

Energy efficient RF lamination of flat glass and ceramics for solar and armor applications

Shawn M. Allan*

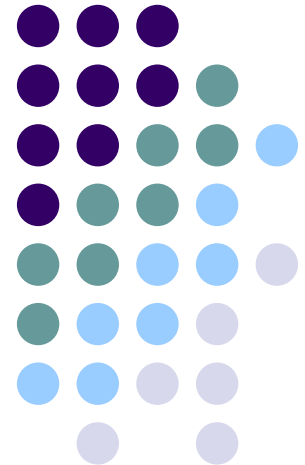
Morgana Fall, Dr. Holly Shulman, Ceralink Inc

Ceralink Inc.

Rensselaer Technology Park
Troy, New York

**33rd International Conference and Exposition on
Advanced Ceramics and Composites**

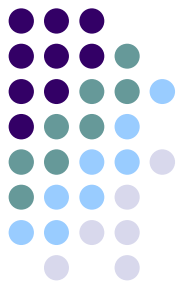
Daytona Beach, Florida
January 18-23, 2009



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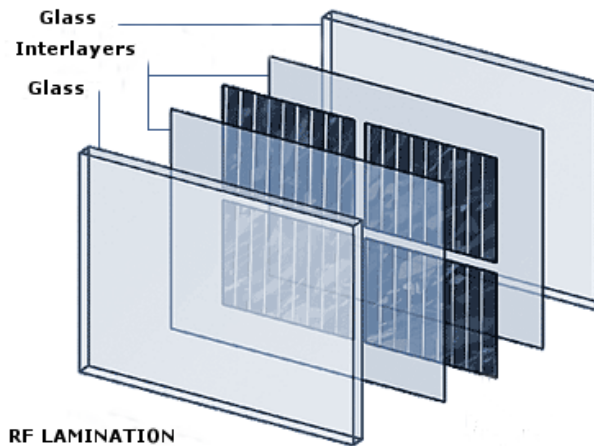
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Introduction

- Products and markets
- Opportunities for manufacturing alternatives
- Development of low energy lamination
- Conclusions



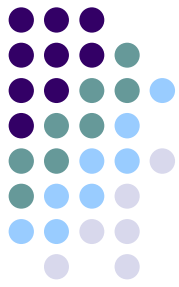
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Products and Markets

Laminated composites: Armor, Solar, Glass



Lamination is used for:

- ❁ Transparent armor and shields
- ❁ Photovoltaic panels
- ❁ Auto safety glass
- ❁ Architectural glass

Need for Alternative Manufacturing Methods:

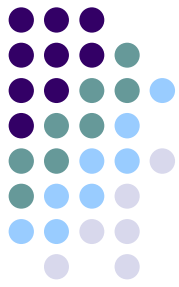
- ❁ Growth of transparent armor market
- ❁ Price pressures on photovoltaics
- ❁ Vehicle ejection standards
- ❁ Energy Costs



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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
- **Glass**
 - Flat, curved, textured, tempered
- **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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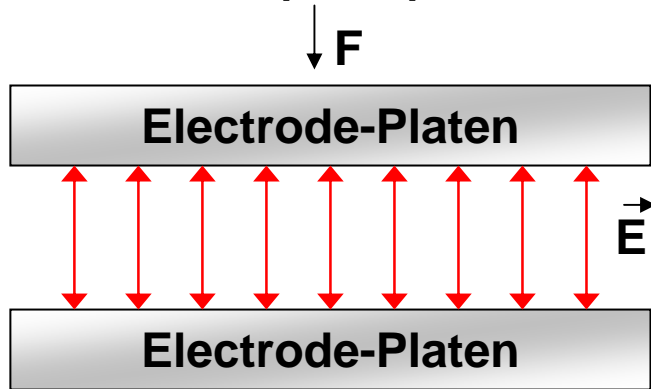
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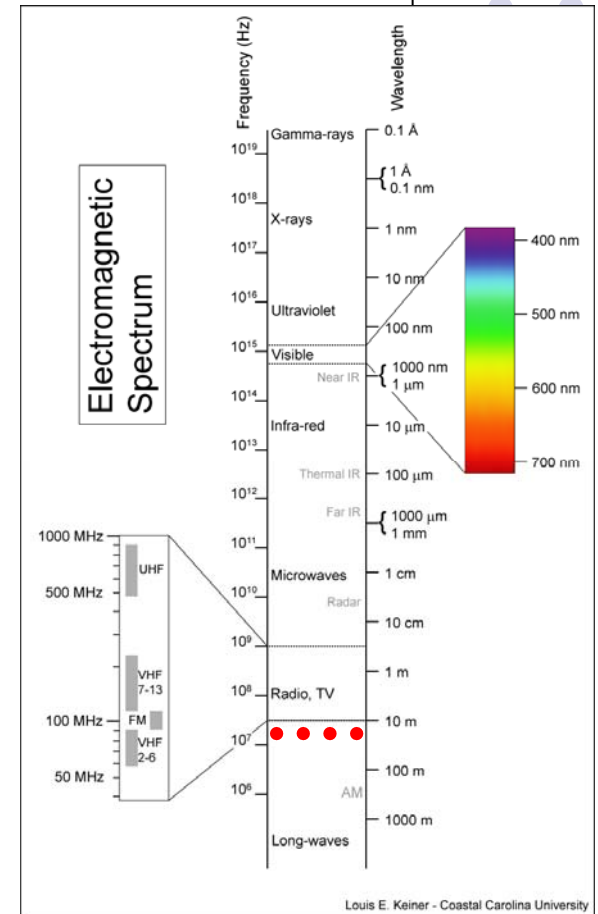


