NREL

Transforming ENERGY

Laser Welded Edge Seals for Polymer-Free Glass/Glass Modules

David Young, Nick Bosco, Tim Silverman

DuraMAT

Durable Module Materials Consortium

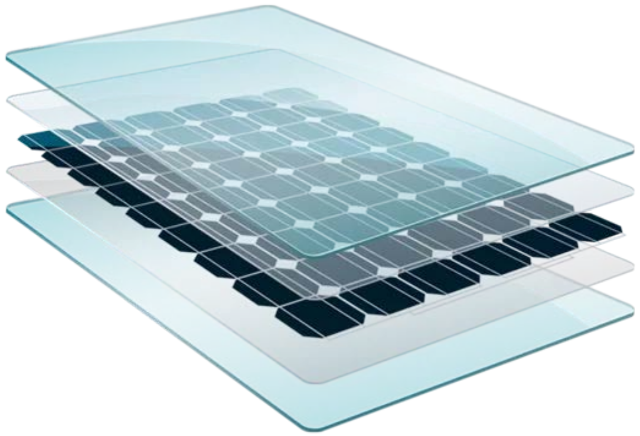
Spark Project

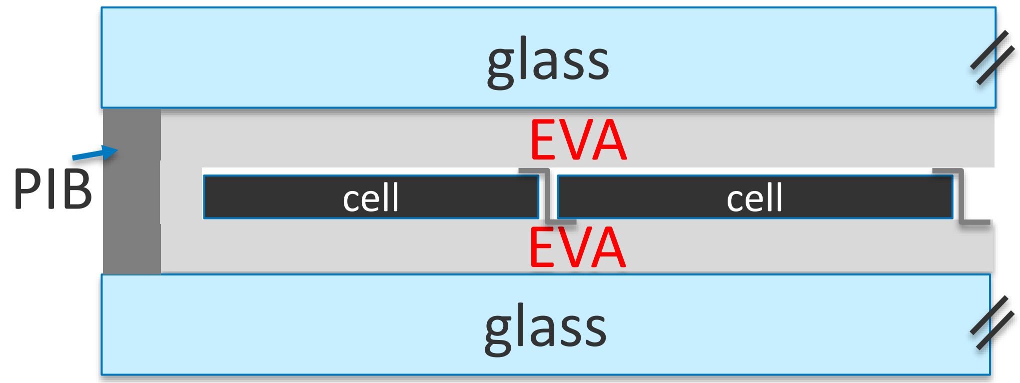
Photo from iStock-627281636

Redesign the module

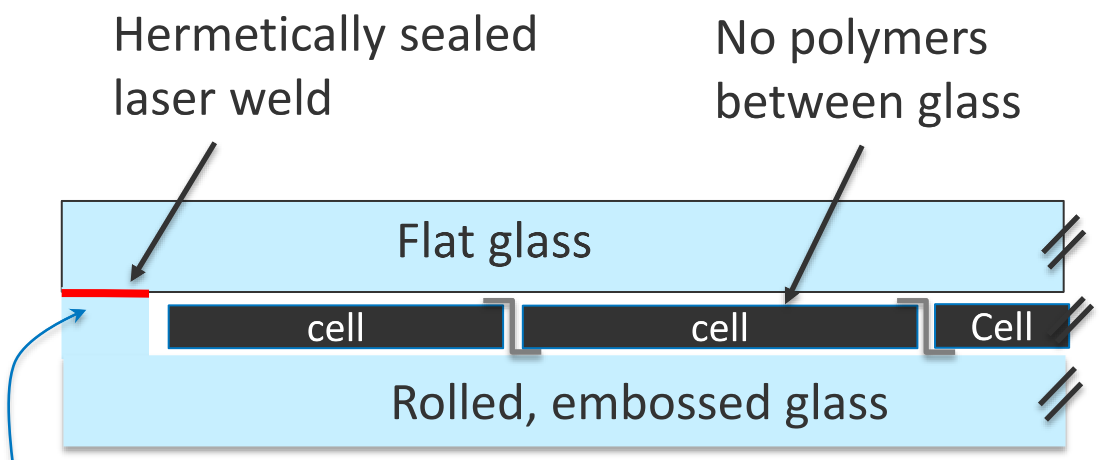
Part of a larger project to redesign modules by adding value to the glass

Traditional glass/glass module





New glass/glass module

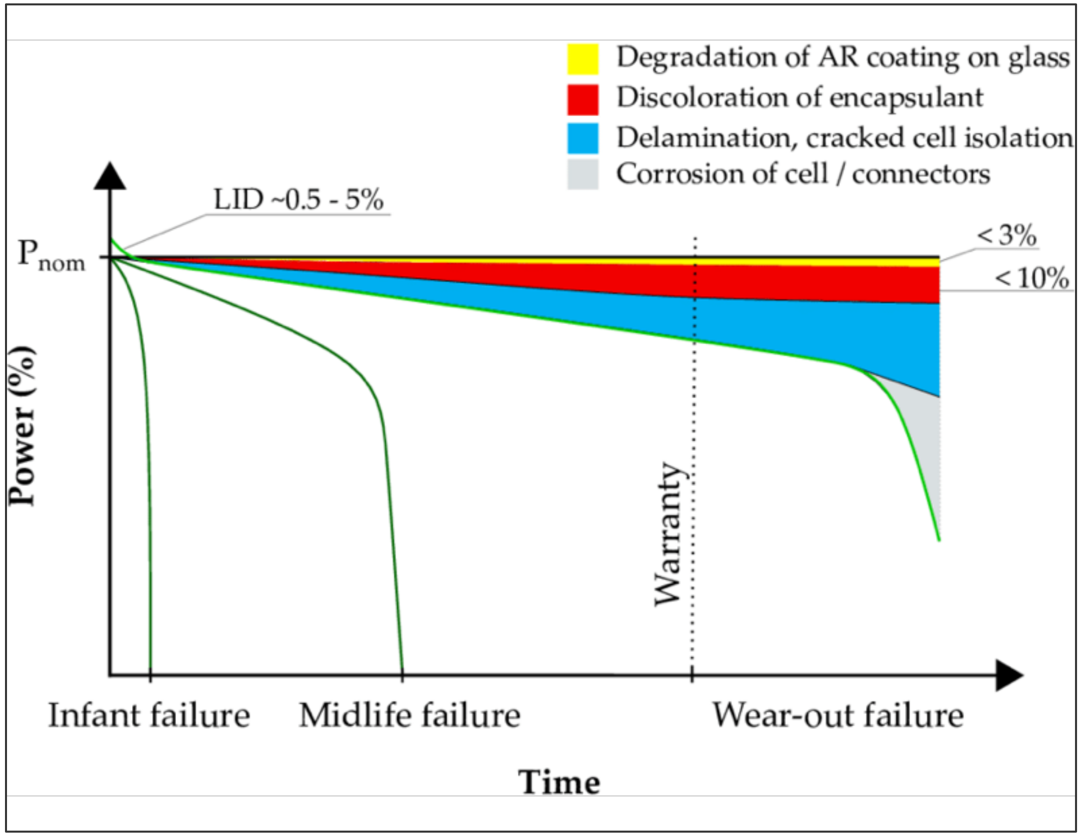


https://www.cleanenergyreviews.info/blog/solar-panel-components-construction

Why pursue a glass edge seal?

Step towards a polymer-free module

Module Degradation Mechanisms



Benefits of the new design:

- No polymer degradation
  - Discoloration
  - Delamination
  - No polymer-related corrosion or PID
- Hermetically sealed module -> no moisture & controlled atm
  - One less barrier for perovskites
- Easily recycled module (glass, metal, semiconductor)
- Potentially less expensive than lamination
  - No polymers and only local heating at the weld
  - Fast sealing times (< 15 mins, current lamination time)
  - Cap Ex ~ laminators
- Potential route to 50-year modules (lower LCOE)

Challenges to new design:

- Strick dimensional tolerance for rolled glass
- Metal/glass feed through (known, but not tested for PV)
- Mechanical strength of glass/glass weld

This work →

Previous work to redesign modules

No back sheet → Glass/glass modules

No encapsulant → Apollon Solar, Abound Solar, Next Gen PV (CSU)

No polymer edge seal → Glass edge seal

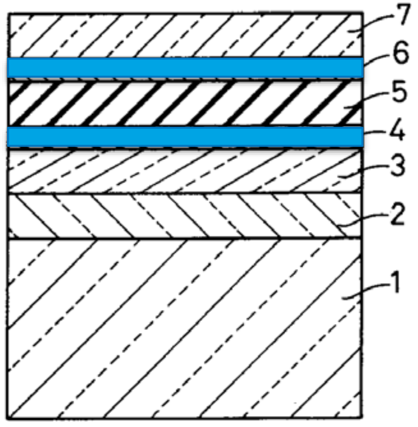


FIG.4

Applicant: **MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.**
1006, Oaza Kadoma
Kadoma-shi,
Osaka-fu, 571 (JP)

1995

Low melting-point frit

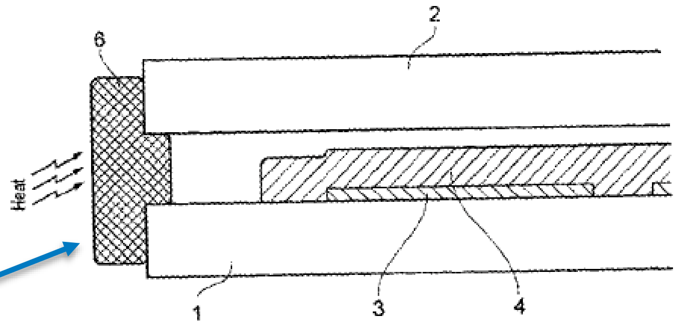


FIG. 4

Renewable Energy Corporation ASA
PO Box 594, 1302 Sandvika, Norway

2010

Other literature

Kind, H., et al., A. Laser glass frit sealing for encapsulation of vacuum insulation glasses. *Physics Procedia* **56**, 673-680 (2014).

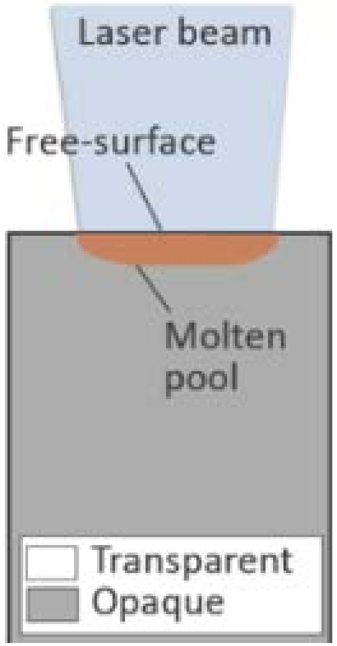
Emami, S., et al. Low temperature hermetic laser-assisted glass frit encapsulation of sodalime glass substrates. *Optics and Lasers in Engineering* **96**, 107-116 (2017).

Glass/Glass Laser Welding: Ultrafast pulses enable crack-free welds

"Old Way" – long pulse

Continuous wave or ns pulsed lasers

- Free-surface weld
- Linear absorption in "opaque" materials
- Frit/glass has CTE mismatch



- E. K. Pfitzer, and R Turner: J. Phys. E: Scientific Instruments, 1, (1968) 360.
- Y. Arata, H. Maruo, and I. Miyamoto: Proc. Symp. Electron and Ion Beam Science and Technol. 7th Int. Conf., (1976) 111.
- M. Watanabe, and K. Satoh: Tech. Repts of Osaka Uni-versity, 1(13) (1951).
- T. Terasaki: Proc. 12th Int Offshore and Polar Engineer-ing Conf., Kitakyushu, Japan, (2001) 332.
- T. Terasaki: J. Jpn. Welding Soc., 78, (2009) 55.

