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Exceptional service in the national interest

Sandia National Laboratories

Power on Demand

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. 2011-XXXXP

Power on Demand,

By Command,

With the Wave of

Your Hand

Vipin P. Gupta

Materials, Devices, and Energy Technologies

Nov 14, 2015

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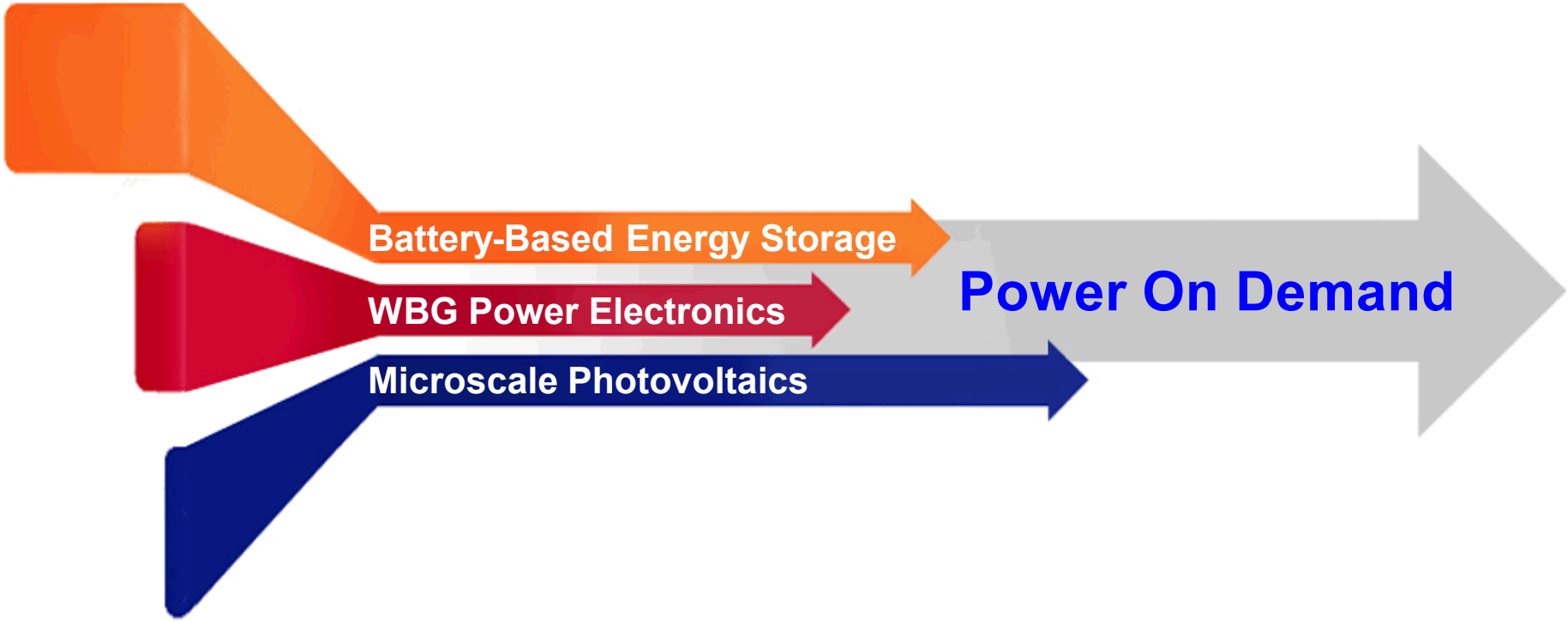
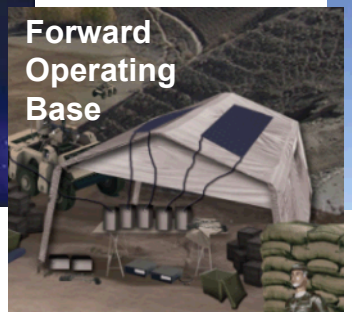
Our Historical Mission

