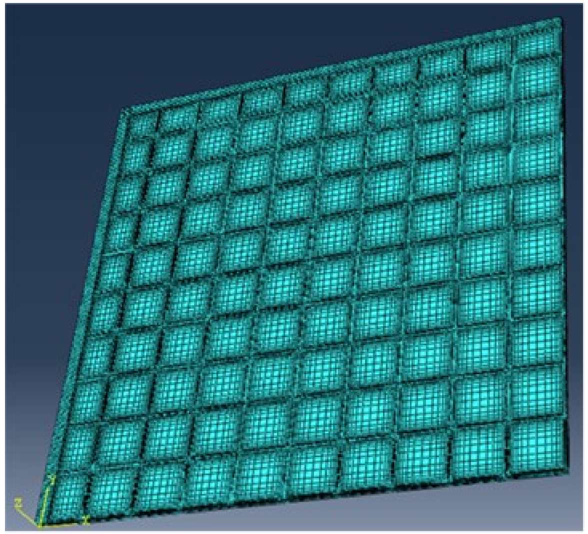
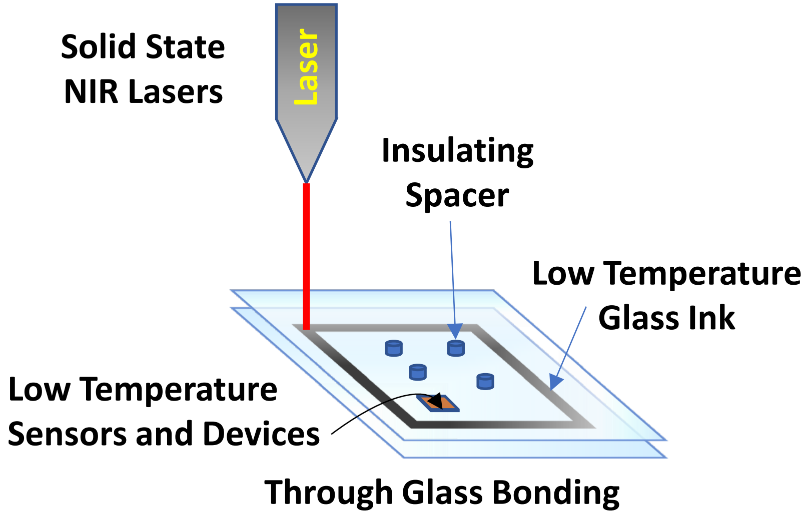
Pulse Strengthened and Laser Edge Sealed Vacuum Insulation Glazing

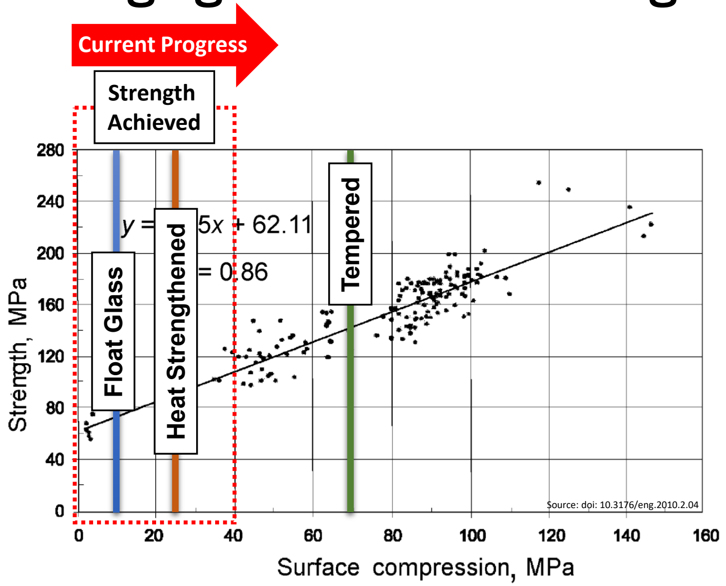
3D VIG Abaqus Model



Laser –Assisted Hermetic Seal



Plasma Arc Lamp Processing for Emerging Windows Technologies



Oak Ridge National Laboratory
Pooran Joshi, Senior Scientist
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Project Summary

Timeline:

Start date: October 1, 2018
Planned end date: December 31, 2021

Key Milestones

1. Go/No-Go: Demonstration of glass strengthening through pulse thermal processing; 09/30/2019
2. Go/No-Go: Finalization of VIG components meeting design criterion; 09/30/2020
3. Final prototype VIG sample: Performance and reliability analysis under various operating conditions; 12/31/2021 (No-cost Extension)

Budget:

Total Project $ to Date:

- DOE: $1,365,000
- Cost Share: No

Total Project $:

- DOE: $1,500,000
- Cost Share: No

Key Partners:

WinBuild, Inc.

Project Outcome:

Scalable, low-cost processing strategy for glass strengthening and sealing is proposed to impact the thermal performance of insulating glass units. A combination of large area photonic processing, additive manufacturing, and laser encapsulation techniques is proposed to realize a vacuum glazing technology meeting the cost, performance, reliability, and throughput demands.

Team

Dr. Pooran Joshi: Senior R&D staff with over 20 years of experience in low-temperature materials, process technology, and device integration for flexible electronics, display technology, and photovoltaics

Dr. Mahabir Bhandari: R&D staff with research focus on building components and integration, including fenestration development and performance characterization

Mr. Thomas Muth: R&D staff; Over 28 years of experience career converting metals into useful forms for performance advantage and profit

Dr. Sarma Gorti: Senior R&D staff; Expertise in modeling and simulation of metals and alloys

Dr. Ahmed Hassen: R&D staff; Experience in composite material manufacturing, characterization and qualifications methods

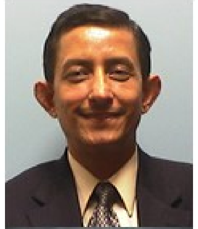
Mr. Bipin Shah: Over 23 years of experience in building energy efficiency research and technology advancement

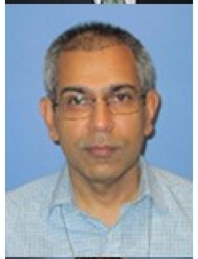
Lingyue Zhang (PhD Student): Laser processing

Wenyuan Zhu (PhD Student): VIG Modeling

Dr. Seungha Shin: Professor, University of Tennessee, Expertise in Multiscale, Multiphysics simulations

ORNL




WinBuild

UTK



Challenge

Problem Definition

Windows only take up between 5-10% of a home's total surface area that is exposed to outside temperatures but account for as much as 30-45% of the heat lost in a home.

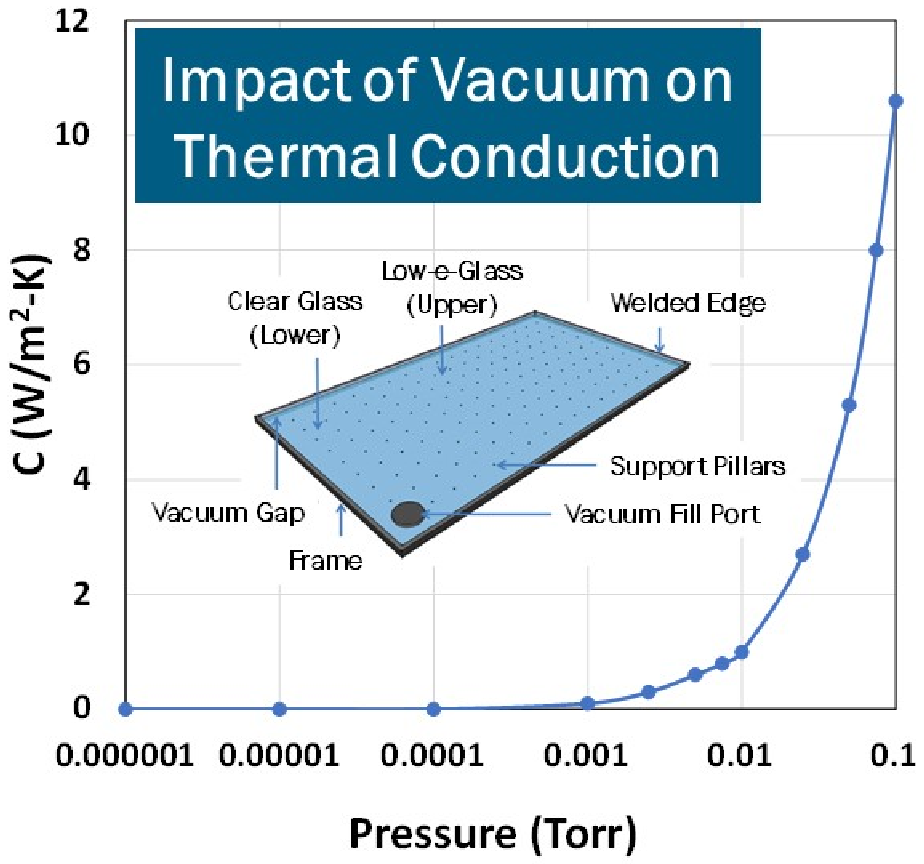
Opportunity

→ Scout estimates the heating energy use associated with windows conduction as 2 Quads.

