

New Lamination Method for Armor Panels

Shawn M. Allan*

Morgana Fall, Dr. Holly Shulman, Ceralink Inc

Ceralink Inc.

Rensselaer Technology Park
Troy, New York

Materials Science & Technology 2009,
and the 111th Annual Meeting of American Ceramic Society

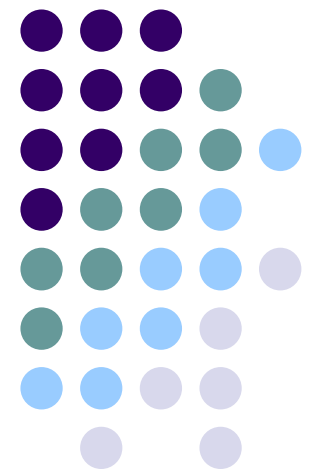
Structural Materials for Aerospace and Defense:
Challenges and Prospects

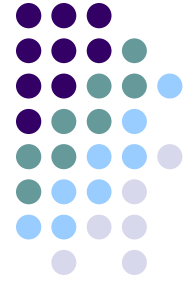


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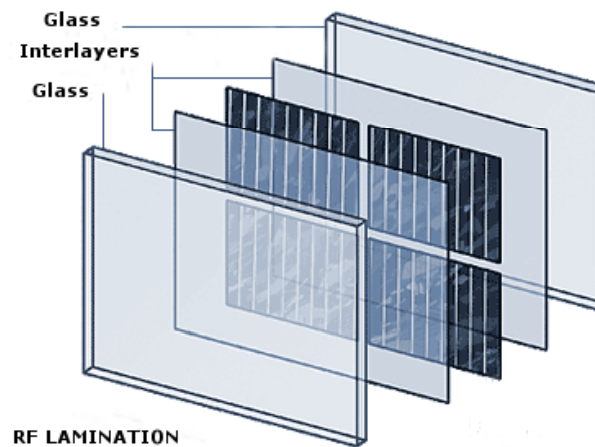
Pittsburgh, PA
October 26, 2009





Introduction

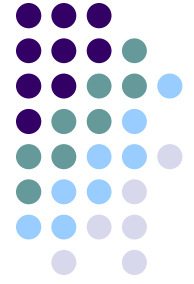
- Laminated Transparent Armor
- RF Lamination Technology
- Application of RF Lamination to Armor
- Conclusions



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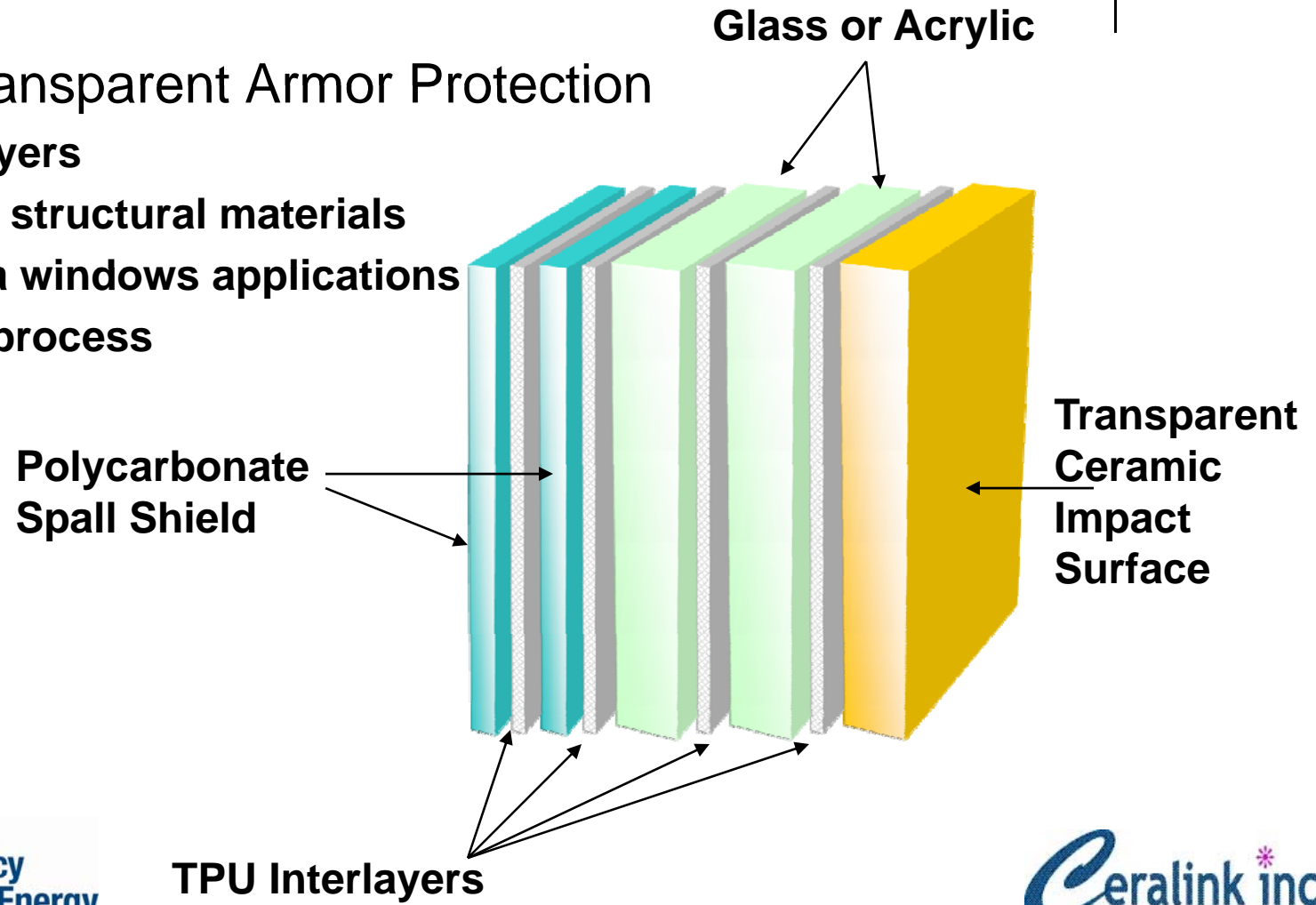




Laminated Transparent Armor

Hi-Tech Transparent Armor Protection

- Several layers
- Dissimilar structural materials
- Small area windows applications
- Same RF process



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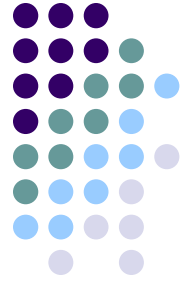
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TPU Interlayers

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.



