Novel Lamination Method for Transparent Armor Panels

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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
  - 5 engineers/scientists
  - 3 student engineers
  - 2 business & support
Ceralink Collaborations

- **Industry**
  - BASF
  - General Electric
  - United Technologies
  - 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 – 200 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
FastFuse Overview
Products

FastFuse is applicable to most glass laminated products:

- Transparent armor
- Solar/PV panels
- Automotive glass
- Architectural glass
  - Lighting panels
  - Mirrors
  - Furniture
  - Curtain walls
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
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)
  - Ceralink offers feasibility testing and process development
  - Licensing and/or partnering to commercialize specific applications
  - General license packaged with equipment

- DoE Industrial Grand Challenge (2010-2011)

- Ceralink and Thermex Thermatron working to bring 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®
FastFuse Process
RF Lamination Technology

Method to make laminates faster and more efficient

- 0.5 to 3 minute cycles
- Cuts energy over 90%
- Heats interlayer directly
- Does not heat glass
- Applies pressure
- Uses existing equipment
- Allows fast development
  - 50+ experiments in 1 day
  - Custom one-off manufacturing

Thermex Thermatron
RF Press with shuttle
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, nyons, polyesters*

Conductive materials transmit RF
FastFuse Applications
Laminated Transparent Armor

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

Polycarbonate Spall Shield

TPU Interlayers

Glass or Acrylic

Transparent Ceramic Impact Surface

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
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

ASTM C1172 visual inspection Passed

ATPD 2352 – Army Transparent Armor Purchase Specs
  Meets or exceeds optical specs
  Ballistic performance equivalent to autoclaved
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”  \(6 \text{ ft}^2\)
- 24” x 24”  \(4 \text{ ft}^2\)
- 18” x 16”  \(2 \text{ ft}^2\)
- 12” x 12”  \(1 \text{ ft}^2\)
- 9” x 9”  \(0.56 \text{ ft}^2\)
- 6” x 6”  \(0.25 \text{ ft}^2\)
- 4” x 4”  \(0.11 \text{ ft}^2\)
FastFuse Process Layers

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

Energy Consumed: 0.76 kWh

47.5 kWh / 1,000 ft²

Autoclaving energy 1150 to 4000 kWh / 1,000 ft²
RFPresses

4 ton, 18” x 20”

19 ton, 30” x 40”

700 ton, 48” x 120”
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
Embedded electronics

- Light emitting diodes (LEDs)
- Sensors

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

Before Press

9V battery on film leads
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
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”
- Ceralink established an on-site laboratory for FastFuse™ R&D
- Ceralink is seeking innovative manufacturers to implement FastFuse™
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