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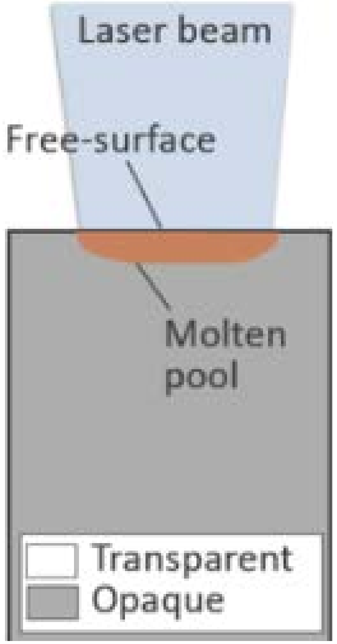

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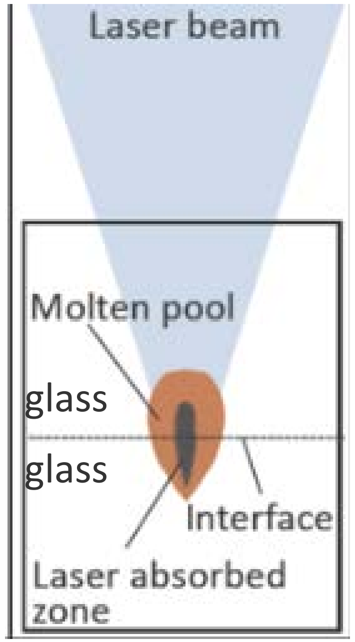
- M. Watanabe, and K. Satoh: Tech. Repts of Osaka Uni-versity, 1(13) (1951).
- T. Terasaki: Proc. 12th Int Offshore and Polar Engineer-ing Conf., Kitakyushu, Japan, (2001) 332.
- T. Terasaki: J. Jpn. Welding Soc., 78, (2009) 55.

"New Way" – short pulse

ps or fs lasers

- No frit
- Closed surface weld
- Nonlinear absorption in "transparent" materials
- No CTE mismatch



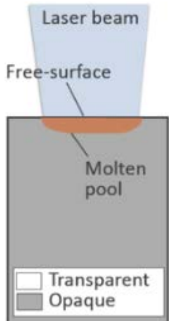
Nonlinear optical absorption process due to free electrons from multiphoton thermal ionization and avalanche ionization

Miyamoto *et al., JLMN-Journal of Laser Micro/Nanoengineering Vol. 15, No. 2, 2020*

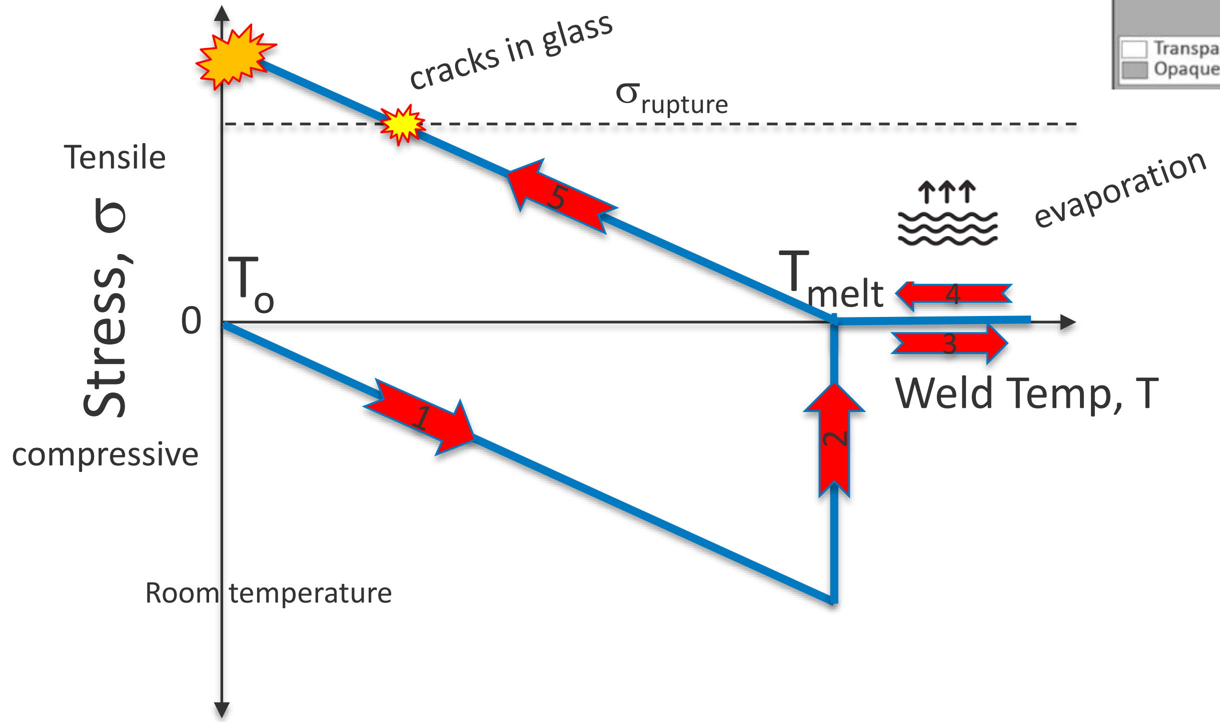
ns Laser Welding: Stressed and cracked welds

"Old way" – ns laser

Weld at a "Free surface"



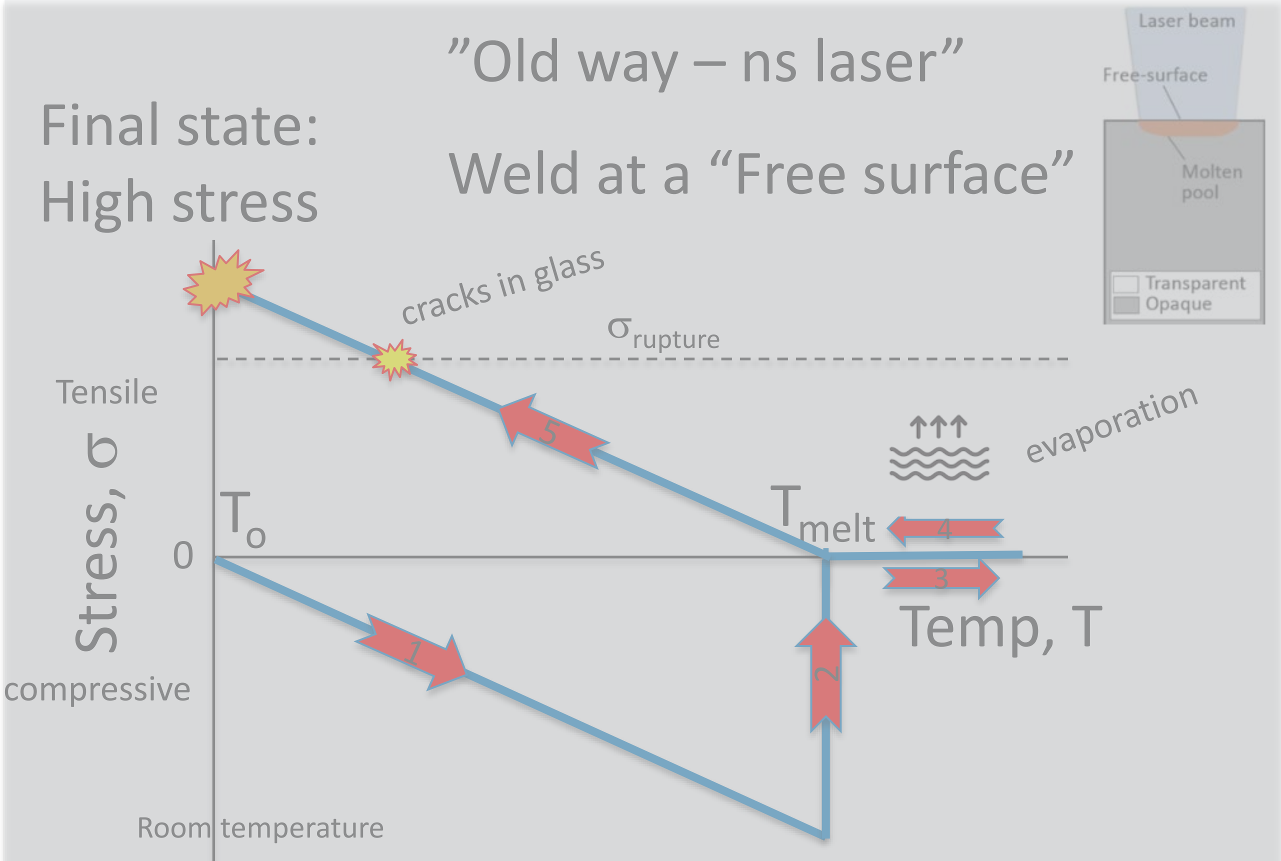
Final state:
High stress



- shrinkage stress formation by plastic deformation during cooling
- Crack free welds only possible with low CTE glasses

Miyamoto *et al., JLMN-Journal of Laser Micro/Nanoengineering Vol. 15, No. 2, 2020*