→ Vacuum insulated glazing (VIG) for residential and commercial use is a promising technology to meet the rigorous R-10 thermal performance requirements.

Technology Challenges

→ Key challenges of cost, performance, and reliability must be overcome for technology adoption and widespread deployment.



Proposed Concept

→ Scalable, low-cost processing strategy for glass strengthening and sealing is proposed to realize a VIG technology meeting the cost, performance, reliability, and throughput demands.

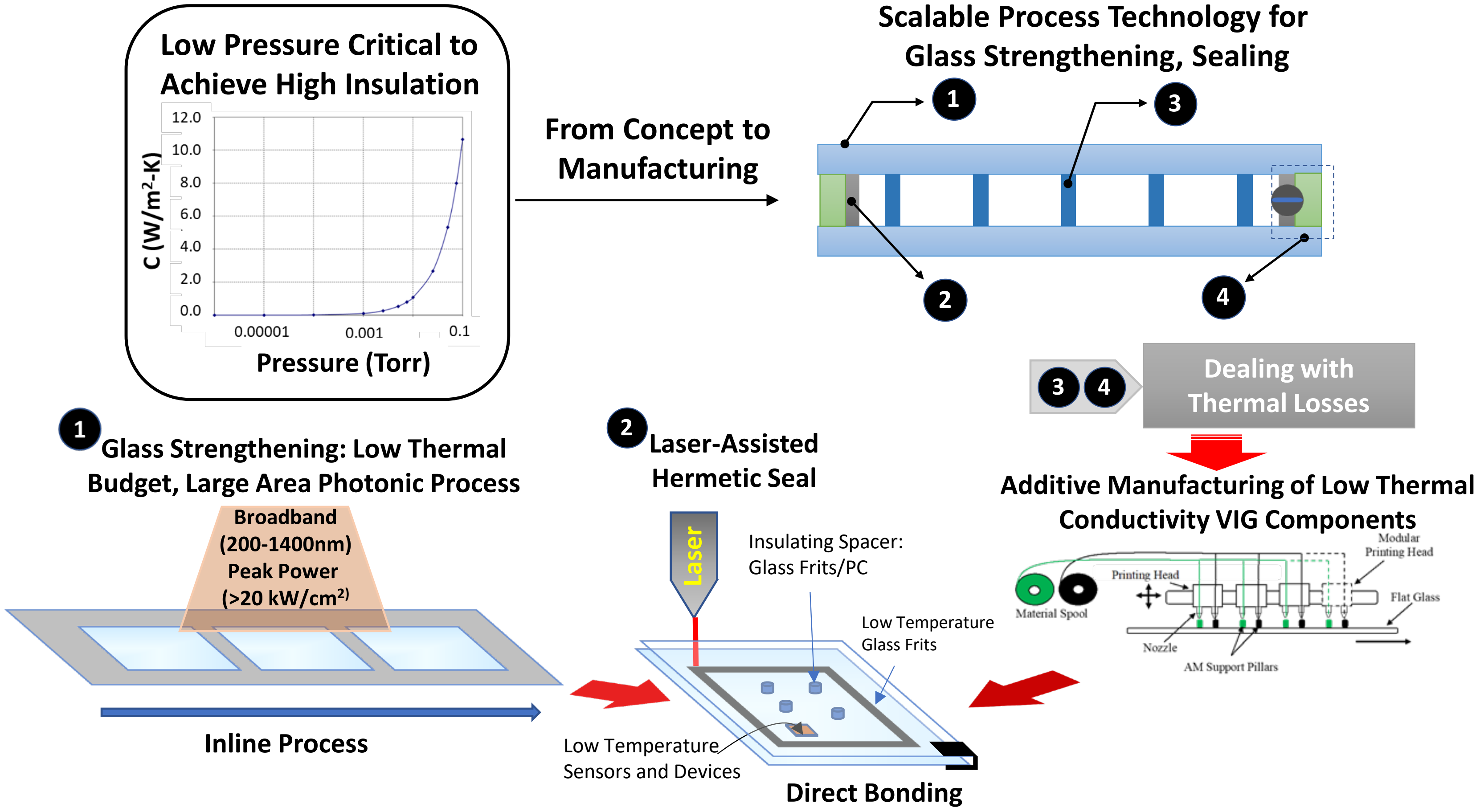
Approach

Approach: Scalable, low-cost processing strategy for glass strengthening and sealing is proposed to impact the thermal performance of insulating glass units.

→ A combination of large area photonic processing, additive manufacturing, and laser encapsulation techniques is proposed to realize a vacuum glazing technology meeting the cost, performance, reliability, and throughput demands.

Specific R&D Focus Areas Include:

- Modeling of VIG components to analyze impact on heat flow and energy saving opportunity
- Pulse thermal processing for in-line glass strengthening for use by a glass manufacturer
- Low thermal budget laser-assisted hermetic sealing of printed edge seal
- Additive manufacturing of VIG components: flexible edge seal; pillars, custom valve for edge incorporation



Impact

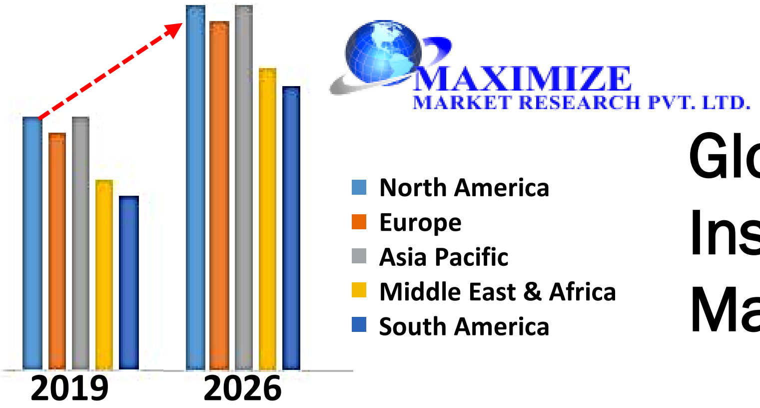
VIG Technology Penetration

- VIG Market Projected to reach USD 6.59 Billion by 2027
- Demand for Green Buildings: Reduction of energy consumption of windows up to 75% compared to a single glazed unit
- Strict regulations on carbon emissions are likely to propel VIG market for building & construction

Market Projection

Impact of Project

- Scalable, high throughput process to impact glass strength independent of glass thickness
- Low thermal budget laser-assisted hermetic sealing eliminating high temperature processing steps
- Additive manufacturing and integration of VIG components



Global Vacuum Insulated Glass Market, by Region

Impact on Building Technology: The low-cost VIG unit would contribute significantly towards reducing energy consumption; even with 30% market adoption, the savings would be more than 600 TBtu

