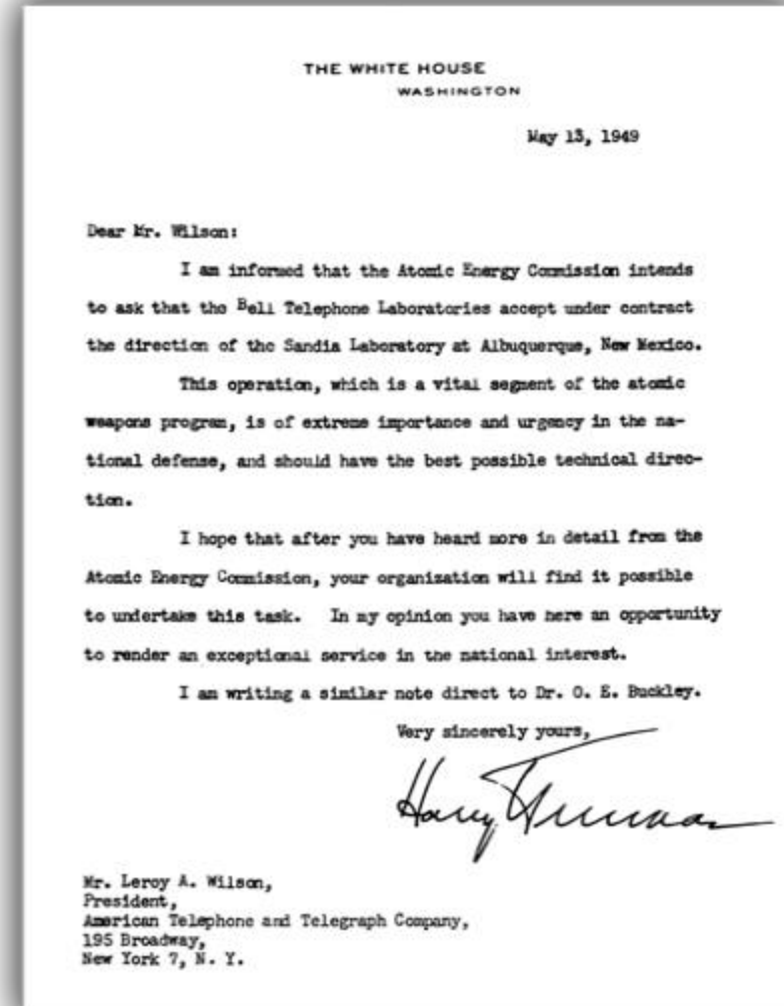
U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND No. 2012-5130P

Organization of the talk

1. Sandia National Laboratories Overview
    1. Overview and Mission areas
        1. Defense Systems and Assessments
        2. Nuclear Weapons
        3. International Homeland and Nuclear Security
        4. Energy, Climate, and Infrastructure Security
            1. Overview
            2. Mission and Objectives
            3. Recent Accomplishments
        5. Science and Engineering Foundations
            1. Microsystems
            2. Facilities
        6. Workforce
2. Solar microsystems
    1. Motivation
    2. CdTe micro/nano solar cells
    3. GaAs multijunction cells
    4. Concentrators
    5. Flexible Silicon

Sandia's History



THE WHITE HOUSE
WASHINGTON

May 13, 1949

Dear Mr. Wilson:

I am informed that the Atomic Energy Commission intends to ask that the Bell Telephone Laboratories accept under contract the direction of the Sandia Laboratory at Albuquerque, New Mexico.

This operation, which is a vital segment of the atomic weapons program, is of extreme importance and urgency in the national defense, and should have the best possible technical direction.

I hope that after you have heard more in detail from the Atomic Energy Commission, your organization will find it possible to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

I am writing a similar note direct to Dr. O. E. Buckley.

Very sincerely yours,

Harry Truman

Mr. Leroy A. Wilson,
President,
American Telephone and Telegraph Company,
195 Broadway,
New York 7, N. Y.

Sandia's Sites

Albuquerque, New Mexico

Livermore, California

Kauai, Hawaii

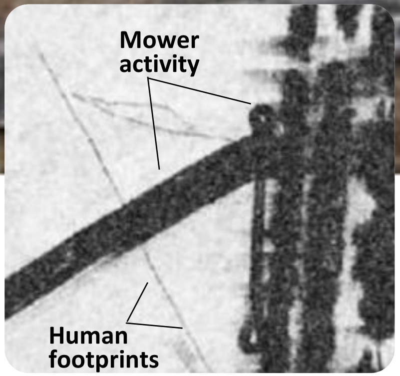
Waste Isolation Pilot Plant, Carlsbad, New Mexico

Pantex Plant, Amarillo, Texas

Tonopah, Nevada

Defense Systems and Assessments

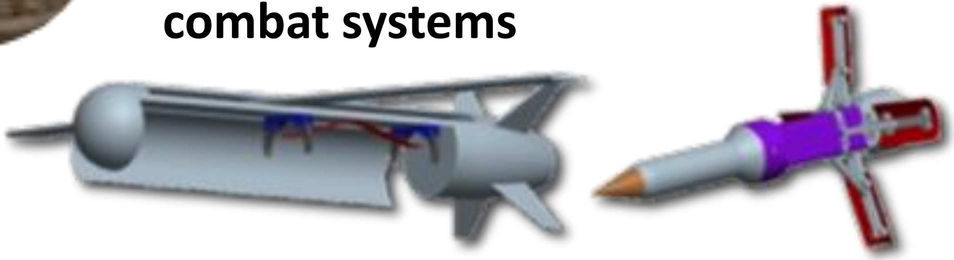
Synthetic aperture radar

Support for NASA

Support for ballistic missile defense

Ground sensors for future combat systems



Nuclear Weapons

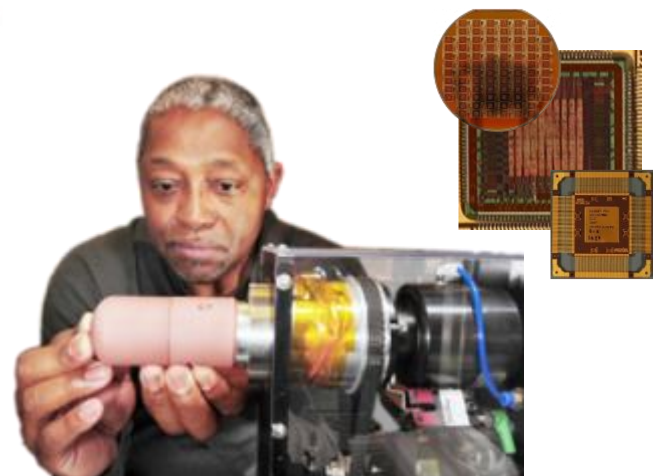
Pulsed power and radiation effects sciences

Design agency for nonnuclear components

- Neutron generators
- Arming, fuzing and firing systems
- Safety systems
- Gas transfer systems

Warhead systems engineering and integration

Production agency



International, Homeland, and Nuclear Security

Critical asset protection

Homeland defense and force protection

Homeland security programs

Global security

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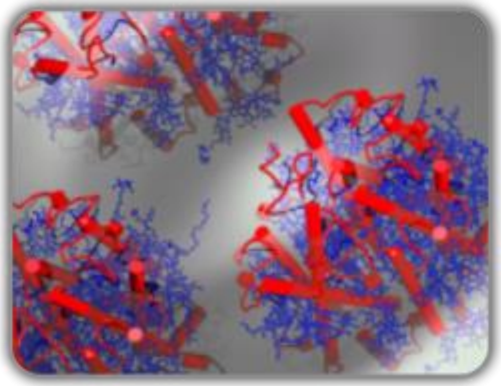
Energy, Climate, and Infrastructure Security

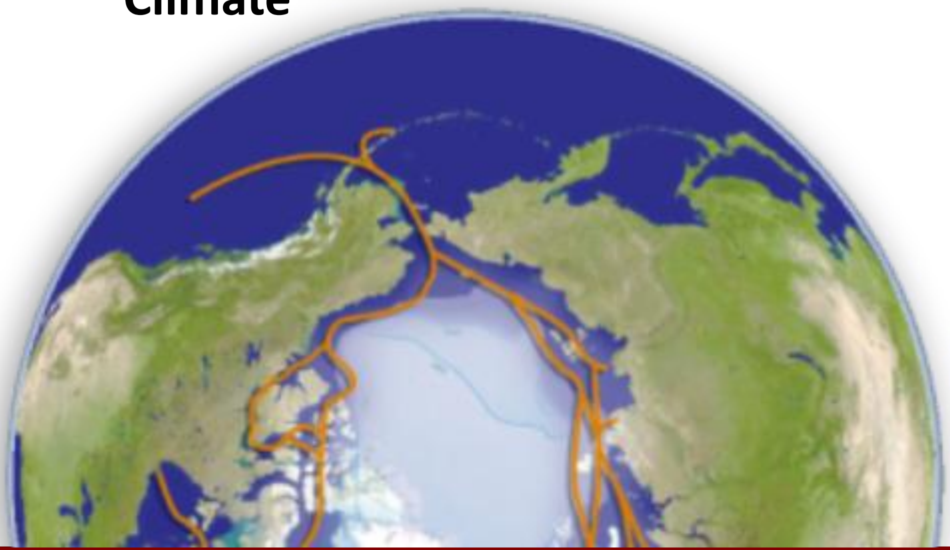
Energy

Infrastructure

Crosscuts and enablers



Climate



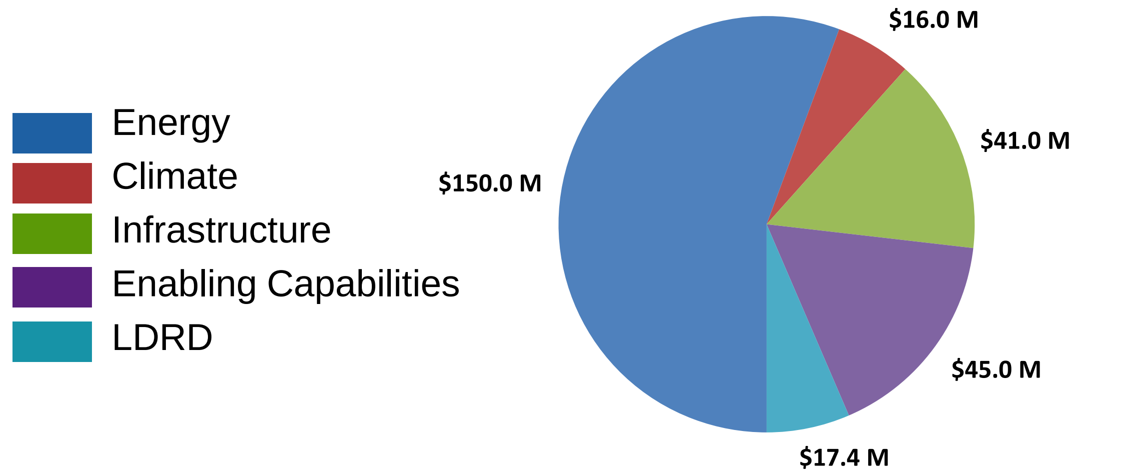
jbei
Joint BioEnergy Institute

2012-2015 ECIS SMU Strategic Plan

Our Vision:

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure security problems.