Transparent Armor Lamination Challenges



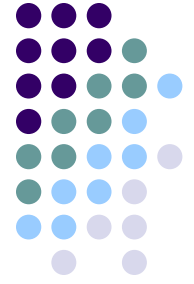
- Thick structural layers
- Multiple interlayers
- Results in much longer autoclave cycles
- Stresses between high CTE PC spall shields and lower CTE glass & ceramics



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State of the art glass lamination

- **Interlayers**
 - **TPU** - Thermoplastic Polyurethane - **Armor**
 - **PVB** - Polyvinyl butyral – **Auto, Security**
 - Clear, printed
 - **EVA** - Ethylene vinyl acetate – **Solar, Decorative**
 - Clear, colored, opaque
- **Methods**
 - Pre-processing rolling (de-airing)
 - Autoclave (PVB, TPU)
 - Vacuum oven (EVA)
- **Features**
 - Large batches, 1 to 6 hour processes
 - Slow process development
 - **Energy Intensive!!**



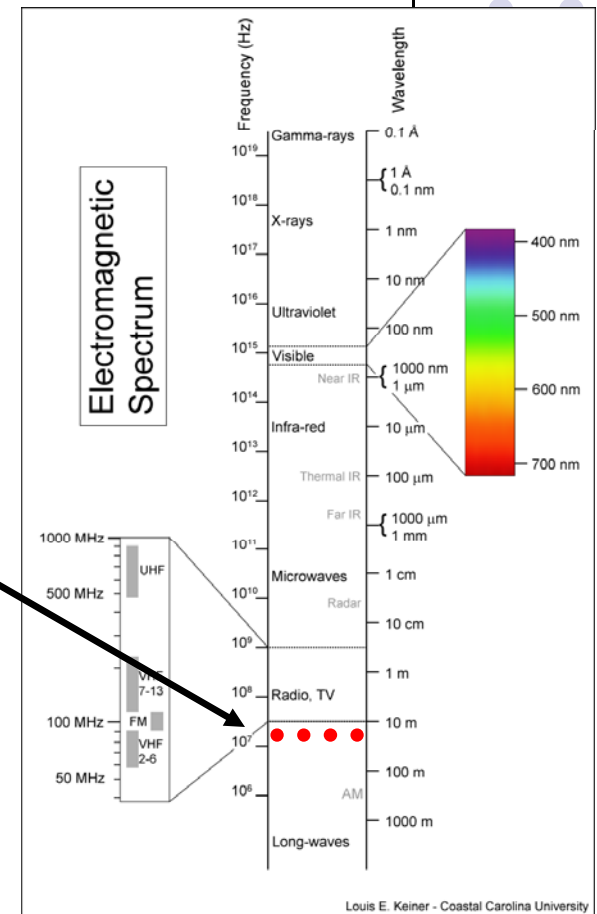
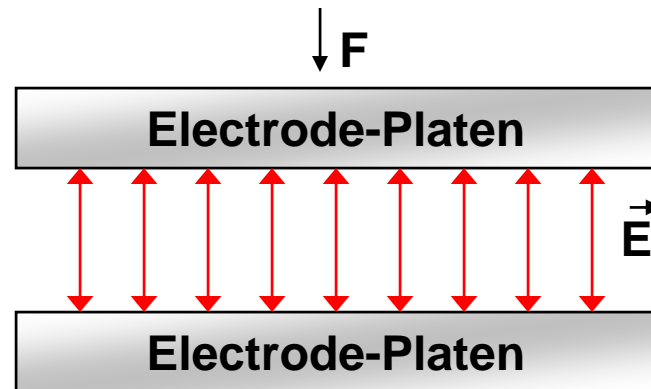
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RF Technology

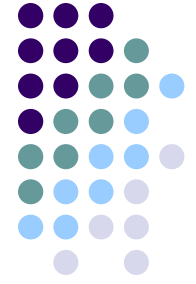
- We applied **RF heating** to **Glass Lamination**
- RF widely used for paper, wood, and plastics
- 27.12 MHz field between parallel electrodes
- Creates dielectric heating
- Press platens are RF source (electrodes)