RF Technology

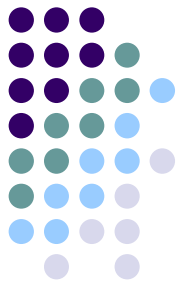
- We applied **RF heating** to **Glass Lamination**
- **27.12 MHz** field between parallel electrodes
- **Electrodes are also press platens**



- **Dielectric heating**
- **Used widely for drying paper and wood, and sealing plastic packaging**



RF (1 to 300 MHz) dielectrically heats materials



RF Lamination Technology

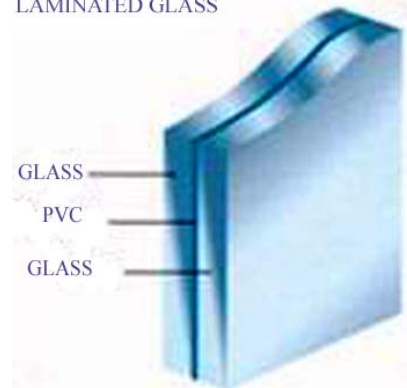
Method to make laminates faster and more efficient

- ~ 1 minute cycle
- Cuts energy up to **90%**
- Heat interlayer directly
- Existing equipment
- Apply pressure
- **Fast development**
 - ♻️ 50+ experiments in 1 day



**Thermex Thermoatron
RF Press with shuttle**

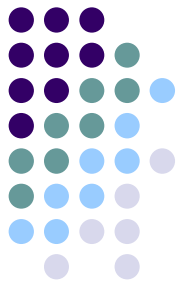
LAMINATED GLASS



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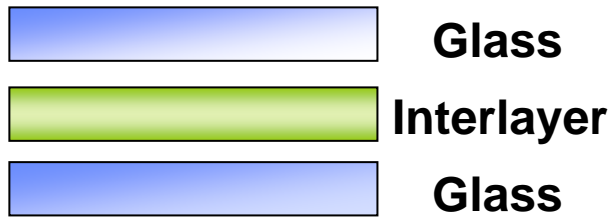
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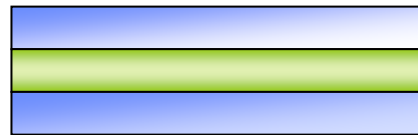
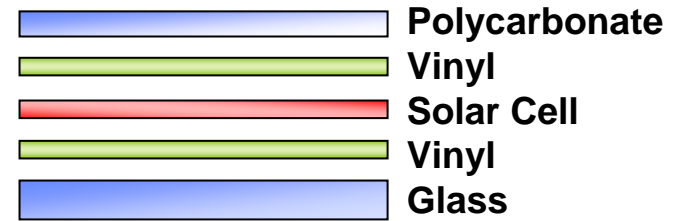


RF Lamination Technology

Basic – Autoglass



Complex – Solar Cell, Armor



Prelaminate



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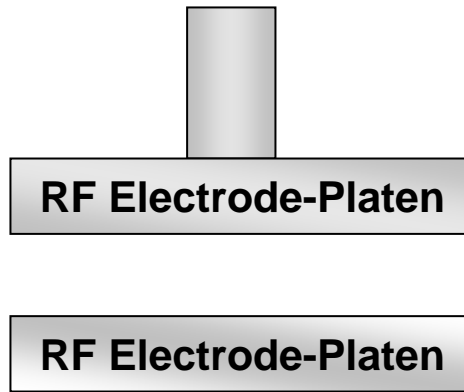
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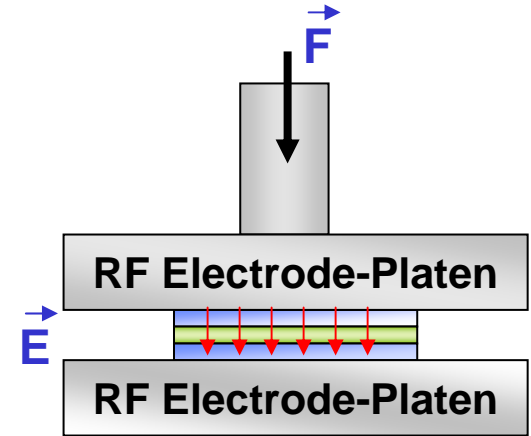
RF Lamination Technology