Glass/Glass fs Laser Welding: Stress-free and Crack-free



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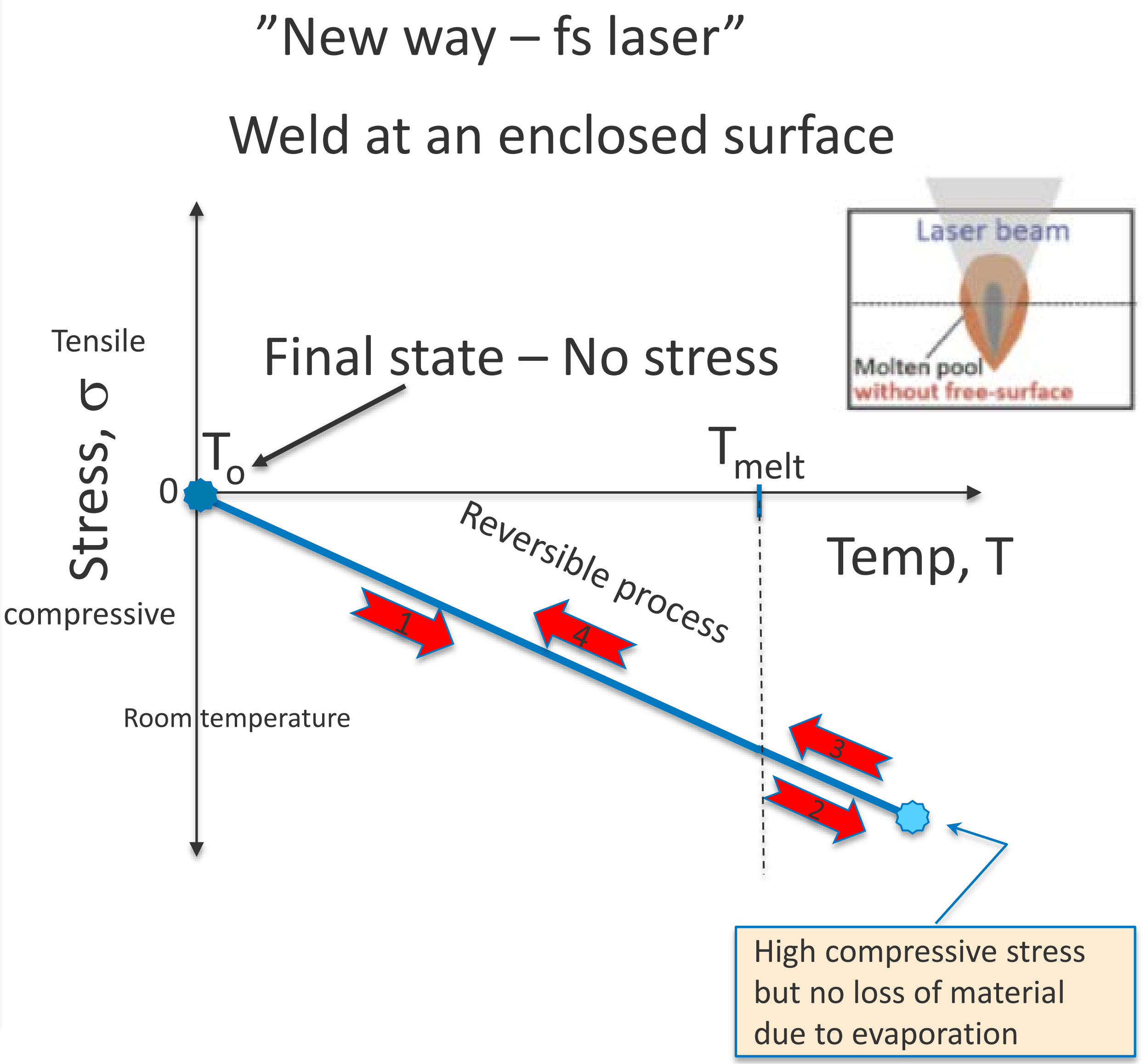
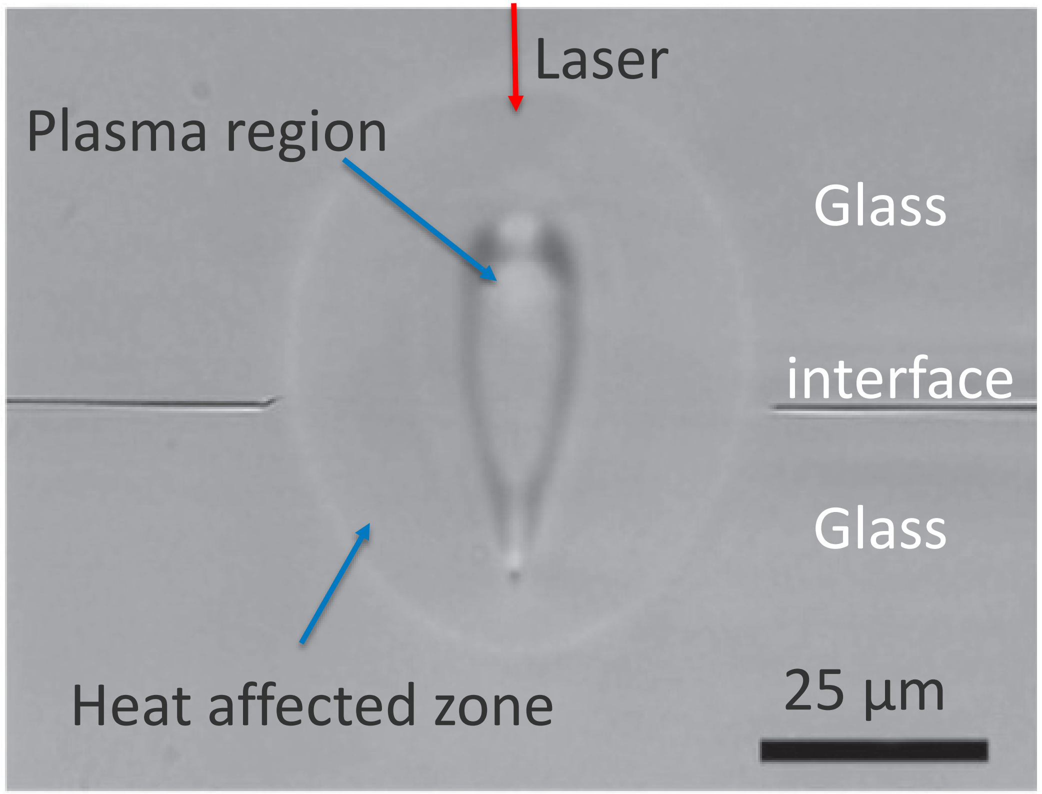
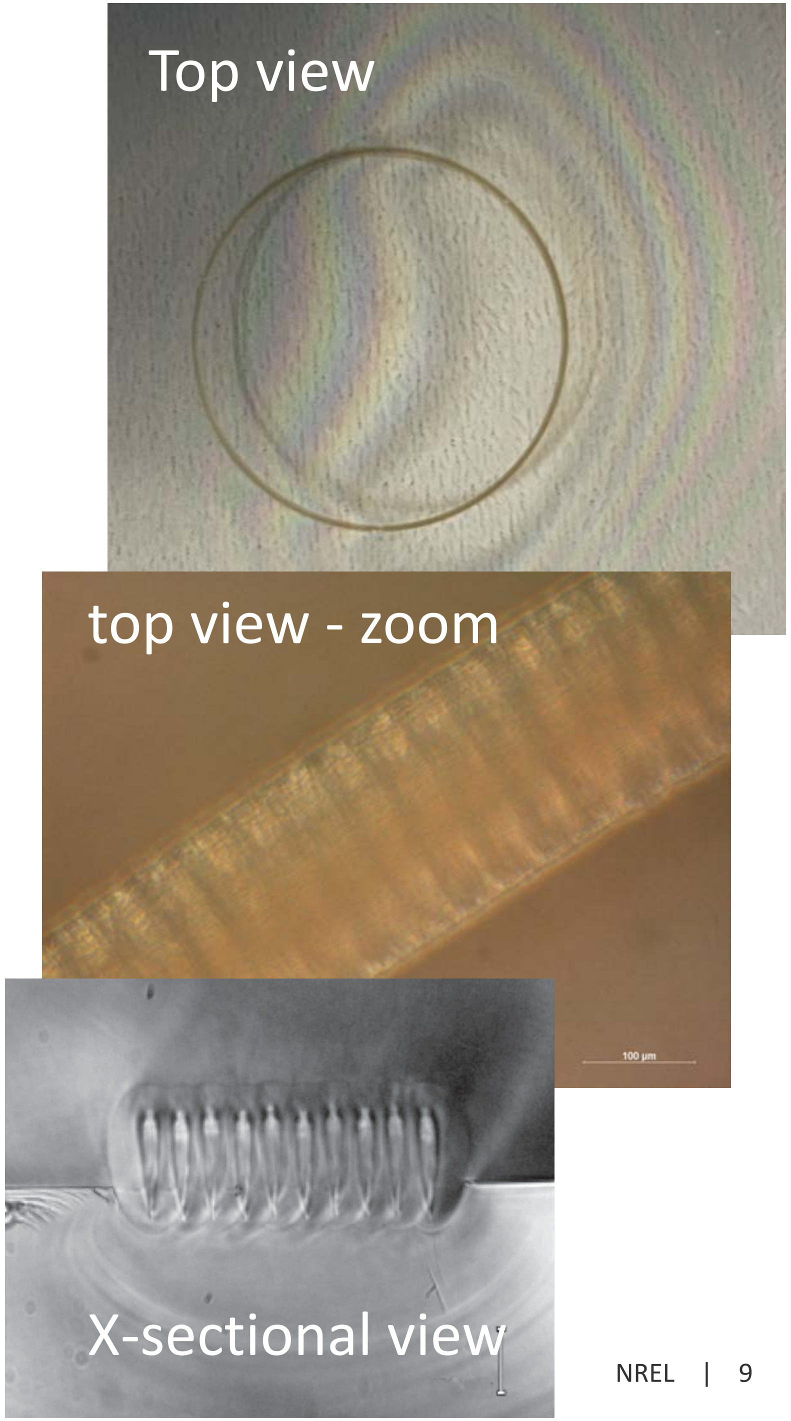


Miyamoto *et al.*, *JLMN-Journal of Laser Micro/Nanoengineering Vol. 15, No. 2, 2020*

Example of fs glass/glass laser weld

Cross-section of glass/glass fs laser weld



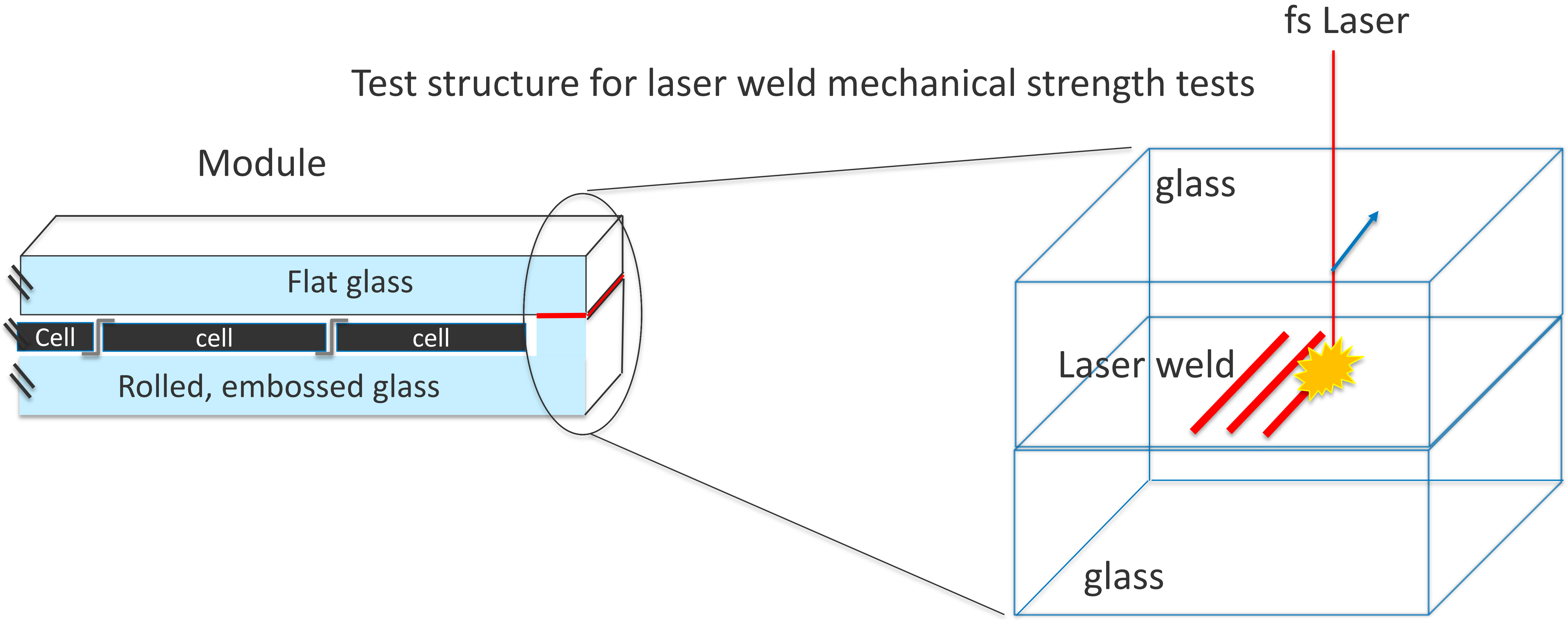


- Weld is a function of (laser power, pulse length, repetition rate)
- Already used in medical devices and laser head manufacturing

Handbook of Laser Welding Technologies, edited by S. Katayama, Elsevier Science & Technology, 2013.

