# Towards Very High-Performance Thin-Film Photovoltaic Cells: Designs & Implementations


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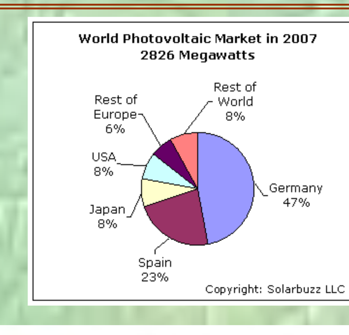
## Why Photovoltaics (PV)?

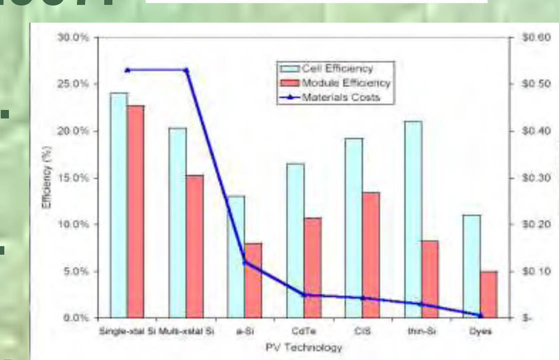
- **Increasing global energy demand**
  *PV is the major and most promising renewable energy source.*
  *PV systems are mature and reliable.*
- **Global warming**
  *PV provides carbon-free electrical energy.*
- **Sustainable development**
  *PV offers affordable and potentially unlimited electricity for both grid and local distribution, with various uses.*

## Why Thin-Film PV?

### Market driving forces:




♦ PV produced over 2826 MW in 2007.




♦ PV generated $17.2 billion in 07.

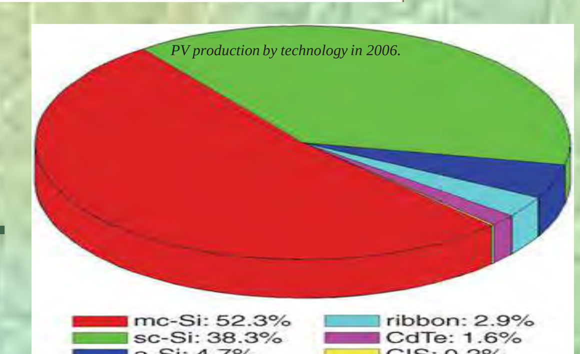
♦ 62% increase in 2007 over 2006.

♦ 88% of PV is c-Si and 12% is TF.

♦ Acute shortage of PV-grade Si supply.

♦ Thin film PV production doubled in 07.

♦ Thin films: fastest growing PV sector.




### Technology driving forces:

♦ Thin films technology is the focus for current and next generation PV devices.

♦ Technological merit of thin films over other approaches.

♦ Shift to Thin-film technology allows to address continuing demand for:

- ■ *Enhanced performance*
- ■ *Improved reliability*
- ■ *Increased lifetime*
- ■ *Reduced costs*

## How to Achieve High-Performance Thin-Film PV devices?

**Need for significant breakthroughs in thin-film PV:**

Existing Thin-Film PV Technologies: *Improved efficiency and/or lower fabrication cost;*

Future Thin-Film PV Technologies: *Novel materials, designs, processes and devices.*

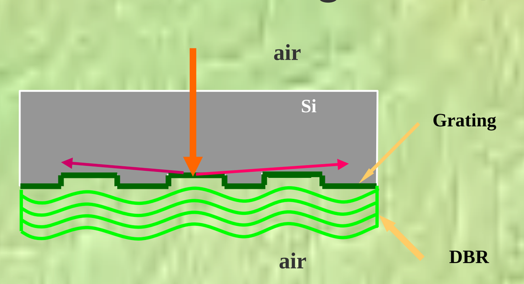
**Proposed research:**

*We propose three major areas of investigation in thin-film photovoltaics and thermophotovoltaics (TPV) as described below. These three research projects address some of the most challenging barriers and opportunities to realising the full potential of the thin-film PV sector worldwide.*