FY12 Projected Budget = $269.4M



ECIS strategy targets national security missions

- *Reduce our dependence on foreign oil*
- *Increase deployment of low carbon stationary power generation*
- *Understand risks and enable mitigation of climate change impacts*
- *Increase security and resiliency of critical infrastructures*
- *Strengthen the nation's S&T base in energy, climate, and infrastructure*

Recent Mission Accomplishments

Sandia National Laboratories

2012 R&D 100 50th ANNIVERSARY

WINNERS:
- Sandia Cooler
- MEPV

JCESR JOINT CENTER FOR ENERGY STORAGE RESEARCH

JCESR: Public-Private Partnership Awarded $120M to Develop Energy Storage

Sandia technology was used to remove radioactive material from more than 43 million gallons of contaminated wastewater at the damaged Fukushima Daiichi plant.

Unmanned Aircraft Test Flights Completed at Oliktok Point

Groundbreaking ceremony at the Scaled Wind-Farm Technology (SWIFT) Facility at Texas Tech University

IDART Information Design Assurance Red Team

"Clean Sweep" Red Team report for the Department of Labor

Sandia Experts Lead Technical Investigation of Hydrogen Release Incident

***Popular Science* magazine names Greg Nielson "One of the 10 most promising young scientists working today"**

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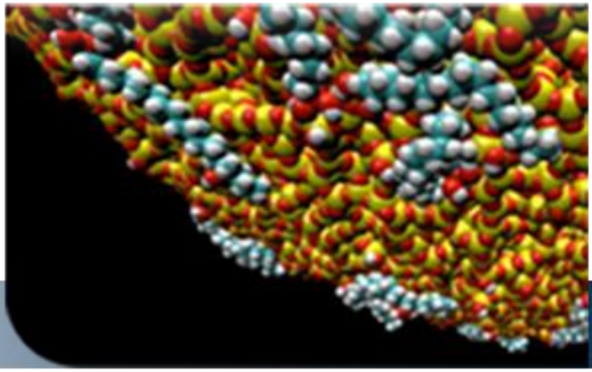
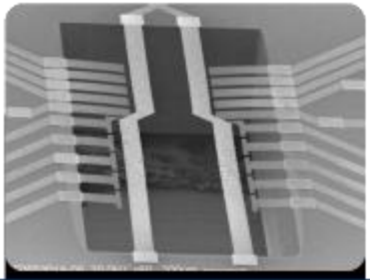
Science and Engineering Foundations

Computing and information science

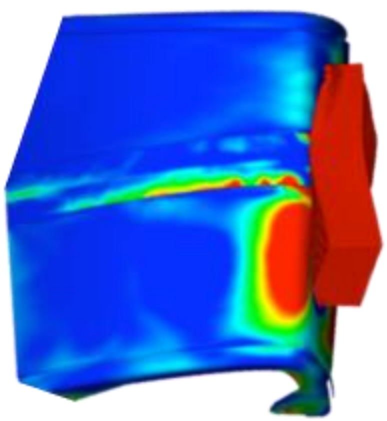
Materials science



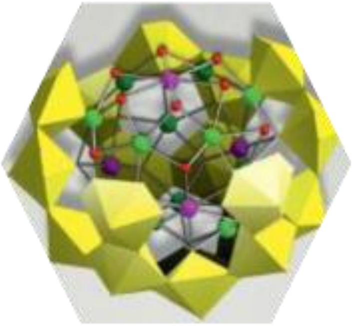
Nanodevices and microsystems



Engineering sciences

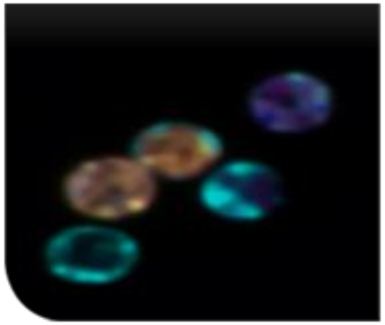


Geoscience



Radiation effects and high-energy density science

Bioscience



Microsystems Science, Technology, and Components Center

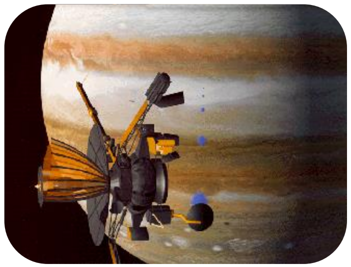
We are a research, development and production capability that converts concepts into working hardware.

- **We have key infrastructure**
- **We design, develop, fabricate, and qualify products**
- **We partner with industry, universities, and government laboratories to rapidly convert the most advanced concepts into hardware.**

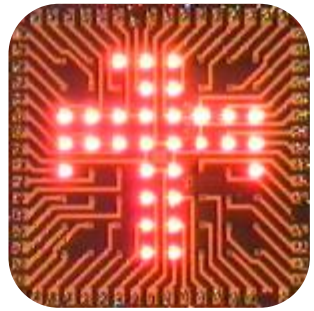
Sandia has a long history in Microelectronics and Microsystems

Laminar Flow Clean Room

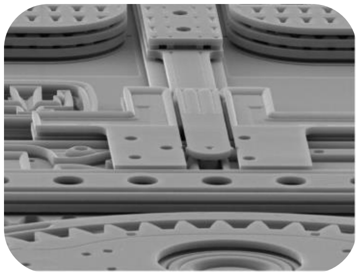
Design/Build Galileo ICs



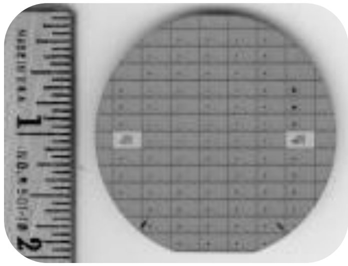
High Efficiency VCSEL



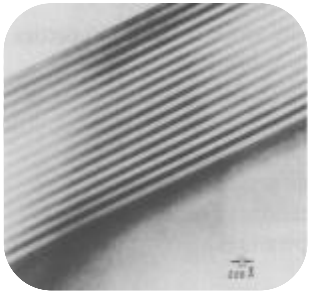
5-Level Surface Micromachining



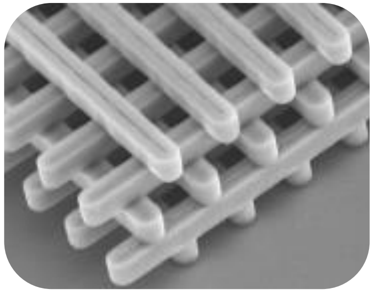
Microsystems-Enabled Photovoltaics



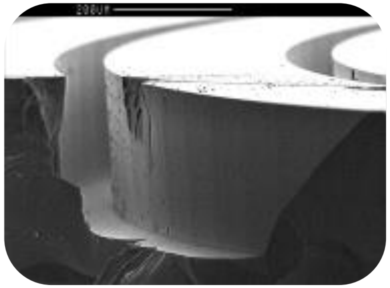
Radiation-Hardened CMOS



Strained-layer Superlatices



Photonic Lattice



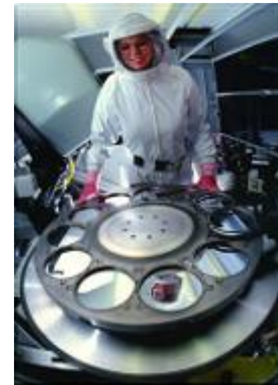
MicroChemLab

Quantum Computing

1960s 2000s

Silicon Fabrication Facility

- Total clean room area 34,500 Square Feet
- 22 Separate laminar flow clean room bays
- 11,900 square feet of class 1 clean room space
- In-house microelectronics technology & facility to deliver specialized IC products



Microfabrication Facility

- 14,900 sq. ft. Class 10 and Class 100 clean room space

Microsystems Laboratory (MicroLab)

- Workspaces to support approximately 274 personnel
- 40 Chemical, electrical, and laser light laboratories

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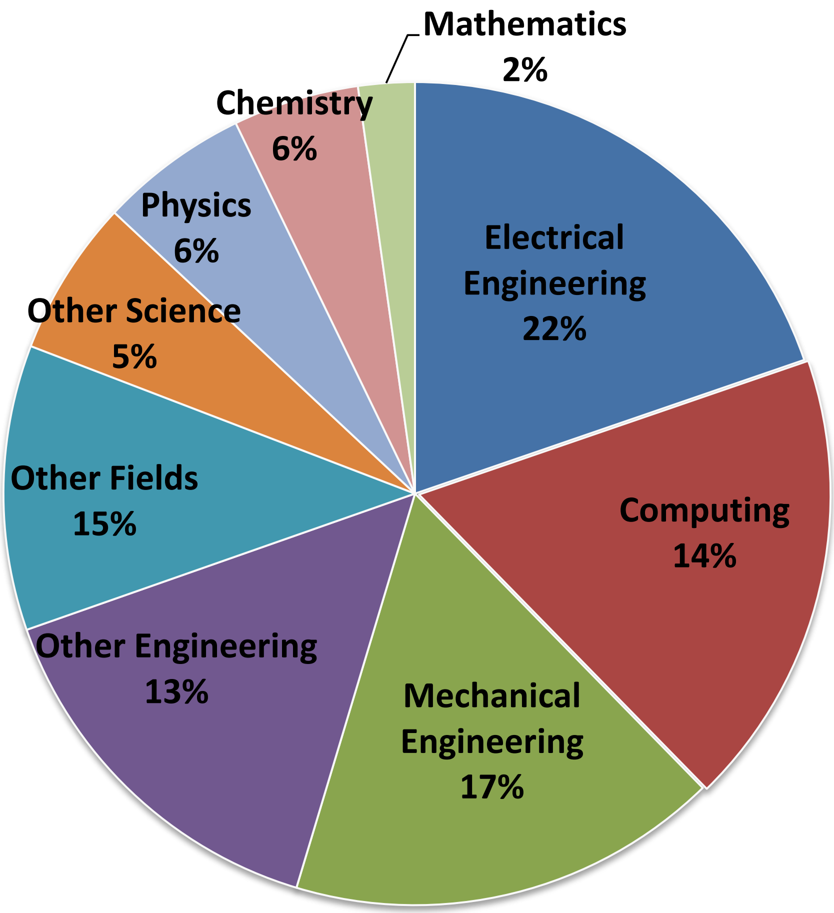
Our Workforce

- On-site workforce: 11,711
- Regular employees: 9,494
- Gross payroll: ~$1.046 billion

Data as of April 12, 2013

R&D staff (4,799) by discipline



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"Don't get me wrong: I love nuclear energy! It's just that I prefer fusion to fission. And it just so happens that there's an enormous fusion reactor safely banked a few million miles from us. It delivers more than we could ever use in just about 8 minutes. And it's wireless!“