Prelaminate



RF Press



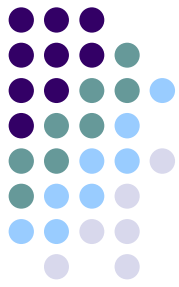
RF Energy
& Pressure
~1 minute



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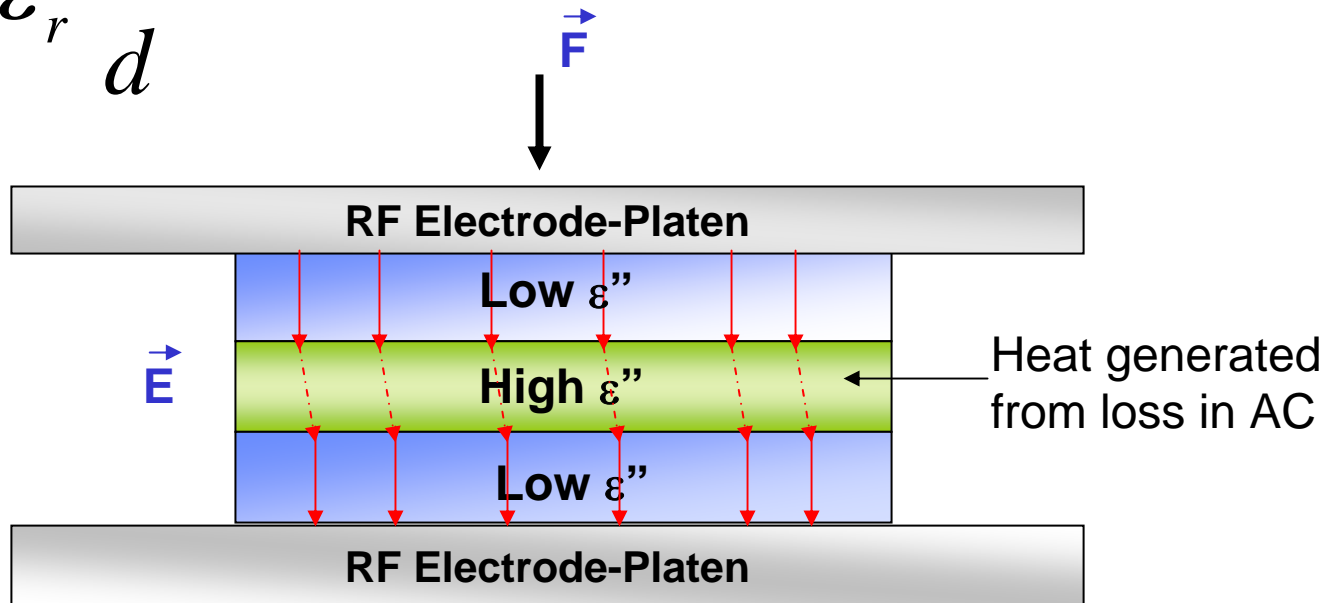
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RF Lamination Technology

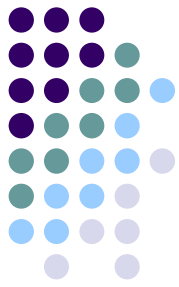
$$C = \epsilon_r \frac{A}{d}$$



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Lamination Feasibility Overview

Ceralink has established feasibility for many laminate systems

- Autoglass
- Multilayer armor
- Dissimilar Materials
- Interlayer inserts
 - Decorative Films
 - Solar Cells
 - Colored and Printed Interlayers
- Metallized glass
- Plastics
- Ceramics

Process Variables

- RF Power 10 to 20 Watts/cm²
- Time 10 to 120 seconds
- Pressure 20 to 350 PSI
- Area 100 to 1850 cm²
(16 to 288 in²)

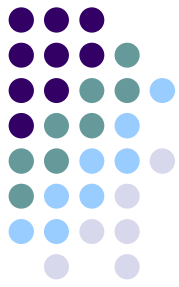


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Structural Layers & Interlayers



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

- **Clear & Tinted Glass**
 - Auto
 - Window
- **Metallized Low-E Glass**
- **Acrylic – Acrylite®**
- **Polycarbonate – Lexan®**
- **Multiple Glass Layers**
- **Alumina to Glass**
- **Glass to Polycarbonate**
- **Silicon Solar Cells to Glass**

PVB

- DuPont Butacite®
- Solutia Saflex®

Printed PVB

- DuPont SentryGlass Expressions®

EVA

- Sekisui S-LEC® EN Film
- Bridgestone EVASAFE™
- Kin Yong Fa
 - clear, colored, opaque

TPU

- Deerfield Urethane Dureflex®



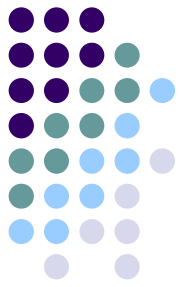
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Feasibility Examples