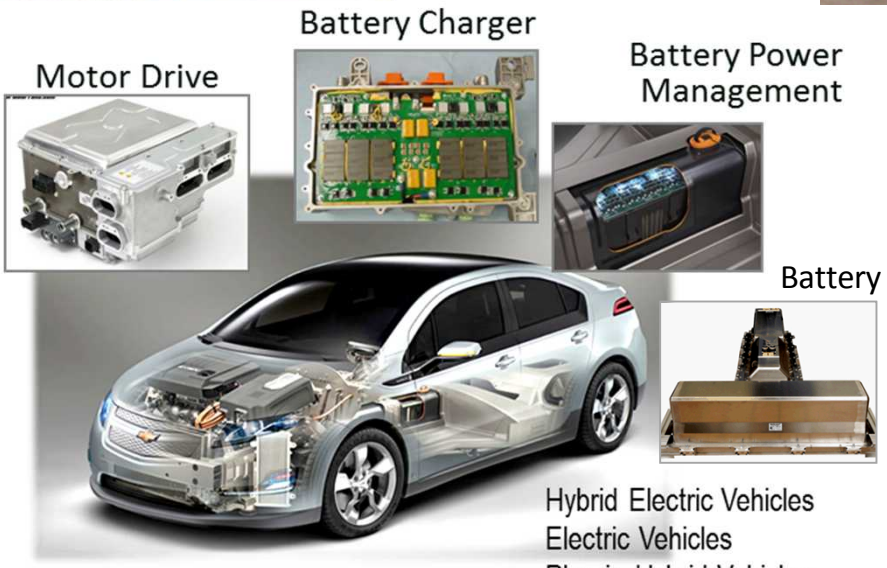
- Deliver electrical power in a controlled, safe and secure way for nuclear weapons
- Develop greater functionality, with ever decreasing size and weight requirements