William McDonough

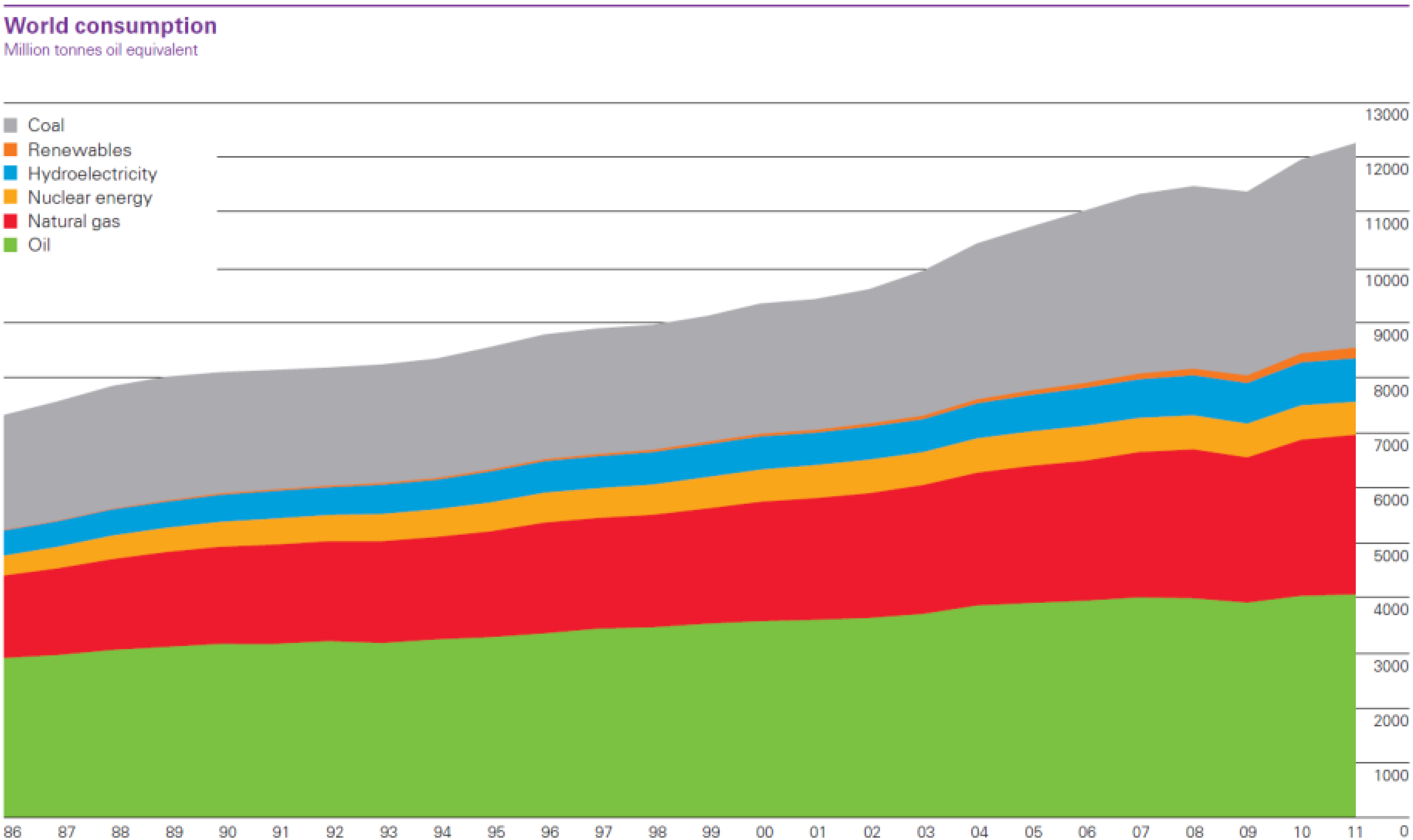
The consequences of having inexpensive energy are immense

"Energy is the single most important challenge facing humanity today"

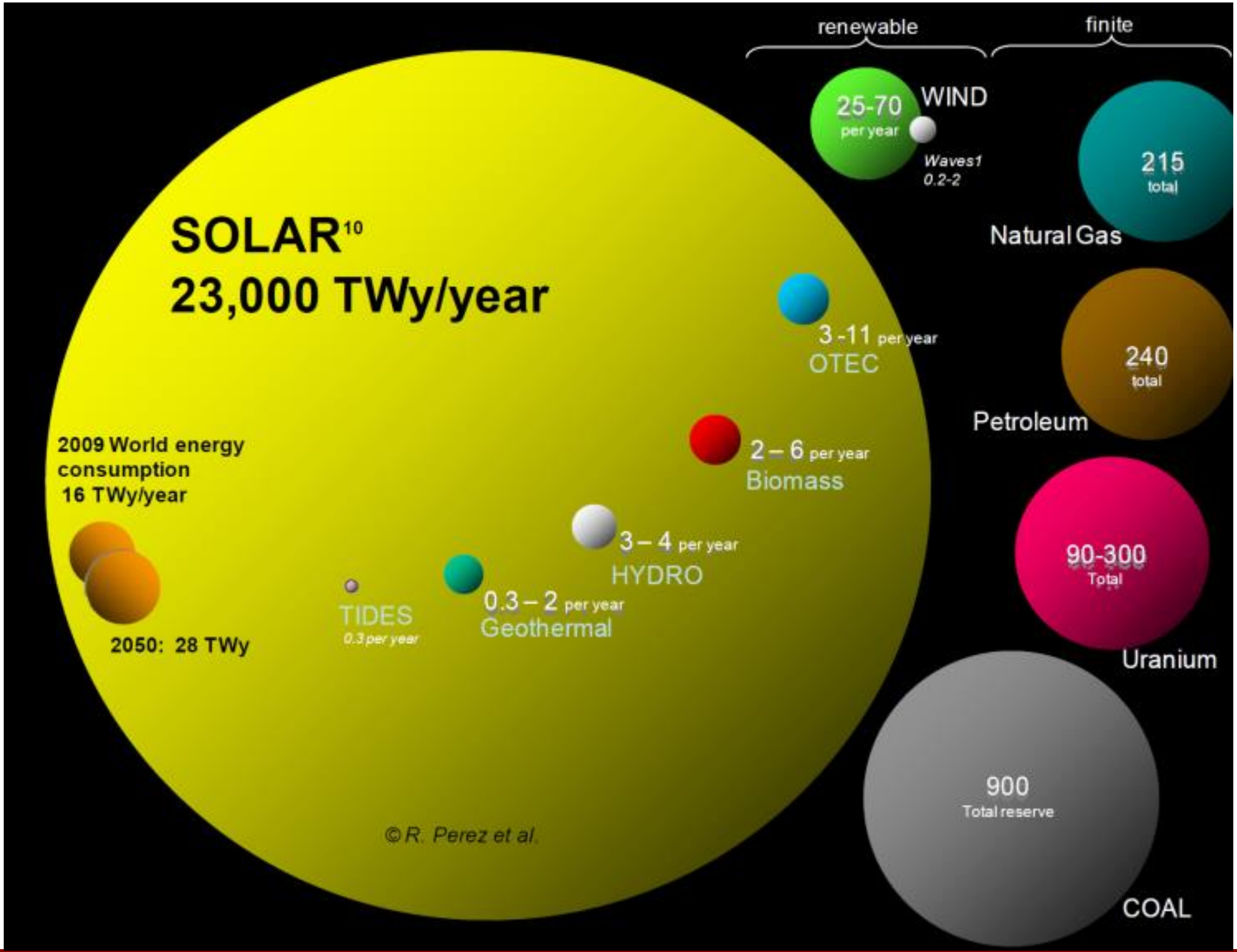
Nobel Laureate
Richard Smalley

Dr. R. E. Smalley, "Top Ten Problems of Humanity for Next 50 Years", Energy & Nanotechnology Conference, Rice University, May 3, 2003

How are we going to meet this increasing demand while considering the environment and social impacts?



- **From all the sources of energy there is one that is remarkably abundant and renewable**



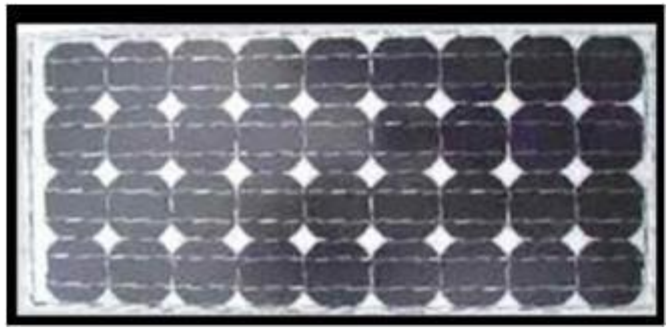
Energy Policy Volume 39, Issue 11, November 2011, Pages 7290–7297

- **Photovoltaics**
  - Method to directly transform the radiation from the sun into electrical energy through the photovoltaic effect.
  - It is composed from several solar cells
  - Advantages
    - Clean
    - Uses renewable energy from the sun
    - Virtually maintenance free
    - Noise free (no moving parts)

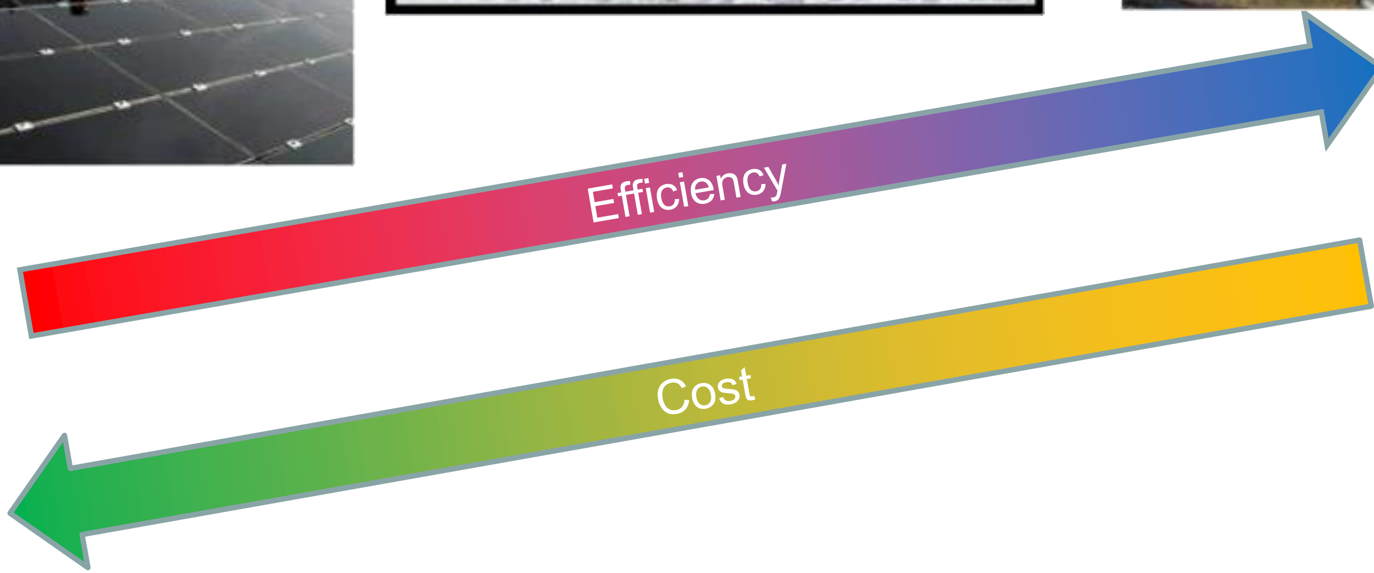
Current technologies are based on concepts proposed 30-40 years ago

