Novel Lamination Method for Transparent Armor Panels

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Ceralink Inc.
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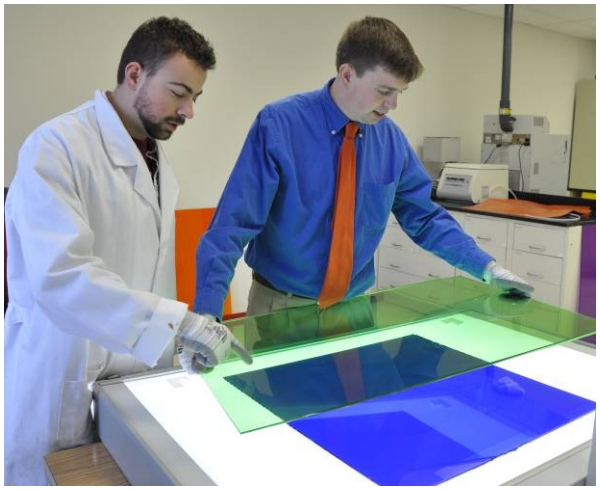
Outline

- Ceralink
- Intro to FastFuse™
- Products
  - Demonstrated applications
- Process
  - How FastFuse works
  - Demonstrated sizes
  - Energy
  - Quality



Ceralink

- Materials processing and technology development
- Focus on innovative manufacturing technologies
- Specialize in microwave & RF heating
- Founded in 2000 by Dr. Holly Shulman
- 3,200 sq. ft. facility in Troy, NY
- Small, woman owned business
  - 6 engineers/scientists
  - 1 co-op student engineers
  - 2 business & support

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Ceralink Collaborations

- Industry
  - BASF
  - General Electric
  - Pilkington Industries
  - Touchstone Research Laboratories

- Government
  - New York State Energy Research & Development Authority (NYSERDA)
  - U.S. Department of Energy
  - NSF
  - NASA
  - U.S. Navy, Marine Corps

- University
  - Rensselaer Polytechnic Institute
  - Worcester Polytechnic Institute
  - Florida International University
  - Alfred University
  - University of Illinois at Urbana-Champaign

FastFuse Process
Lamination state-of-the-art

- **Methods – FastFuse Competition**
  - Autoclave (PVB, TPU) → 100 – 300 psi
  - Vacuum oven (EVA)

- **Features**
  - Large batches, 1 to 6 hour processes
  - Slow process development
  - **Energy Intensive**

- **Interlayers**
  - **TPU -** Thermoplastic polyurethane – **Armor**
  - **PVB -** Polyvinyl butyral – **Auto, Security**
    - Clear, printed
  - **EVA -** Ethylene vinyl acetate – **Solar, Decorative**
    - Clear, colored, opaque
  - Liquid resins/UV curable interlayers

Glass Autoclave

Vacuum Laminator
in US Glass Magazine 2009

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FastFuse Overview
Products

FastFuse is applicable to most glass laminated products

- Transparent armor
- Solar/PV panels
- Automotive glass
- Architectural glass
  - Mirrors
  - Furniture

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FastFuse™ Overview

- Glass lamination → new application using RF equipment
- Substantial process time & energy savings – **over 90%**
- Ceralink applied for U.S. patent pending
- DoE and NYSERDA supported - $950,000
- Total investment - $1.6 Million 2006-2011
- Featured at www.FastFuse.net

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FastFuse Overview
RF Lamination Technology

- DoE sponsored initial R&D (2006-2009)
  - Feasibility established for many laminate systems
  - 90+ % energy and time savings validated
  - Several industry contacts established
- NYSERDA sponsoring commercialization (2009-2011)
  - Feasibility testing and process development
  - Partnering to commercialize specific applications
- DoE Industrial Grand Challenge (2010-2011)
  - Pilkington Industries, University of Illinois Urbana-Champaign
  - Curved window lamination
- Ceralink and Thermex Thermatron bringing FastFuse™ to industry

FastFuse Applications

Structural Layers & Interlayers

Ceralink has established feasibility for several flat laminated products

- Clear & Colored Glass
- Metallized (Low-E) Glass
- Acrylic
- Polycarbonate
- Ceramics
- Silicon PV cells
- Polyester films