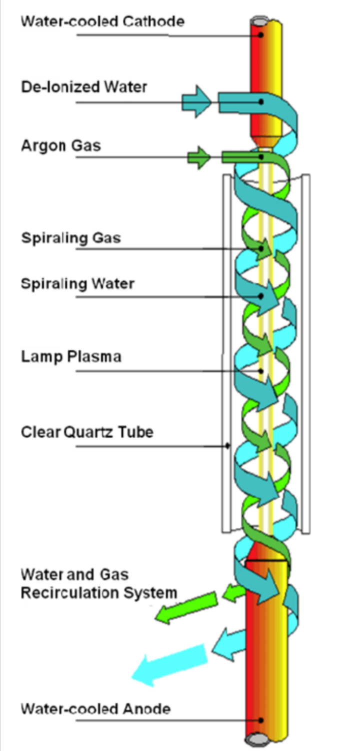
Glass Strengthening: Plasma Arc Lamp Processing

Goals

→ Low thermal budget Pulse Thermal Process to impact Glass Strength: Rapid, Clean, Noncontact

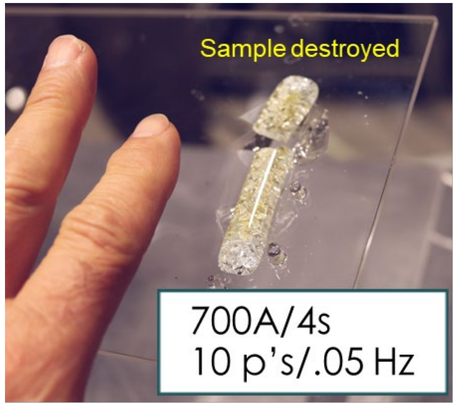
→ Scalable Solution for Future Technology : Impact Compressive Strength of Thin Glass (~0.7mm)

Plasma Arc Lamp

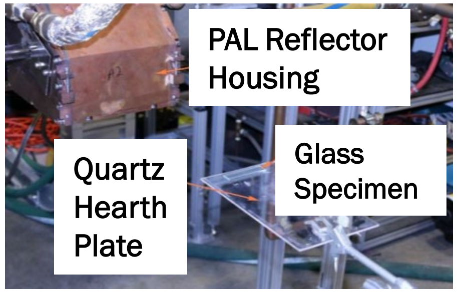


Broadband spectrum: 0.2-1.4 μm

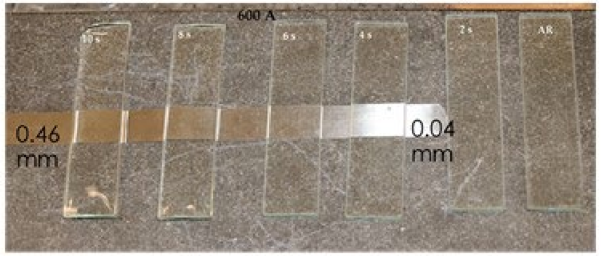
Process Window



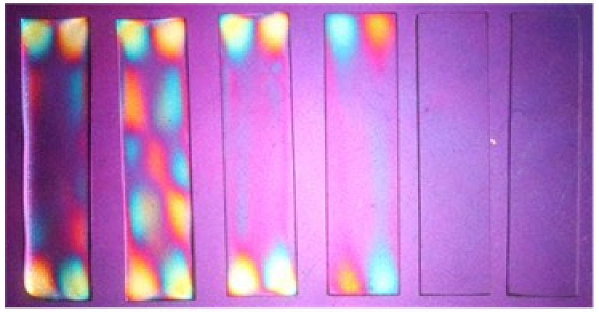
PAL Setup



Focused on Single Pulse 600 A
Varying Time: 2 s, 4 s, 6 s, 8 s, 10 s

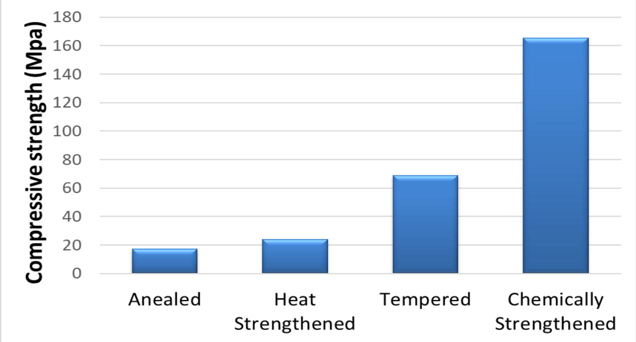


Polarized Light Images



Dimensional change with Increased Concavity

Current Technology



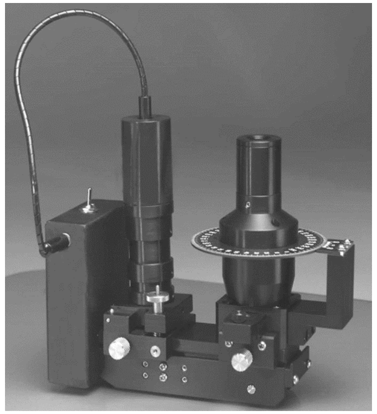
Increased cupping with exposure time

→ PAL shows Controlled Influence on the Glass Stress Condition

Glass Strengthening: Plasma Arc Lamp Processing

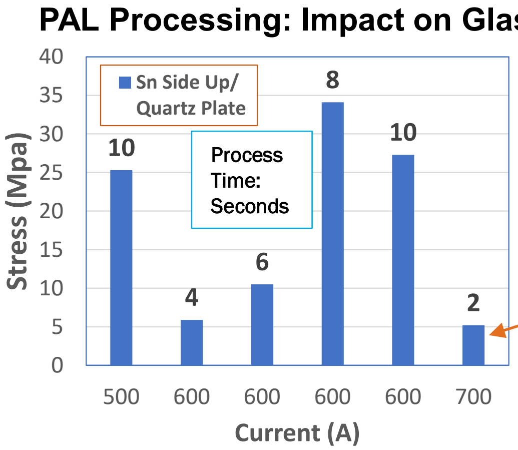
New Capability Development

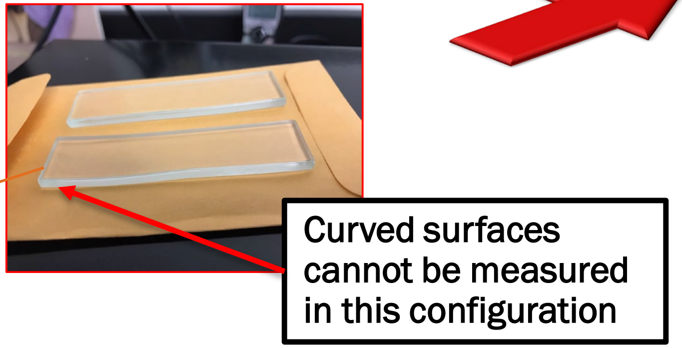
Nondestructive Analysis of Surface Stress