Concentrated PV

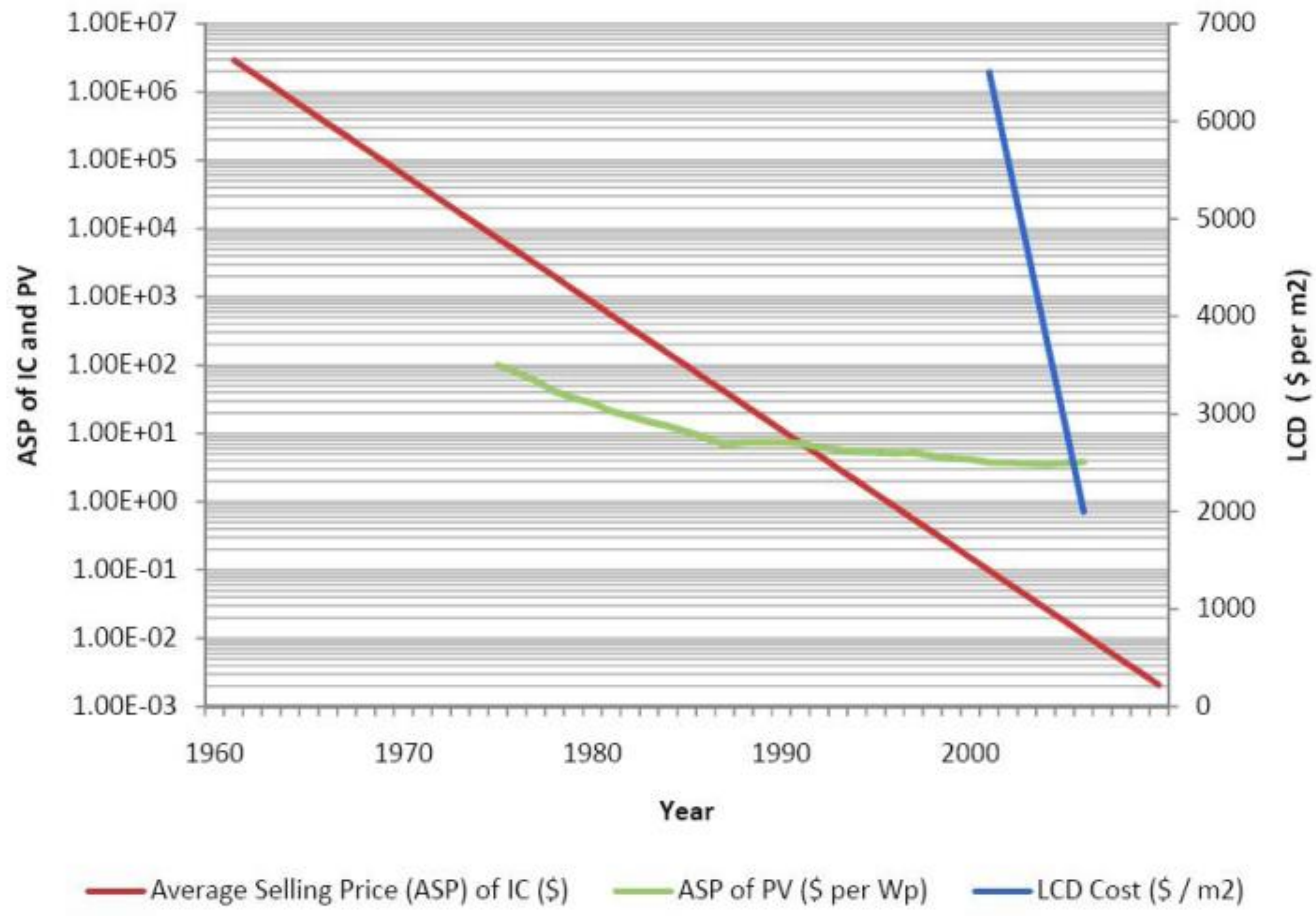
C-Si PV



Thin Film PV

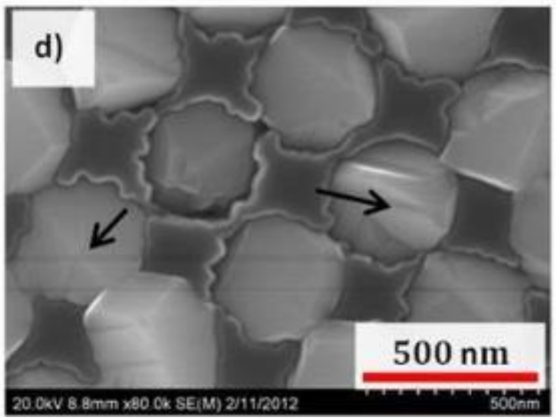


The use of a different technology to create PV is necessary to lower the costs

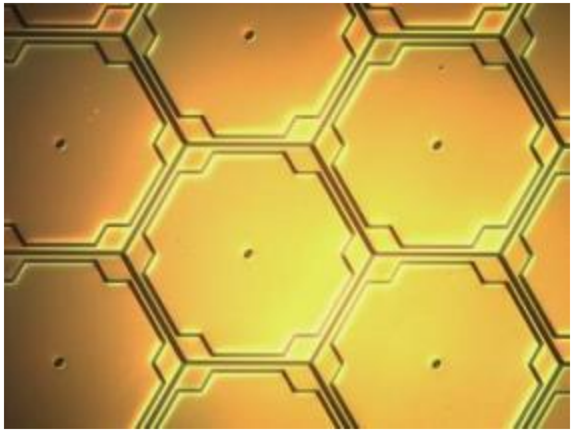


Rajendra Singh, "Why silicon is and will remain the dominant photovoltaic material" Journal of Nanophotonics, Vol. 3, 032503 (16 July 2009)

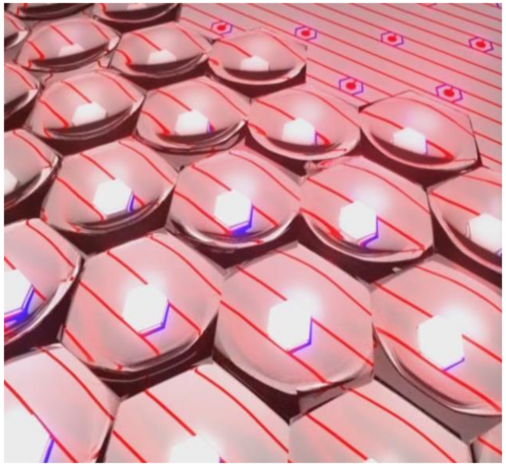
Research areas



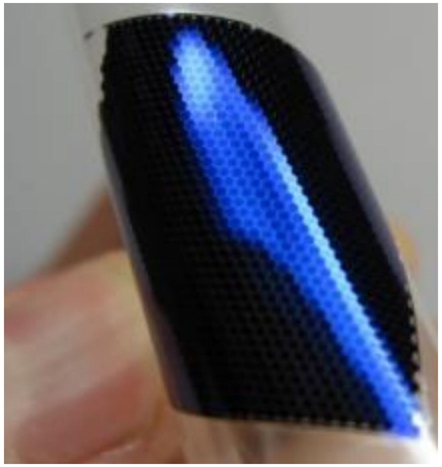
1. CdTe nanogrowth for high efficiency thin films



2. GaAs and III-V materials with multijunction

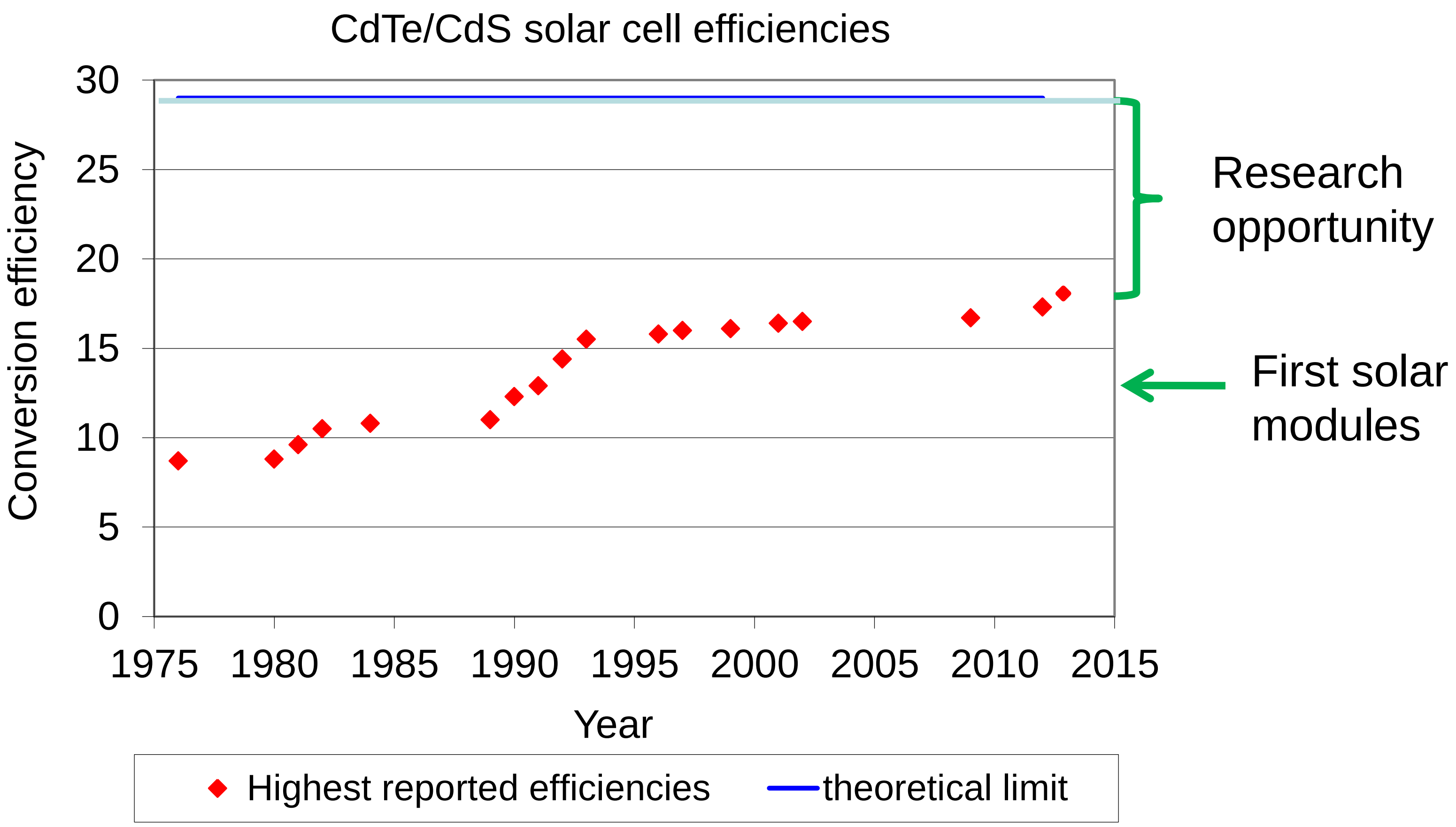


3. Microconcentrators

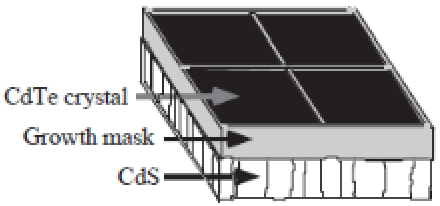


4. Crystalline silicon flexible film

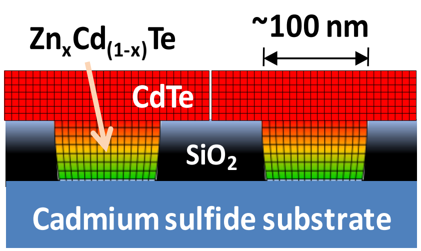
CdTe cell efficiencies have increased little over 18 years