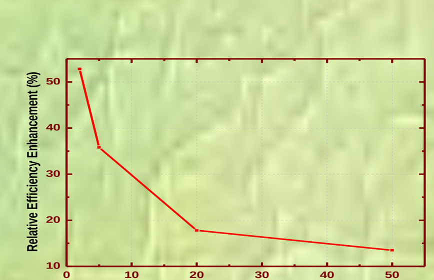
### High-efficiency thin-film Si PV cells with novel light trapping

Current Si thin-film solar cells suffer from low efficiency (13% vs 29%) due to their insufficient absorption of long-wavelength photons.

This research explores the use of advanced photonic crystal structures combined with a grating to extend, by several orders of magnitude, the optical path length in PV cells.




*A combination of grating and 1D photonics crystal has near unity reflectivity and redirects vertically propagating light to a lateral vector.*

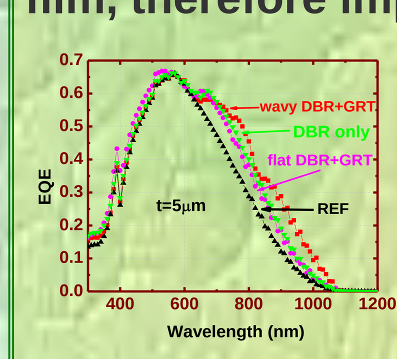



*Relative efficiency enhancement vs. cell thickness for solar cells with optimized back reflectors.*

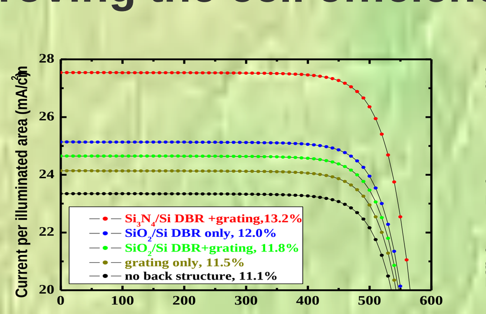
DBR alone shows only a doubling of the path length for photons with wavelengths longer than 700nm.

The grating alone improves the efficiency by scattering photons into the thin Si film, extending the photon path length even further (L. Zeng, PhD, MIT, 02/2008).

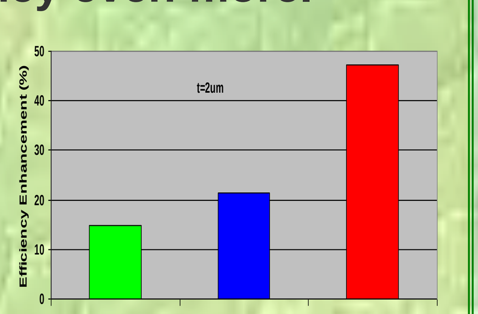
The combination of both methods, labeled TPC, extends photon path length and prevents scattering out of the Si film, therefore improving the cell efficiency even more.