PVB – Polyvinyl butyral
- DuPont Butacite®
- Solutia Saflex®
- Sekisui S-LEC®

Printed PVB
- DuPont SentryGlass Expressions®

EVA – Ethylene vinyl acetate
- Sekisui S-LEC® EN
- Bridgestone EVASAFE™
- Kin Yong Fa
  - clear, colored, opaque

TPU – Thermoplastic polyurethane
- Deerfield Urethane Dureflex®
- Huntsman Krystalflex®

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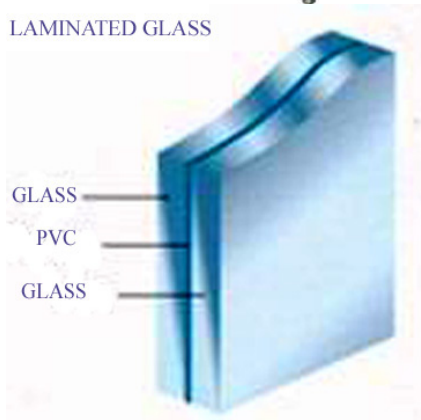
FastFuse Process
RF Lamination Technology

Method to make laminates faster and more efficient

- **0.5 to 3 minute cycles – most products**
- **Up to 5 minutes for thick armor panels**
- Cuts energy over **90%**
- Heats interlayer directly
- Applies pressure
- New process using existing equipment
- Allows fast development
  - 50+ experiments in 1 day
  - Custom one-off manufacturing
  - Rapid quality feedback

Thermex Thermatron RF Press with shuttle



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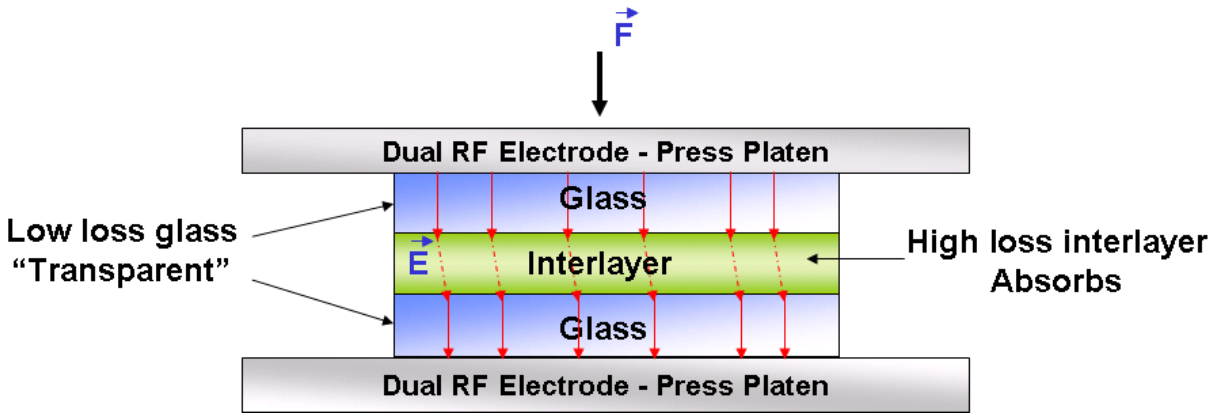
FastFuse Process
RF Lamination Technology



Rapidly alternating electric field creates friction – *Dielectric Heating*

Polar "lossy" materials tend to heat
Vinyls, polyurethanes

Non polar materials will not heat
Olefins - polyethylene, polypropylene, PTFE, ETFE

Intermediate materials include
Acrylics, polycarbonate, glass, nylons, polyesters

