FABRICATE-ON-DEMAND VACUUM INSULATING GLAZINGS

2016 Building Technologies Office Peer Review

James W. McCamy Ph.D., mccamy@ppg.com
PPG
Project Summary

Timeline:
Start date: 10/01/2014
Planned end date: 09/30/2017

Key Milestones
1. Edge Seal and Pillars Are Feasible: 12/31/2015
2. Demo Edge Seal and Pillars in VIG: 12/31/2016
3. Prototype VIG Built: 09/30/2017

Key Partners:
Gyrotron Technologies, Inc.
GED Integrated Solutions, Inc.
Oak Ridge National Lab

Budget:
Total Project $ to Date:
• DOE: $634,281
• Cost Share: $332,059

Total Project $:
• DOE: $1,650,000
• Cost Share: $857,723

Project Outcome:
Design a fabricate-on-demand manufacturing process to overcome the cost and supply chain issues preventing widespread adoption of VIGs.

Enable commercially-viable VIG windows that meet or exceed the cost and performance metrics.
Purpose and Objectives

Problem Statement:
High-performance windows (HPW) made using Vacuum Insulated Glazing (VIG) units can yield substantial energy savings only if manufacturing costs and customer needs are met. VIG manufacturing is expensive and lacks flexibility in product offerings and therefore has had limited acceptance and success.

Target Market and Audience:
- Window Manufacturers
- Residential Market (~1600TBtu)
- Anticipated Savings: 2 Quads

Impact of Project:
- Overcome the cost and supply chain issues
- Provide high adoption rate and market penetration
- Units would enter the market as early as 2018
Approach

Approach:
Improve three areas impacting VIG adoption
• Edge Sealing
• Pillar Design/Placement
• Evacuating the VIG

Key Issues:
Technical solutions solve one or more issues
• Reduces mechanical stresses to improve yield
• Lowers capital equipment requirements
• Increases production throughput

Distinctive Characteristics:
The manufacturing process focus reduces cost and eliminates the barriers that prevent smaller manufacturers from entering into the market.
Approach – FEA Model-based Design

- Maximum tensile stresses are within design criteria with a safety factor of 1.8
- Both flex and rigid edge seals are viable designs
## Lap-shear Test Results Summary

<table>
<thead>
<tr>
<th>Bond Type</th>
<th>Results</th>
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</thead>
<tbody>
<tr>
<td>Glass-to-Glass</td>
<td>Successful with maximum Shear Strength of 2.8 MPa and 2.1 MPa for two different frits</td>
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<tr>
<td>Glass-to-Metal 1</td>
<td>Successful with maximum Shear Strength of 2.5 MPa and 2.2 MPa for two different frits</td>
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<td>Glass-to-Metal 2</td>
<td>Successful with maximum Shear Strength of 3.4 MPa with one frit and failure in glass with second frit</td>
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<td>Glass-to-Metal 3</td>
<td>Unsuccessful with debonding at surface coating interface</td>
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<tr>
<td>Glass-to-Metal 4</td>
<td>Unsuccessful with no bond formed or heavy glass cracking for all samples</td>
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Candidate materials: performance

Polymers can perform as well as or better than many ceramics and metals.
Approach – Evaluation of Additive Manufacturing

- ABS pillars (Diameter: 1mm) printed directly on glass
- Pictures taken under polarizing filters show stress after evacuation
- Pillar shows a cracked edge under vacuum
- Spacing between inner surfaces reduced by ~1/2

[Images showing the comparison between 760 Torr and 1 Torr conditions, with a graph indicating the evacuation process with ABS 3D printed spacers.]
Approach – Prototype Fabrication

Prototype VIG

- 9" x 10" unit
- Glass-to-glass seal successfully applied and fired
- Cylindrical zirconia spacers
- Evacuated to target vacuum and sealed
Approach – Process Design and Incremental Cost Analysis

- Production rate: 60%
- Capital cost: $2.2MM
- Installed cost: >$13/ft²
Progress and Accomplishments

Accomplishments:

Technical metrics of the project were reached or are achievable

✓ VIG design meets performance goals of DOE roadmap
  ✓ At least one material and process for the edge seal
  ✓ At least one material and process for pillars
  ✓ Small area prototypes fabricated using identified materials

✗ Materials and design for low-cost evacuation process does not meet cost goals of DOE roadmap

✗ A process evaluation showed the capital and fabrication costs exceeded both the window manufacturer’s expectations and the market acceptance threshold

✓ Alternate high-performance window designs and fabrication processes were identified that can meet the performance and cost targets
Progress and Accomplishments

Market Impact:
• Market research guided the technical work
  – Discussions and interviews with window manufacturers
  – Critical acceptance criteria for market acceptance established

High-performance window, insulated glazing unit technology #1 and #2 are VIG designs from BP1. Technology #3 and #4 are candidates proposed for BP2.
Progress and Accomplishments

Awards/Recognition:

• No awards or recognition to report

Lessons Learned:

• High performance windows will play an important role in energy savings
• Value exists in market for an alternate window design to the standard triple IGU
• The role of each step in the supply chain must be considered, and these needs, acceptance criteria, and constraints must be met
• Flexibility in the performance / cost relationship is important to achieve increased adoption rate and market penetration
Project Integration and Collaboration

Project Integration: The project team includes technology partners and manufacturing equipment providers. PPG supplies both glass and toll-produces IGUs. PPG has a vast certified fabricator network for both residential and commercial glazings.

Partners, Subcontractors, and Collaborators:

- **PPG Industries, Inc.** is the world’s largest coatings company, and a supplier of flat glass, fiber glass, and specialty materials.
- **Gyrotron Technologies, Inc.** provides advanced thermal process heating solutions using high-frequency microwave beam technology.
- **GED Integrated Solutions** is a global system solution provider to the window and door industry.
- **Oak Ridge National Lab** helps to ensure America’s security and prosperity by addressing its energy, environmental, and nuclear challenges.

Communications: No presentation to report
Next Steps and Future Plans:

• Budget Period 1 Continuation Review completed

• PPG recommended a redirection to pursue an alternate high-performance window IGU design that meets both the performance and cost goals
REFERENCE SLIDES
Project Budget:

BP1: $966,340  ($634,281 Federal, $322,059 Cost Share)
BP2: $970,230  ($637,003 Federal, $333,227 Cost Share)
BP3: $571,153  ($378,716 Federal, $192,437 Cost Share)
Total: $2,507,723  ($1,650,000 Federal, $857,723 Cost Share)

Variances: None

Cost to Date: All BP1 funds spent

Additional Funding: None

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<thead>
<tr>
<th>Budget History</th>
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<tr>
<td><strong>DOE</strong></td>
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<td>$475,545</td>
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## Project Plan and Schedule

- Budget Period completed within planned duration
- Three-month (estimated) redirection period underway
- New SOPO proposed to DOE
- Same duration BP2, abbreviated BP3

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<thead>
<tr>
<th>Major Milestones</th>
<th>FY2015</th>
<th>FY2016</th>
<th>FY2017</th>
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<td>Q1 (Oct-Dec)</td>
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<td>Q2 (Jan-Mar)</td>
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<td>Q3 (Apr-Jun)</td>
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<td>Q4 (Jul-Sep)</td>
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<td>FY2015</td>
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<td>FY2017</td>
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### Past Work
- Edge Seal and Pillars Are Feasible: 12/31/2015
- BP1 Continuation Process/Redirection

### Current/Future Work
- Demo Edge Seal and Pillars in VIG: 12/31/2016
- Prototype VIG Built: 09/30/2017