PVB, EVA and TPU



DuPont
Butacite® **PVB**
in tinted glass



Deerfield
TPU
in glass

Solutia Saflex®
PVB in clear
glass



DuPont
SentryGlass®
Printed PVB
in clear glass



Kin Yong Fa **EVA**
with printed acetate insert

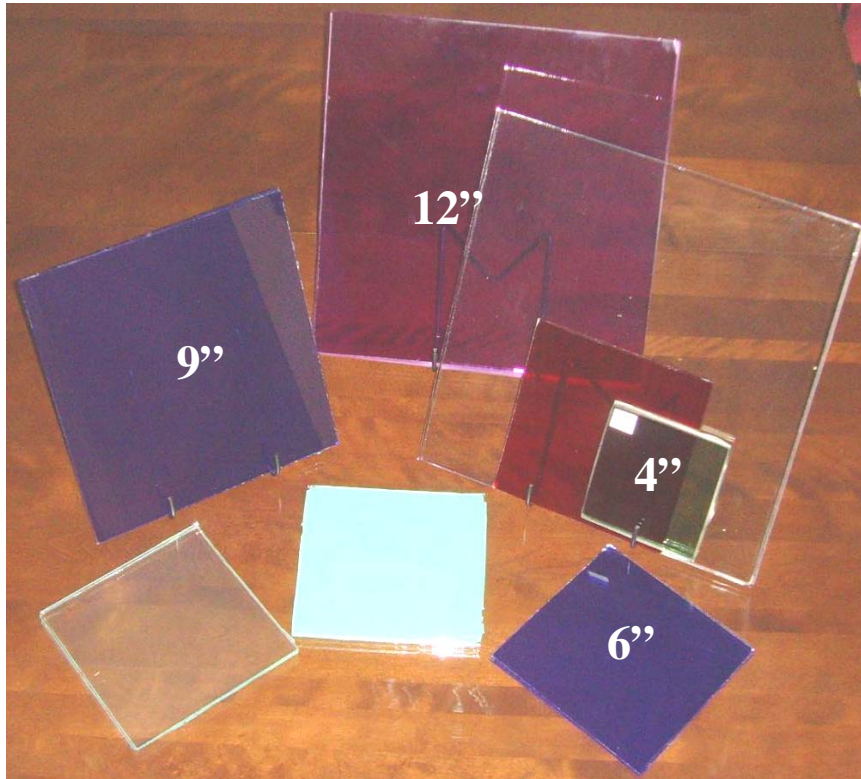
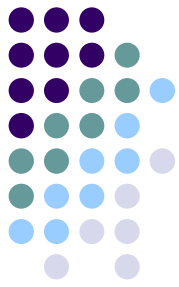


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RF Lamination Process Scale-up



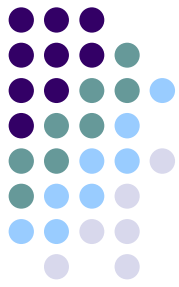
2 square feet



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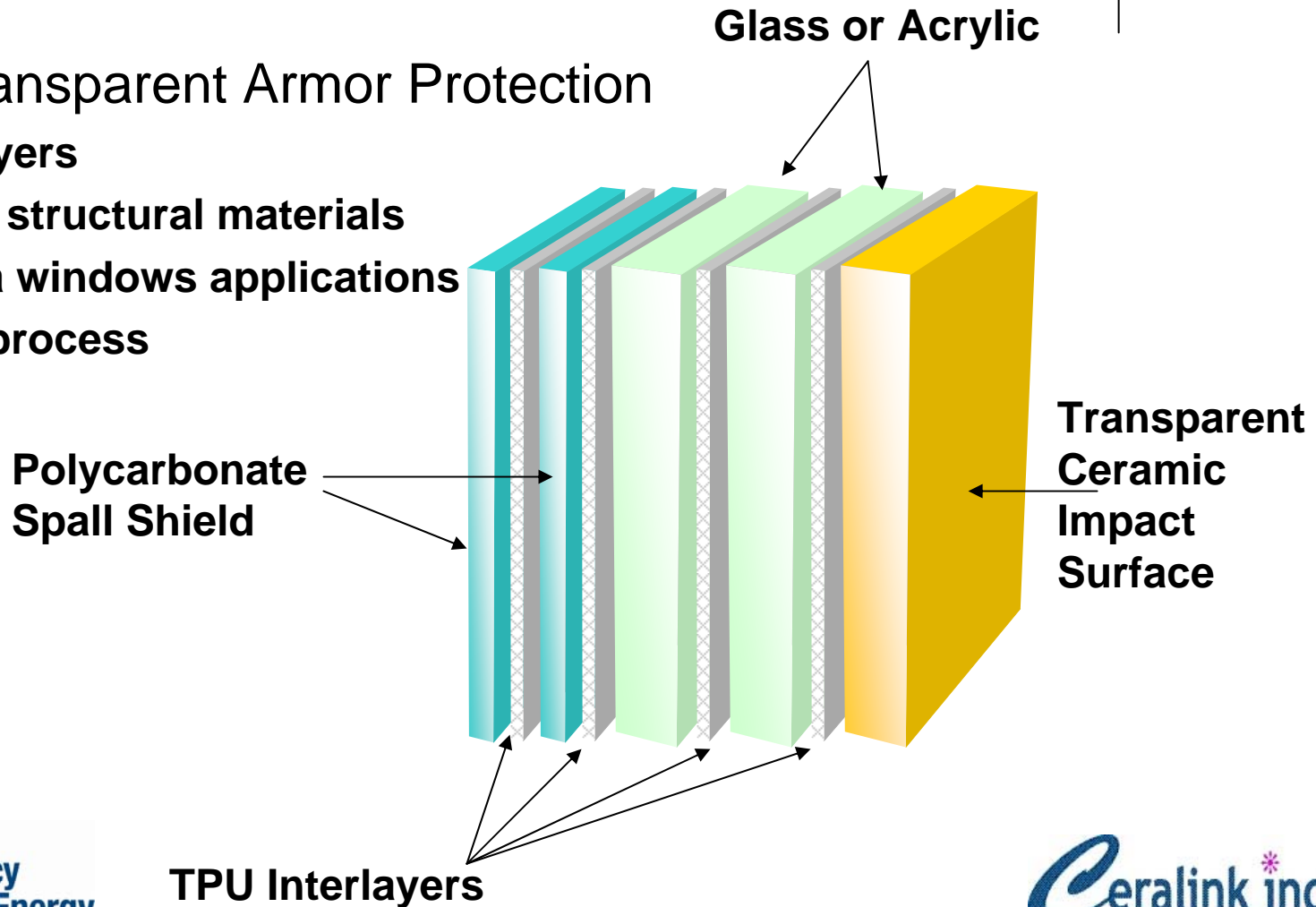




