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GLASS PERFORMANCE DAYS 2017

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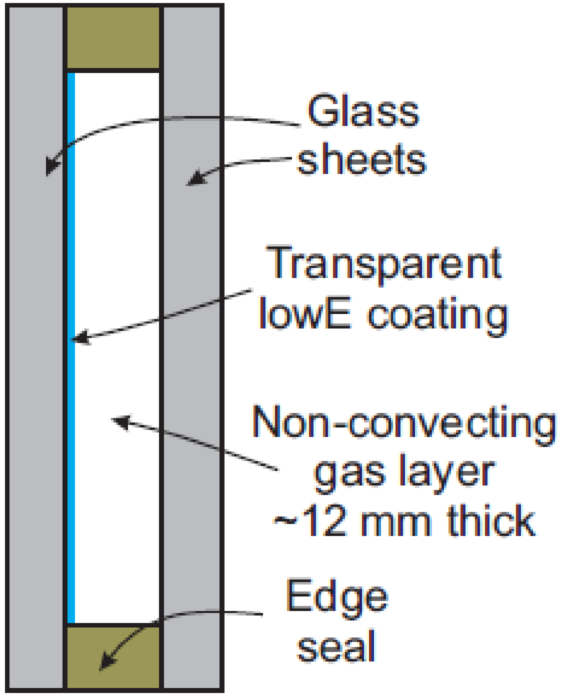
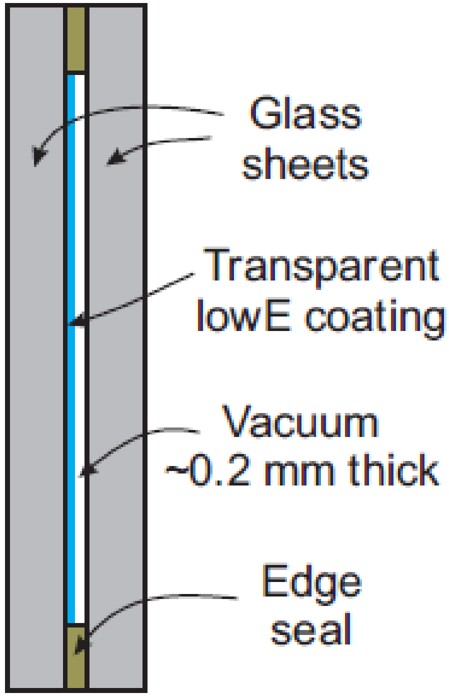
Vacuum Insulating Glass – Past, Present and Prognosis

Richard Collins

Vacuum Insulating Glazing (VIG) is
conventional Insulating Glazing (IG or double glazing),
with the ~12 mm thick gas layer replaced by
a very narrow (~0.2mm) evacuated space

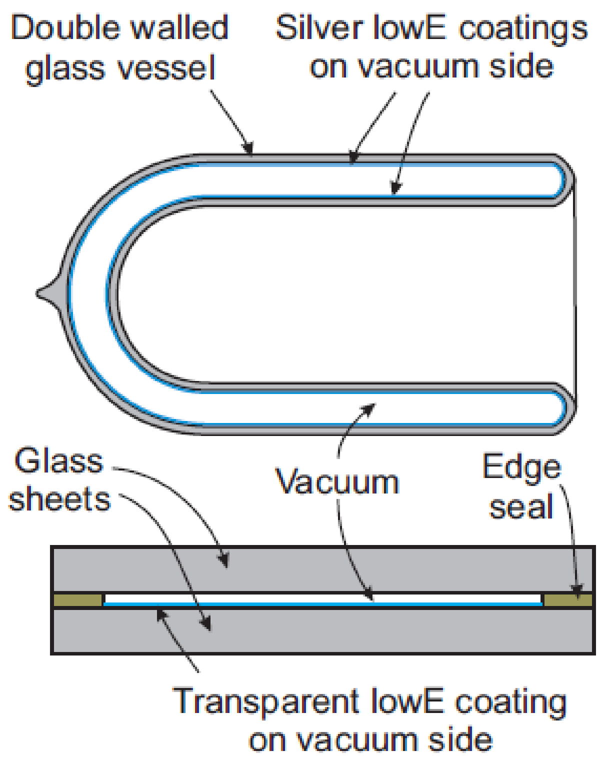




Insulating mechanisms in VIG

VIG achieves high levels of thermal insulation using the same principles as the Dewar flask:

- The vacuum eliminates heat flow between the glass sheets by gas conduction and convection
- Internal (transparent) LowE coatings reduce radiative heat flow to a low level