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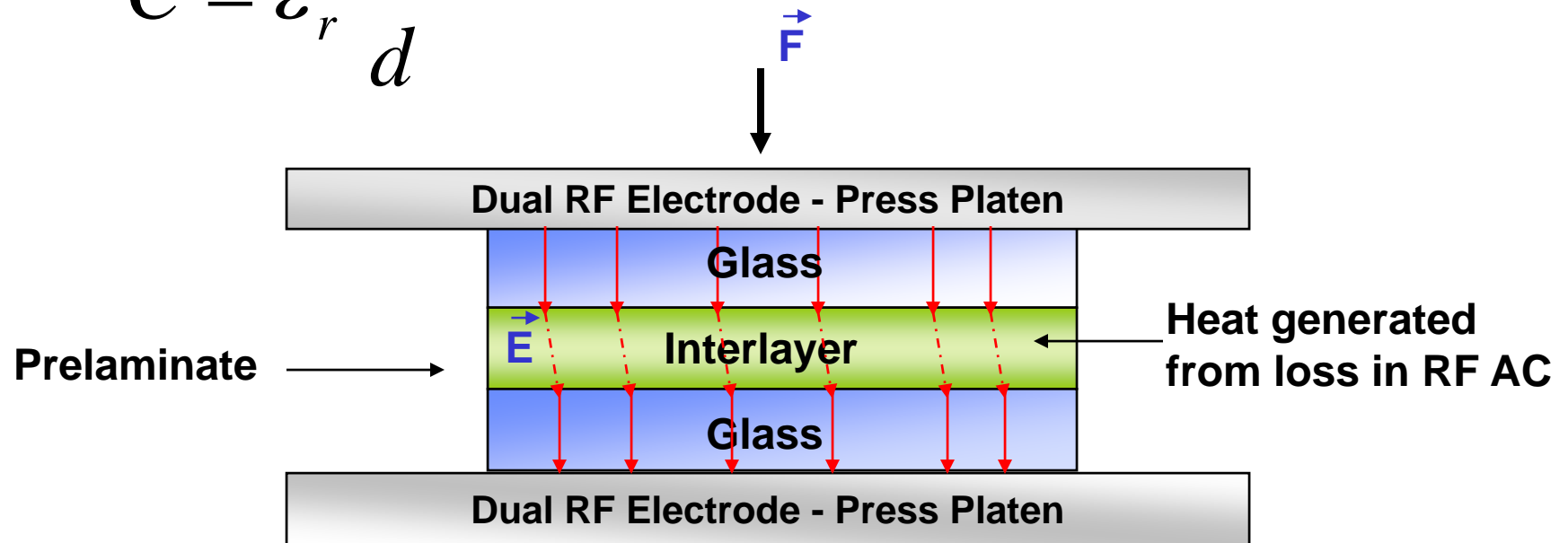
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RF Lamination Technology

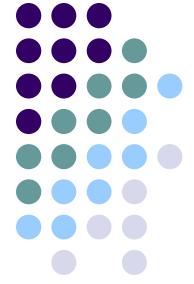
$$C = \epsilon_r \frac{A}{d}$$



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RF Lamination Technology

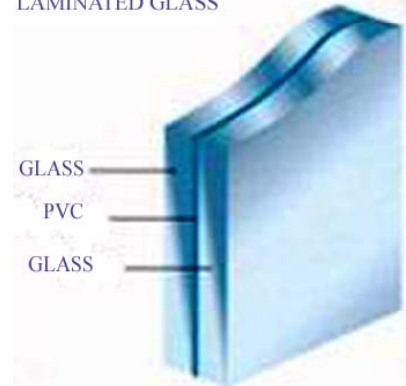
Method to make laminates faster and more efficient

- **0.5 to 3 minute cycles**
- Cuts energy over **90%**
- Heats interlayer directly
- Applies pressure
- Uses existing equipment
- **Allows fast development**
 - ♻️ 50+ experiments in 1 day



**Thermex Thermanon
RF Press with shuttle**

LAMINATED GLASS

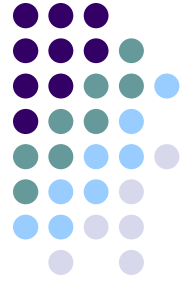


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RF Lamination 2009 Progress



- 3-fold laminable area gain
 - $2 \text{ ft}^2 \rightarrow 6 \text{ ft}^2$ (2' x 3')
- 12-fold single press throughput gain
 - $2 \text{ ft}^2 \rightarrow 24 \text{ ft}^2$ (4, 2' x 3' panels)
- 1" to 1.5" thick structures
- Light emitting diode (LED) lamination

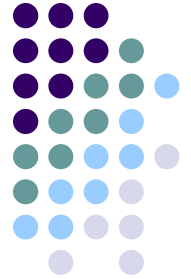


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RF Presses



4 ton, 18" x 20"



19 ton, 30" x 40"



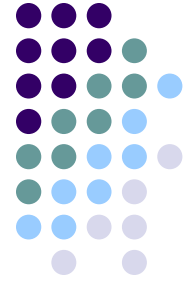
700 ton, 48" x 120"



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Structural Layers & Interlayers

Ceralink has established feasibility for several materials used in laminated products:

- Clear & Colored Glass
- Metallized (Low-E) Glass
- Acrylic
- Polycarbonate
- Ceramics

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

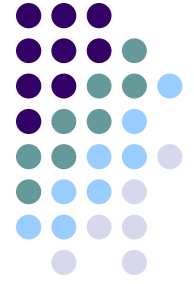
- Deerfield Urethane Dureflex®



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RF Laminated Area

Demonstrated sizes

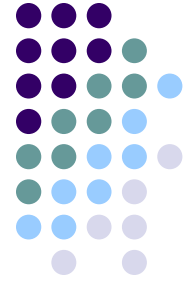
36" x 24"	6 ft²
24" x 24"	4 ft²
18" x 16"	2 ft²
12" x 12"	1 ft²
9" x 9"	0.56 ft²
6" x 6"	0.25 ft²
4" x 4"	0.11 ft²



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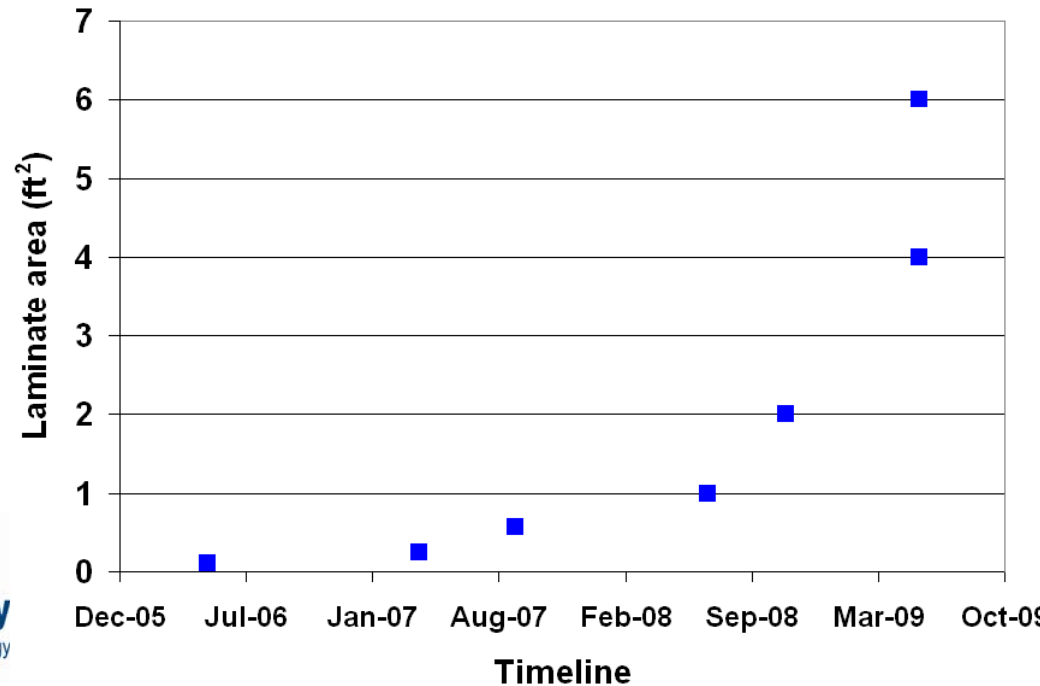
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RF Laminate Size Progress