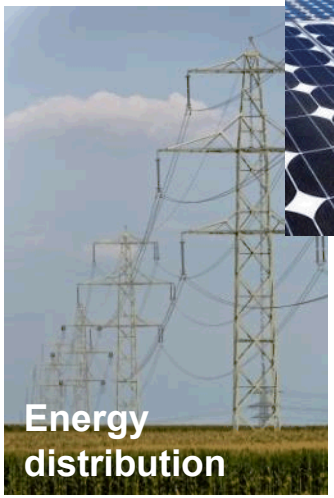
Three Technology Thrusts



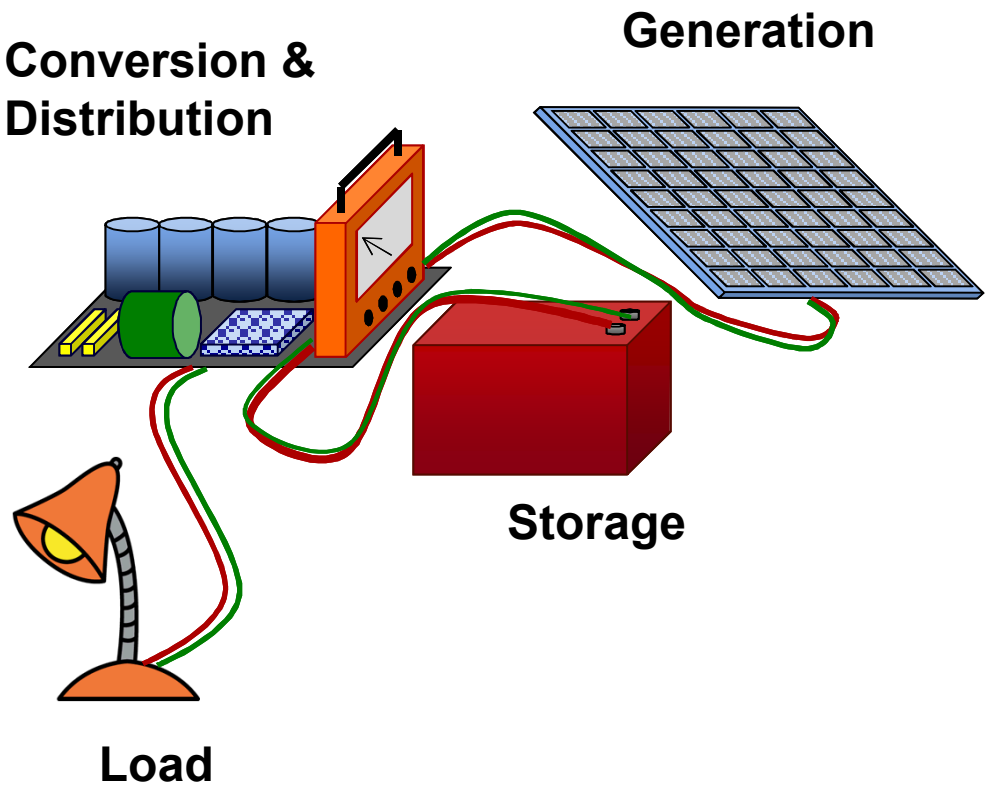
Specific Applications





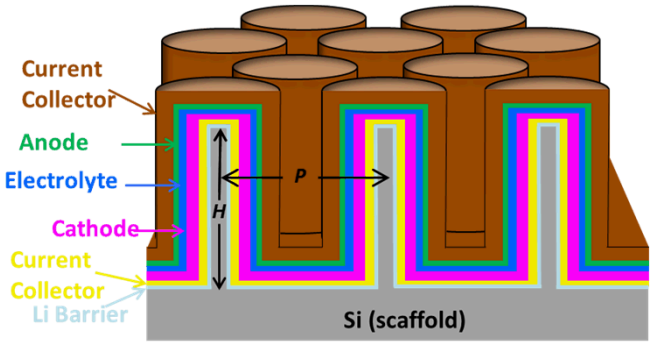


Our Goal



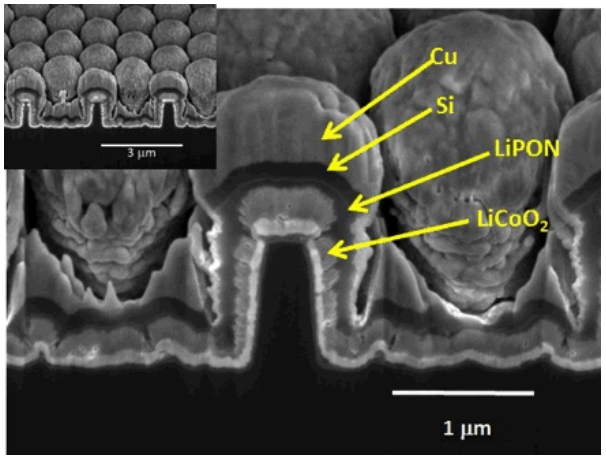
By 2025, demonstrate a 10X decrease in the size, weight and added power consumption of one or more electrical power systems for both stationary and mobile applications

3-D Solid State Batteries



Technical Challenges:

- **Power**: For high power, ion mobility through the electrolyte is often the bottleneck.
- **Durability and lifetime:** Irreversible side reactions, which are especially susceptible in liquid electrolytes, consume active material and rob batteries of capacity over time.
- **Safety:** Most Li-ion battery fires are caused by ignition of the volatile electrolyte during overheating.



Prospective Solution:

- **Power:** Solid-state electrolytes enable tuning of ion conductance through materials modification.
- **Durability and lifetime:** Solid-state electrolytes have limited side reactions, dramatically increasing shelf-life and overall durability. It also enables new anode and cathode combinations that allow for increased energy density.
- **Safety:** Solid electrolytes eliminate the danger of aerosolization, reducing flammability.