Conductive materials transmit RF

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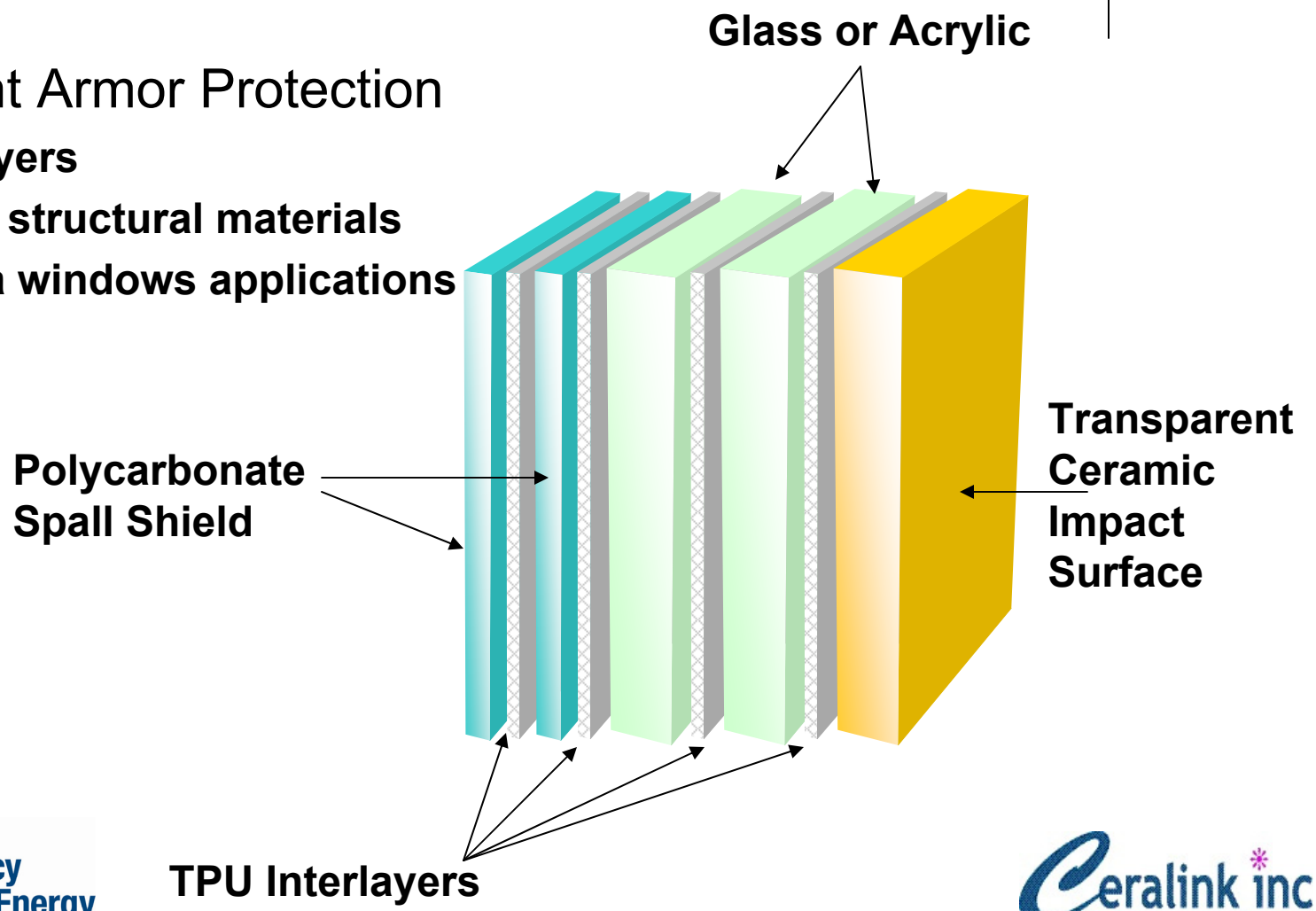
FastFuse Applications
Laminated Transparent Armor

Transparent Armor Protection

- **Several layers**
- **Dissimilar structural materials**
- **Small area windows applications**



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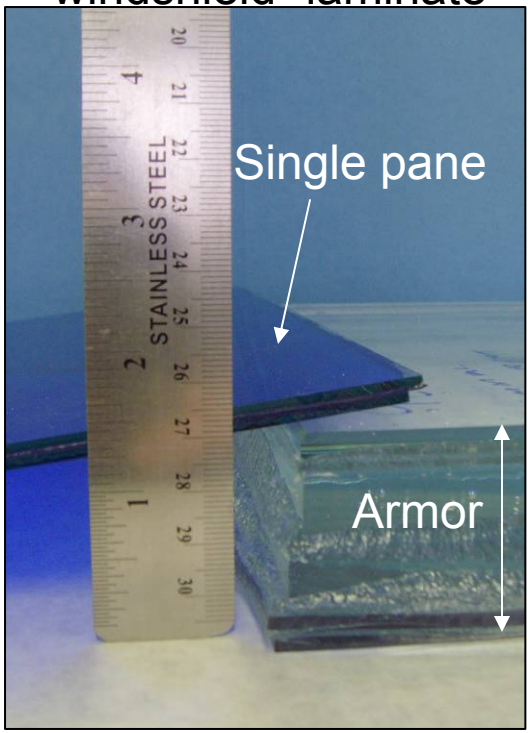
Patel, P.J., A.J. Hsieh, and G.A. Gilde, *Improved Low-Cost Multi-Hit Transparent Armor*, in *25th Army Science Conference*. 2006: Orlando, FL.