Multilayer Lamination

Hi-Tech Transparent Armor Protection

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

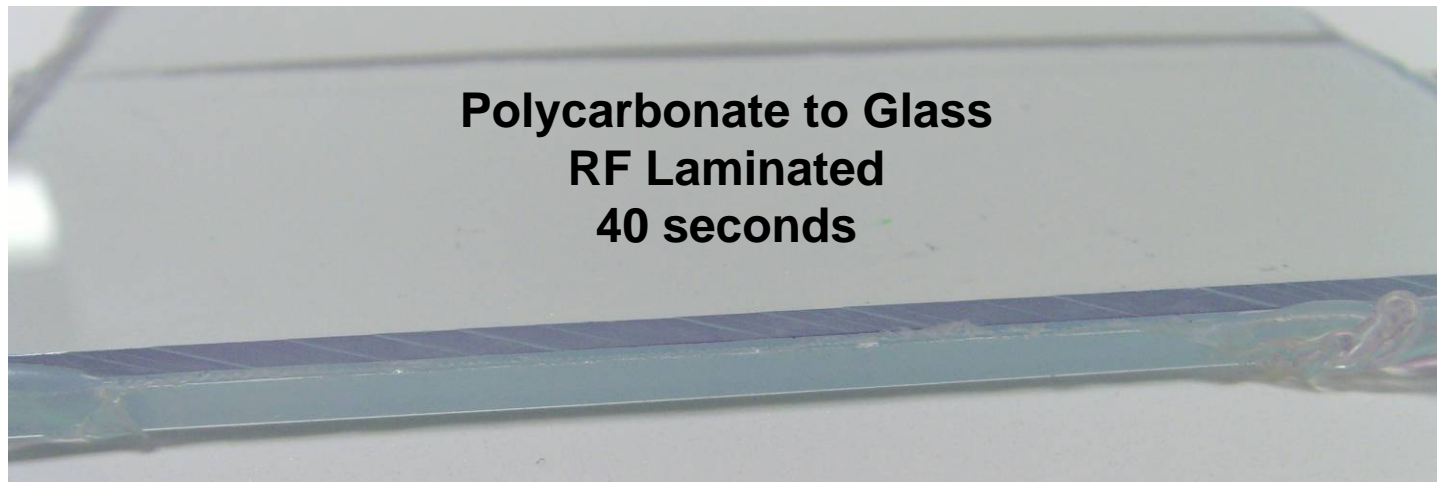
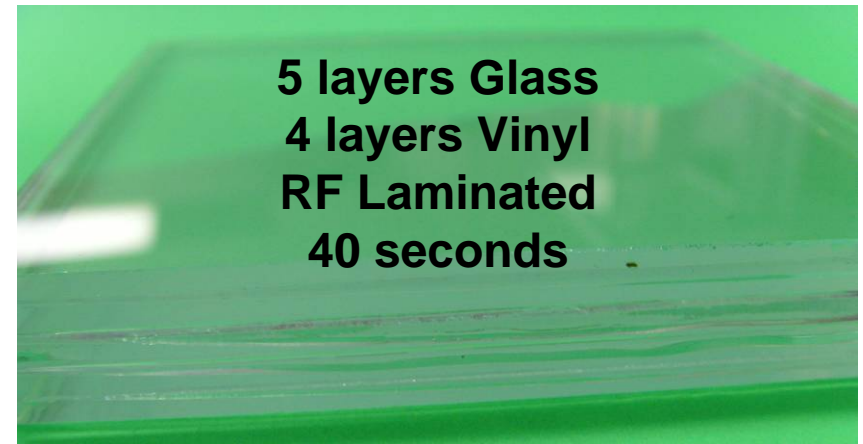
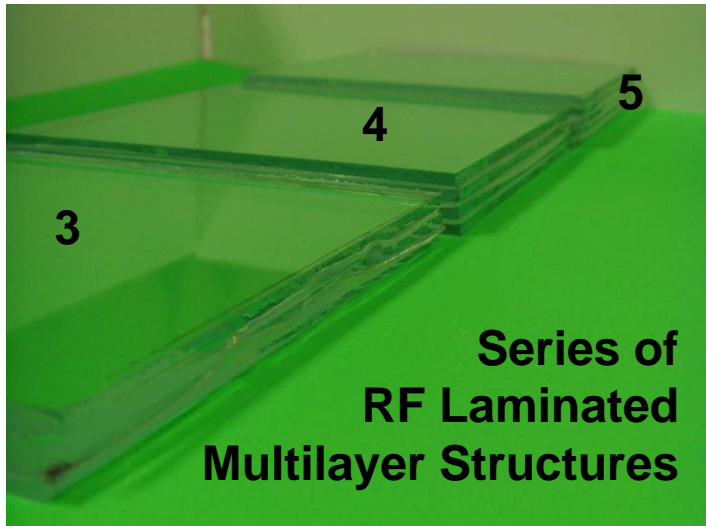
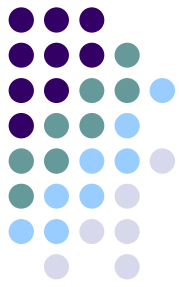