We propose nanopatterning and lattice matching to enhance cell performance

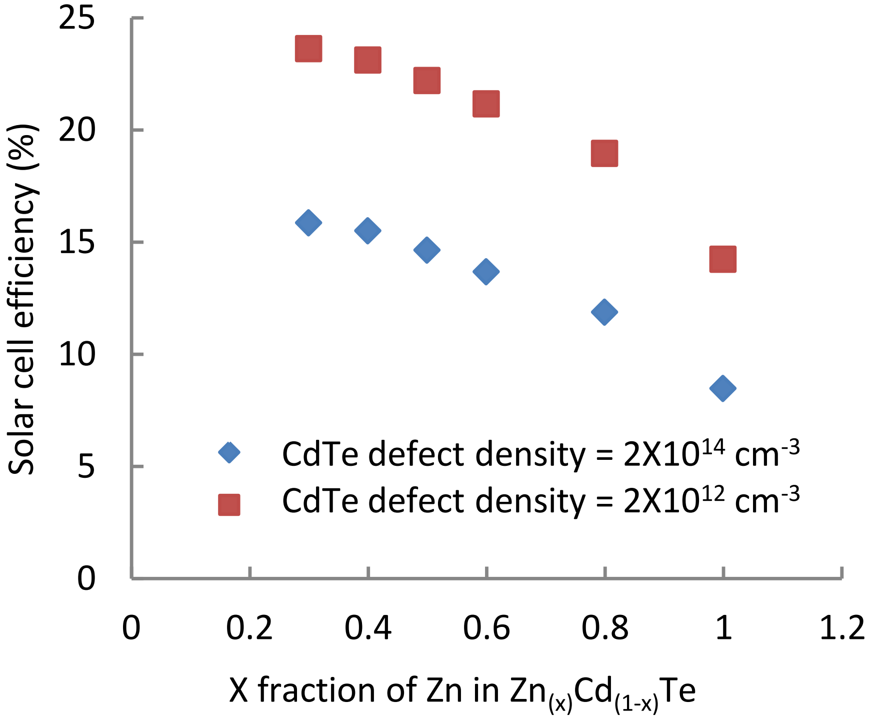


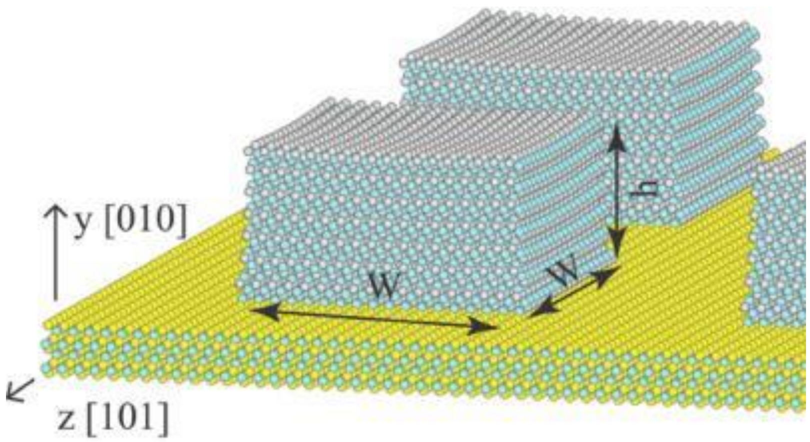
- Nanopatterning → 1. Improved uniformity; 2. Reduced defects
- Lattice matching → 2. Reduced defects
- Graded Bandgap → 3. Increased current; 4. Improved contact



High efficiencies

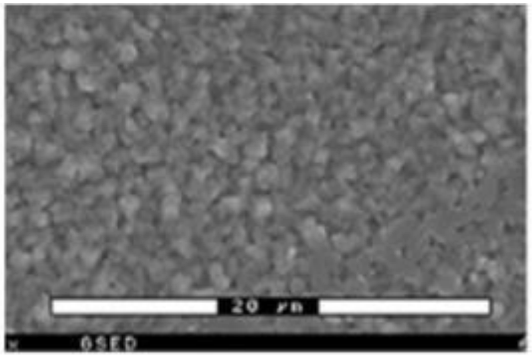
Simulations show that reducing defect density enhances performance

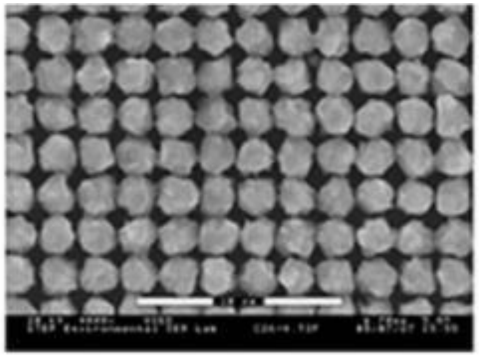


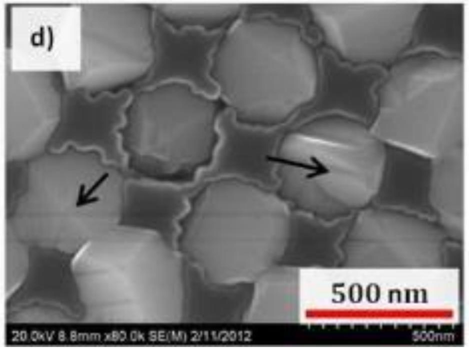


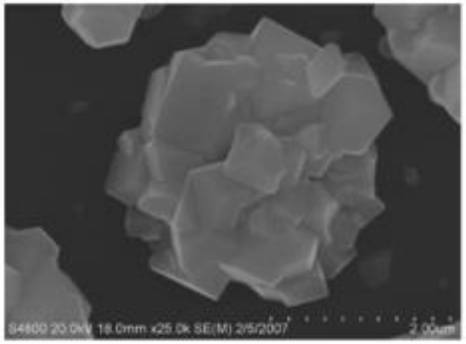
Cruz-Campa et. al. Towards Dislocation-free ZnCdTe Solar Cells Through Nanoscale Crystal Growth And Compositional Grading, Conference Proceedings of the EU PVSEC conference, 2012

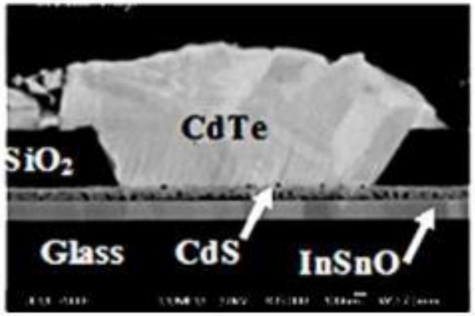
So far we have been able to demonstrate that micro-scale cells have less defects

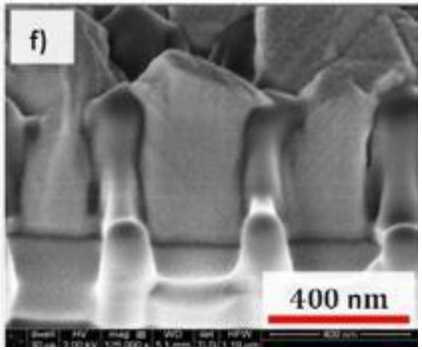






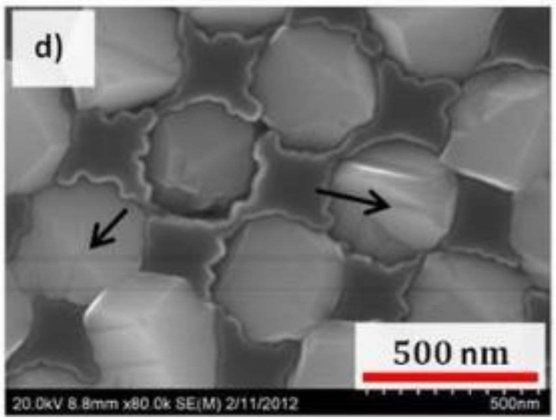






Brandon Aguirre, J Cruz-Campa et. al. Towards Dislocation-free ZnCdTe Solar Cells Through Nanoscale Crystal Growth And Compositional Grading, Journal of electronic Materials, 2013 submitted

Research areas



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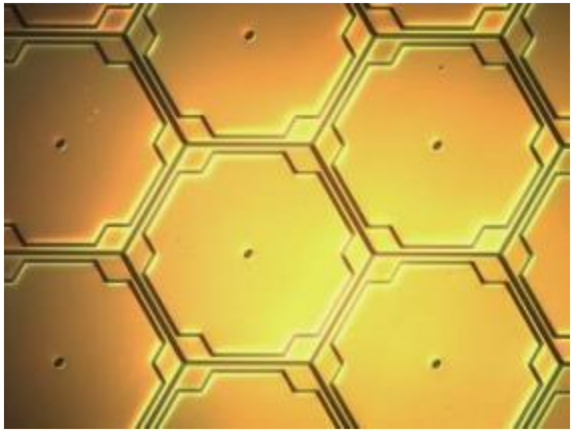
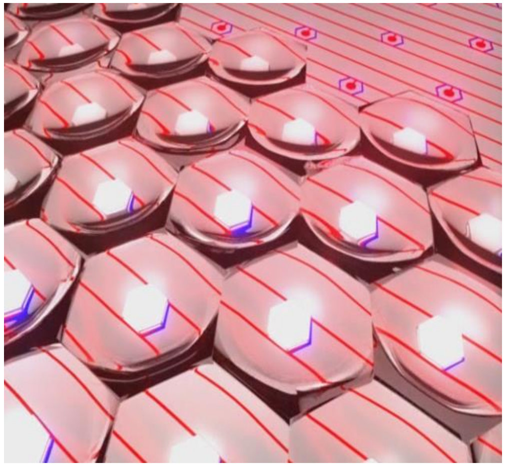
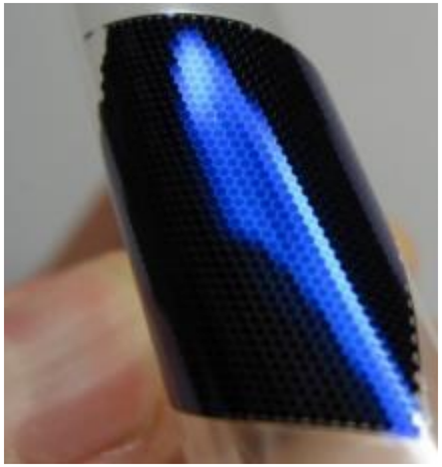