Experiment: Laser Weld Module Glass

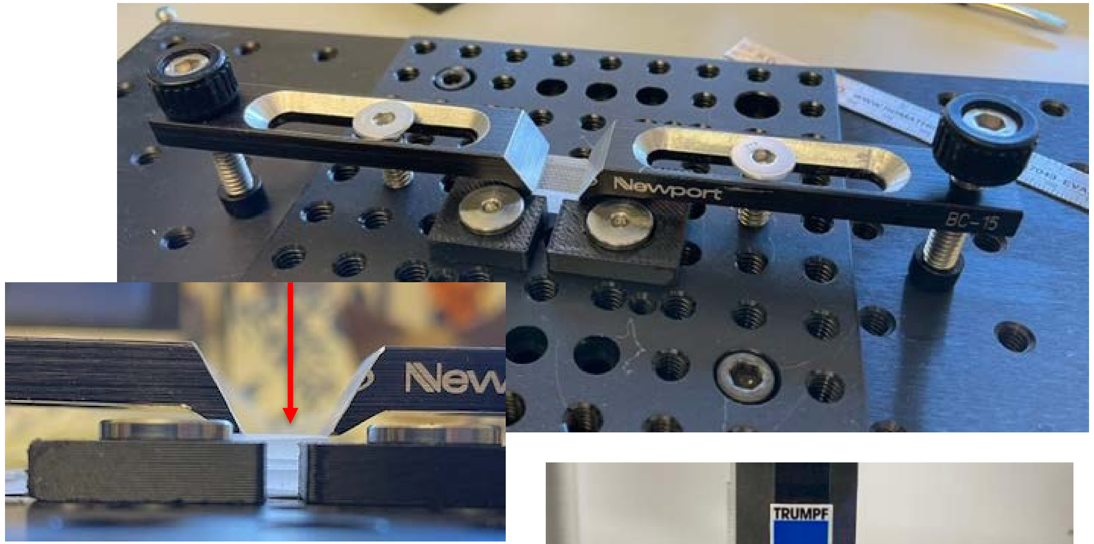
Test structure for laser weld mechanical strength tests



- 10 mm x 12 mm x 3.2 mm SolLite glass
- Professionally cut and cleaned

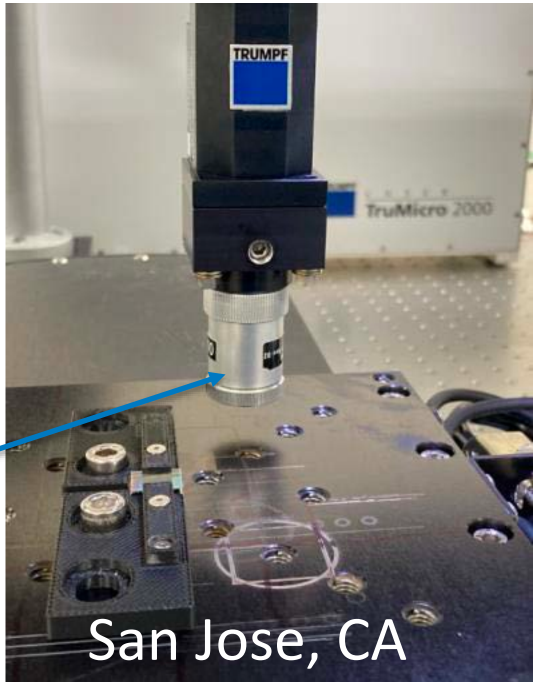
Glass/Glass laser welding at Trumpf Laser Inc.

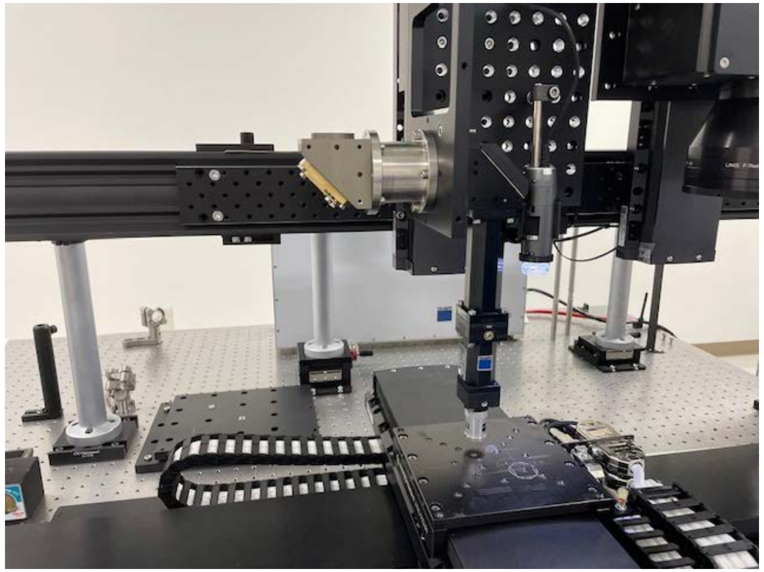
Jig to press glass pieces together



glass/glass
gap < ~8 µm

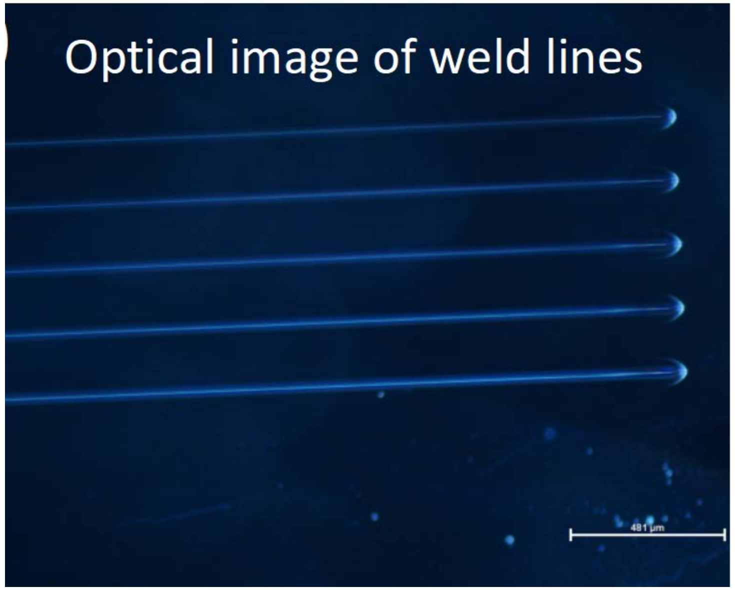
Gaussian to Bessel beam shape lens





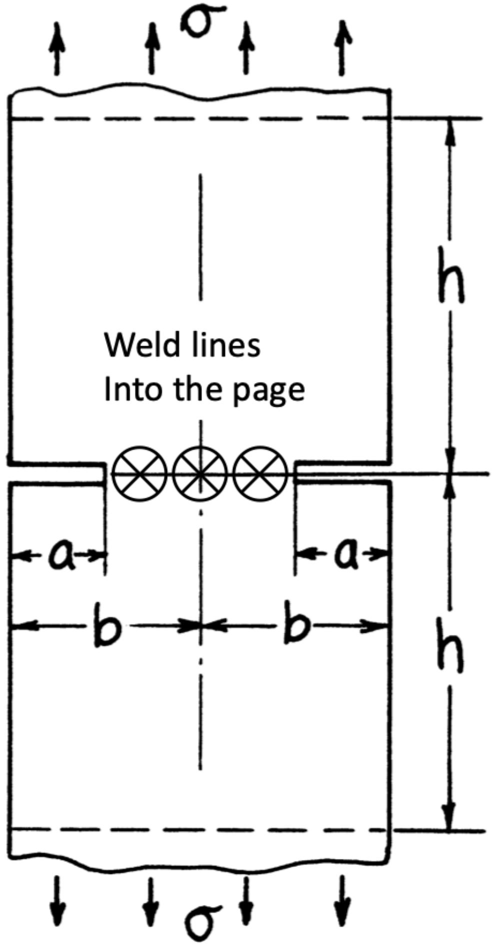
Laser Specs:
20 W fiber laser
1030 nm, 350 fs – 20 ps pulse
Pulse Energy 100 µJ

Welding specs:
2.6 W, 400 fs pulse, 200 kHz
10 mm/s translation

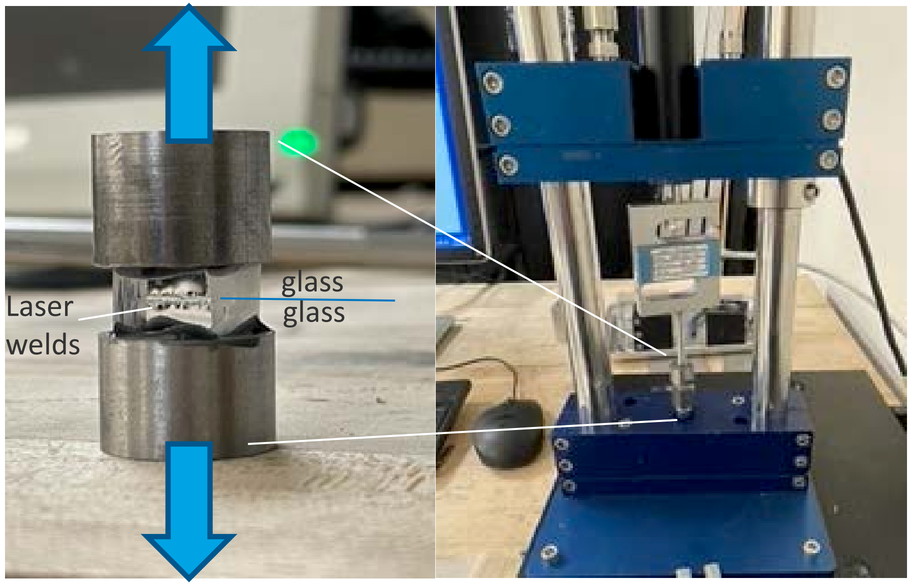


Smooth, uniform welds

Weld Stress Intensity Factor Measurements

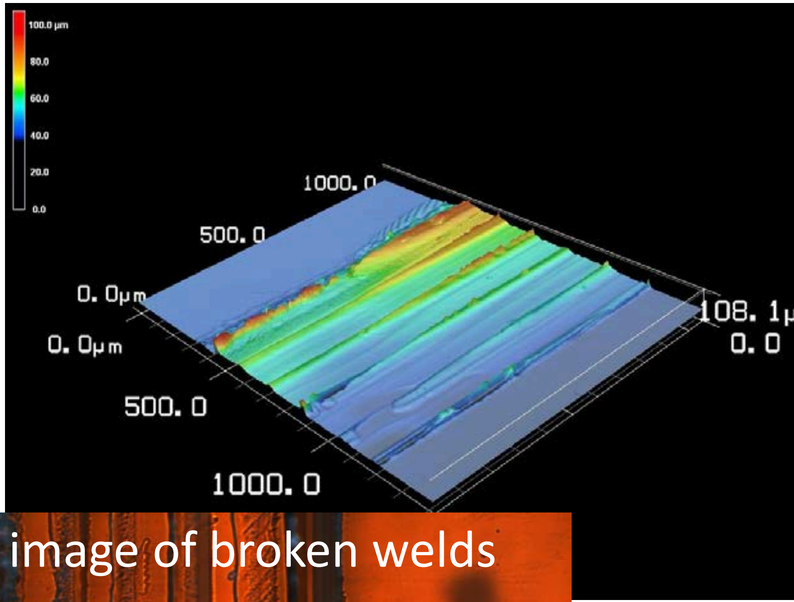


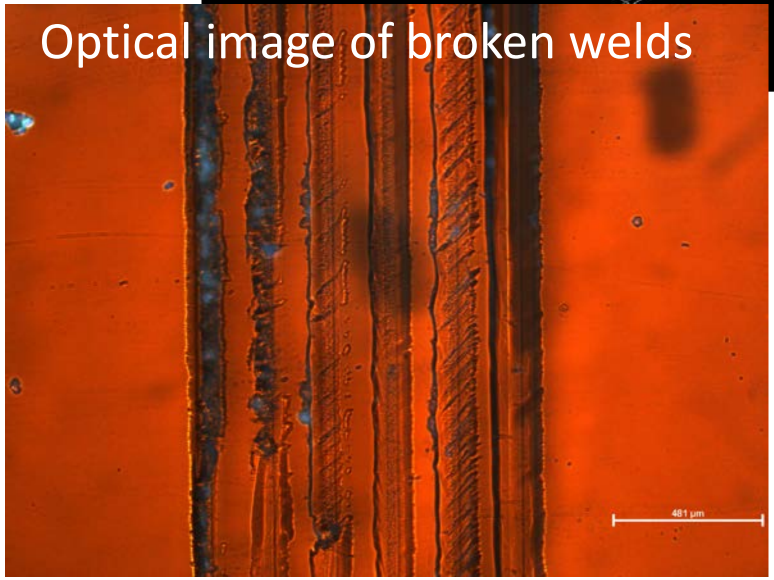
Pull glass until weld fails (measure max force)