Microscale Photovoltaics (www.mepv.gov)

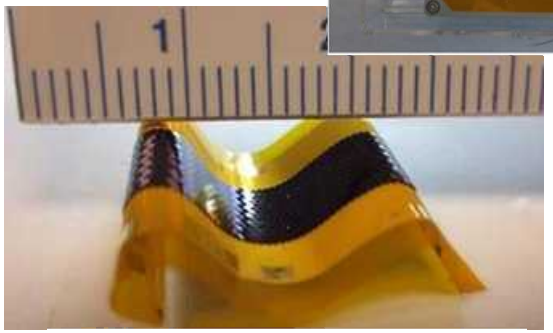
Technical Challenges:

- **Cost**: Validating a probable path to the lowest cost electricity option
- **Massive Parallel Assembly:** Developing tools to handle and place microscale PV cells quickly and accurately
- **Design Prototyping:** Building designs that show advantages associated with going small

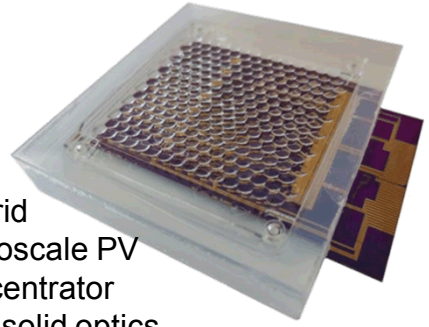
Prospective Solutions:

- **Cost:** Modeling $/W$_p$ at the cell, module, and system level
- **Massive Parallel Assembly:** Micro Chiplet Printing, 2-D Spreading
- **Design Prototyping:** Building PV patches and devising new CPV designs

Pair of Sandia microscale PV modules currently operating on Int'l Space Station



Flexible microscale PV module



Hybrid microscale PV concentrator with solid optics

MEPV

Microsystem Enabled Photovoltaics

ARPA-E MOSAIC Award: Micro Chiplet Printer

Project Objective

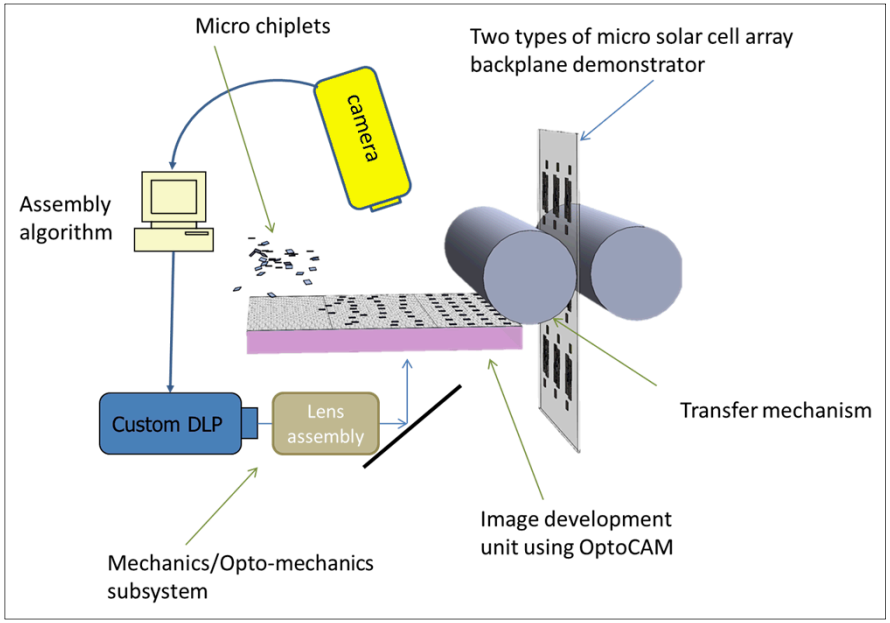
Develop a prototype that can print microscale PV cells onto a concentrated PV backplane

Approach

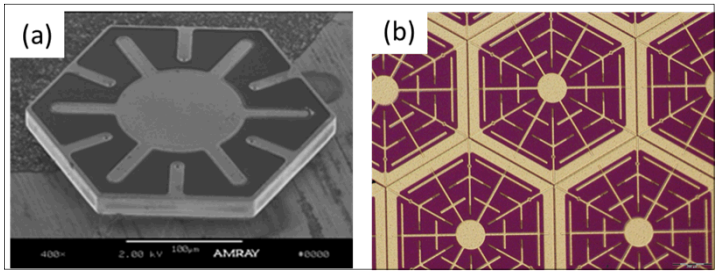
Use PARC's digital xerographic process for parallel, high-throughput assembly of microscale chips and Sandia's microscale PV cells as the "ink"