2. GaAs and III-V materials with multijunction



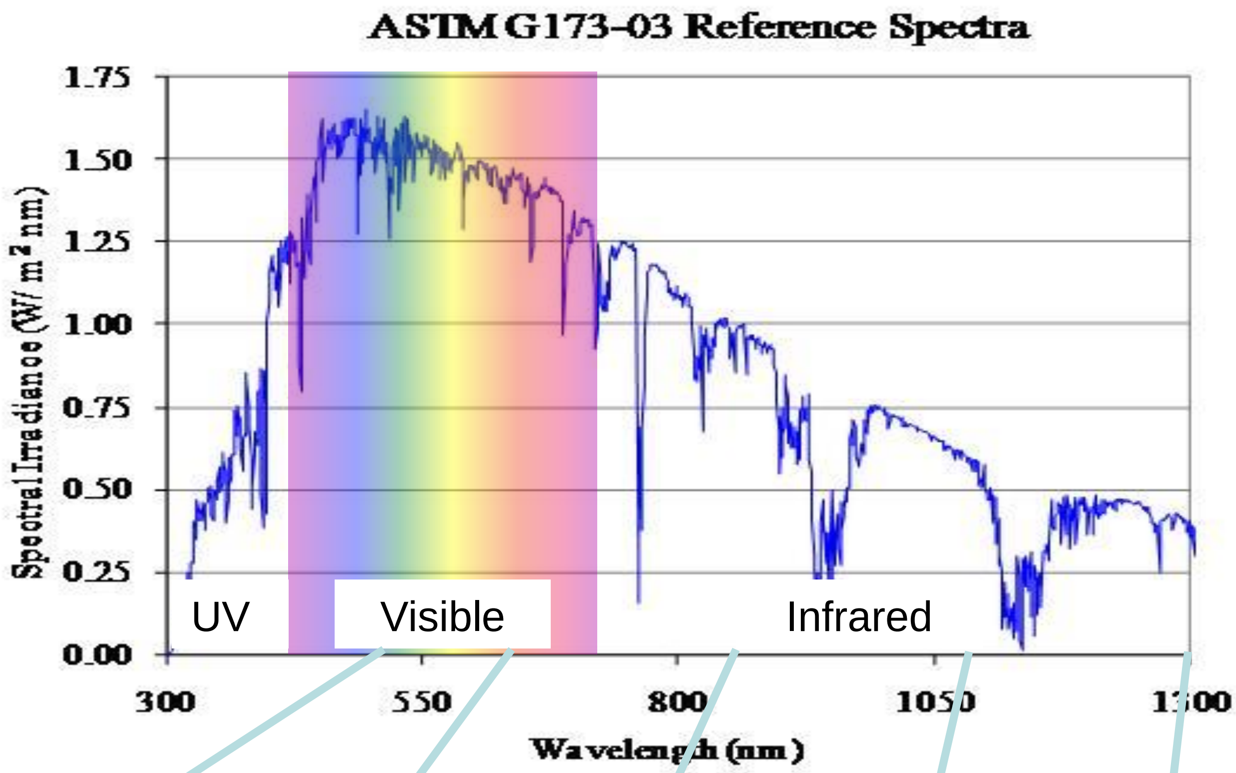
3. Microconcentrators



4. Crystalline silicon flexible film

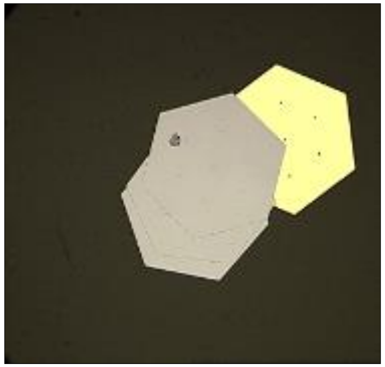
We are developing a stack of independently connected materials that best absorb each of the parts of the spectrum

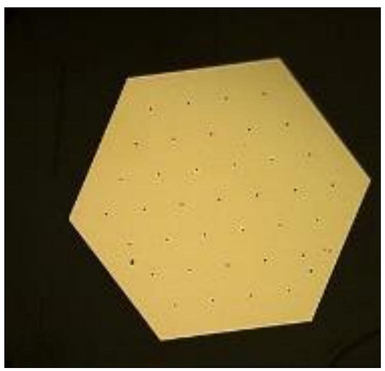
Sandia National Laboratories



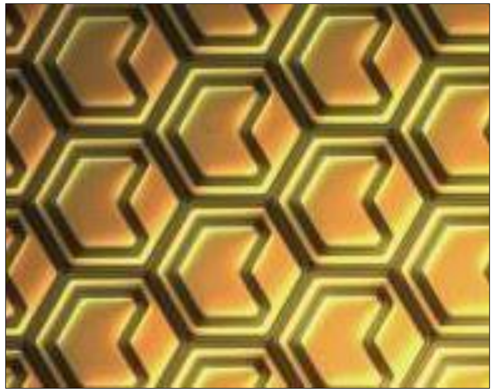
Material	InGaN 2.2 eV	InGaP 1.85eV	GaAs 1.4eV	Si 1.1EV	InGaAsP 0.9eV	InGaAs 0.6eV
Wavelengths best absorbed	Less than 560nm	Less than 670nm	Less than 886nm	Less than 1127nm	Less than 1378nm	Less than 2070nm

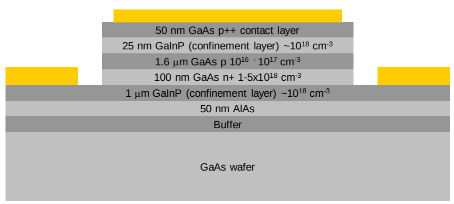
Our III-V designs have evolved into a more complex, more functional cells



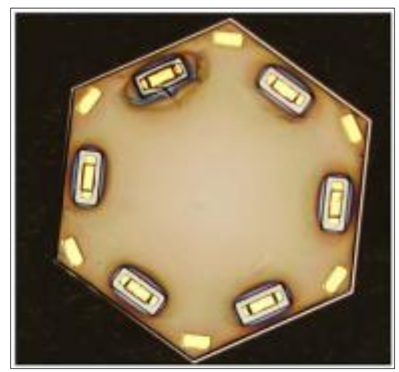


Single junction with front-back contacts

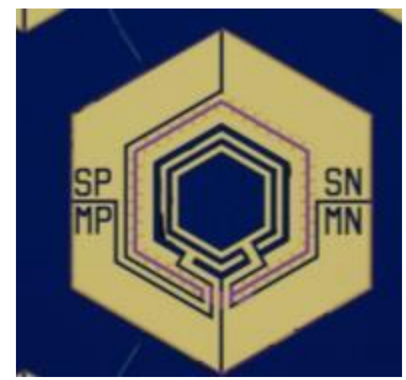




Single junction with all back contacts at different levels



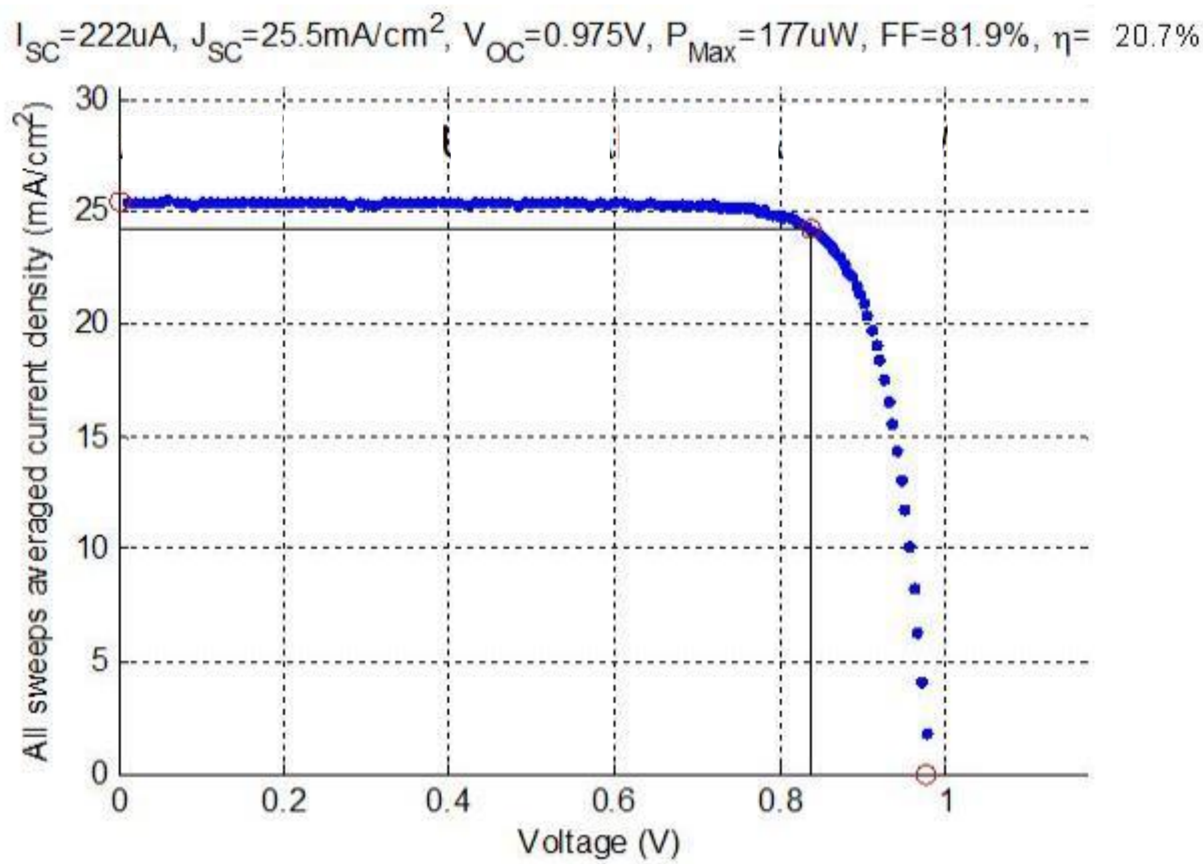
Double junction with all back contacts at the same level



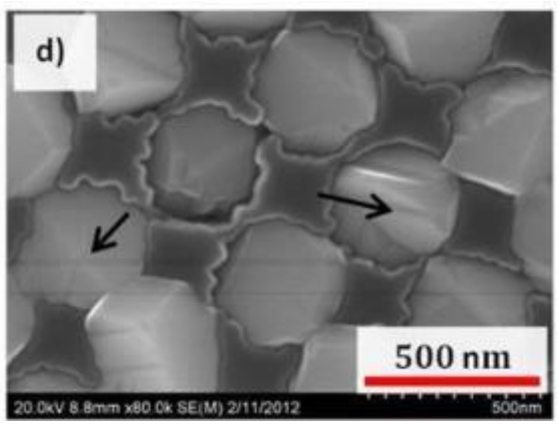
Bonding of cells and silicon receiving substrate

A. Tauke- Pedretty, J. Cruz-Campa et al. Resistance Considerations for Stacked Small Multi-junction Photovoltaics Cells, PVSC 2013

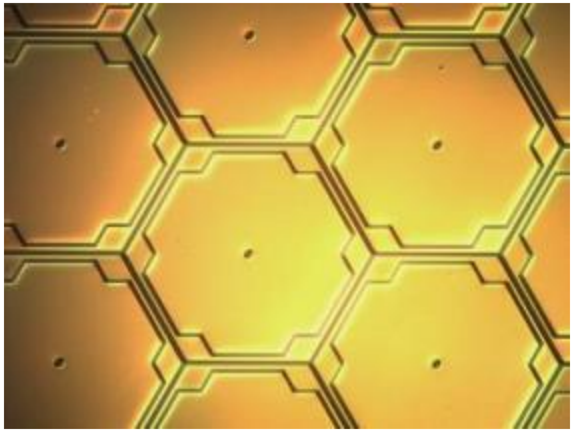
The performance per gram is outstanding: only 3 microns of material used!