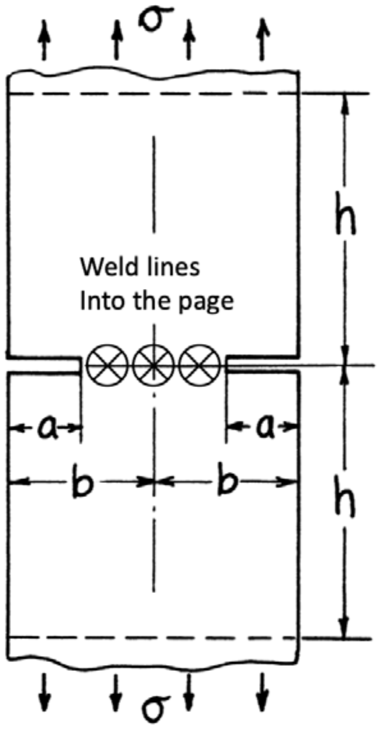
Dynamic Mechanical Analyzer

3D image of glass surface after breaking weld




Optical image of broken welds

Weld Critical Stress Intensity Factor vs % laser power, weld lines, spacing



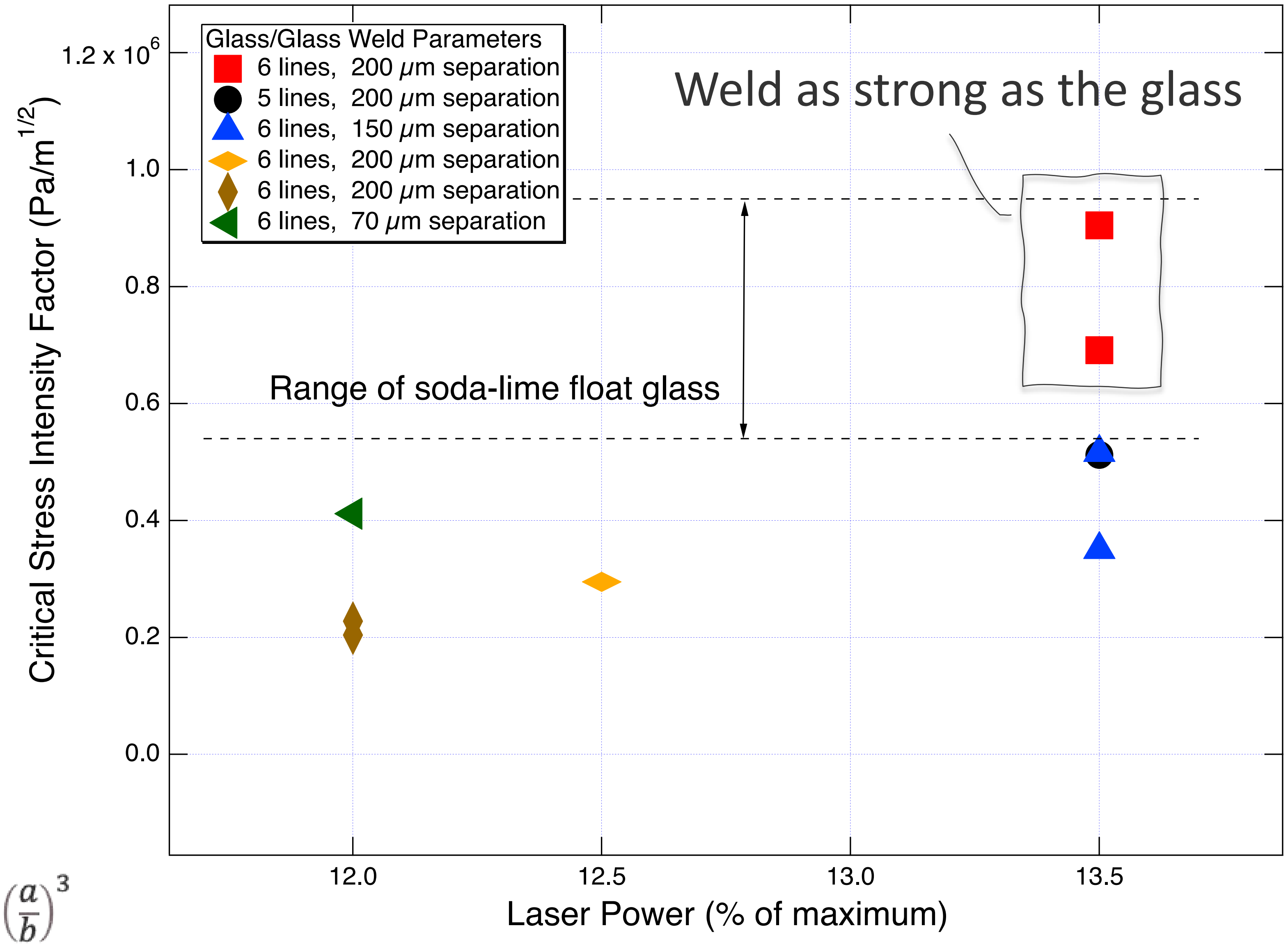
Stress Intensity factor, K_I

$$K_I = \sigma\sqrt{\pi a}F(a/b)$$

Geometric factor

$$F(a/b) = \frac{1.22 - 0.56\left(\frac{a}{b}\right) - 0.015\left(\frac{a}{b}\right)^2 + 0.091\left(\frac{a}{b}\right)^3}{\sqrt{1-\left(\frac{a}{b}\right)}}$$

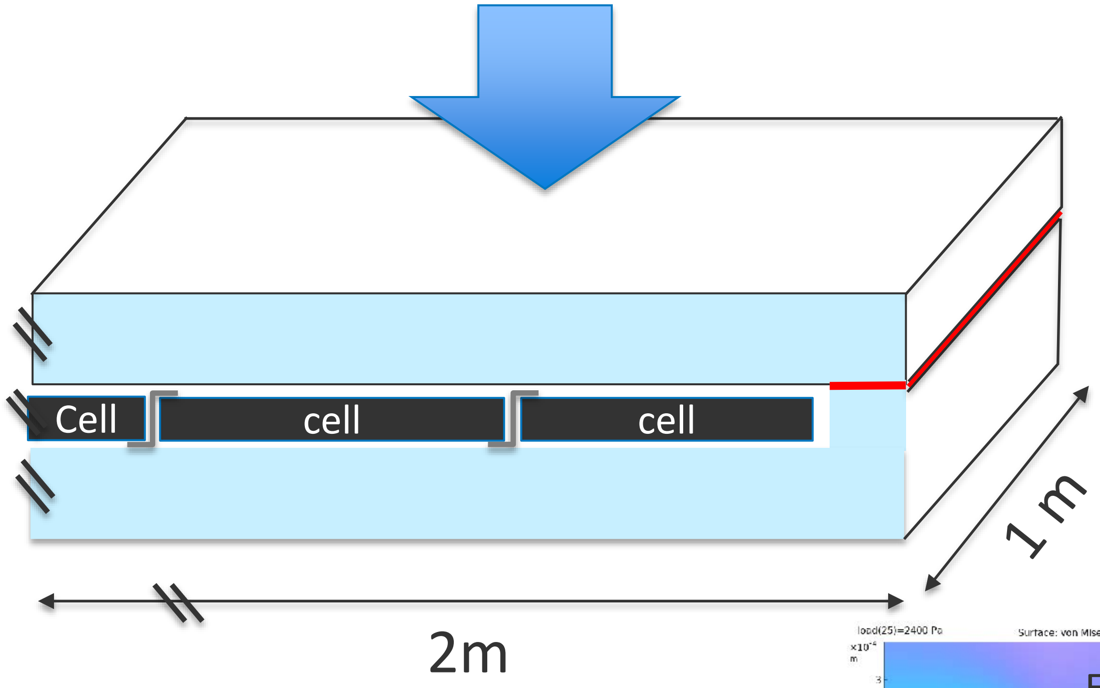
Benthem 1972



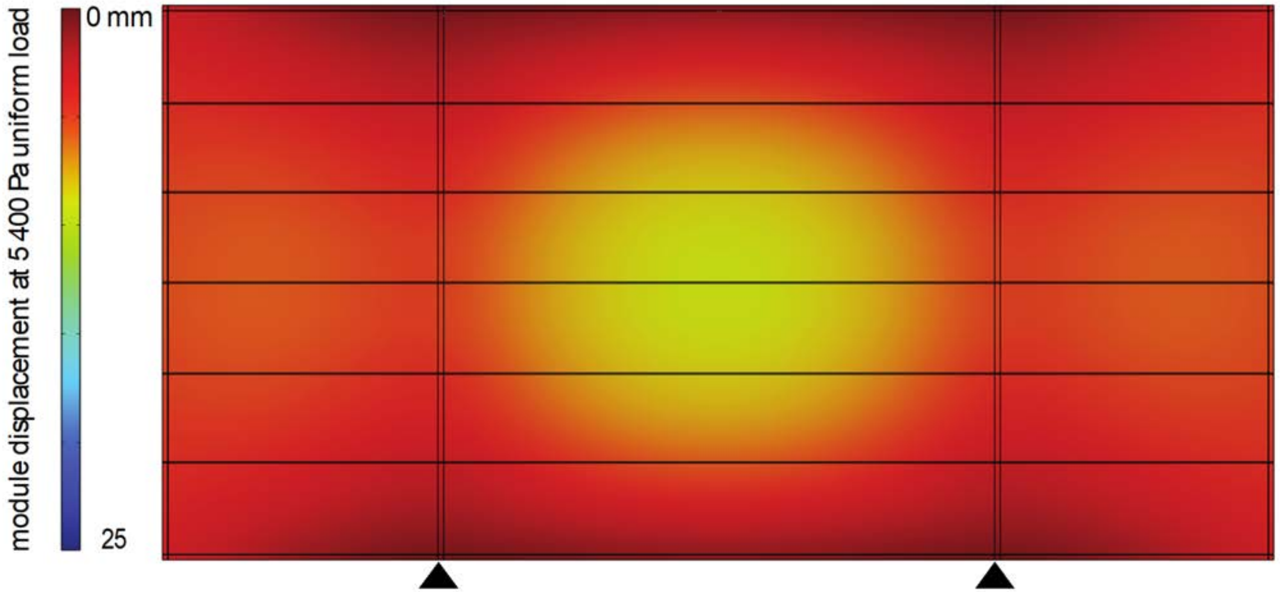
COMSOL model of laser welded glass/glass module: Static Load Test