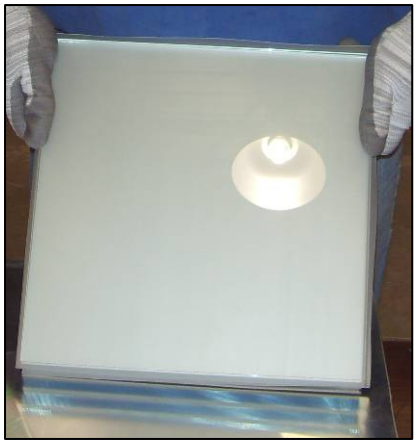
FastFuse Applications
Laminated Transparent Armor

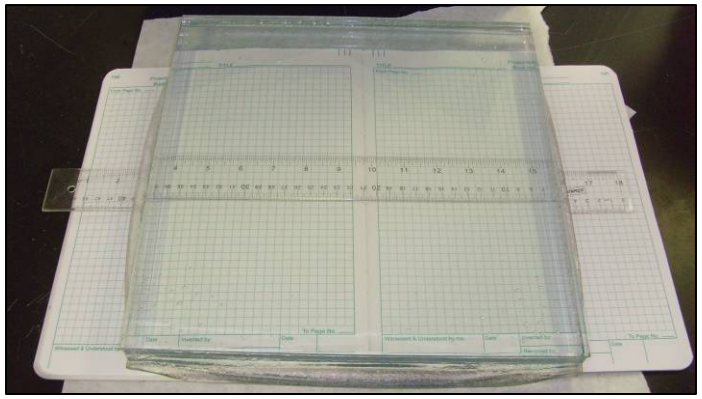
Armor thickness compared to single-pane "windshield" laminate



Vacuum bag with panel loaded into RF Press for FastFuse lamination

5 minute press





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FastFuse Process Quality

EN ISO 12543-4 Accelerated environmental testing

Boil, 100 °C, 2 h
Bake, 130 °C, 2 h

- Sekisui S-LEC EN **Passed**
- Bridgestone EVASAFE **Passed**
- Deerfield A4700 TPU **Passed**

- Baked PVB bubbles
  - due to use of "aged" PVB – resolving with Pilkington

ASTM C1172 visual inspection **Passed**

ATPD 2352 – Army Transparent Armor Purchase Specs

Meets or exceeds optical specs
Ballistic performance equivalent to autoclaved

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Environmental Quality

Deerfield A4700 TPU – RF laminated, aged 2 years

- Submerged in 100 °C boiling water for 2 hours
- Sample **passed** testing
  - no new bubbles
  - no delamination
  - no hazing

Deerfield A4700 TPU

FastFuse Process
RF Laminated Area

Demonstrated sizes

36” x 24”	6 ft^2
24” x 24”	4 ft^2
18” x 16”	2 ft^2
12” x 12”	1 ft^2
9” x 9”	0.56 ft^2
6” x 6”	0.25 ft^2
4” x 4”	0.11 ft^2

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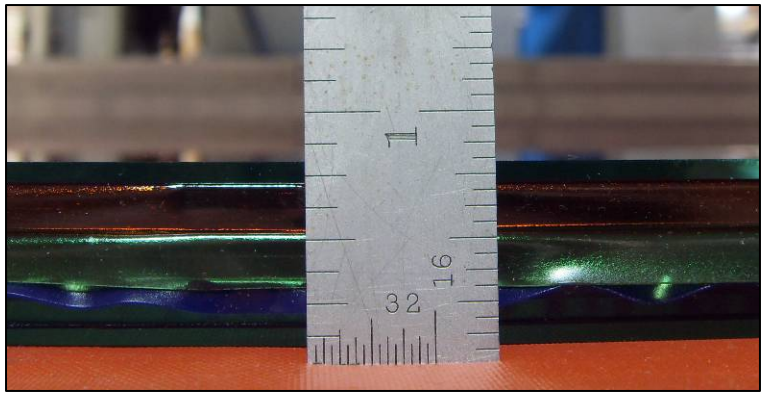
FastFuse Process Layers