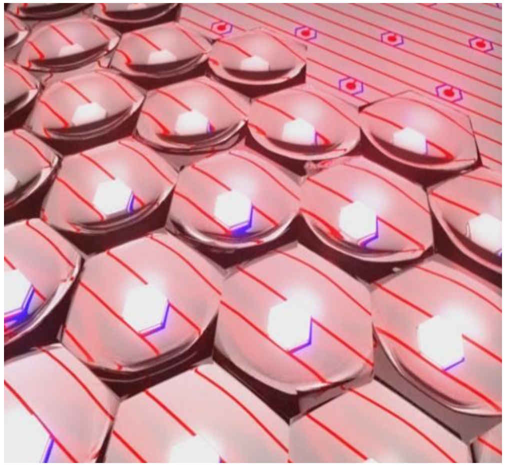
Research areas



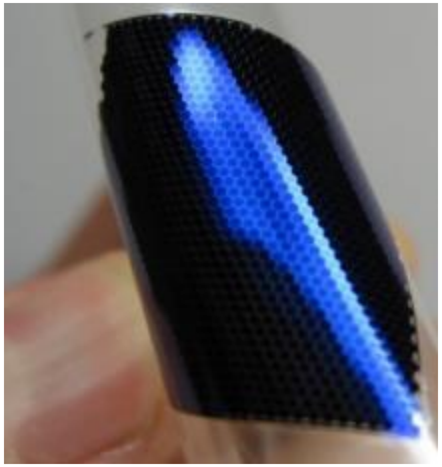
1. CdTe nanogrowth for high efficiency thin films



2. GaAs and III-V materials with multijunction



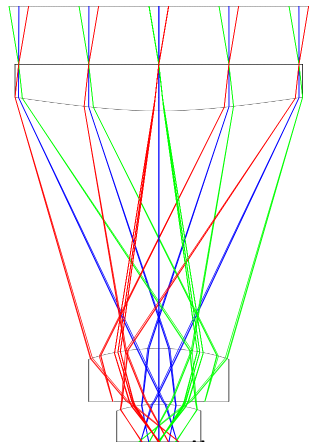
3. Microconcentrators



4. Crystalline silicon flexible film

Our approach has a defined path to make solar the least expensive energy source

Small cells



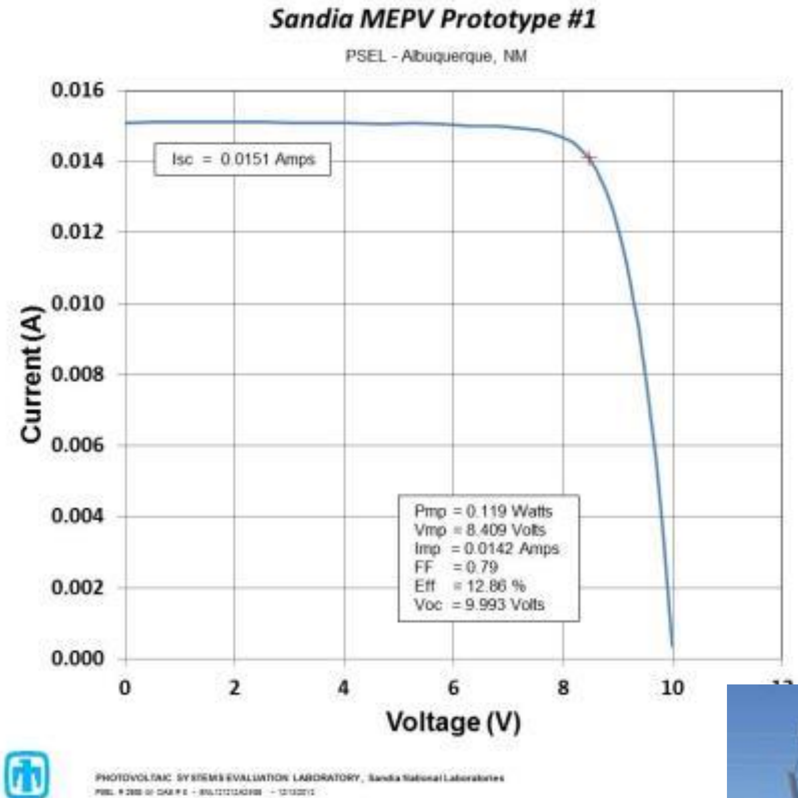
New optical refractive designs for tracking

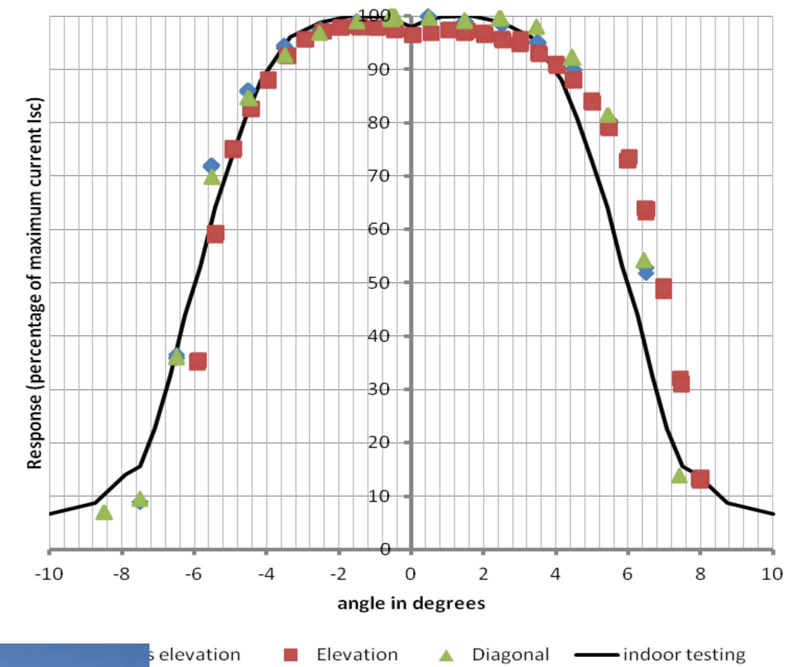
Low-cost, coarse 2-axis tracking with high acceptance angle and flat external surface

Use of mature microsystems technologies

The team was able to simulate, design, fabricate, and test a fully functional prototype

Outdoor testing of Prototypes had very encouraging results





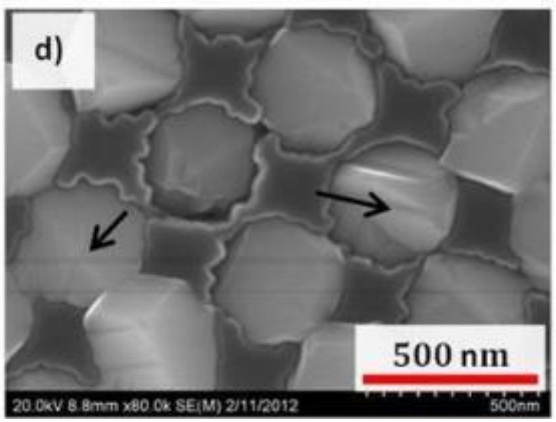
Above 12% efficiency

4 degrees acceptance angle

*This IV curve assumes perfect optics (effective concentration of 15.1X vs 36X)

Research areas

Sandia National Laboratories



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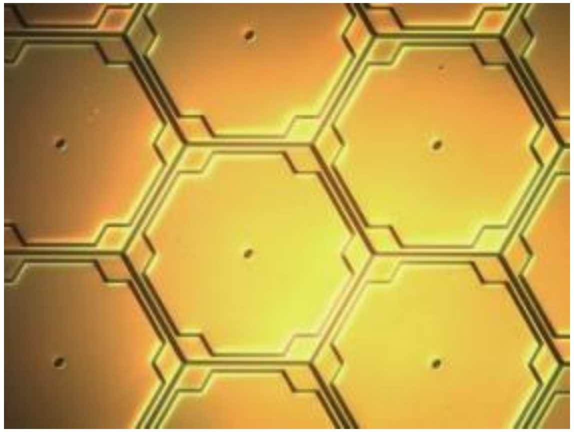

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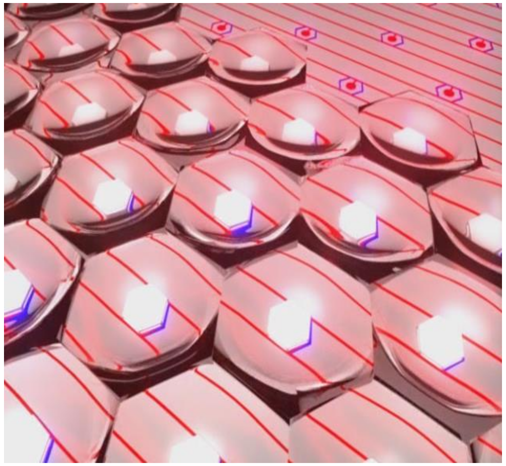
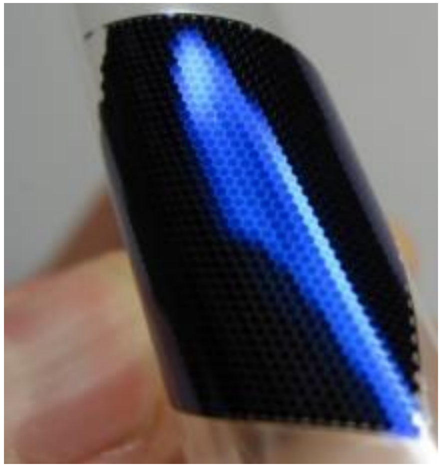
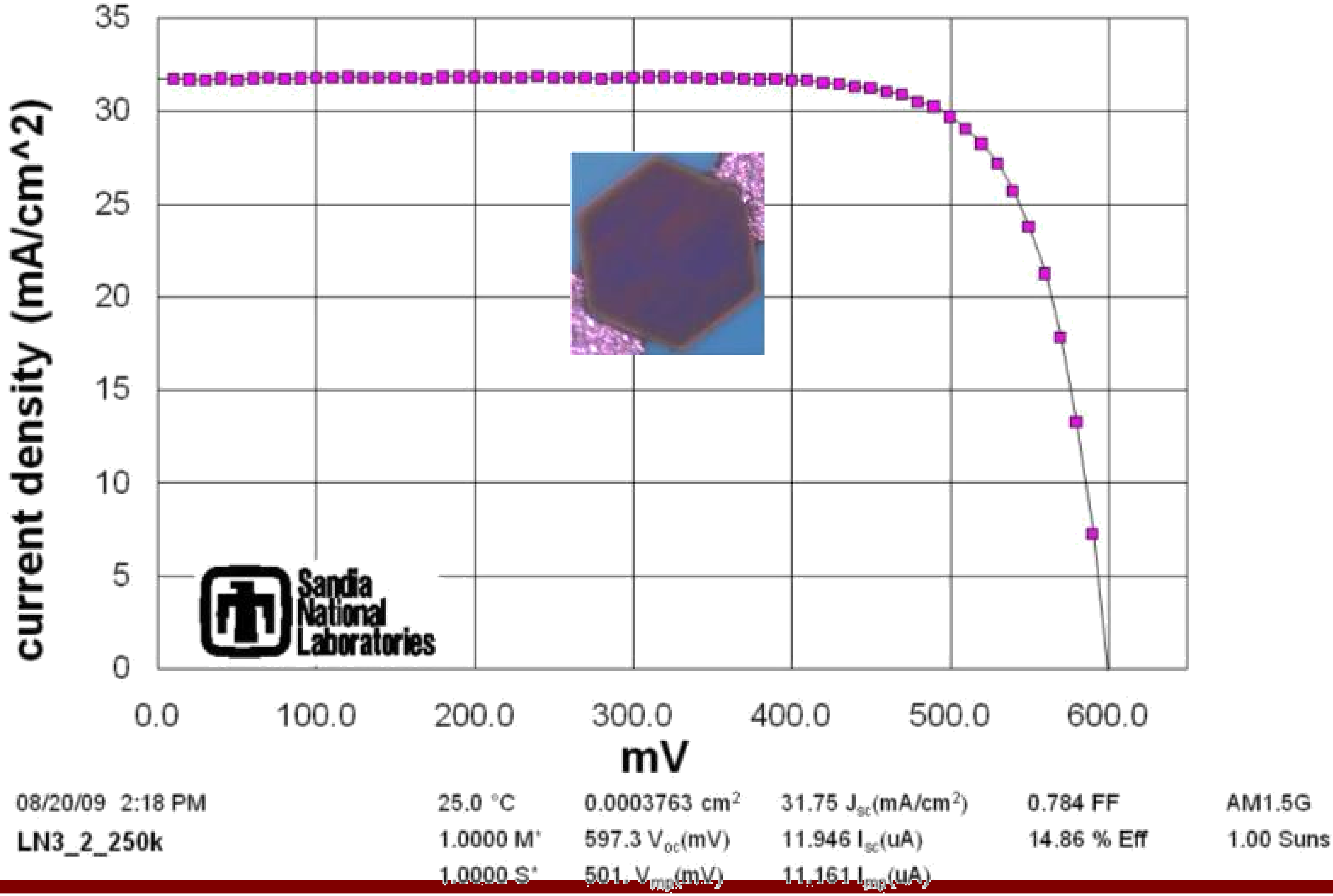


