Outline

- Photovoltaics: Growth and Market
- Technology Directions & Challenges
- About CAPDS
- CAPDS Research Strategy
- Highlights

http://www.capds.uwaterloo.ca
World Annual PV Market

Year | Grid-connected | Off-Grid
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1999 | 69 MW | 107 MW
2004 | 838 MW | 212 MW
2009 | 7,553 MW | 360 MW
2014 | 18,104 MW | 546 MW
2014 | 47,231 MW | 572 MW

Worldwide PV Application and Growth Prediction

- **Grid-connected**
  - Residential grid
  - Commercial grid
  - Utility grid

- **Off-grid**
  - Communications
  - Cathodic protection
  - Transportation signals
  - Defense
  - Water pumping
  - Village power
  - Consumer items
Examples of Incentives

Feed-in-Tariff (FIT)

- **France**: 0.312 EUR/kWh (2008), 0.328 EUR/kWh (2009)
- **Germany**: 0.460 EUR/kWh (2003), 0.574 EUR/kWh (2004), 0.545 EUR/kWh (2005), 0.518 EUR/kWh (2006), 0.492 EUR/kWh (2007), 0.468 EUR/kWh (2008), 0.430 EUR/kWh (2009)
- **Spain**: 0.320 EUR/kWh (2009)
- **USA**: 0.320 USD/kWh (2009) (FL)

**Ontario Feed-in-Tariff (FIT)**

- 64 - 80 cents per kWh (<10kW)
- 44 - 71 cents per kWh (>10kW)

In 2008, about 290 Solar PV contracts were signed with a capacity of 526 MW.

There are about 300 solar energy companies (sales, wholesales, manufacturers, installers,..) operating in Canada.
Photovoltaics
Growth and Cost

PV global market growth prediction over the next 5 decades

What about the cost?
- Historically, every doubling of the volume produced prompted a cost decrease of about 20%.
- Module prices are now in the $3 – $5 /Watt, depending on the technology.
- Cost-parity with fossil-fuel based energy is expected to be achieved over the years.

“Affordability” goals and view of the Research Community

Should “reaching cost-parity” be the main goal?
- No.

Innovative material technologies and device concepts can bring the cost further down – much cheaper than traditional electricity.

The current, fast-growing PV market is based on traditional technologies.
→ Researchers have a dual role

(Data source: IEA solar PV roadmap 2010)
Technology Needs and Directions for Future PV

Technology Improvements
Innovation
Fine-tuning

New Concepts
Nanotechnologies
Ultra-high efficiencies
CAPDS R&D Approaches

"Mature" Technologies

- Silicon Wafer Technologies
  - Crystal Growth
- Thin film Technologies
  - Thin-film Deposition
  - Material Improvement
  - Improved Device Design
  - Fine-line Screen-printing
- Module Technologies

The "Middle-ground" Approach

- Some advanced concepts deployed on traditional technology platforms

"Future" Technologies

- Nanotechnologies: Engineered materials & Novel device architectures
  - Spectral-engineering
  - Plasmonic Thin-films
  - Smart Modules
  - Multiple Exciton Devices
  - Hot carrier PV Devices
  - Intermediate Bandgaps

Short - to - Medium Term

Long Term

"Middle-ground" Approach
About CAPDS

**Funding & Projects**

**CAPDS Research Activities**

**Funding**
- Industry
  - Funding Agencies
    - Federal
    - Provincial
    - University

**Research**
- Address industrial technology challenges
- Technology advancement for high performance
- Improvement in base semiconductor materials
- Affordable technologies (cells, modules)
- Fundamental research on Novel materials for PV
- Nanotechnologies
- Plasmonics
- New device concepts and Architectures for future PV

**Funding Agencies:**
- Natural Sciences & Engineering Research Council
- Canada Foundation of Innovation
- Ontario Innovation Trust
- Ontario Centres of Excellence
- Ontario Research Fund

**Collaboration with other Universities:**
- University of Toronto
- McMaster University
- University of Western Ontario

**Involvement of more than 8 faculty members from UW**
About CAPDS
Infrastructure

The Facility

- 14,000 ft² facility entirely dedicated for PV research
- Consists of several state-of-the-art laboratories

- PV METROLOGY AND CHARACTERIZATION LAB
- NANO-PHOTOVOLTAIC LABORATORY
- CLEANROOM FACILITY FOR DEVICE PROTOTYPING
- THIN-FILM AND ELECTROCHEMISTRY LAB
- HIGH TEMPERATURE PROCESSING LAB
- SILICON CRYSTAL GROWTH LAB
- INGOT AND WAFER PROCESSING LAB
- SCREEN-PRINTING LABORATORY
- HIGH-THROUGHPUT PROCESS FACILITY
- MODULE LAMINATION FACILITY
- COMPUTATION AND SIMULATION LAB

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Research Activities

- GROWTH OF BULK SEMICONDUCTOR CRYSTALS
- MATERIAL IMPROVEMENT TECHNIQUES
- ADVANCED THIN FILMS FOR PV DEVICES
- PHOTOVOLTAIC DEVICE DESIGN AND SIMULATION
- DEVICE FABRICATION TECHNOLOGIES
- NANO-STRUCTURE FORMATION (TOP-DOWN AND BOTTOM-UP)
- NANO PHOTOVOLTAIC DEVICE DESIGN AND FABRICATION
- TECHNOLOGY SCALE-UP AND HIGH THROUGHPUT PROCESSES
- ADVANCED LAMINANT MATERIALS AND MODULE ARCHITECTURES
- BACK-END ELECTRONICS
- HEALTH AND SAFETY EFFECTS OF NEW TECHNOLOGIES

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Crystal Growth
- Czochralski ingot pulling
- Poly-Si feedstock
- Impurity gettering
- Wafer characterization
- Fabrication of test PV cells
- New technology for Si ribbons

Wafering Technologies
- Wire-saw cutting
- New types of wires
- Reduced kerf losses
- Reduced crystal damage
- Dynamic modeling
**Stacked films for Quantum Dots**

- Deposition of stacked thinfilm layers
- Nano-scale thickness
- Formation of embedded Quantum Dots

**Epitaxial Thin Films**

- Perfect crystallinity throughout the film
- Abrupt PN junction
- High active carrier concentration
- Low sheet resistance
Process Scaling for High Throughput

**Fine line Screenprinting**
- 8” x 8” print area capability
- Semi-automatic fine line printing
- Alignment capability
- Conveyor belt IR lamp processing

**Module-making Capability**
- “Mini” (60 cm x 60 cm) modules
Formation of Nanowires

- Simple, top-down processing
- Photoluminescence down-shifting
- Spectral Engineering
- New device structures
New Device architectures for nanowire-based solar cells

- Filling the gaps by the epitaxial film for closely packed nanowires.

- Subsequent passivation and metalization is possible.

Void free planarization of wires
Quantum Dots for Photon shifting layers in Solar cells

- Tunable absorption/emission properties
- Broad absorption spectrum
- Simple deployment from solution by spin coating/drop casting

Absorption and Emission Spectra of Different Sizes Synthesized CdSe QDs