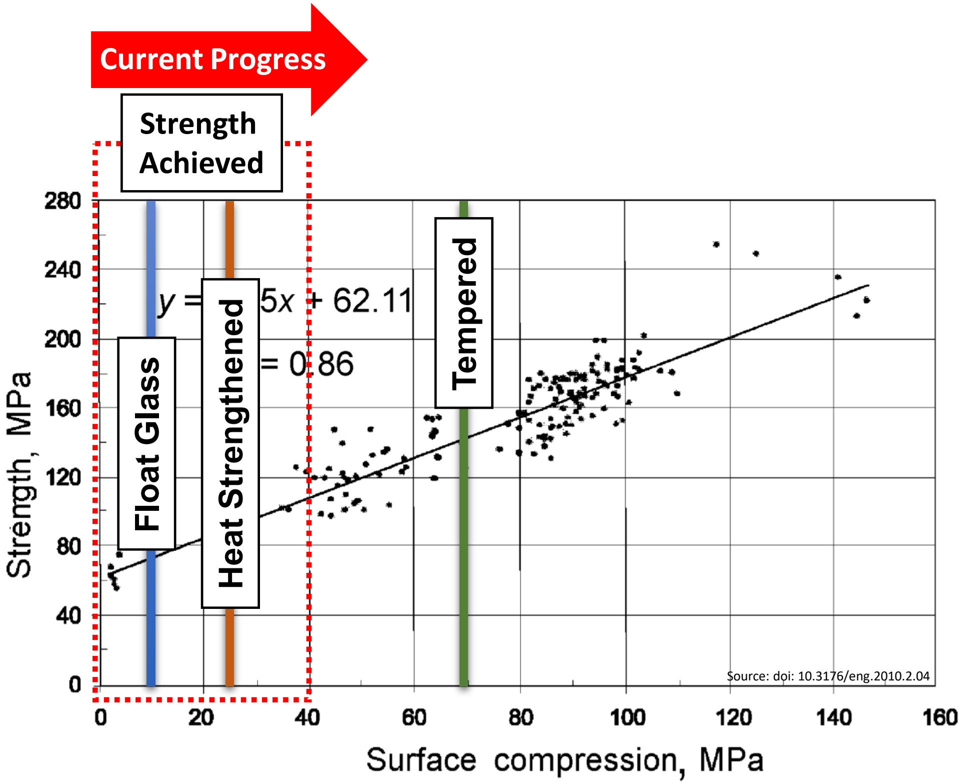


- Surface Stress in Tempered, Heat-Strengthened, or Annealed Glass
- Compliant with ASTM C1048, C1279, EN-12150, EN-1863

→ Photonic Pulse Thermal Processing to Impact Glass Strength







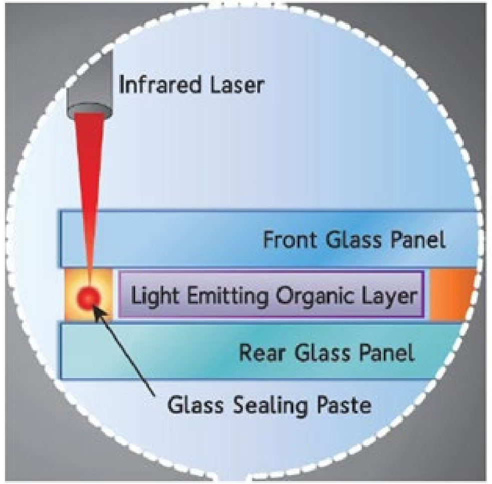
→ Even a Short Process Time (<10s) Significantly Impacts Glass Strength

→ Photonic Processing to Impact Thin Glass Strength for Emerging Window Technologies

Hermetic Edge Seal: Printing and Laser processing Pathway

Edge Seal Ink → **Digital Printing** → **Thermal Curing**

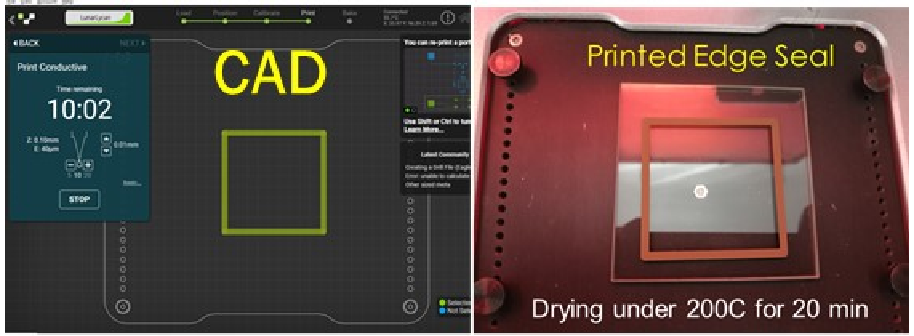
Glass Ink



Model No.: AMO11, AMO12
Paste Solid Content: 55%
Viscosity: 60 kcps
Binder: EC Binder, etc.
Solvent: α-Terpineol, BCA, etc.)

New YEK Ink: 100-150 kcps

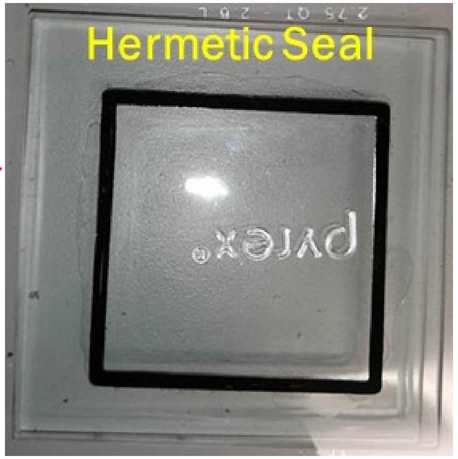
Digital Material Printing: Edge Seal



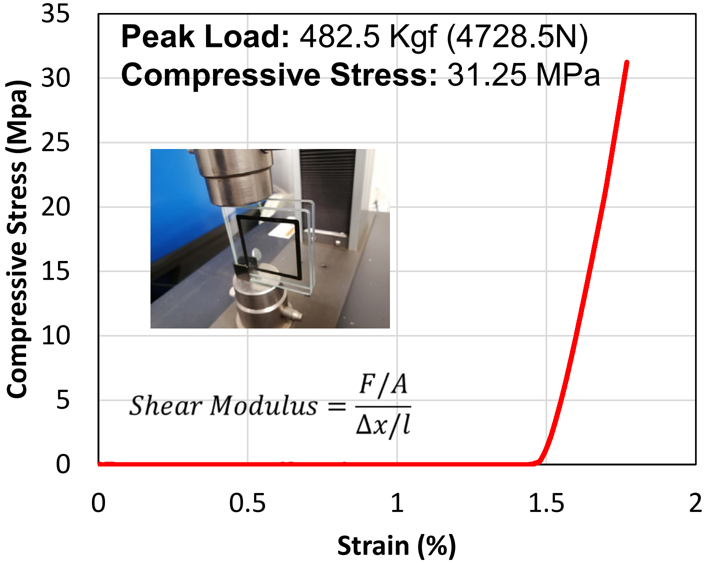
Process Steps:

- Select Ink
- Multi-pass Digital Printing (d~0.5mm)
- Thermal Curing
- Testing

Glass-to-Glass Bonding



Mechanical Testing

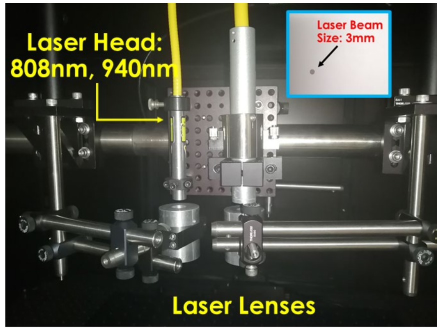


→ High Mechanical Strength
→ No water seepage detected (after 7+ days of soaking)

Hermetic Edge Seal: Printing and Laser processing Pathway

Edge Seal Ink → **Digital Printing** → **Laser Curing**

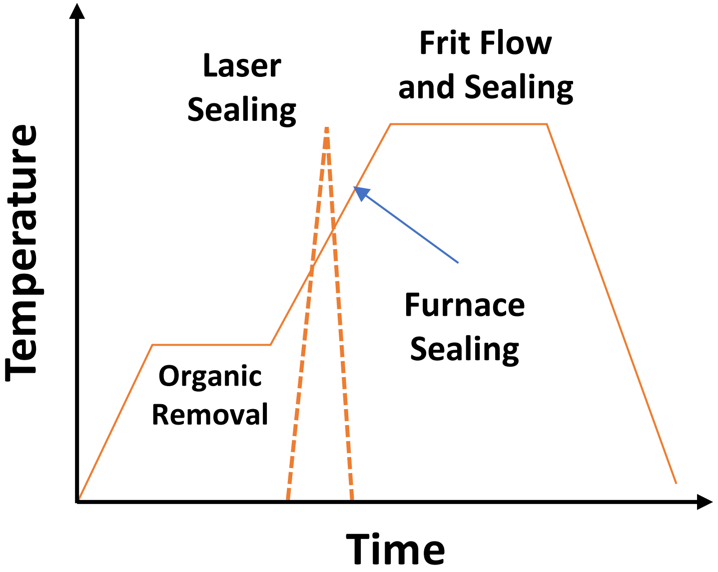
New Capability Development
NIR Solid State Lasers
for
Materials Processing