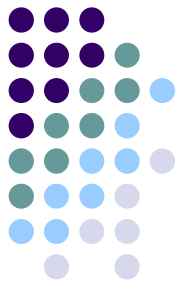
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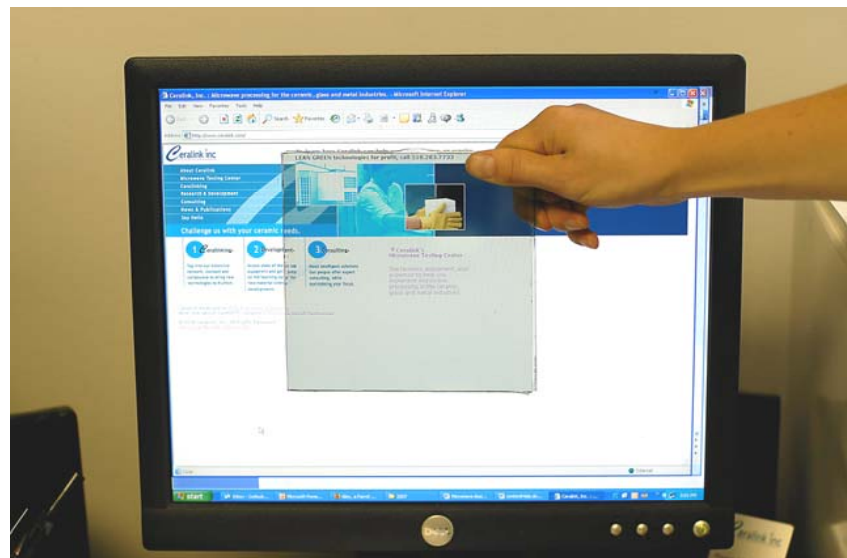
RF Laminated Multilayers





Metallized Low-E Glass

- Glass is metallized on one side for tinting, IR reflection
- Capacitive coupling transmits RF across metal layers
- Low-E Glass was laminated with EVA
- Conductive material a success → Photovoltaics next?

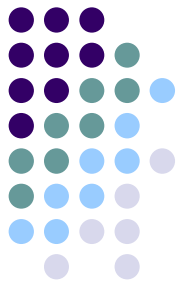


RF Laminated Low-e Glass
150 mm x 150 mm



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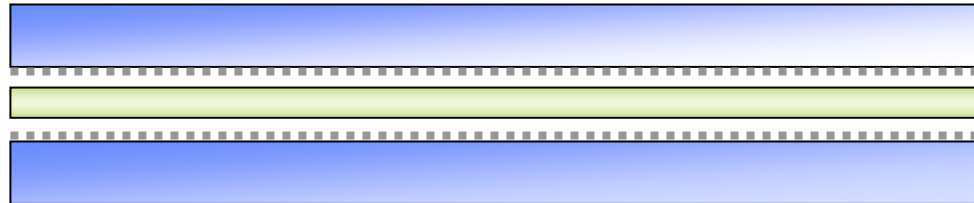