Essential features of VIG

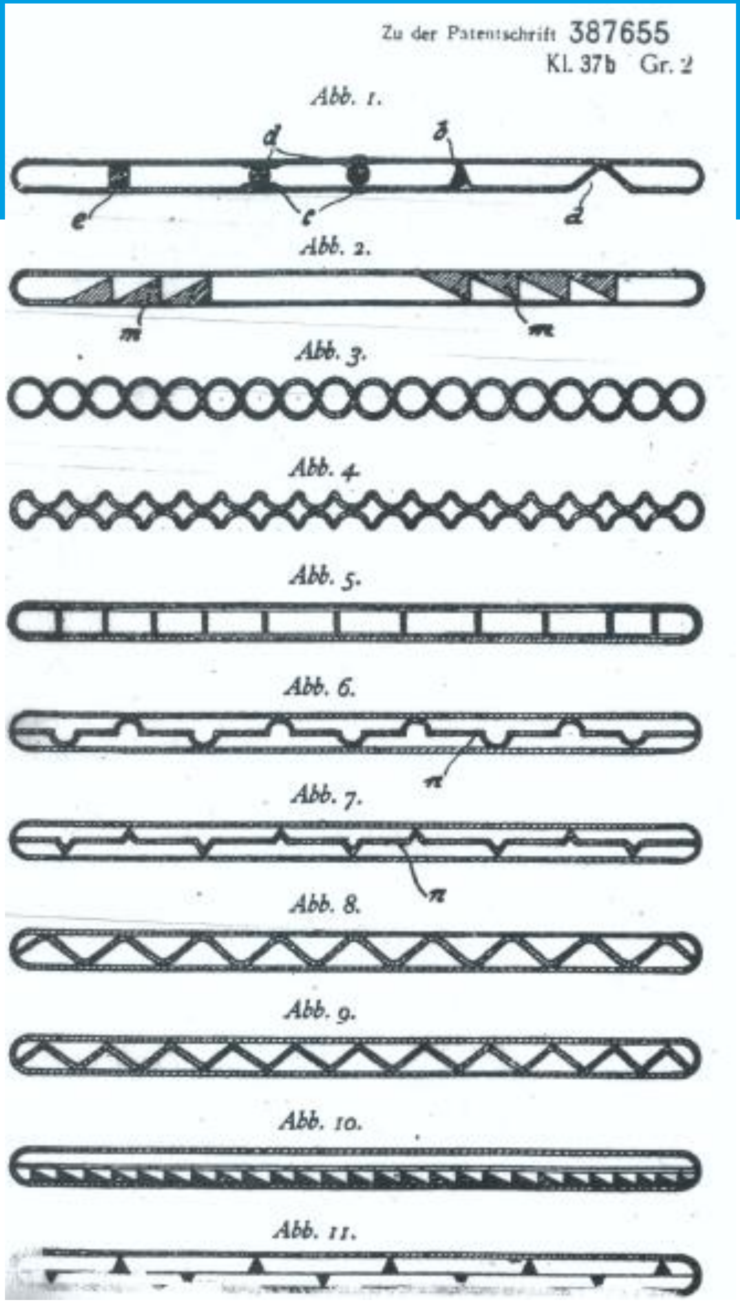
- Hermetic (leak free) edge seal
- High, stable vacuum (<10^{-6} atmosphere)
- Internal supports to keep glass sheets apart under atmospheric pressure (10 tonnes/m^2)
- Internal transparent LowE coating
- An acceptable design compromise between:
  - reducing heat flow through the support pillars (requires less, and smaller pillars); and
  - limiting stresses in the glass due to atmospheric pressure (requires more, and larger pillars)
- Ability to withstand large temperature differences

Potential advantages of VIG

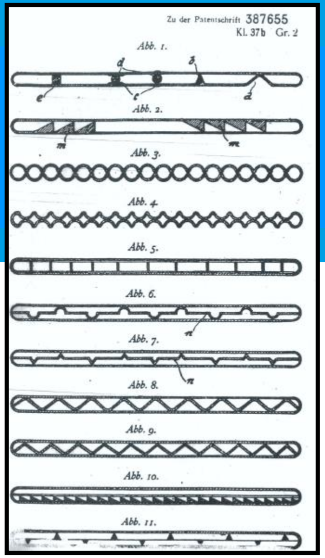
- Very high levels of thermal insulation possible
- Very thin structure – marginally greater than the total thickness of the two glass sheets
- The hermetic edge seal is impermeable to gas, which should lead to very high reliability in practical installations