Laser 1: Fiber Laser	
Parameter	Specs
Wavelength (nm)	808 nm
Power (W)	0-100 W
Target Beam size Range for Processing (mm)	0.5-5.0 mm
Type	CW

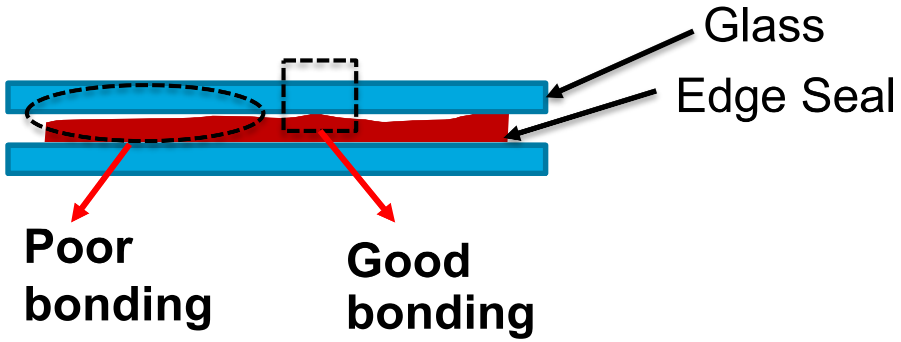
Laser 2: Fiber Laser	
Parameter	Specs
Wavelength (nm)	940 nm
Power (W)	0-400 W
Target Beam size Range for Processing (mm)	0.5-5.0 mm
Type	CW

Low Thermal Budget Edge Sealing



Glass Frit Temperature $T = \frac{KP}{a^2\sqrt{vD\varepsilon L}}$

K: Scaling coefficient, P: Laser power, a: beam diameter, D: Heat diffusivity, ε: laser radiation absorption by frit, L: Frit height



Laser Processing: Key Considerations

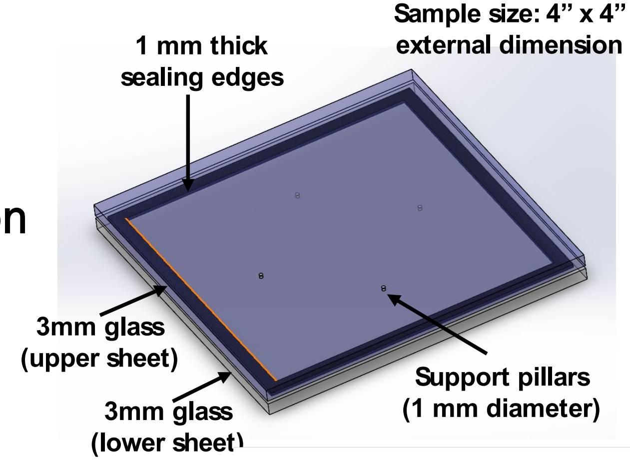
- Ink Rheology: Laser energy absorption and Thermal compatibility
- Printed layer thickness and surface profile
- Bond strength after laser processing
- Hermetic sealing characteristics

Hermetic Edge Seal: Printing and Laser processing Pathway

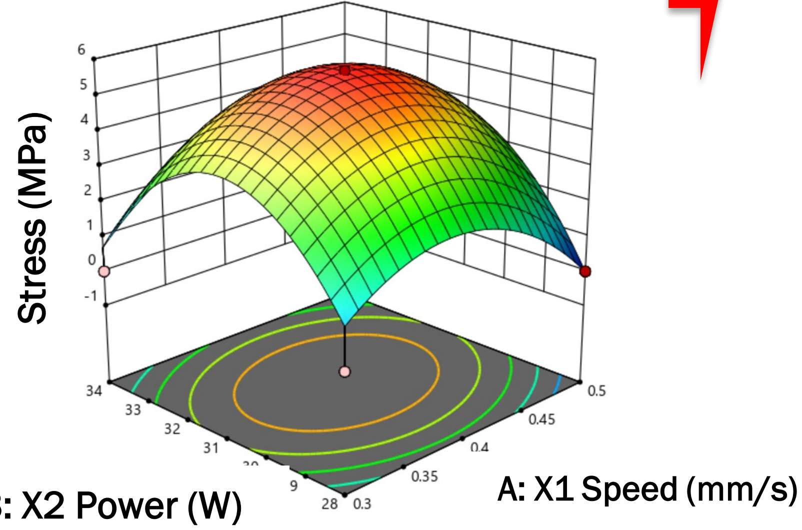
Optimizing Edge Seal Laser Process

Laser Process Control: Speed ⟷ Power ⟷ Stress

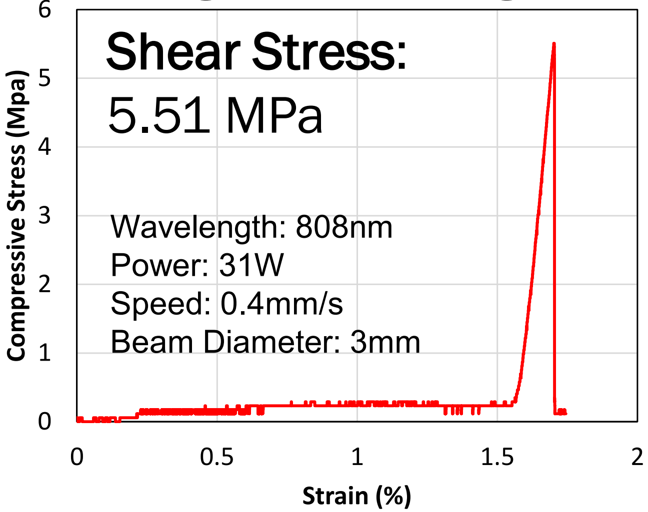
VIG Configuration



COMSOL Heat Transfer Analysis



Edge Seal Strength



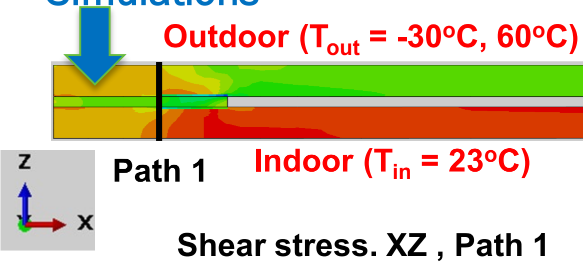
Hermetic Seal Test

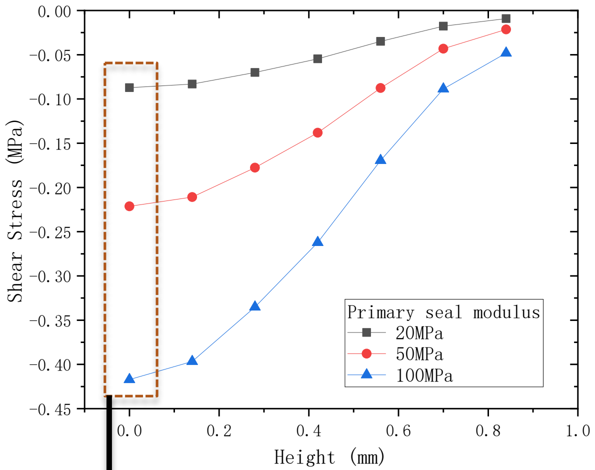
Both 808nm and 940nm Lasers Effective in Creating Glass-to-Glass Bonding