*EQE of solar cells with different backside structures.*

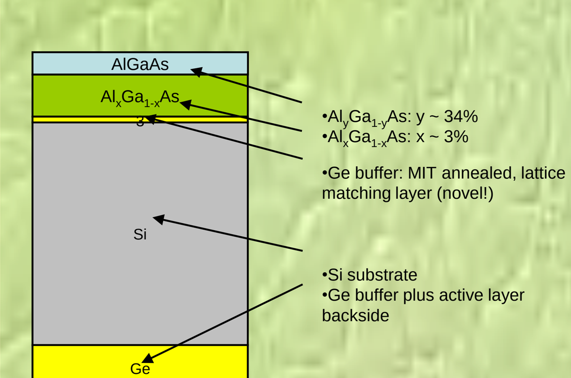



*I-V characteristics of solar cells with different backside structures.*

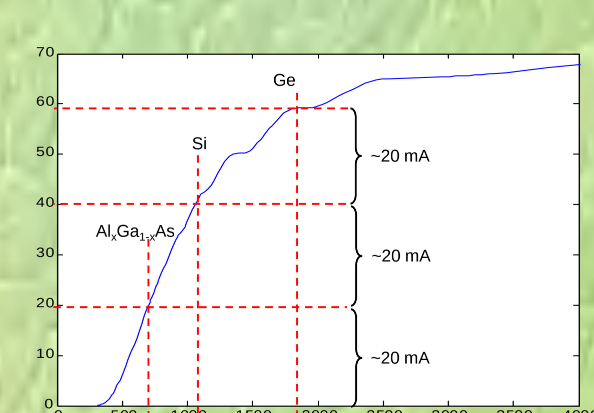



*Efficiency enhancement of solar cells with different backside structures.*

### AlGaAs/Si/Ge tandem PV cells for ultra-high efficiency




*Structure of $Al_yGaAs/Al_xGaAs/Si/Ge$ tandem PV cells.*




*Cumulative Current Density of AM1.5G to be generated by each cell.*

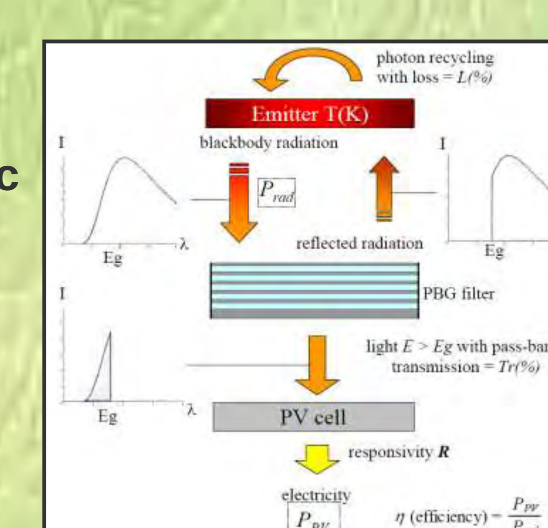
- To design and implement a tandem cell innovation based on $(AlGaAs)^m$/Si/Ge structures.
- Multiple AlGaAs layers (m) with different compositions can be used.
- Our simulation shows that the efficiency of the tandem cell with m=2 can be as high as 58 % under AM1.5G and should increase with m up to the theoretical limit.
- AlGaAs will be epitaxially grown on the font on Si wafer.
- Ge will also be used as part of the tandem cell on the backside of the wafer for NIR photocurrent generation.

The concept of "Double-junction Three-terminal Photovoltaic Devices" is being used (M. Emziane et al., *J. Appl. Phys.,102 (2007) 074508.)*

Although initially focusing on TPV and conventional PV (i.e. PV under one sun illumination), this proposed research can be extended, as appropriate, to investigate the performance of the resulting PV cells under solar concentration.

### Ge-based thin-film TPV cells with photon recycling

Thermophotovoltaics is the conversion into electric power of the IR radiation emitted by a heat source using a device that is similar to a photovoltaic cell.




*Schematic of a TPV system with a photon recirculation scheme.*

The goal of the proposed research is to develop monolithic TPV cells based on a Ge epitaxial layer on Si wafers, with a photon recirculation scheme (filters) to enhance the overall device performance.

Using a suitable PBG filter on top of the Ge PV cell, the reflectance for the below-gap radiation will be maximized while the reflectance for the above-gap radiation will be minimized.

Hetero-epitaxial Ge on Si has two advantages over bulk Ge for TPV applications:

- The size of Si wafer, making Ge devices cost-effective;
- The thermal-mismatch induced strain shrinking its bandgap and making it even more suitable for IR conversion from a heat source.

## Long-Term Ambition & Broader Impact:

- ♦ Establish an advanced and viable PV research activity at Masdar Institute of Science and Technology;
- ♦ Develop new manufacturable thin-film PV devices, and low-cost fabrication processes;
- ♦ Provide technical foundations and solutions for the local PV industry that is being established;
- ♦ Innovate, and help establish new start-up companies in the PV-related sector;
- ♦ High-quality training for indigenous staff, know-how, human development, and job opportunities.

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Question or comment?


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