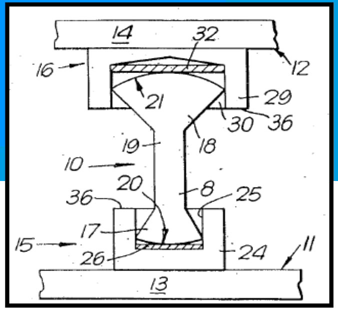
History of VIG

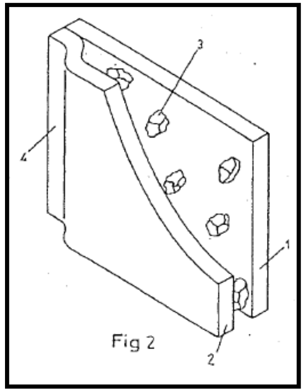
- First description: 1913 patent by A Zoller
- Zoller's Claims include:
  - Many configurations of internal supports
  - Multiple glass sheets

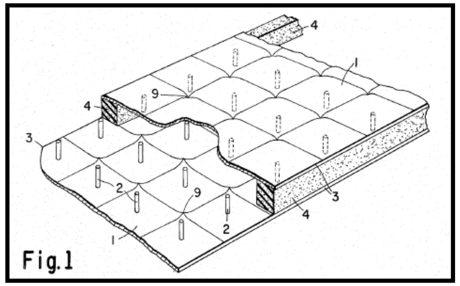


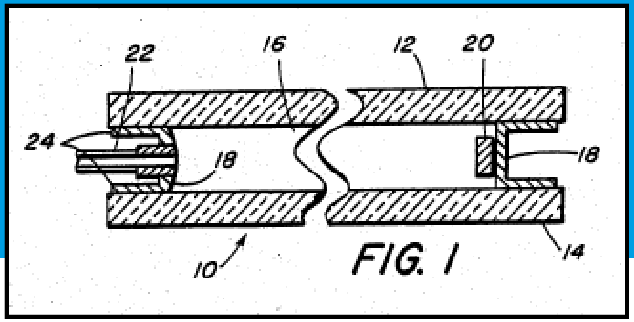
VIG prior art
1913 – 1987

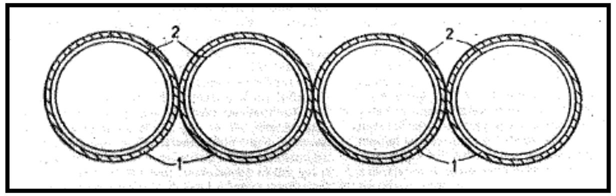