3. Microconcentrators



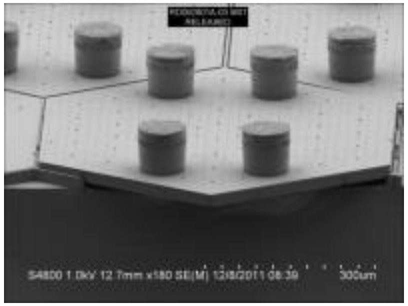
4. Crystalline silicon flexible film

Sandia has produced the most efficient silicon cell for the amount of silicon used!



We have used the ultrathin silicon cells to create functional flexible prototypes

Leverages high-quality single-crystal Si and current IC/MEMS industry tools and infrastructure to achieve high performance and rapid scalability

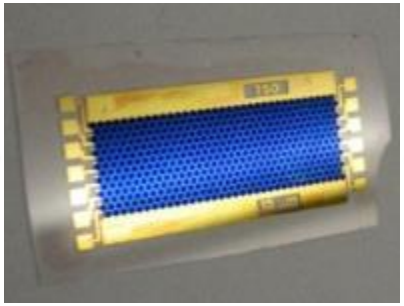


Uses standard wafers, fab tools, and solder interconnects to take advantage of fundamental scaling benefits in PV cells.

→

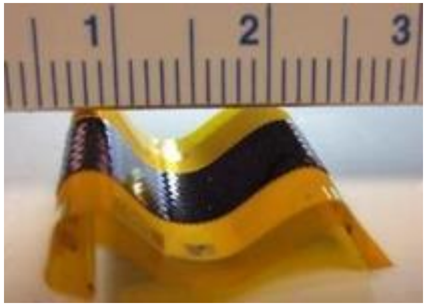
Assembly process compatible with existing electronics assembly tools and many substrate types

→



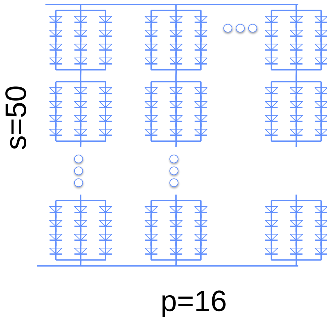
Large array of cells on wafer assembled and interconnected in one alignment/solder reflow step

→



Result is record setting performance in bend radius, W/kg produced, and overall module efficiency for highly flexible PV.

Logical Connections

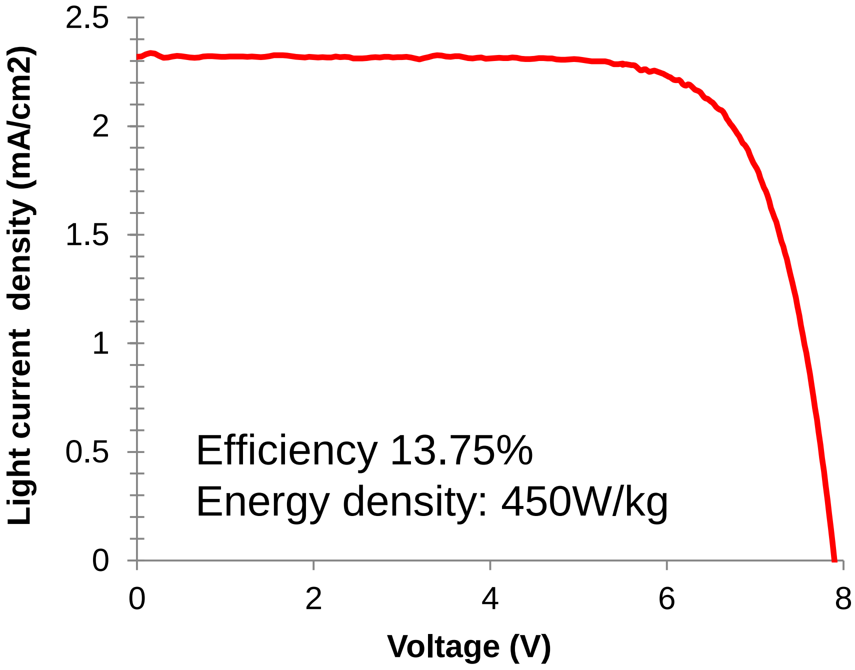


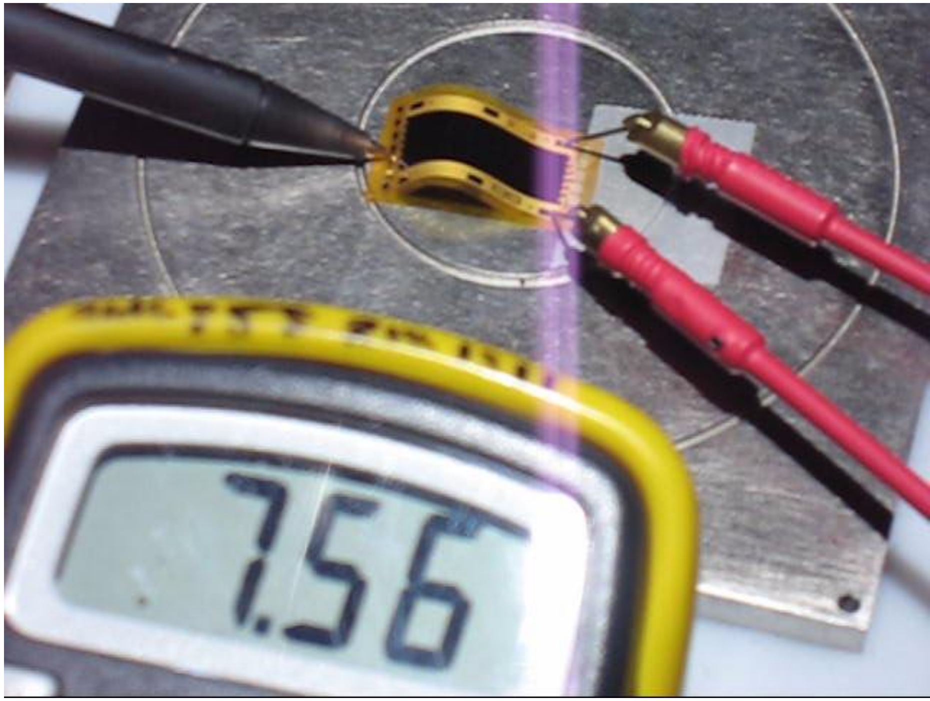
MEPV Cell Interconnect Network

Large numbers of MEPV cells in a module allow a sophisticated cell interconnect network circuit that provides:

- High tolerance to cell failures and or damage (holes, abrasions, etc.)
- Significantly better shading performance than current PV modules
- Direct high voltage output
- Potential for reconfigurable power output

Sandia is the first one to prove such a high energy density with such a small bending radius





The closest technology to energy density is an order of magnitude lower than what we achieved!

Acknowledgements

Sandia: Murat Okandan, Paul Resnick, Bill Sweatt, Tony Lentine, Vipin Gupta, Jeff Nelson, Carlos Sanchez, Judi Lavin, Peggy Clews, Tammy Pluym, Jonathan Wierer, George Wang, Jeff Cederberg, Bob Biefeld, Willie Luk, Igal Brener, Bradley Jared, Anna Tauke-Pedretti, Jennifer Granata, Charles Alford, Ben Anderson, Robert Biefield, Bradley Jared, Eric Langlois, Olivia Tsai, Scott Paap, Julie Chavez, Jaime McClain, Karen Cross, Terri Romantic, Brandon Aguirre, Jose Chavez, Xiaowang Zhou, Willie Luk, Douglas Pete

Collaborators: Mark Wanlass (NREL), Paul Sharps (Emcore), George Westby (Universal Instruments), Nathan Crane (USF), Mike Haney (UD), (Deposition Sciences), Chris Angeluci (IMI), David Zubia (UTEP), John McClure (UTEP)

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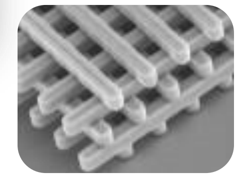
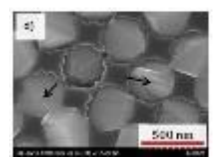
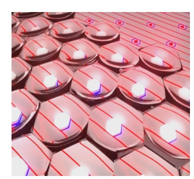
Conclusion



1. Sandia National Laboratories Overview
    1. Overview and Mission areas
        1. Defense Systems and Assessments
        2. Nuclear Weapons
        3. International Homeland and Nuclear Security
        4. Energy, Climate, and Infrastructure Security
        5. Science and Engineering Foundations
        6. Workforce
2. Solar microsystems
    1. CdTe micro/nano solar cells
    2. GaAs multijunction cells
    3. Concentrators
    4. Flexible Silicon





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Don’t forget to visit our booth in the UTEP career expo on September 19 and 20th, 2013 don Haskins Center

Thank you for your attention
Questions?