Project Cost and Duration

~$2 million over 36 months starting in late 2015

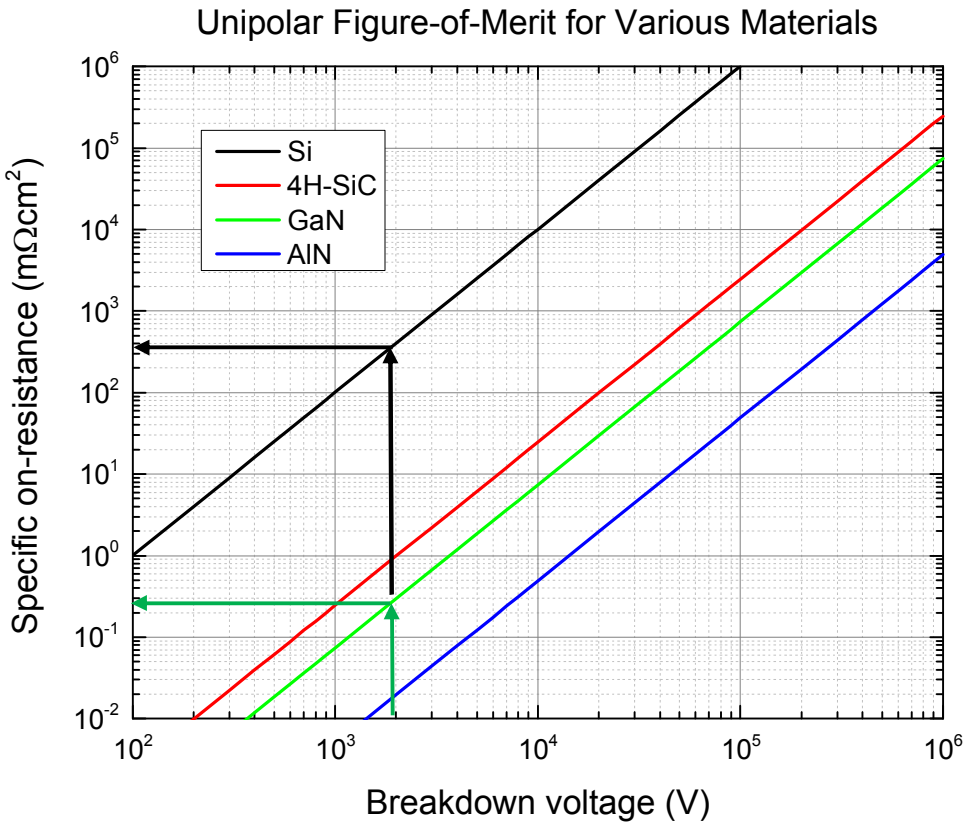


Proposed PARC/Sandia Micro-Chiplet Printer



SEM micrograph of 250 micron released and unreleased PV cells

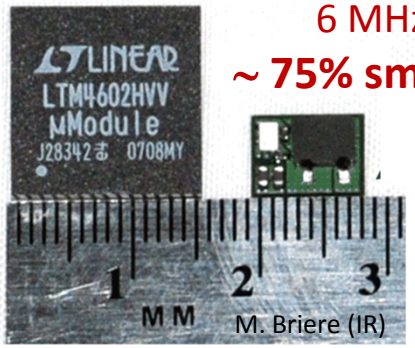
Ultra Wide Bandgap Power Electronics



- **For equivalent breakdown voltage, get lower $R_{on}A$ for WBG device**
  - **For same R_{on}, WBG device can have *smaller area***
  - **Smaller area results in *less capacitance***
  - **Gives a *faster switching transient* and *lower loss per switching cycle***