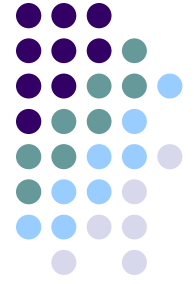
- Increased area 54-fold from 4" x 4" bench scale to 2' x 3'
- Architectural glass (8' x 10') 13-fold larger than current 6 ft²
- Only limitation is current lab press size



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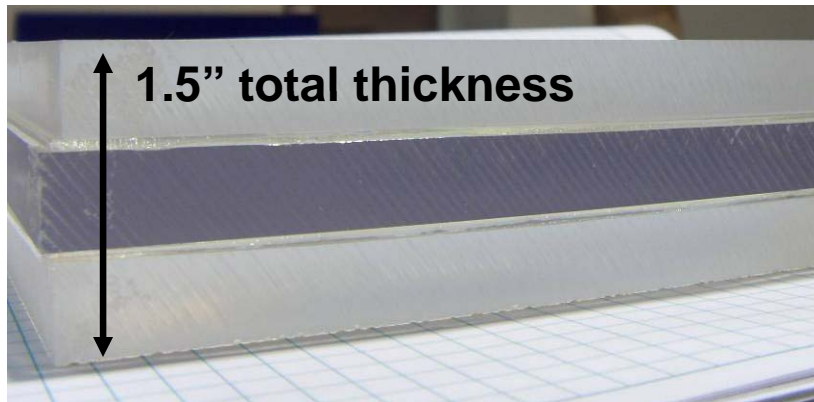
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RF Lamination - Thickness

- RF targets high dielectric loss materials
- Heating (loss) occurs in interlayers
- Field penetrates acrylic, polycarbonate, glass
- Structural layers insulate interlayers → ↑ energy efficiency



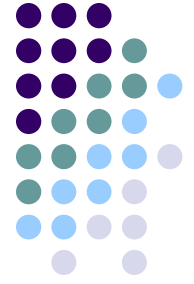
PC-TPU-Acrylic-TPU-PC



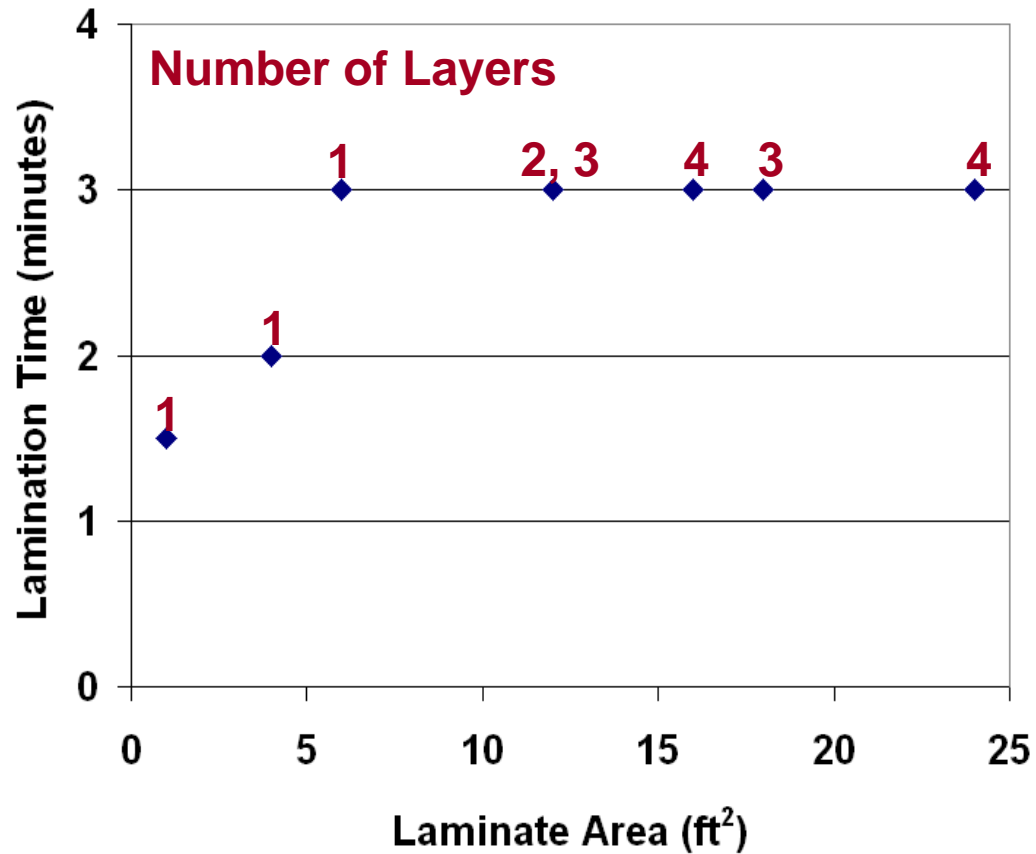
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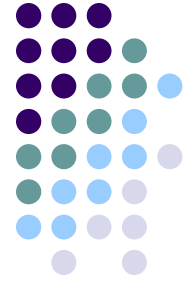


