Material Needs for Thin-Film and Concentrator Photovoltaic Modules

NREL

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Outline

• Solar – a huge success, but still a long way to go

• Material requirements:
  • Low cost
  • High performance
  • Excellent reliability

• Materials for thin-film and concentrator PV
  • Support (substrate, superstrate)
  • Encapsulation
  • Electrical connections (inside and out)
  • CPV – optics, heat sinking, etc.
Solar energy is abundant

Convenient truth: small area can supply our energy needs

Average Daily Solar Radiation Per Month

At 10% efficiency, area needed for US electricity

5-6 kWh/sq m/day

>10 kWh/sq m/day

Two-Axis Tracking Flat Plate

Sunlight reaching earth in 1 hour is enough to power the world for 1 year.
Growth of photovoltaic (PV) industry

Maintaining growth rate requires reduction in cost & adequate availability
Growth of PV industry

If we can maintain the current growth rate, PV will reach major milestones in < 10 yrs.

Annual replacement of electricity capacity for 20 yr cycle
Annual new electricity capacity 1996-2006*

*www.eia.doe.gov/emeu/international/electricitycapacity.html (4012-2981 GW)/10 yr
Ongoing needs motivate use of new materials

- Manufacturability
- Availability
- Low cost
- Performance
- Reliability
Three key approaches to photovoltaic (PV) panels

1. Silicon
   - Reduce cost by reducing use of semiconductor

2. Thin film

3. Concentrator

Two strategies to reduce semiconductor material
Many technology choices

**Best Research-Cell Efficiencies**

- **Multijunction Concentrators**
  - Three-junction (2-terminal, monolithic)
  - Two-junction (2-terminal, monolithic)

- **Single-Junction GaAs**
  - Single crystal
  - Concentrator
  - Thin film

- **Crystalline Si Cells**
  - Single crystal
  - Multicrystalline
  - Thin Si film

- **Thin-Film Technologies**
  - Cu(In,Ga)Se₂
  - CdTe
  - Amorphous Si:H (stabilized)
  - Nano-, micro-, poly-Si
  - Multijunction polycrystalline

- **Emerging PV**
  - Dye-sensitized cells
  - Organic cells (various technologies)

Innovation for Our Energy Future
One “winner” or many technologies?

Alkaline  
Nickel cadmium  
Nickel metal hydride

Lead acid  
Lithium ion  
Lithium

Different technologies for different applications
Thin-film approaches on the market

- CuIn(Ga)Se
- CdTe
- Amorphous silicon
Typical thin-film structures require many materials

CdTe uses superstrate:
- Glass
- ITO or TCO
- CdS
- CdTe
- Metal
- EVA
- Glass for strength

CuInGaSe uses substrate:
- Glass for protection
- EVA
- ZnO or TCO
- CdS
- CuInGaSe
- Molybdenum
- Glass

Not to scale
Monolithic module integration

Contact Cell (Inactive)

Active Cell

Contact Cell (Inactive)

Glass

5 x 120 µm

Conductor

Device

Conductor

w
Substrate/superstrate

Glass is transparent, strong, inert, and relatively cheap
Glass is relatively heavy, breakable, and more expensive than desired
Light-weight, flexible substrates are desired, especially for building-integrated applications
- strong (mechanically, durable to UV, moisture, etc.)
- withstand processing of solar cells
- inexpensive
Packaging is essential to PV reliability

Packaging needs:
- Keep water out
- Resistant to UV
- Resistant to temperature cycling and high temperatures
- Inexpensive
- Front packaging must be transparent (~ 300-1100 nm)
- Adequate adhesion
- Easily processed
Flexible CIGS requires reduced sensitivity to moisture

ZnO (and other transparent conductors) react with moisture, causing increase in series resistance

Two strategies:

- Harden the cell (e.g. Sundaramoorthy, et al 34th PVSC)
- Harden the packaging (barrier coatings)
Electrical connections

Monolithic interconnections avoids need to tab every ‘cell’

Need two wires coming out:

- Connect to end cells
- Bring contacts to junction box
- Junction box (and mounting) has similar requirements to silicon modules

- Pressure-sensitive adhesives are controversial
Variety of material needs for thin-film PV

- Edge seal may allow water into glass/glass module
- Desiccant may be useful
- Adhesion to glass can be problem – add materials/coatings to improve adhesion
- Role of sodium is important in CuInGaSe modules, but sodium can move; may intentionally add sodium
- Currently, the biggest effort with CuInGaSe is to try to put it on a flexible substrate – requires excellent barrier coating unless cell can be hardened to moisture
- Organic PV uses mostly low-temperature processes
Range of concentrator approaches

High concentration
- 35% - 40% cells
- 400X – 1500 X

Low concentration
- 15% - 25% cells
- 2X – 100 X
UV transmission depends on design

Analysis of transmitted optical spectrum enabling accelerated testing of CPV designs

SPIE 2009 David Miller, et al
Bonds to heat sink and optics

- Optical bond with 100% Transmission
  - 50 W/sq cm

Small $\Delta T$ (<10°C)
- Electrical isolation
- No voids
- T cycle OK

DBC (direct bonded copper) performs well, but is expensive
- Intense UV may be a substantial problem, but optics may not transmit UV

IR image of void in die attach
Bosco, et al 34th PVSC
CPV – many parts

CPV has many parts

- Optics – lens, mirrors, (primary & secondary); glass, plastic, metal, film, etc.
- Cell encapsulation – water out, resistant to UV
- Thermal contact – low cost; electrical isolation
- Heat sink – must be electrically isolated, but excellent thermal contact
- Strategy for letting air in, while keeping dirt out (filters?)
Concentrator technology

Creative designs?
Summary

• Solar is growing rapidly and could become a significant source of electricity within our lifetimes
• Packaging is essential to success of PV
• Key material needs for thin-film and CPV include:
  • Structural support (substrate/superstrate, frames, etc.)
  • Electrical connections to cells
  • Electrical connections to outside world
  • Packaging to keep water out
    • Encapsulants
    • Barrier coats
    • Edge seals (maybe even desiccant)
  • Thermal contacts for CPV
  • Optical materials for CPV
Planet powered by renewable energy
By year 2100 or before?

Thank you for your attention!