Flexible Seal for VIG

Edge Seal for VIG: Opportunity
- Rigid Seal
- Flexible Seal

Flexible Seal Structural Simulations

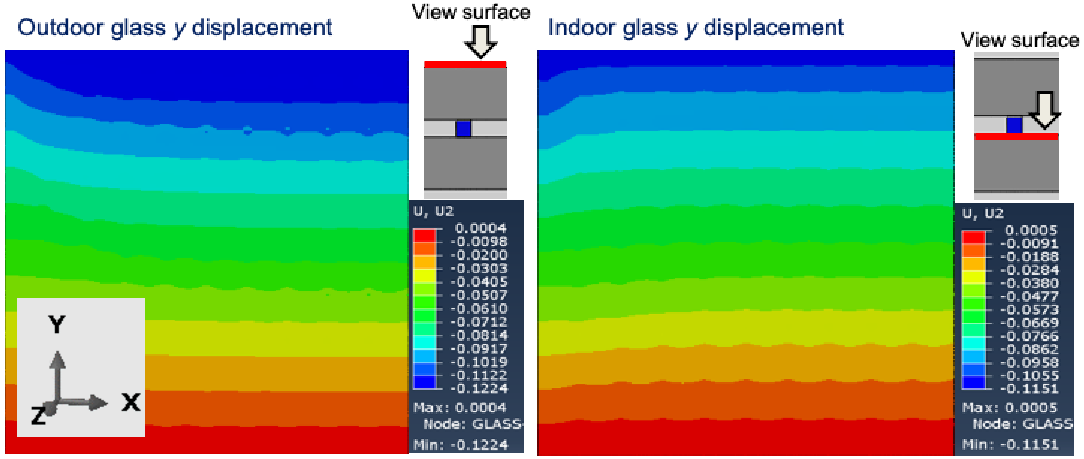




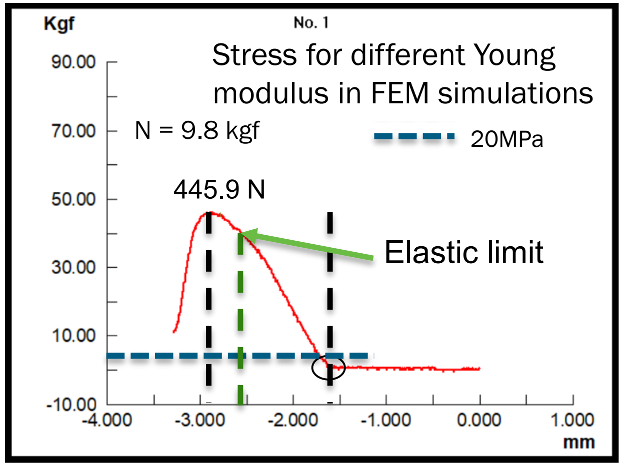
Measured Seal Shear Strength Value (1.17MPa) > Required Value (0.1-0.43 MPa)

Glass Displacement Scenario at 1mTorr

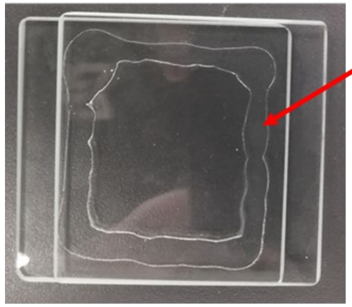
Lower outdoor temperature ($T_{out,\infty} < T_{in,\infty}$; $T_{out,\infty}$ = -30°C, $T_{in,\infty}$ = 23°C)



Ceramic Seal

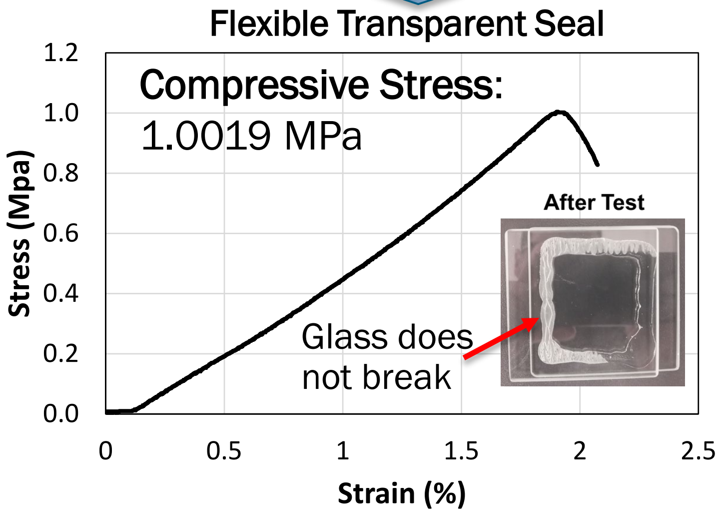


Flexible Transparent Seal



3″×3″ Sample

Hermetic: No water seepage detected after 48+ hours of soaking



Developed Seal Displacement Exceeds (1.6 mm) the Max Glass Displacement of 0.6mm

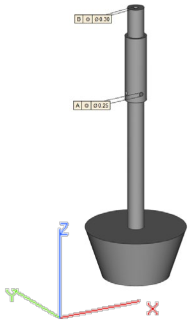
Additive Manufacturing and Integration of VIG Components

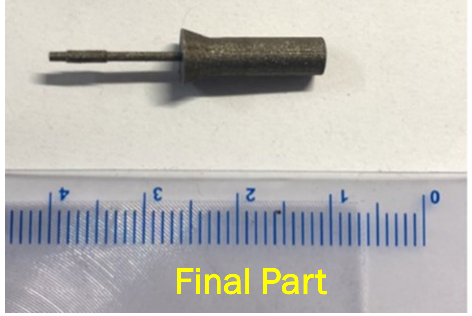
Vacuum Valve Design

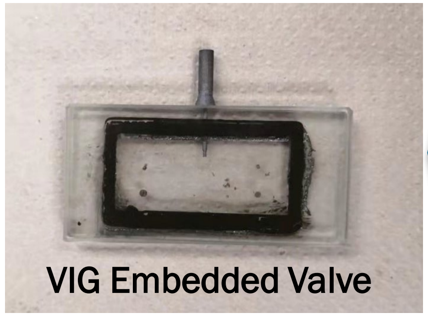
Additive Manufacturing

Laser Powder Bed FormUp 350

- 2 Yb fiber lasers
- 70μm spot size
- Speed up to 10m/s
- Maraging Steel



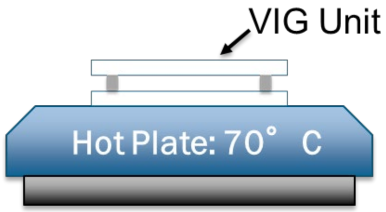


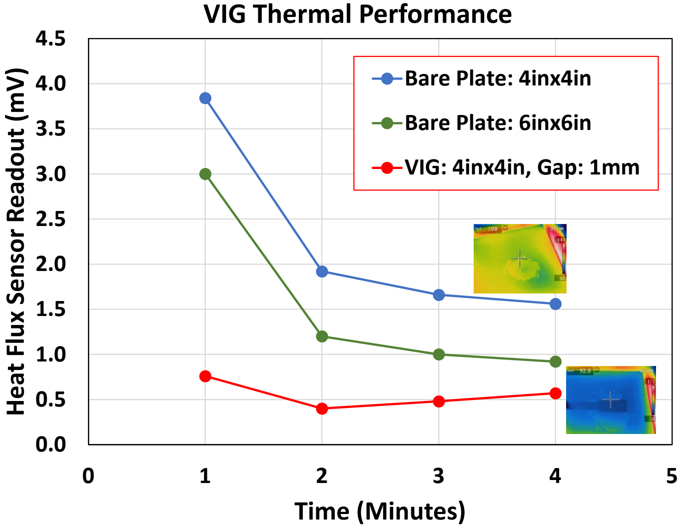


The Valve appears Well-Bonded

VIG Thermal Performance

- Test using Heat Flux Sensor
- Sensitivity: 2.01 μV(W/m^2)
- Vacuum Annealing at 1mTorr

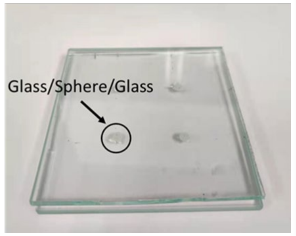


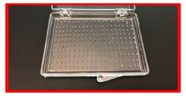


Pillars: Pick-n-Place Approaches

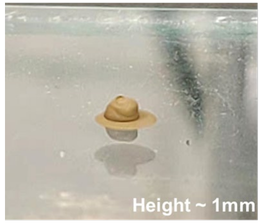
- **Digital Ink Printing**: Ink selection for target spacing
- **Precision Spheres**: Broad range of materials available
- **CNC Cylinder**: Glass ceramic rods cut to dimensions