RF Lamination - Layers



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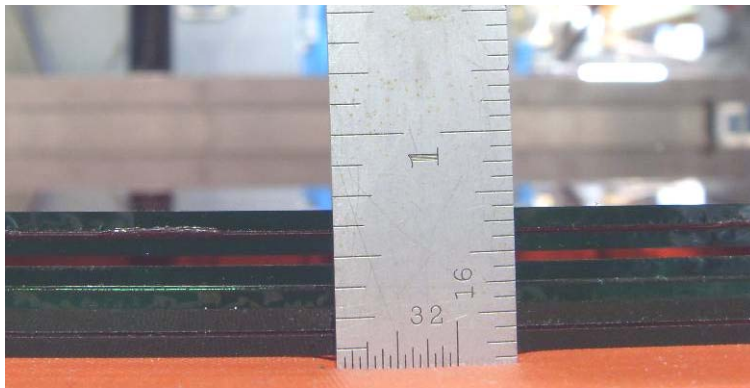


RF Lamination Layers

3 laminates, 2' x 3' each
18 ft² in 3 minutes

Energy Consumed: 0.73 kWh

40.5 kWh / 1,000 ft²

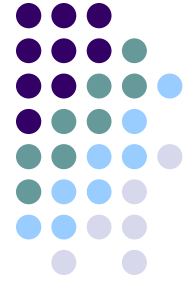


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Autoclaving energy 1150 to 4000 kWh/ 1,000 ft²

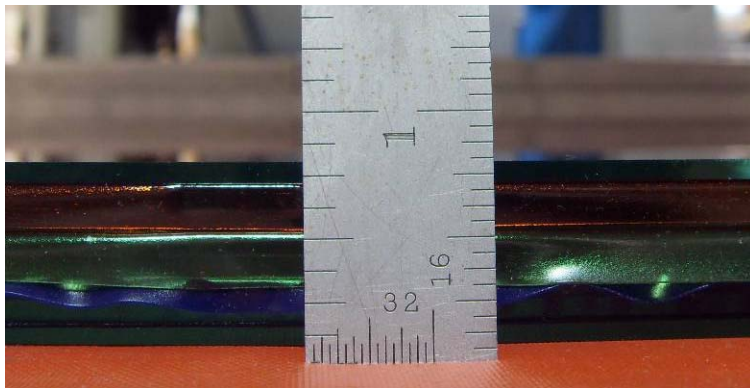
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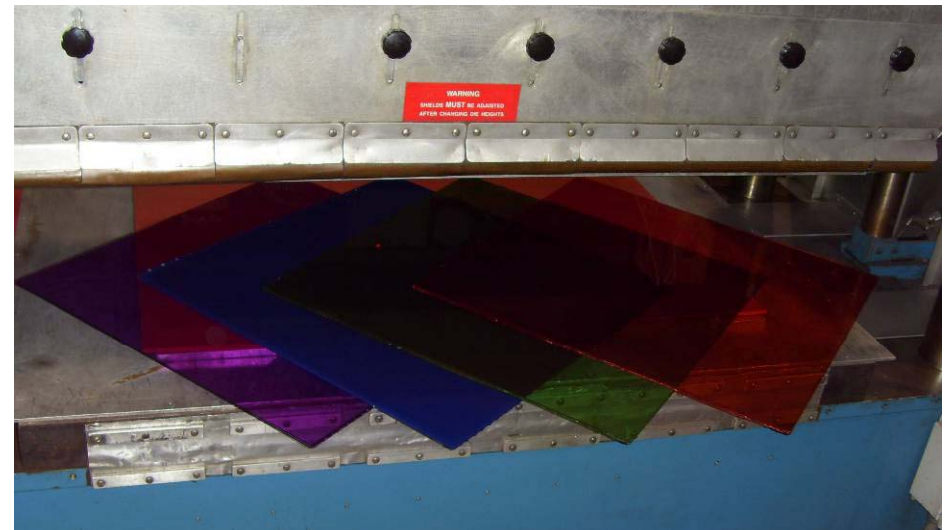
RF Lamination Layers