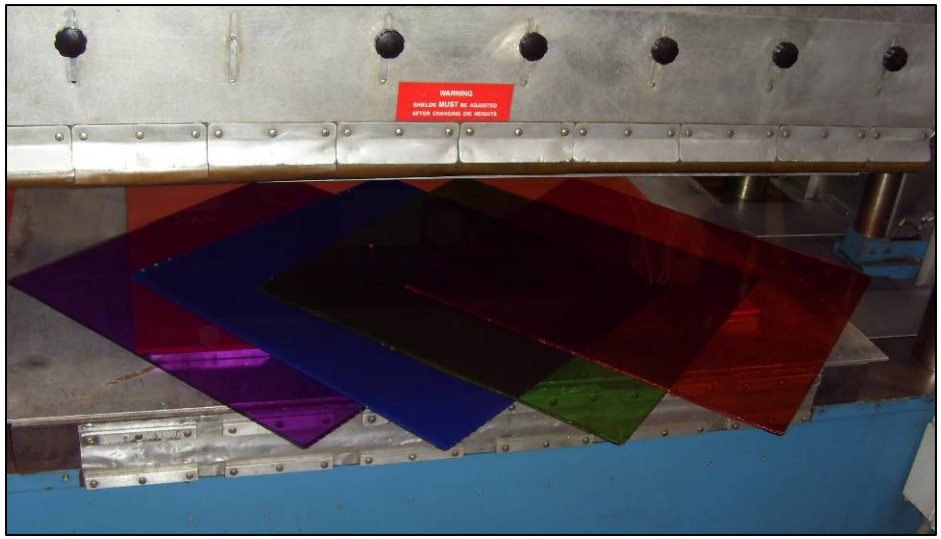
4 laminates, 2’ x 2’ each

16 ft^2 in 3 minutes

Energy Consumed: 0.76 kWh

47.5 kWh / 1,000 ft^2





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Autoclaving energy 1150 to 4000 kWh / 1,000 ft^2

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RF Presses

4 ton, 18” x 20”

19 ton, 30” x 40”

700 ton, 48” x 120”

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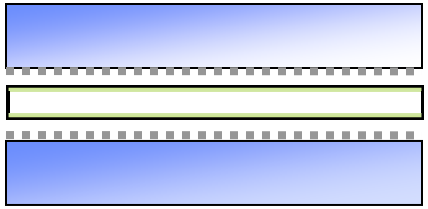
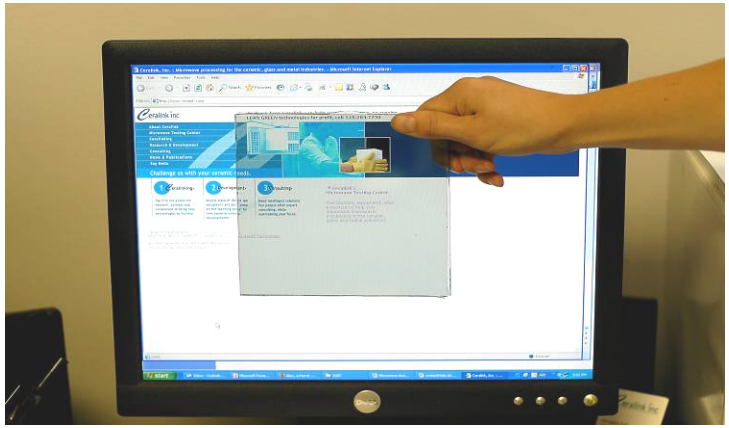
Metallization

- Glass is metallized on one side for tinting, IR reflection
- Capacitive coupling transmits RF across metal layers
- Low-E Glass was laminated with EVA
- Applications:
  - RF shielding
  - Reflective coatings
  - Mirrors