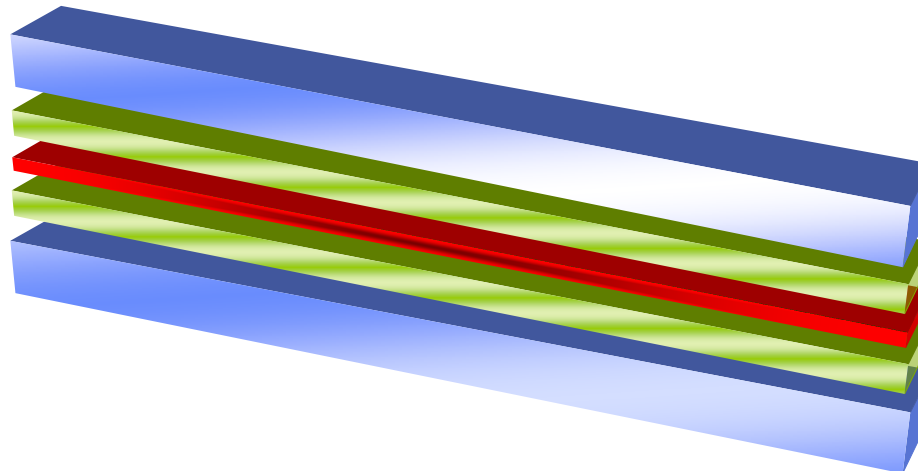
Why is Conductive Lamination Possible?

Capacitive coupling enables heating of vinyl layers between non-grounded conductive layers

Metallized Glass



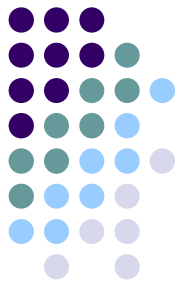
Silicon Solar Panel



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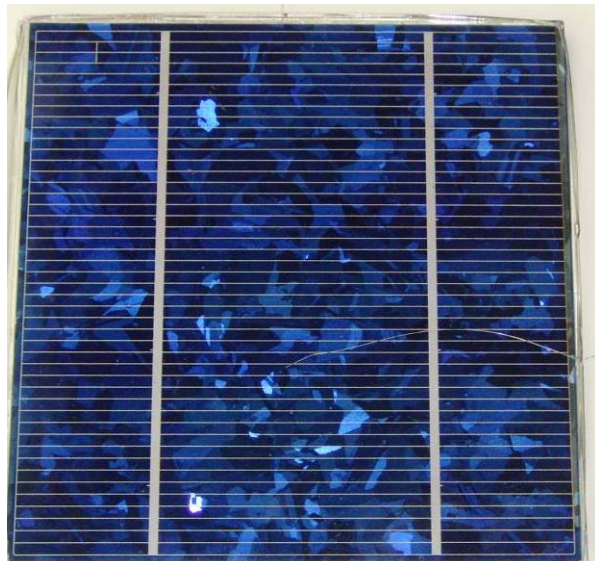
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Solar Cell Lamination

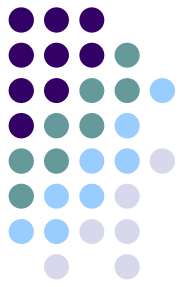
- Solar cells cover part or all of glass area
- Single and Polycrystalline Si laminated



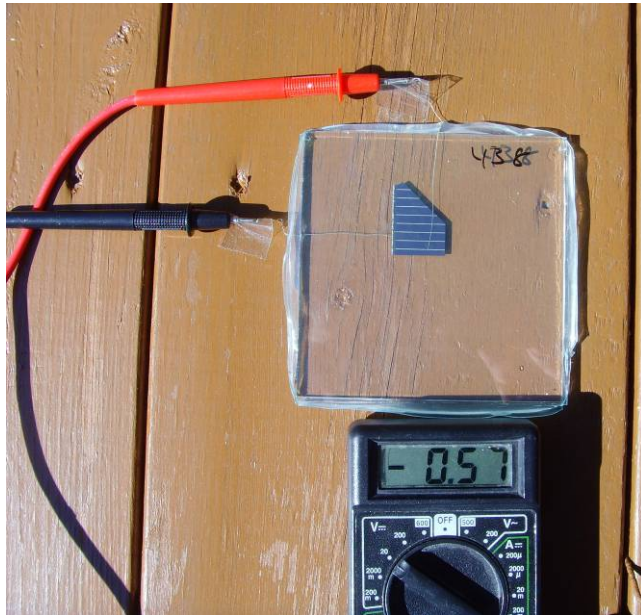
← 4.5" Polycrystalline
Solar Cell
RF Laminated
45 seconds