4 laminates, 2' x 2' each
16 ft² in 3 minutes

Energy Consumed: 0.76 kWh



47.5 kWh / 1,000 ft²

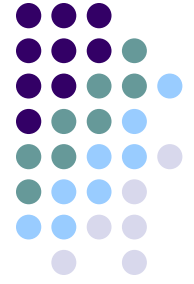


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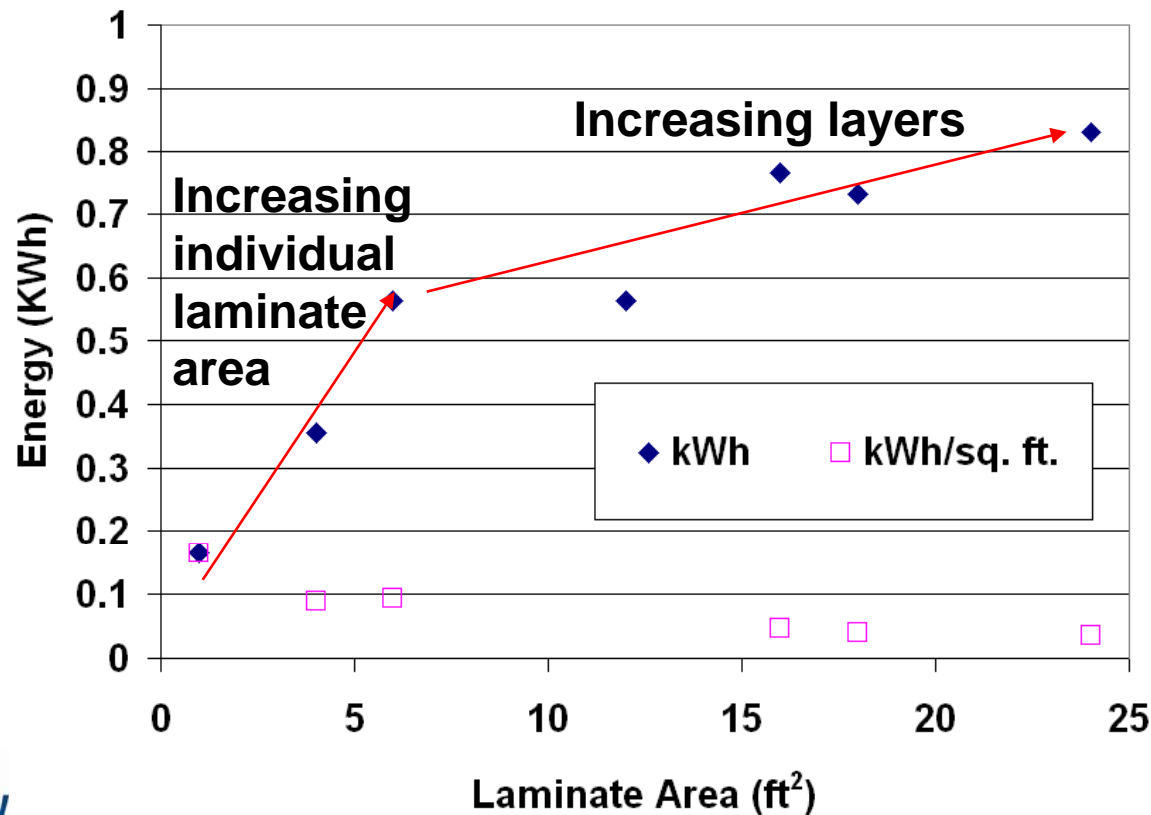
Autoclaving energy 1150 to 4000 kWh/ 1,000 ft²





RF Lamination Energy

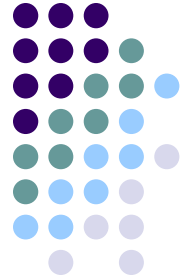
4x increase in area throughput via stacking → 47% energy increase



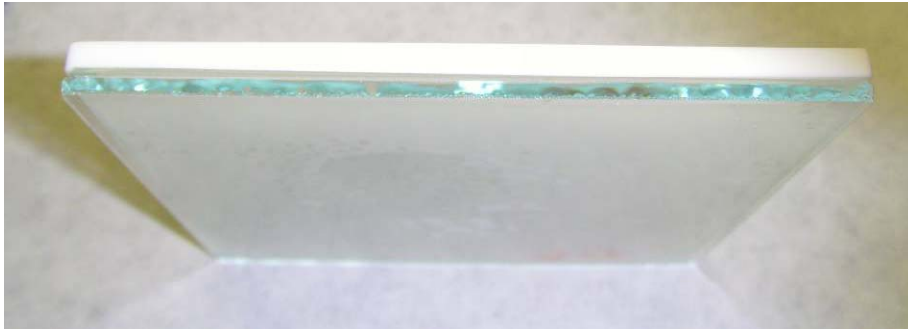
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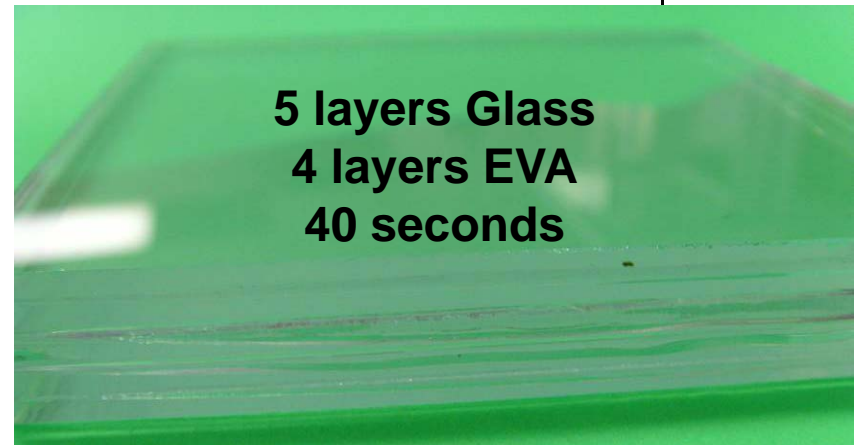




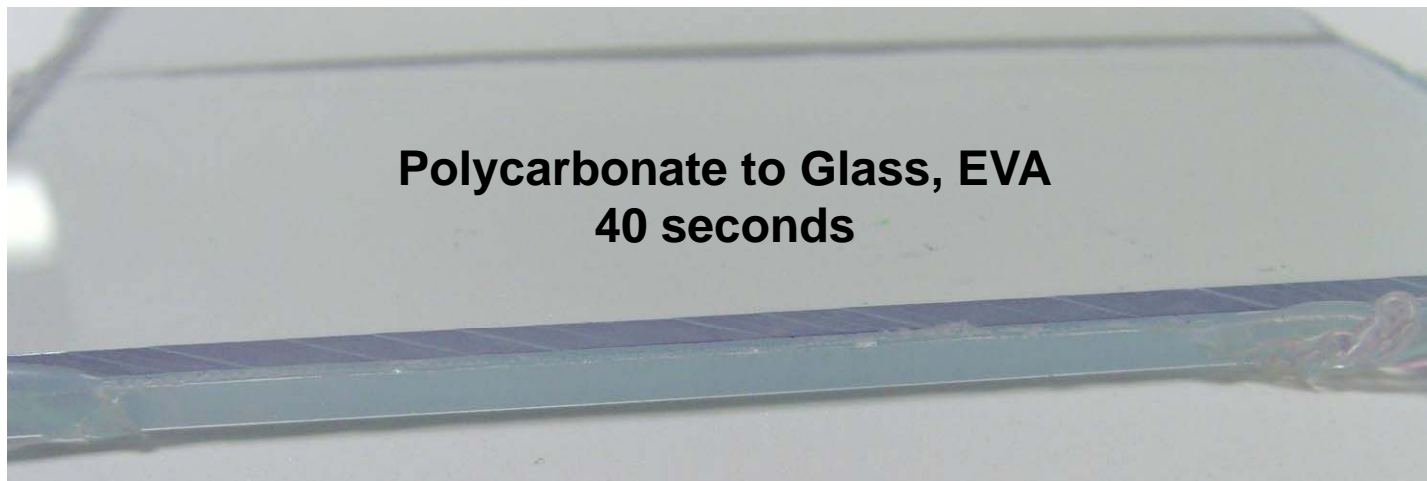
Co-laminated materials



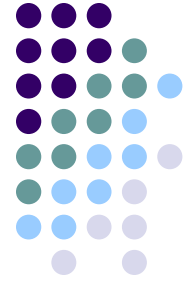
**Alumina to Glass, PVB
RF Laminated
60 seconds**