Metallized Glass

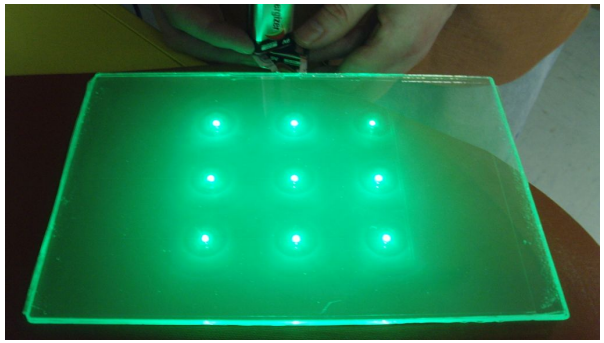


RF Laminated Low-e Glass
150 mm x 150 mm

Embedded electronics

- **Light emitting diodes (LEDs)**
- **Sensors**
- **Antennas**

3-color LED
Blue-Green-White
after press
9” X 9”
glass with PVB



9 Green LEDs
after press
6” X 9”
glass with EVA

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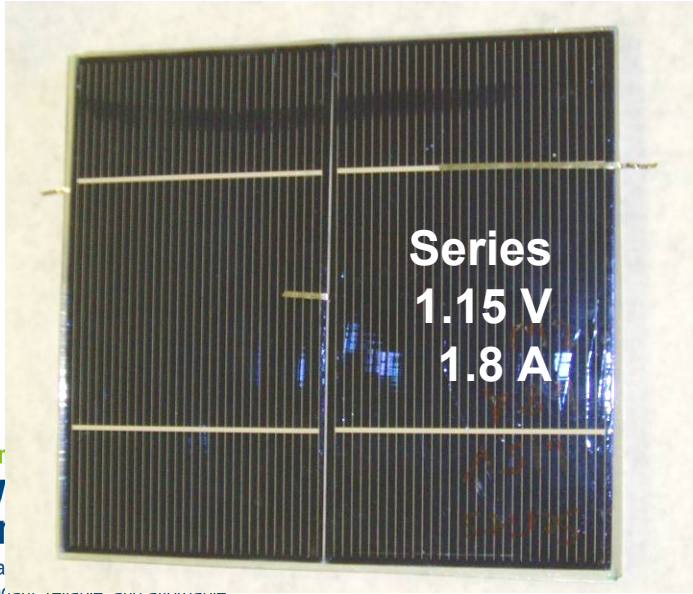
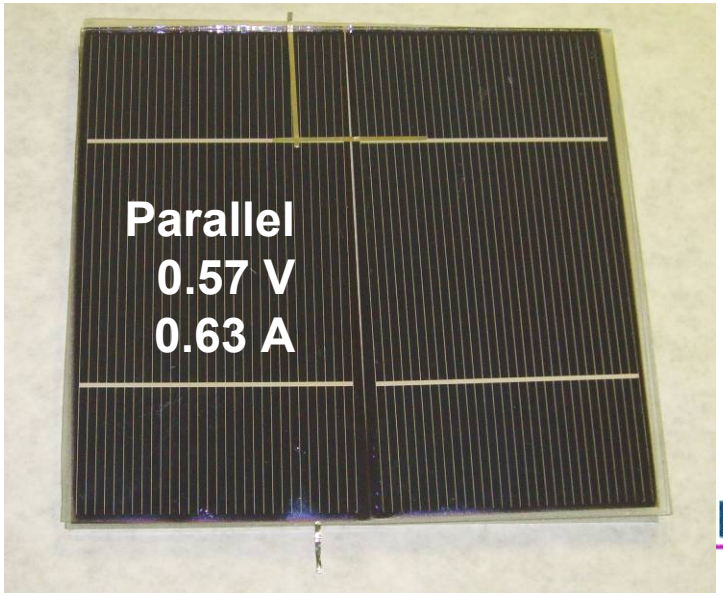
Mobile Solar Power Supply

- Laminated multiple solar cells, series or parallel to control V, I output
- 45 seconds for 6” x 6.5” panel
- Solderless electrical contact between solar cells and leads





FastFuse™ 2011 Roadmap

- Curved window lamination
- Non-destructive ultrasonic adhesion measurements
  - Dr. Henrique Reis, UIUC
- Installation of 180° peel testing, ball-drop test facility
- Temperature uniformity testing with temperature labels
- RF (10-40 MHz) dielectric testing for modeling

RF Lamination Conclusions

- FastFuse™ RF Lamination laminates thick and thin, glass, ceramic and plastic materials significantly faster than conventional autoclaving and vacuum methods
- FastFuse™ is energy efficient, flexible, green alternative for armor
- FastFuse™ is commercially ready for use for sizes up to 24” x 36”
- Press in design for 48” x 60” lamination
- Ceralink established an on-site laboratory for FastFuse™ R&D and demonstrations

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Thank you! Questions?

Ceralink Inc. develops advanced materials, green processes, and new products for industry.

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2007 U.S. patent applied for
RF Press Lamination Technology

nyserda
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