Precision Spheres





Pillar: Multilayer Printing



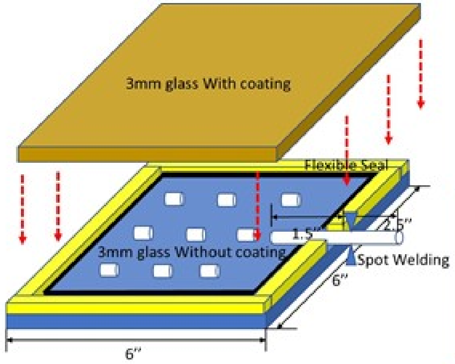
Main Points:

- Measurements dependent on sample size
- Lower heat flow measured across VIG unit
- Glass Outgassing and Getter Material Investigation Underway to analyze impact on thermal performance

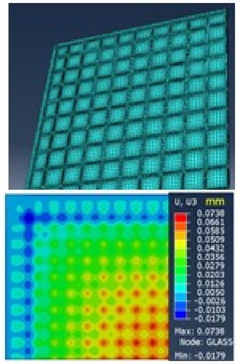
VIG with 3D Printed Valve, Flexible Seal and Composite Pillars

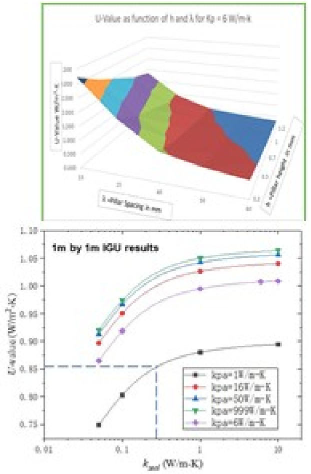
VIG – Oven-Free Flexible Seal, In-plane Valve, Composite Pillar

- Development of Concept Design
- Modeling for Structural/ Thermal Characteristics
- Materials and Parts: Development, Testing, and Optimization
- Prototype Sample (6 in by 6 in)
- Scale sample (20 in by 14 in)



Design of VIG


Structural Optimization

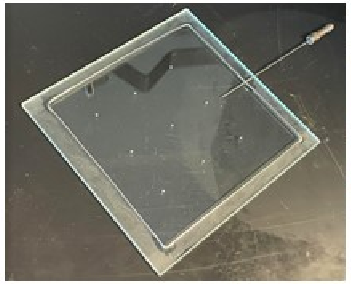


Thermal Optimization

Material Selection

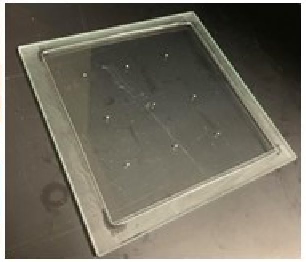

Proprietary Flexible Non-Permeable Sealant


Proprietary - 3D Printed Vacuum Valve


Oven free, in-plane Vacuum Valve Assembly Process

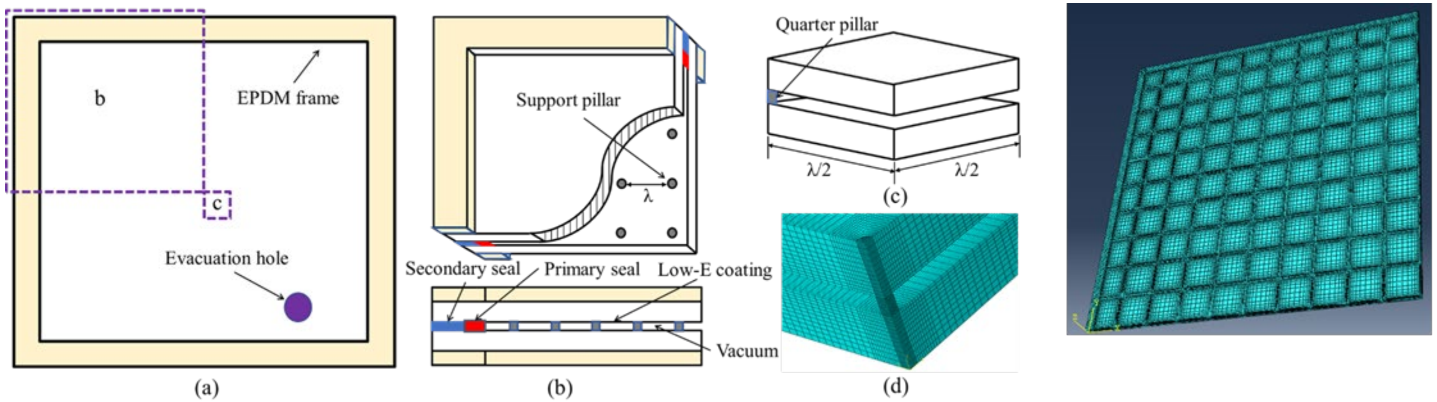

Active Vacuum Pump 0.05 mTorr


Vacuum and Spot Welding Process

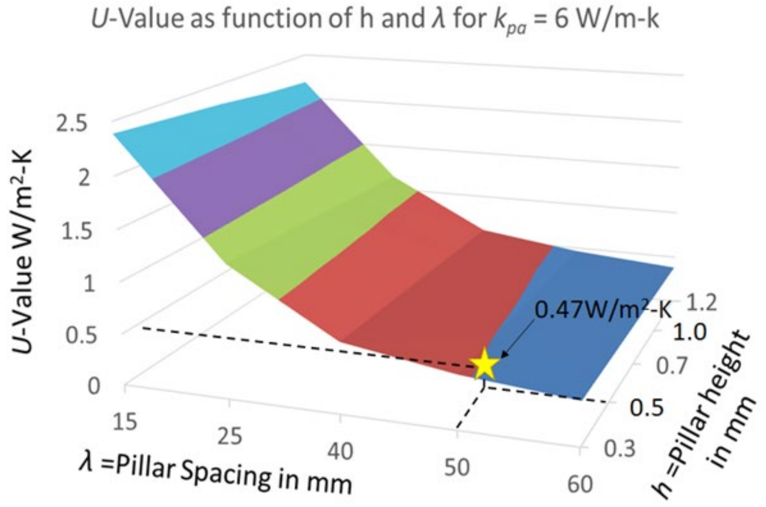

Prototype 6" × 6" Vacuum Glazing

VIG – Thermal Analysis

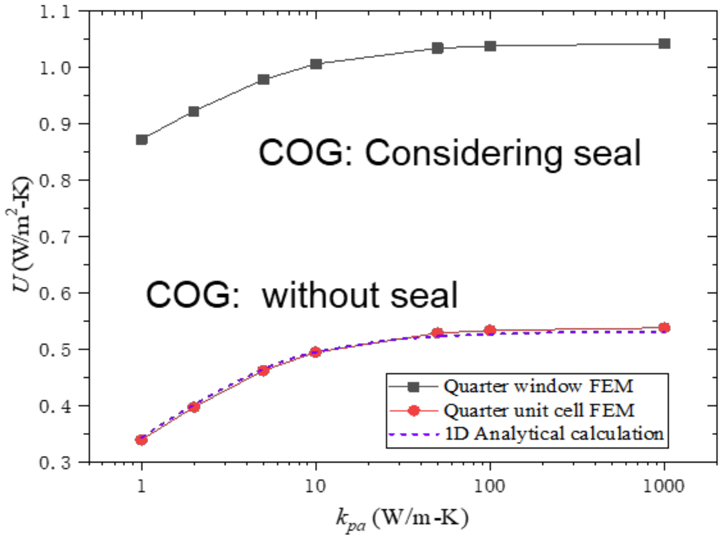
- VIG Performance: Optimized pillar spacing and height, and seal width
- For optimal structural performance and valve accommodation: pillar spacing of 50 mm and height of 1 mm were selected