**5 layers Glass
4 layers EVA
40 seconds**

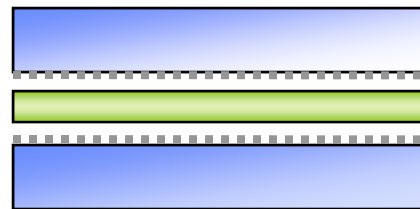


**Polycarbonate to Glass, EVA
40 seconds**

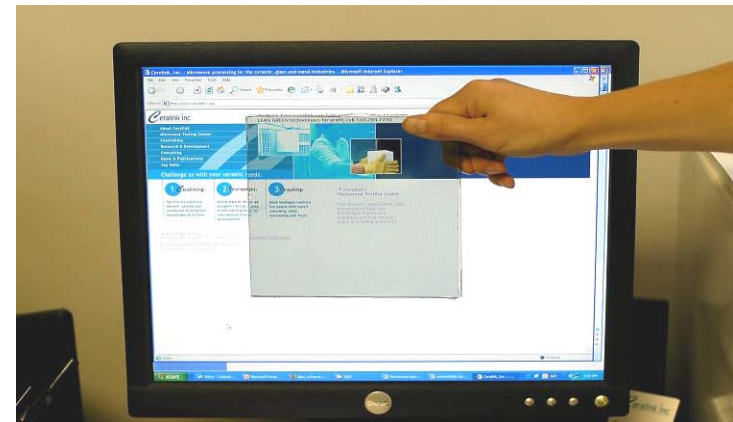


Metallization

- 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



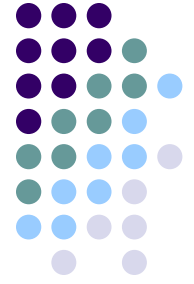
RF Laminated Low-e Glass
150 mm x 150 mm



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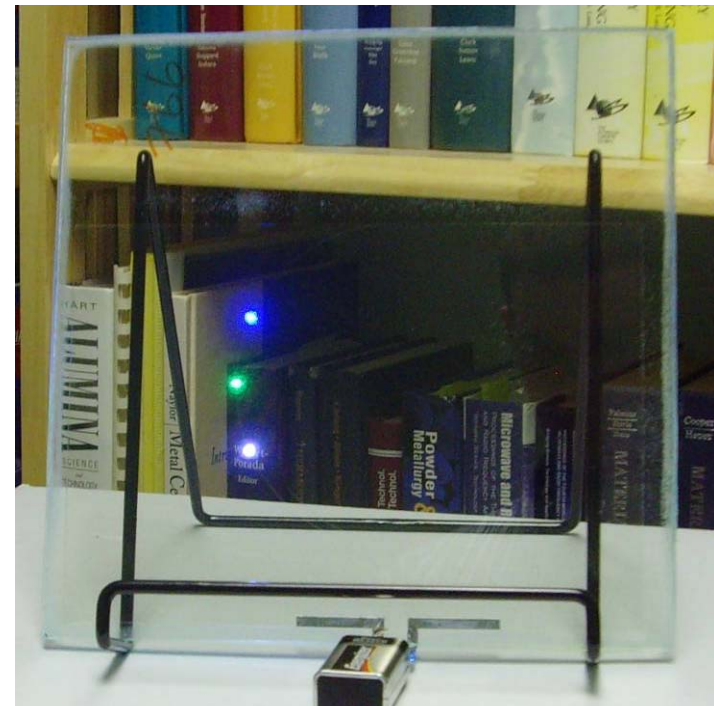
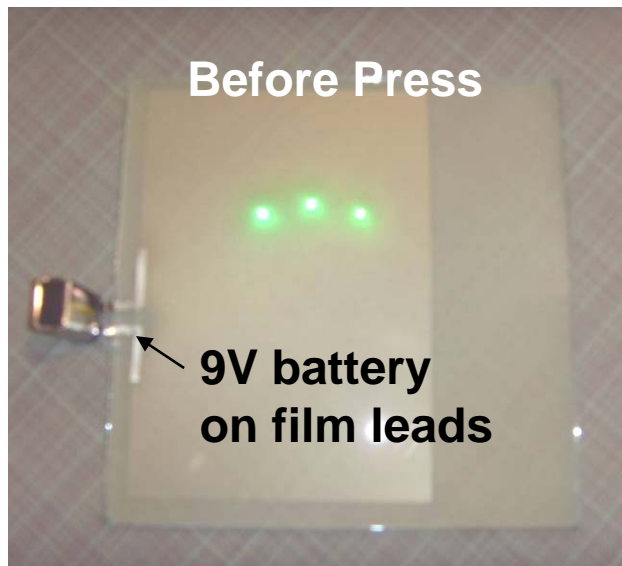
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Embedded electronics

- Light emitting diodes (LEDs)
- Sensors



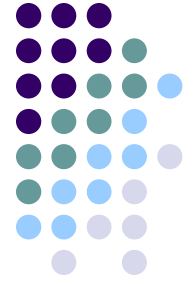
3-color LED after press
Blue-Green-White (top to bottom)
9" square glass with PVB