IEC 61215

5400 Pa uniform pressure
(IEC Static Load Test)

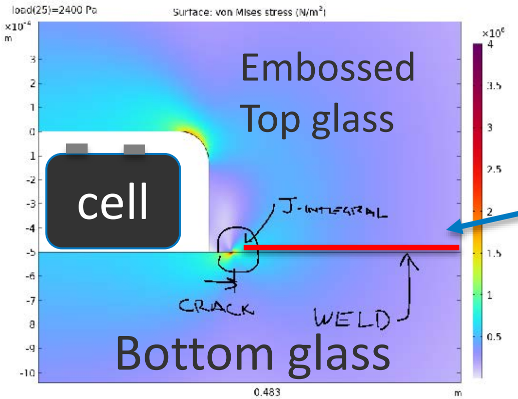


Module Displacement Heat Map



framed and braced module
embossed ribs are welded

COMSOL model of weld

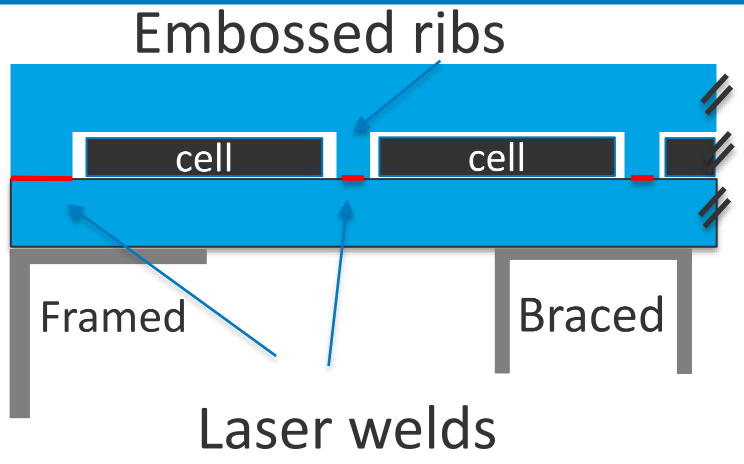


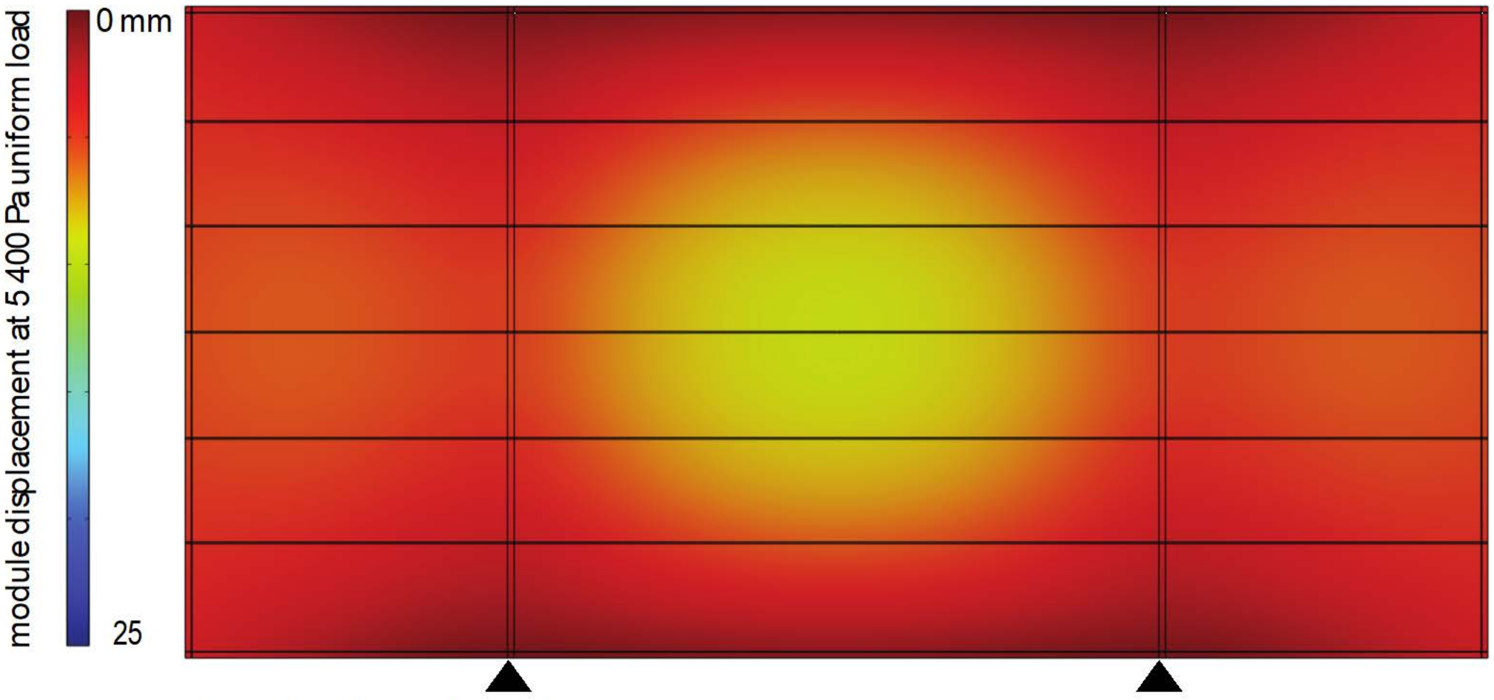
Laser weld

COMSOL model of laser welded glass/glass module: Static Load Test

IEC 61215

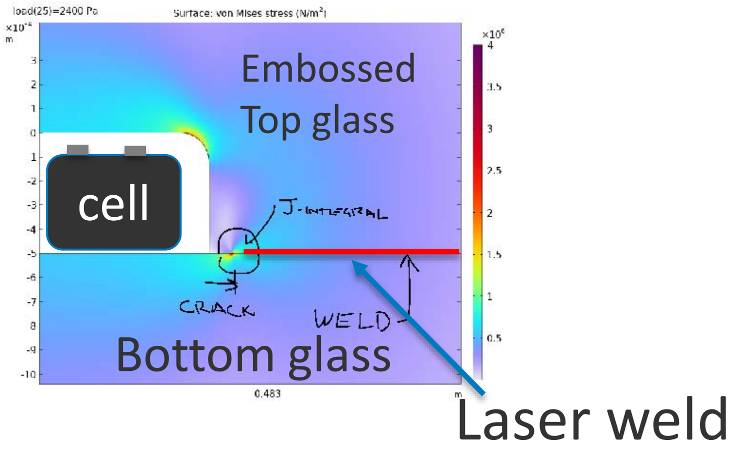
- Framed and braced module
- Embossed ribs stiffen the glass
- Welded edge seals and ribs





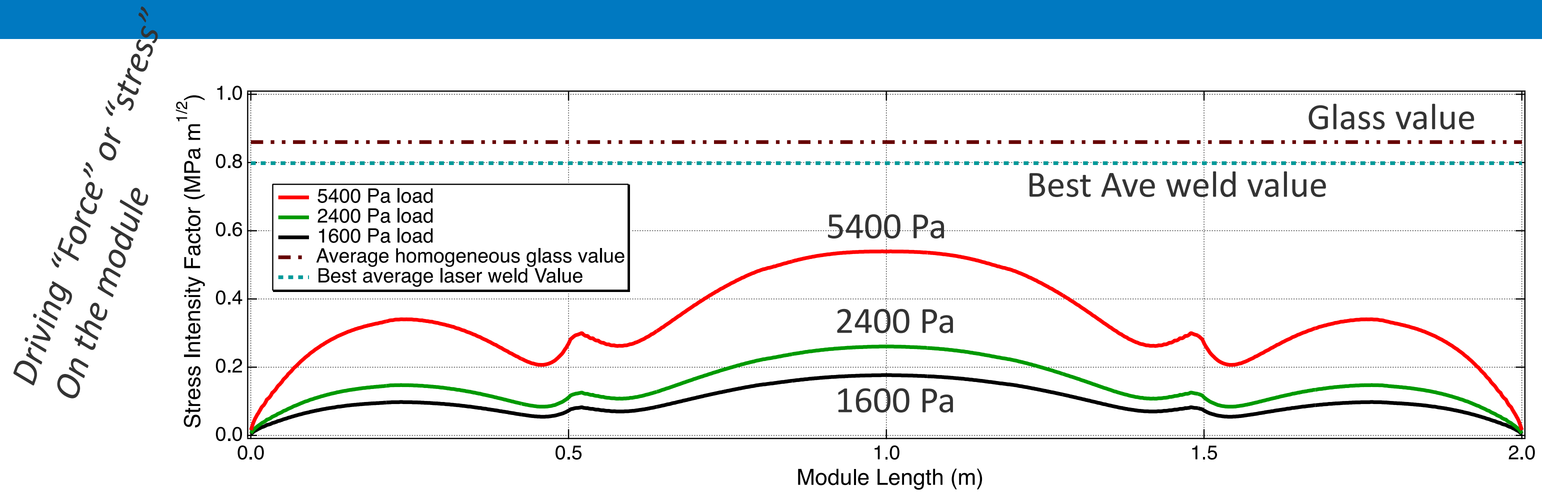
framed and braced module
embossed ribs are welded