Si
15x15mm²
100 kHz

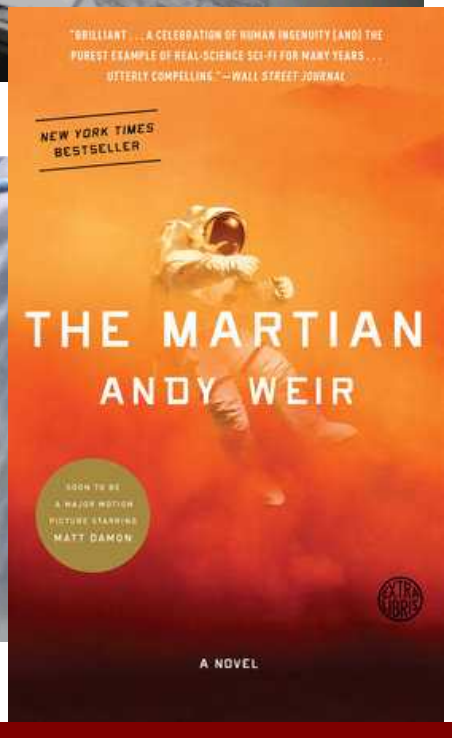
GaN
6x9mm²
6 MHz
~ 75% smaller



1.2 kV, 12 A switch

Scaling that results from the properties of WBG and UWBG materials can be utilized to optimize for switching frequency, conduction loss, and switching loss

Engineering our Future



The use of math and science

to harness energy and matter

for improving the human condition

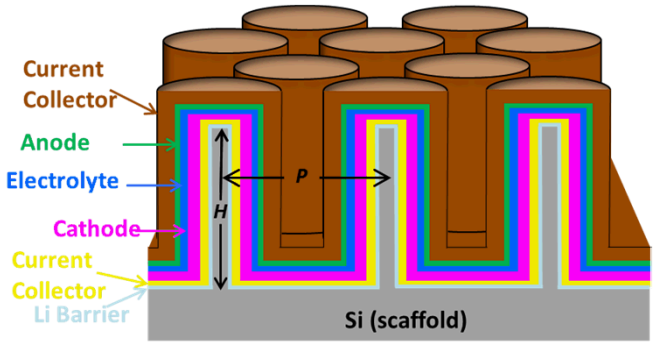
and the places we live.

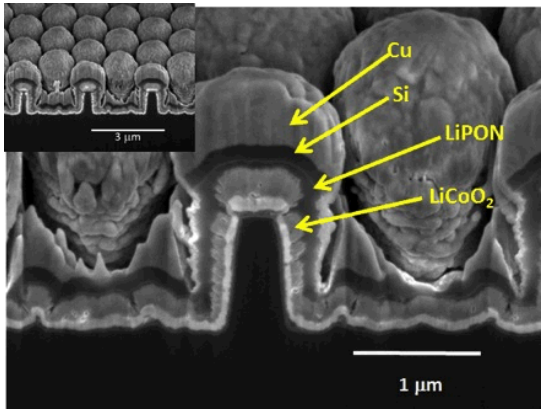
Backup Slides

EFRC: 3-D Solid State Batteries

The Promise:

- 3D batteries offer the promise of *high energy density* and *high power density* in a small footprint area
- 3D geometry maximizing the *active volume per unit area*
- High electrode/electrolyte *surface area*
- Vapor deposition methods developed for planar systems need improvement





A Grand Challenge LDRD on Solid-State Batteries is being written for FY16

Microscale Photovoltaics

- **Goal of the thrust:** Develop capabilities in "special applications photovoltaics", especially for NW & DSA customers
- **Flagship project:** Microsystem-Enabled Photovoltaics Grand Challenge LDRD, completed October 2014; Spin-off company started
- **Synergistic projects underway:** Hybrid Microscale PV Concentrator Operating in Direct and Diffuse Light Conditions (ONR); Camo-Patterned Microscale PV (US Army Natick Soldier RDEC)
- **Synergistic projects being pursued:** NW optical bus needs; ARPA-E MOSAIC, NASA Office of Game Changing Development
- **Materials science challenges:** Microscale PV Cell Bonding, Parallel Assembly