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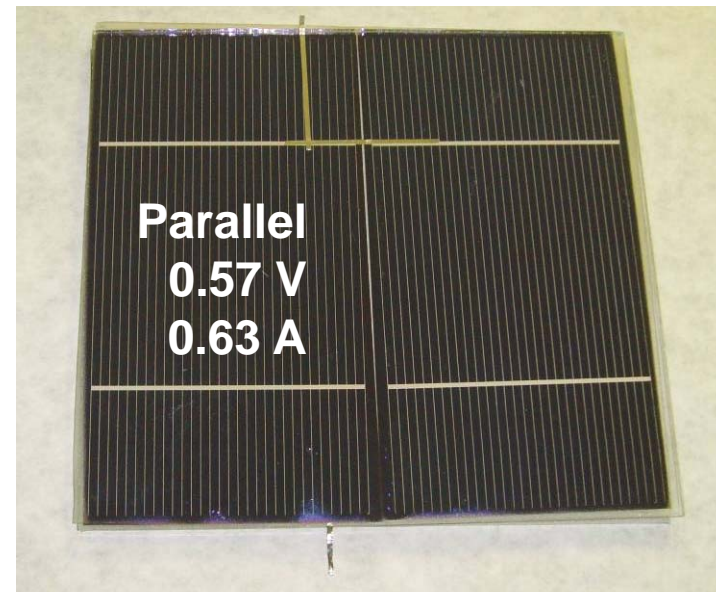
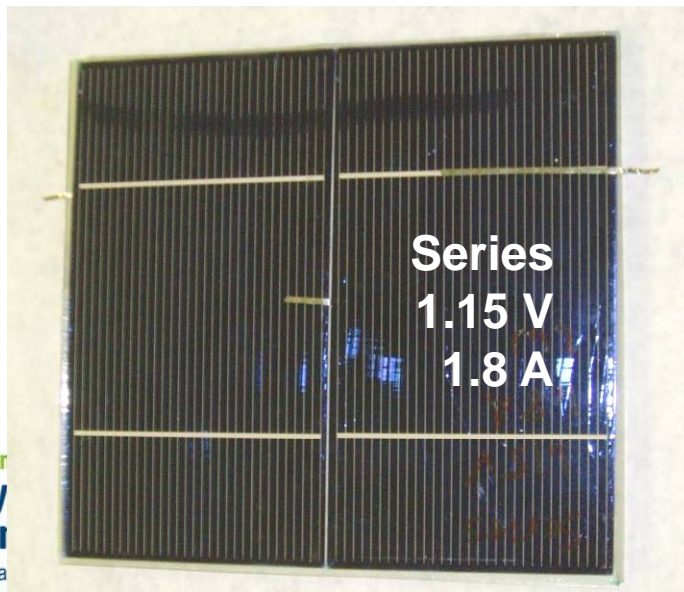
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Mobile Solar Power Supply

- 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



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Durability

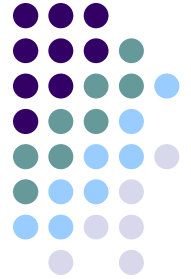
RF laminated glass was subjected to
EU tests from EN ISO 12543-4:

Boil, 100 °C, 2 h
Bake, 130 °C, 2 h

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

ASTM C1172 visual inspection **Passed before and after**

Can point out bake test failure with PVB – working on solution



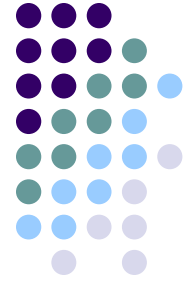
Boil Testing RF
Laminated TPU



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Boil Test Results - TPU

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



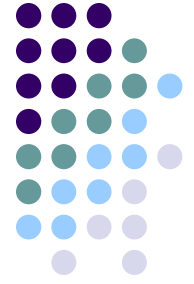
Deerfield A4700 TPU



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Bake Test Results - PVB

Solutia Saflex PVB



DuPont Butacite PVB



40 second RF Lamination times

Aged 2 years

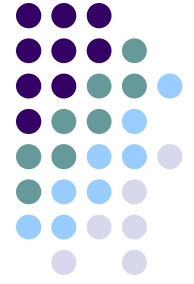
Investigating pre-lamination



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New Opportunities for RF Lamination

- Correlation of process parameters to mechanical performance
- Non-destructive evaluation of adhesion strength
(with Dr. H. Reis, U. of Ill. Urbana-Champaign)
- Ballistics comparisons with conventional lamination
- Multi-dimensional lamination
- Curved structure lamination
- PVB environmental stability progress

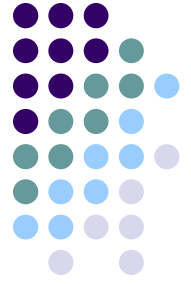


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Opportunities for Armor



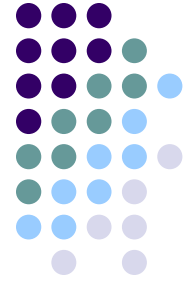
- Uniformity – simultaneous lamination of multilayers
- Time savings – critical development, production
- 95 to 98% energy reduction over autoclaving
- Autoclave alternative



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RF Lamination Conclusions

- Process time is independent of
 - Thickness
 - Number of layers
- Short production cycle times
- Fast development cycles
- Wide materials applicability
- Ceralink offers feasibility testing
 - Equipment through strategic partner
 - Licensing and/or partnering to commercialize specific applications



700-ton RF Press

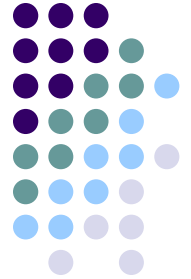


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Acknowledgements



**Visit Thermex Thermatron and Ceralink at Booth 538
at the Expo to see RF Laminated samples**

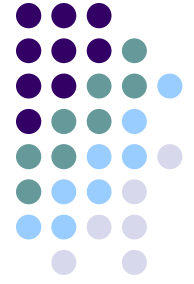


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This material is based upon work supported by the
Department of Energy Office of Energy Efficiency and Renewable Energy
under Award Number DE-FG36-06GO16043.





Thank you! Questions?

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



Contact: Shawn Allan
Sr. Materials Engineer
(518) 283-7733
shawn@ceralink.com



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