**Conventionally
Laminated Solar Cells
at GlassTec 2006
Functional & Aesthetic**



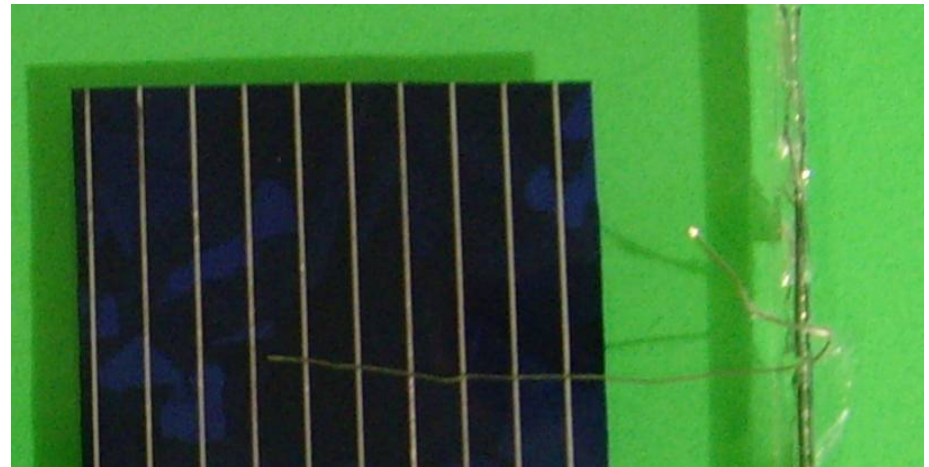
Solar Cell Lamination



Solar cell laminated with RF Press

Rated for 550 mV

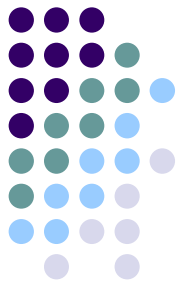
Measured output in full sun **570 mV**



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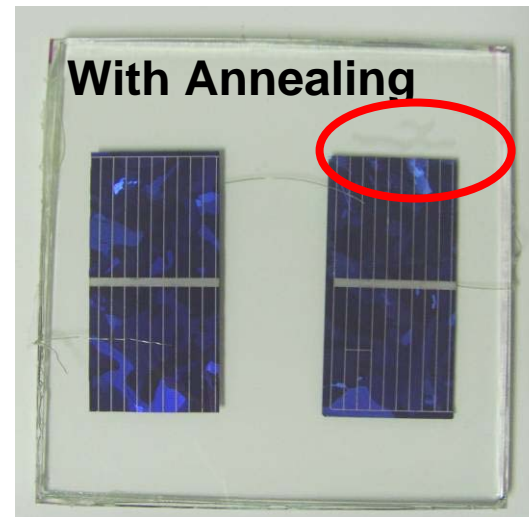
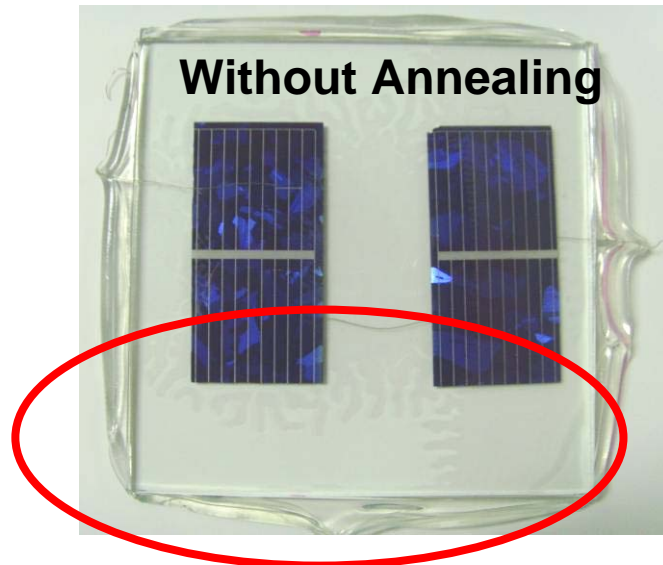
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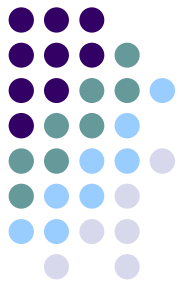


Solar Cells – Partial Panels

- Partial coverage induces stress in vinyl
- Delamination occurs after the vinyl cools due to residual stresses
- Annealing alleviates residual stress in the vinyl
- No anneal required for full size cells



Durability



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

- Boil, 100 °C, 2 h
 - Sekisui **Passed**
 - Bridgestone **Passed**
- Bake, 130 °C, 2 h
 - Sekisui **Passed**
 - Bridgestone **Passed**

Samples were then observed for change of clarity and defects

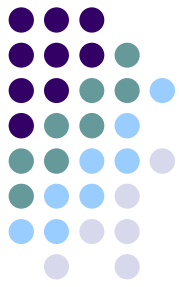


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Rapid Manufacturing and Prototyping



- US Department of Energy sponsored for significant energy savings
- Method offers significant time savings →
Rapid Prototyping & Manufacturing
- RF lamination proven successful for variety of materials
- Single piece workflow
 - QC & flexibility
- Ceralink offers feasibility testing
 - Equipment through strategic partner
 - Licensing and/or partnering to commercialize specific applications



700-ton RF Press

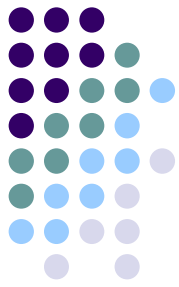


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Acknowledgements



**Visit Thermex Thermatron and Ceralink at Booth 202
at the Expo to see RF Laminated samples**



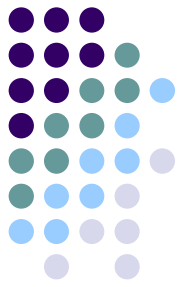
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under Award Number DE-FG36-06GO16043.



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**

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