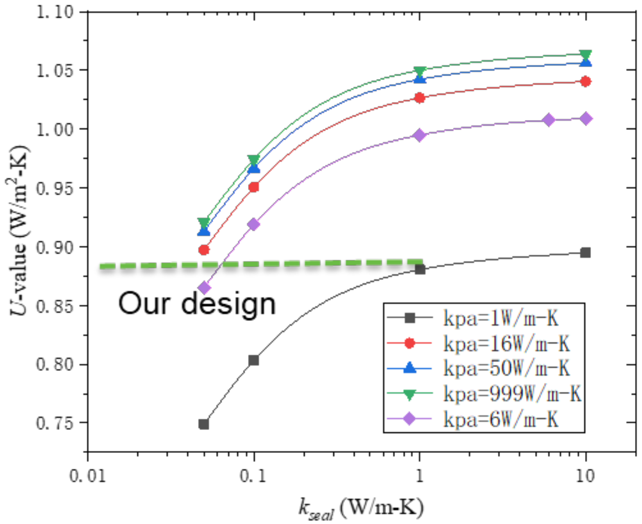
Thermal analysis using quarter model of full VIG including seals and frame (b), and unit-cell near center (c), with refined mesh near pillars (d)



COG U-Value as a Function of Pillar and seal conductivity



COG U-Value with and without considering seal



Whole window (1 m x 1 m) U-Value as a function of pillar and seal conductivity

Stakeholder Engagement

- NDA established with Vitro
  - Visited Vitro glass and IGU Plant to better understand the Glass manufacturing, Low-E coating, Tempering and IGU manufacturing processes.
  - Procured 3 mm glass samples for fabrication and testing of different processes of pillar and edge seal.
- Oldcastle BuildingEnvelop: NDA established.
- YEK Glass Co., Ltd.: Expertise in Ultra Low Temperature Glass Frit. Applications include bonding (adhesion), hermetic sealing (encapsulation), insulation, and protection.
- Participation in Stakeholder Workshop on Research Needs Around Durability of Emerging Fenestration Technologies at NREL

Progress and Remaining Project Work

- Plasma Arc Lamp Processing to Impact Glass Strength
  - → **Low thermal budget PAL processing results in high glass strength matching float glass and heat strengthened glass strengths**
  - → Next Step: Compare performances of thin and thick glasses (Technology Solution for Emerging Thin Glass Windows)
- Laser Process Space for Edge Sealing at Low Thermal Budgets
  - → **NIR Laser processing effective in achieving glass-to-glass bonding with edge seal strength of 5.51MPa and a hermetic seal**
  - → Next Step: Establish laser-ink-thickness-bonding correlation for optimum edge seal gaining from experimental findings (Further engage vendor)
- Design and Implementation of Vacuum Insulation Glazing
  - → Establish quantitative thermal performance of integrated VIG unit as a function of vacuum level
  - → **VIG Specifications Document with focus on Technology Integration Opportunity: ink materials, high throughout processes, discreet component design, and path forward**

Disclosure

Disclosure 201804214, DOE S-138,885: Pulse Strengthened and Laser Edge Fused Sealed Vacuum Insulation Glazing (VIG)

Publication

Effects of Pillar Design on the Thermal Performance of Vacuum Insulated Glazing (Submitted to Energy and Buildings)

Thank you

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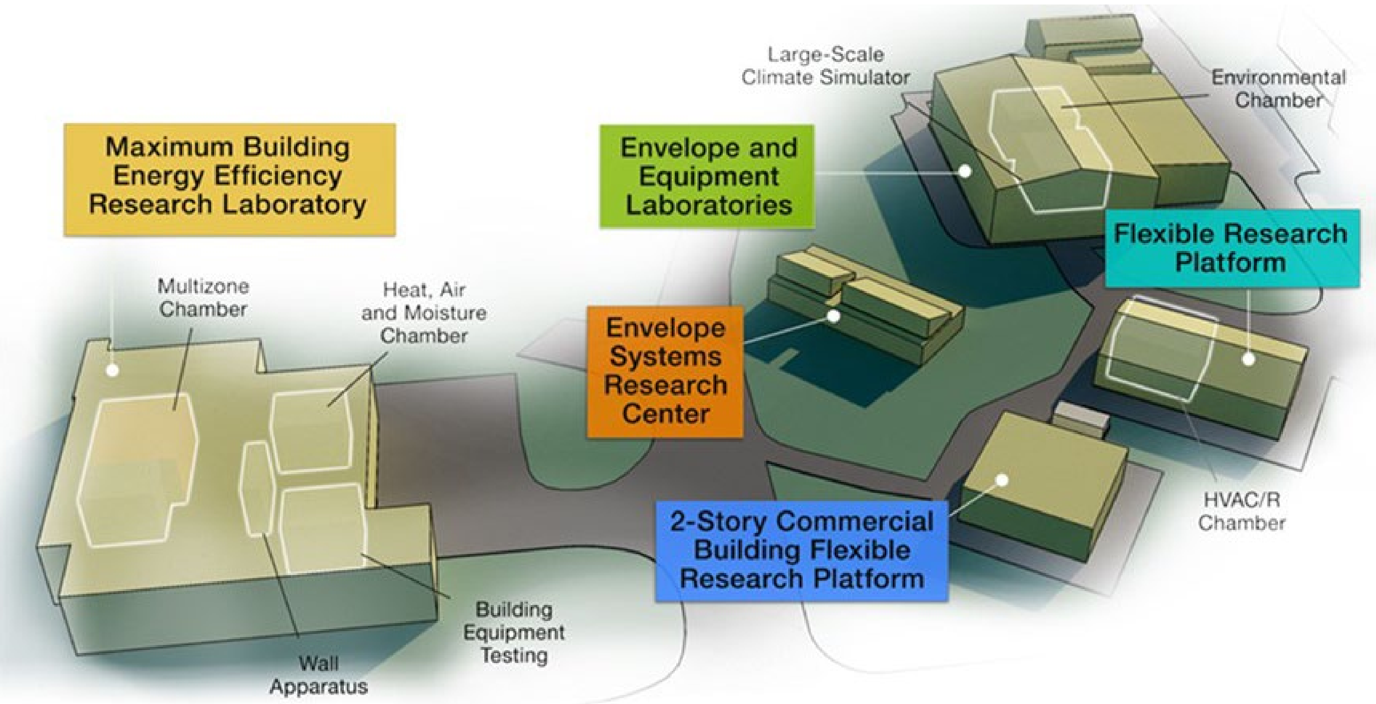

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

Project Budget

Project Budget: $1,500,00 (FY19-FY21)
Variances: No
Cost to Date: $1,365,000
Additional Funding: No

Budget History					
10/01/2018 - FY 2019		FY 2020		FY 2021 – 12/31/2021	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$500,000		$500,000		$500,000	

Project Plan and Schedule

Project Schedule												
Project Start: 10/01/2018		Completed Work										
Projected End: 12/31/2021		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned) use for missed milestones										
		Milestone/Deliverable (Actual) use when met on time										
	FY2018				FY2019				FY2020			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1: VIG technology review, and framework for VIG system and component specifications												
Q2: Thermo-physical modeling of VIG components and system												
Q3: Modeling, conceptual design, and material and process identification for edge seal and pillars												
Q4: Go/No-Go: Develop flexible edge seal for vacuum glazing using 3D printing techniques												
Q5: Fabrication of pillars using additive manufacturing												
Q6: Develop pulse thermal process and perform mechanical measurements to evaluate impact on glass strength												
Q7: Fabricate one-way valve meeting design criterion or alternate method to develop vacuum												
Q8: Go/No-Go: Finalization of VIG components meeting design criterion												
Q9: Evaluate functioning of vacuum levels to maintain thermal performance through ASTM testing												
Q10: Fabricate prototype VIG to conduct ASTM testing												
Q11: Document test and evaluation of thermal and physical performance of VIG testing											No-Cost Extension (12/2021)	
Q12: Final prototype VIG sample												