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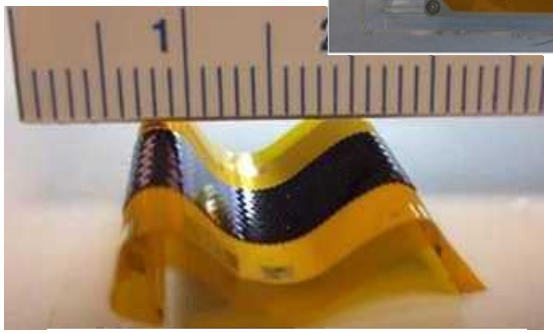
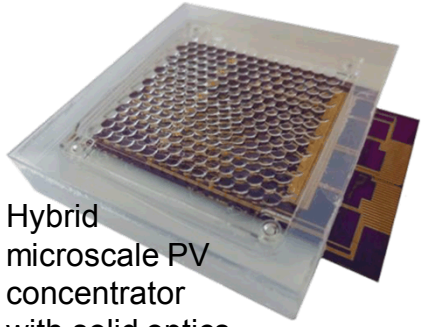


Flexible microscale PV module



Hybrid microscale PV concentrator with solid optics

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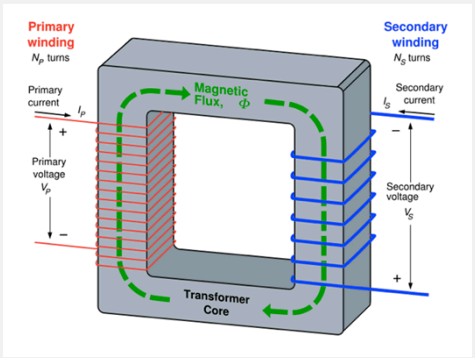
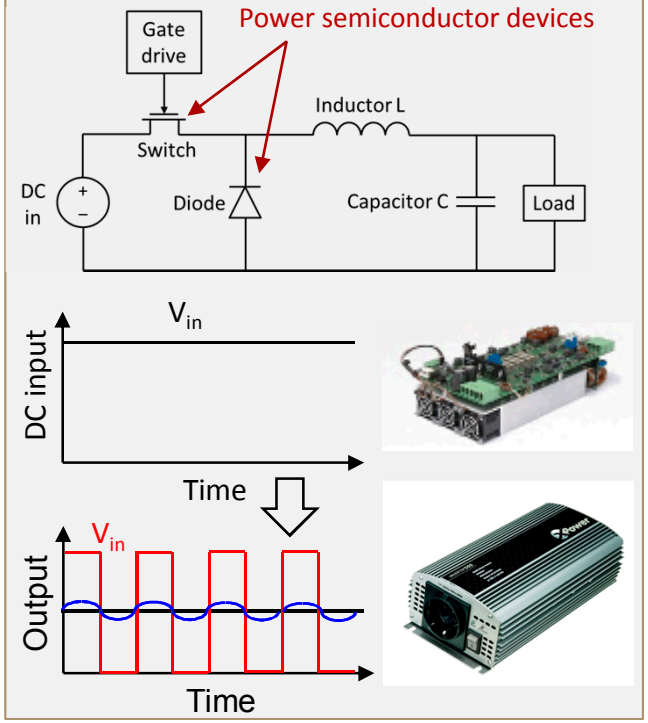
What Are Power Electronics?

- ***Power electronics*: Application of solid-state electronics for routing, control, and conversion of electrical power**

Passive transformers (dumb)



Power Electronics – active switching (smart)



- **Current power electronics are limited by the properties of silicon semiconductor devices**
- **New system capabilities are enabled by:**
  - **Higher switching frequency (enables better SWaP)**
  - **Lower power loss**
  - **Higher temperature operation**

➢ ***Motivation for WBG/UWBG semiconductors***