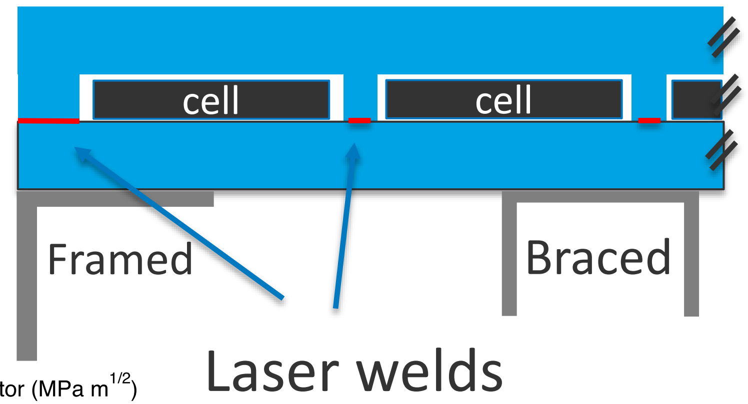
COMSOL model of weld

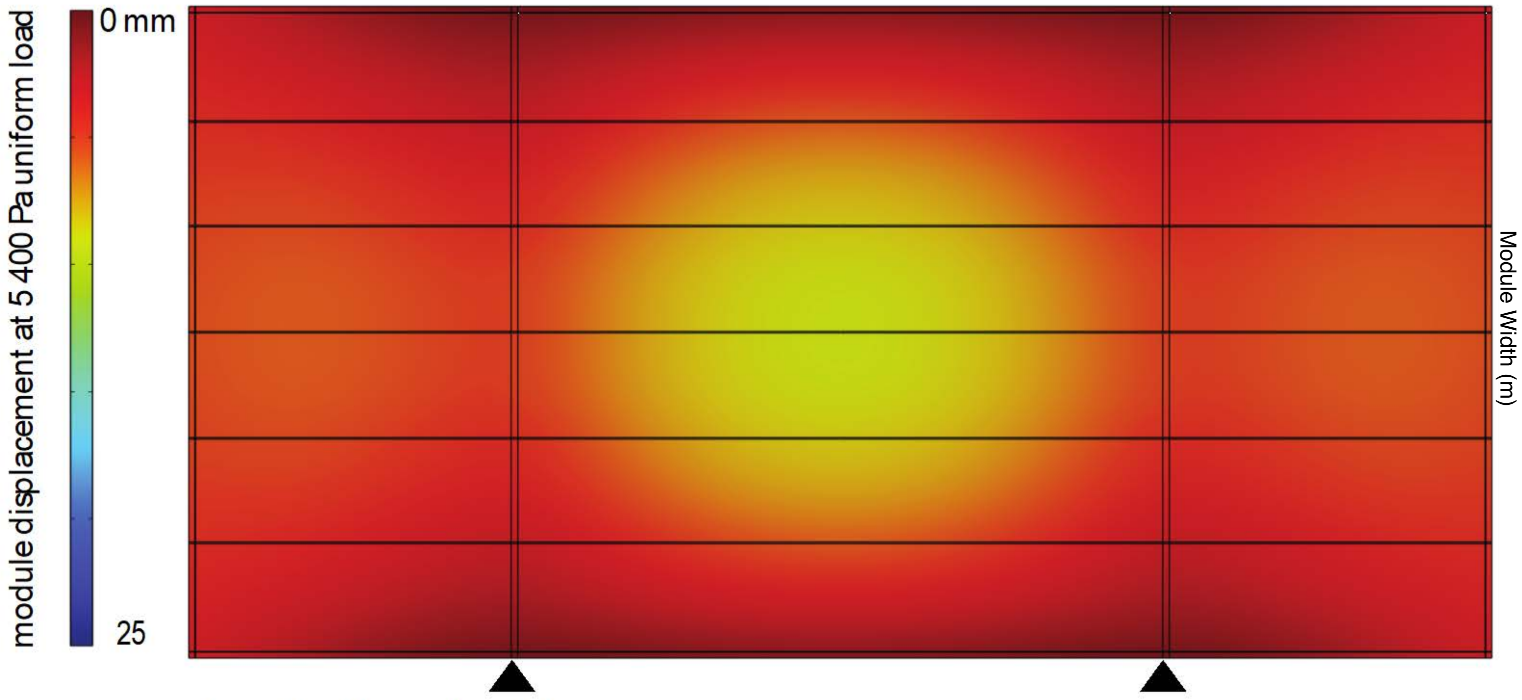


COMSOL model of laser welded glass/glass module: Static Load Test

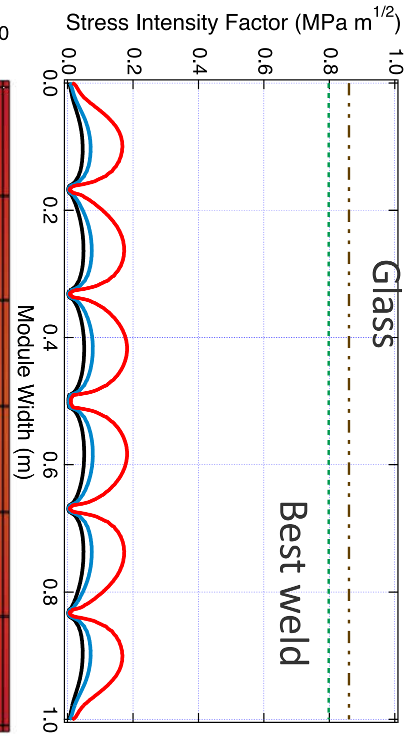
IEC 61215







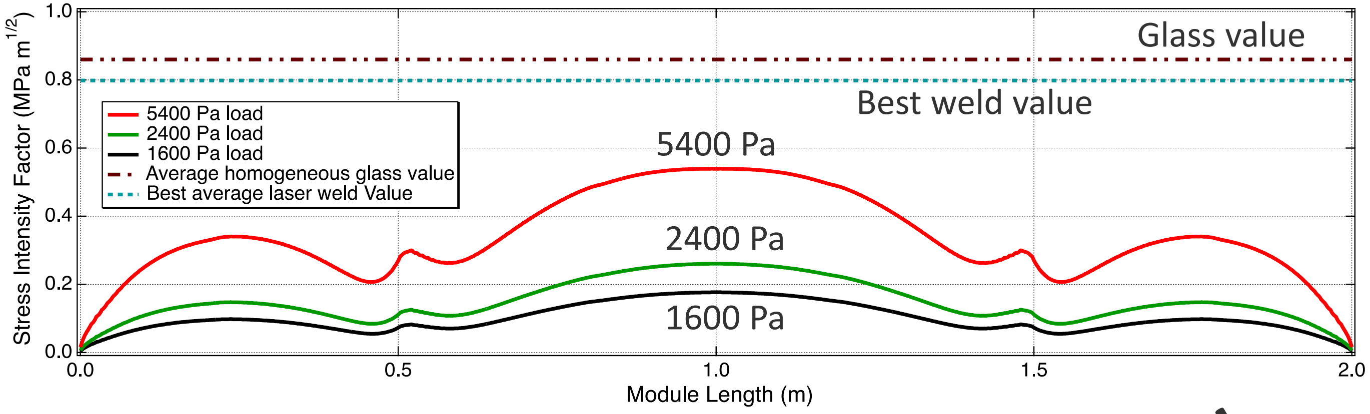
framed and braced module
embossed ribs are welded

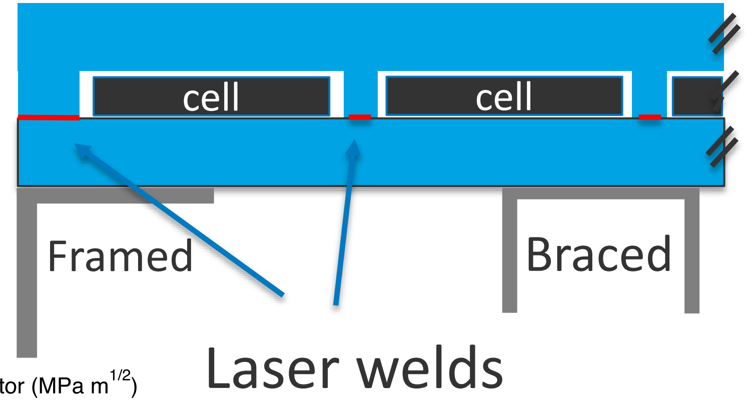


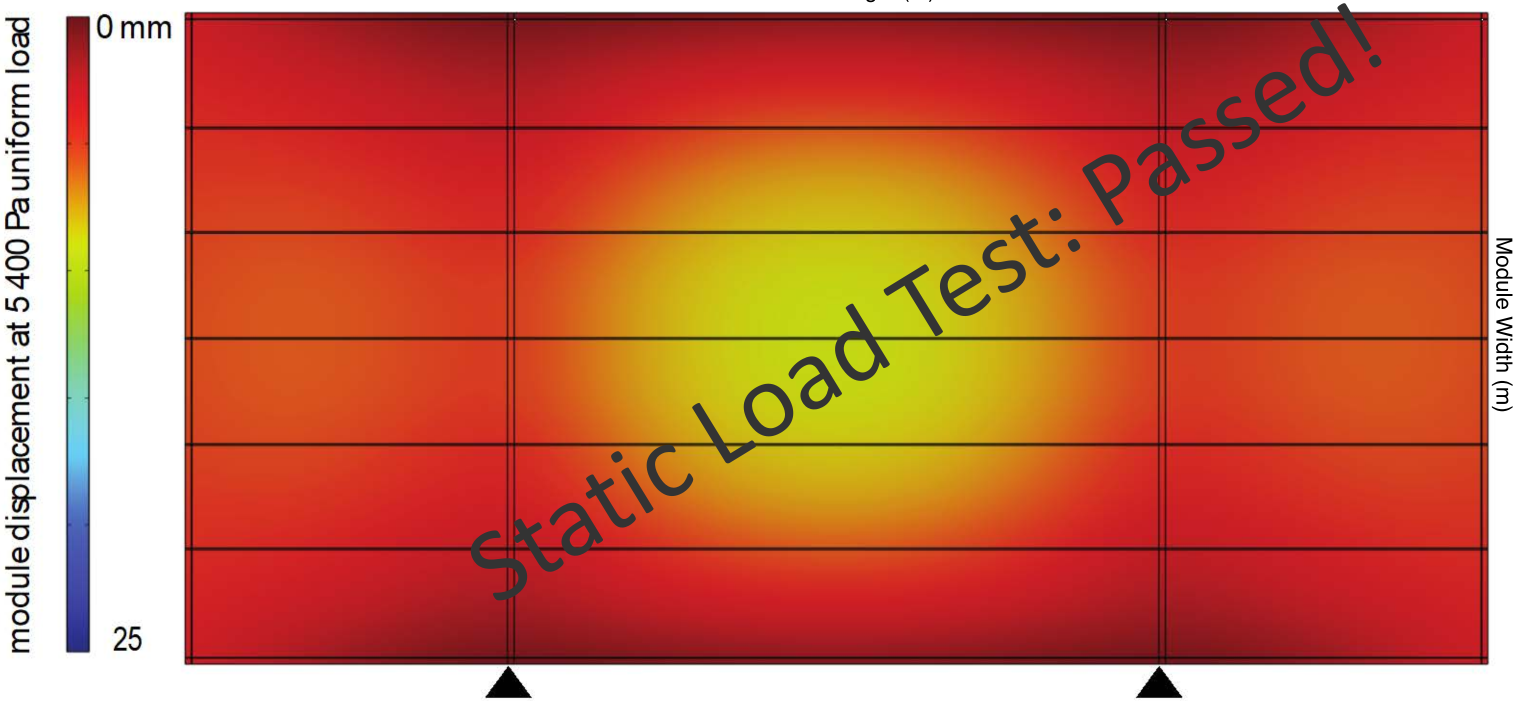
COMSOL model of laser welded glass/glass module: Static Load Test

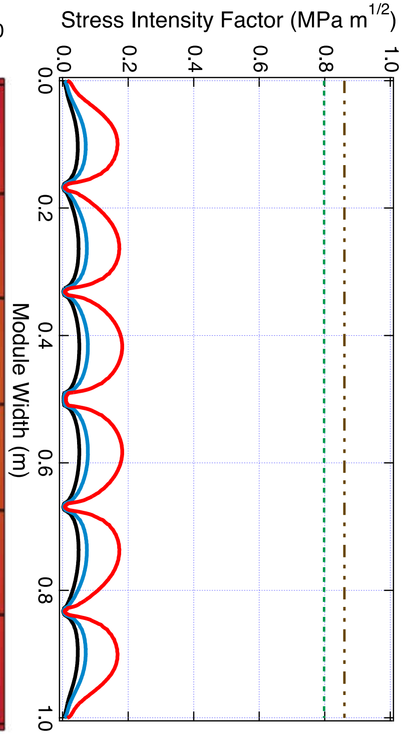
IEC 61215

Driving "Force" or "stress"
On the module





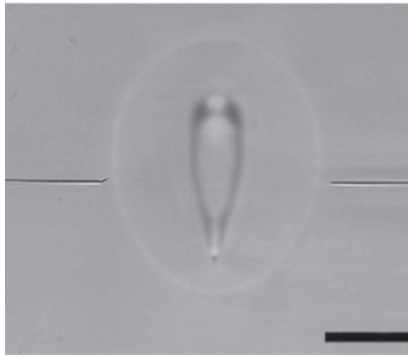


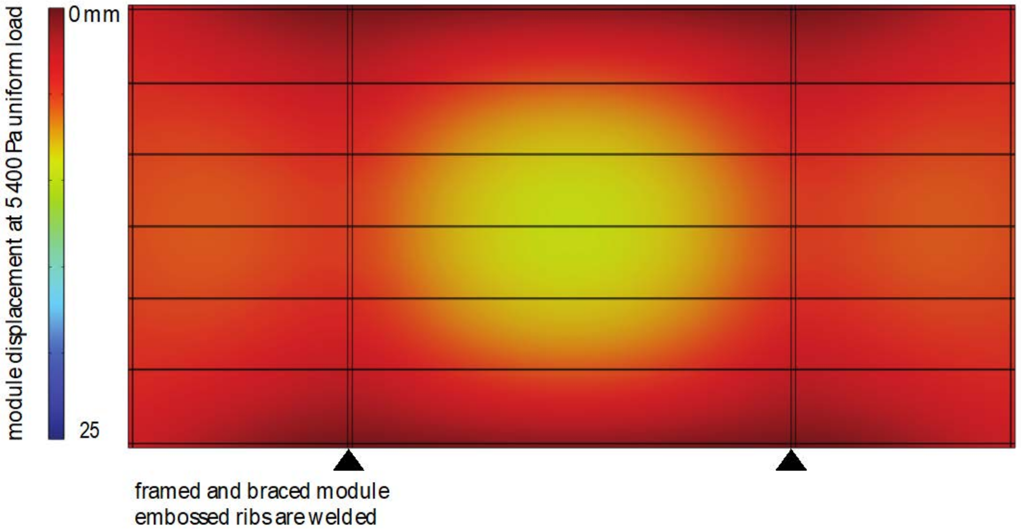


framed and braced module
embossed ribs are welded

Conclusions

- fs lasers enable crack-free and stress-free glass/glass welds
- Welds are nearly as strong as the glass ($K_{I,\,weld} \sim K_{I,\,glass}$)
- Static load test passed. Enabling:
    - polymer-free
    - hermitically sealed
    - recyclable modules





- Next steps:
    - Follow-on funding
    - Develop feed throughs (metal/glass welds already achieved for other devices)
    - Weld mini modules for further IEC module testing

NREL
Transforming ENERGY

Laser Welded Edge Seals for Polymer-Free Glass/Glass Modules

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Thank You

DuraMAT
Durable Module Materials Consortium

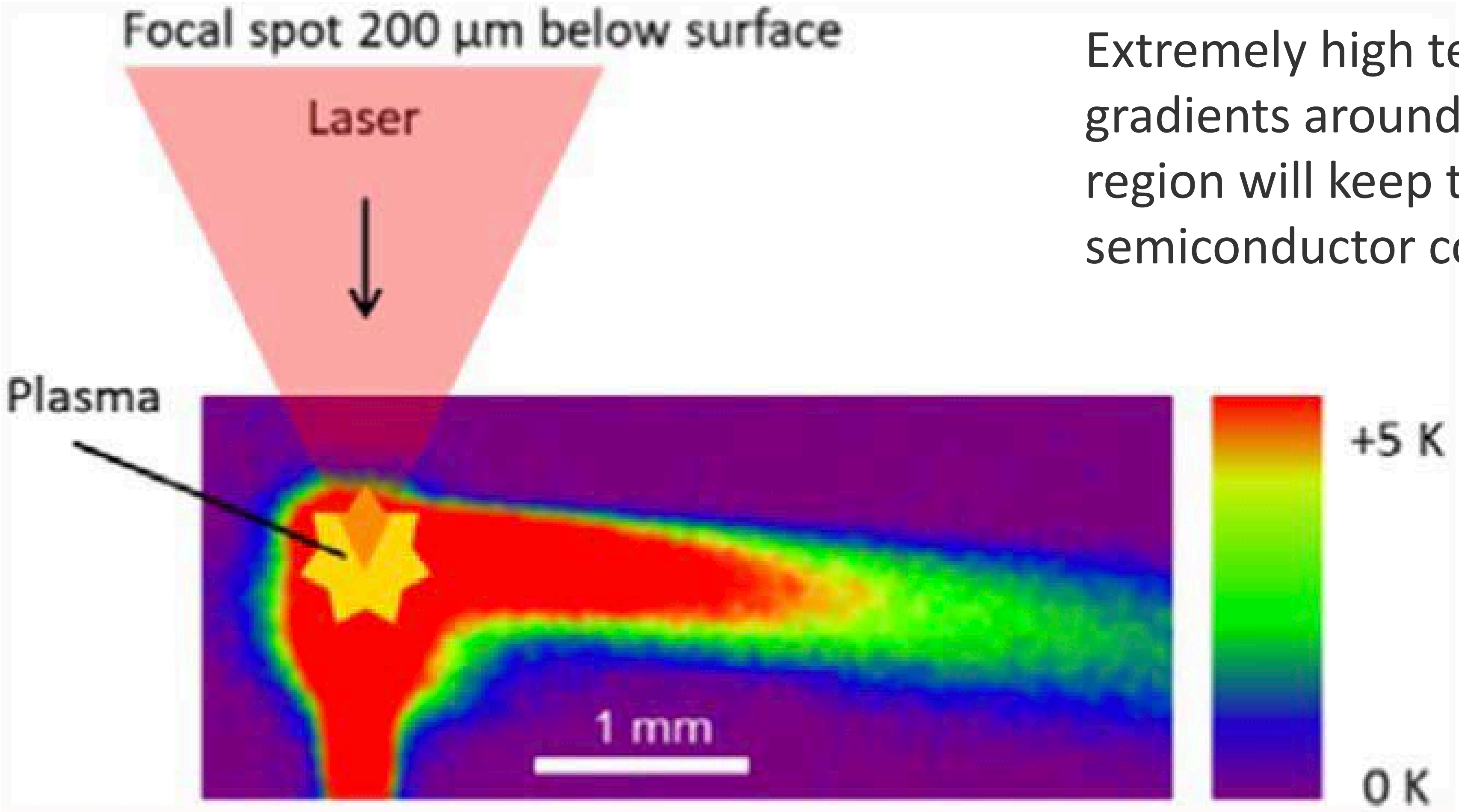
Spark Project

NREL/PR-5900-85686

David Young, Nick Bosco, Tim Silverman
david.young@nrel.gov

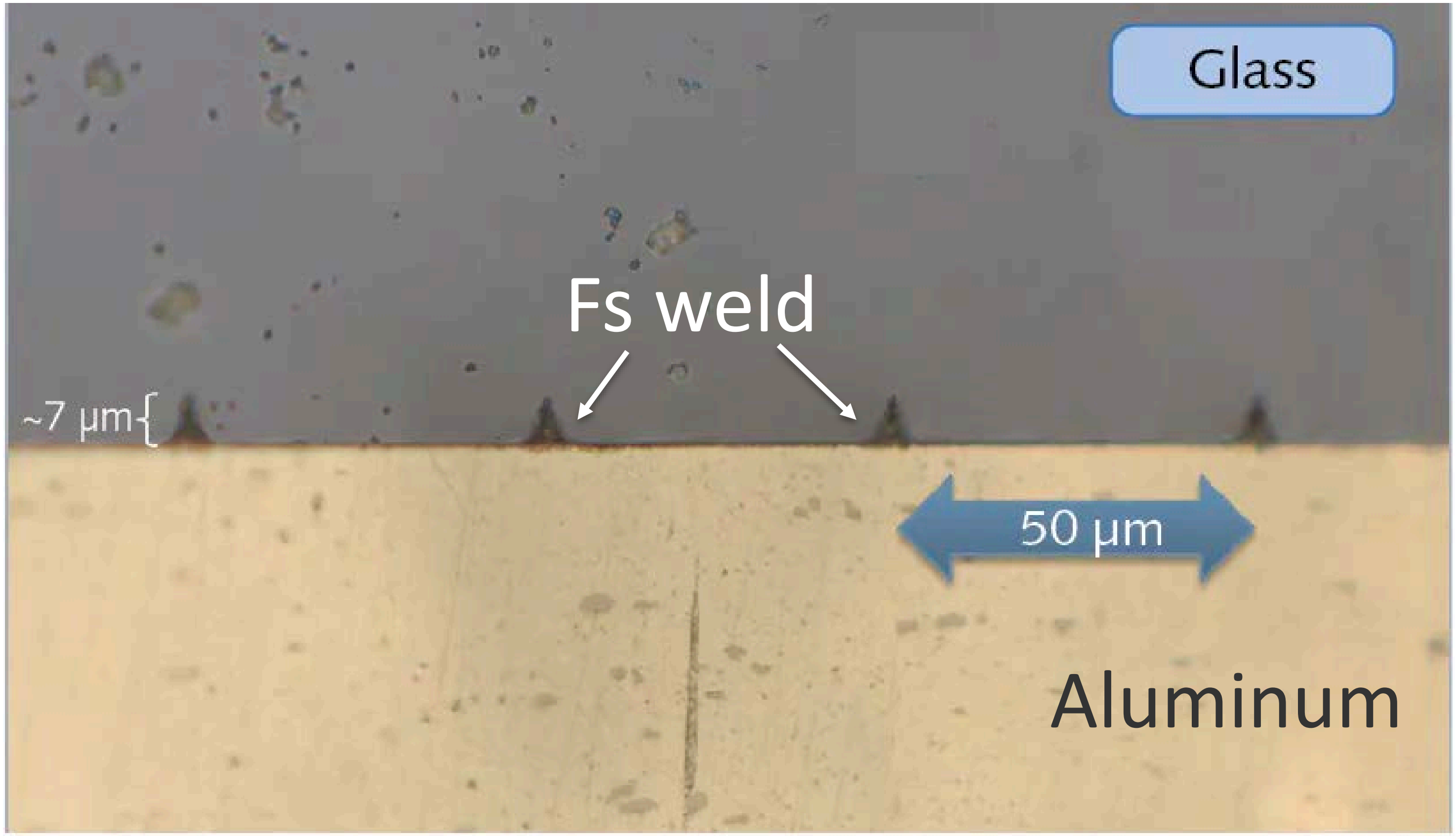
Photo from iStock-627281636

Glass Laser Welding: High Temperature Gradient



Extremely high temperature gradients around the plasma region will keep the semiconductor cool during welding

Glass/Aluminum Welding



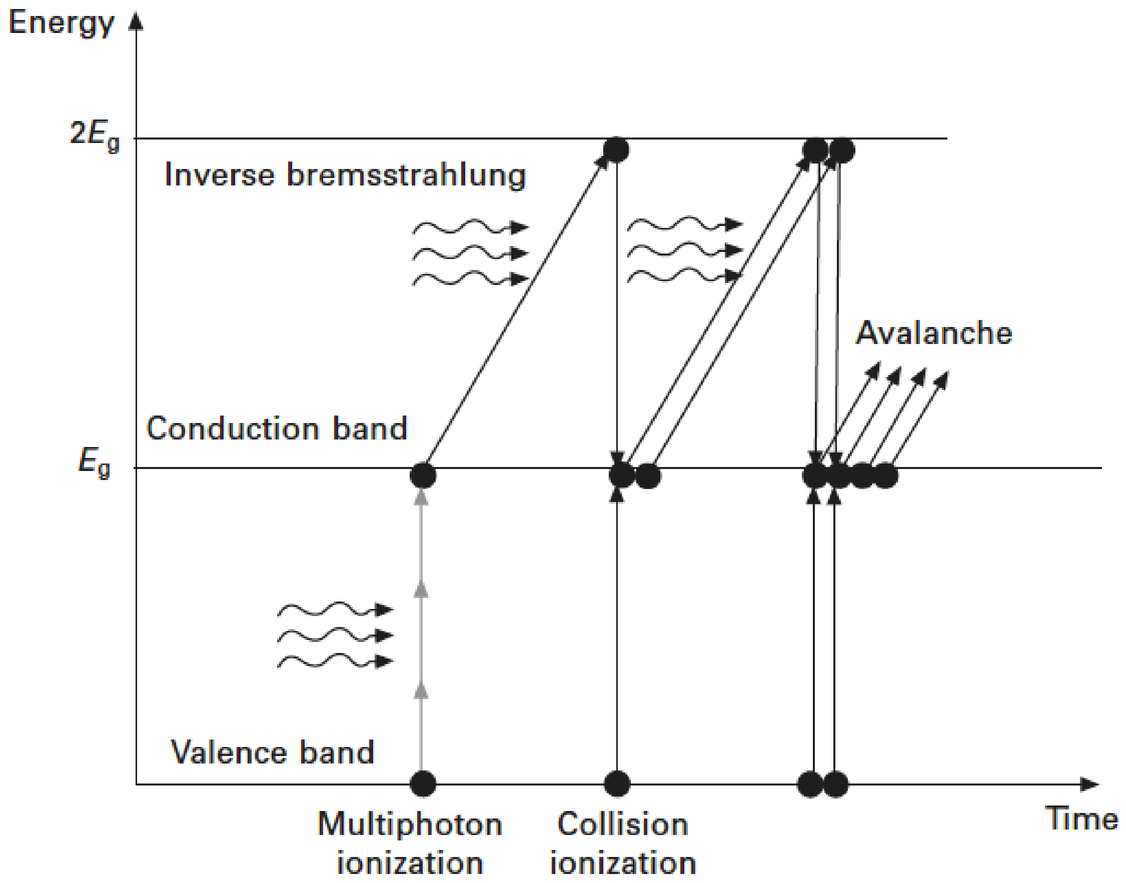
INDUSTRIAL LASER SOLUTIONS

Glass microwelding with ultrashort-pulse lasers

Jim Bovatsek, Terence Hollister

Aug. 18, 2021

Nonlinear absorption process



11.13 Nonlinear absorption process consisting of multiphoton ionization and avalanche ionization.