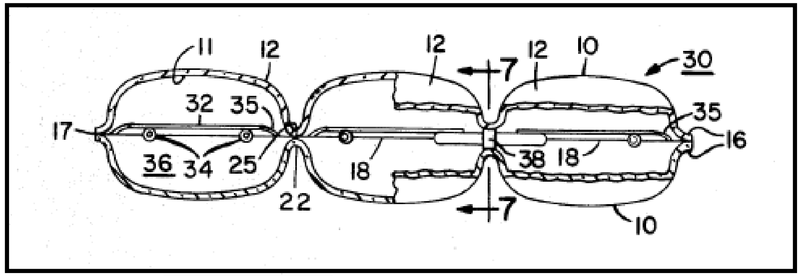


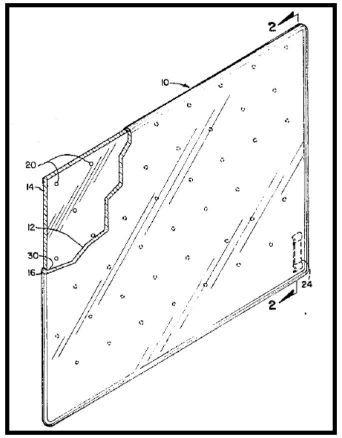


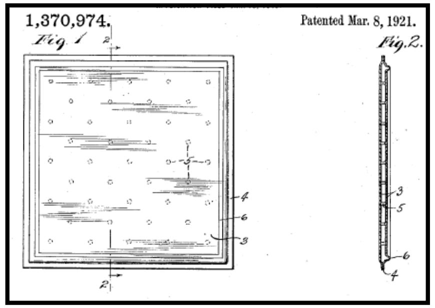


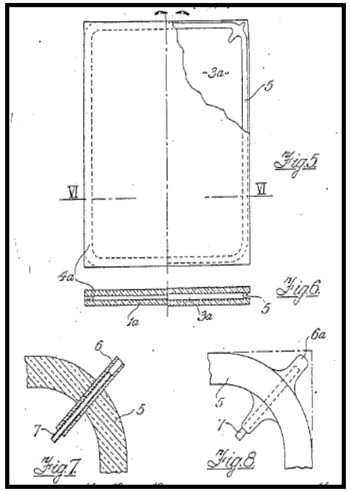


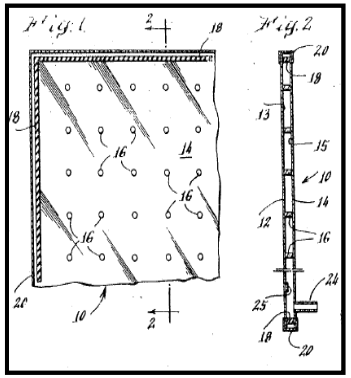


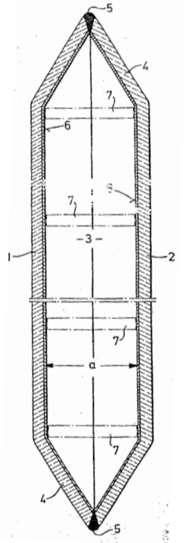


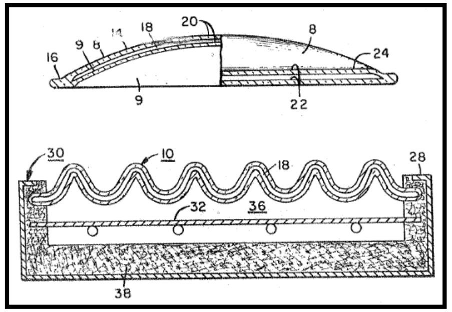


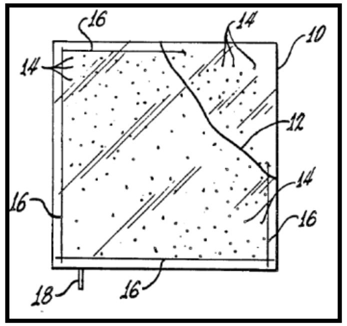












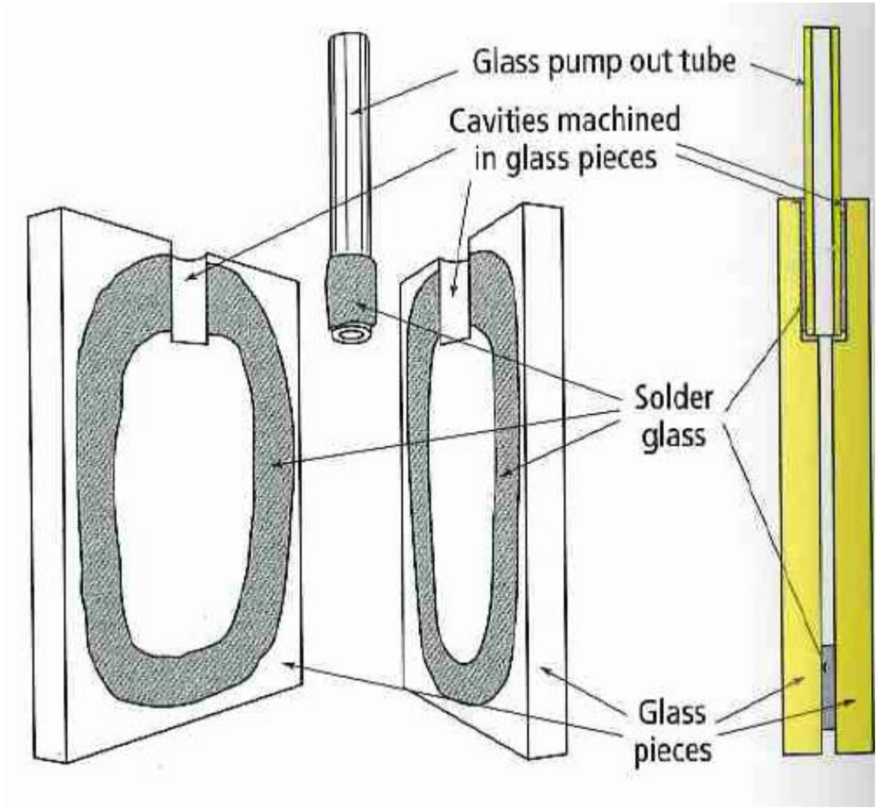
1913 – 1987: Patent Claims

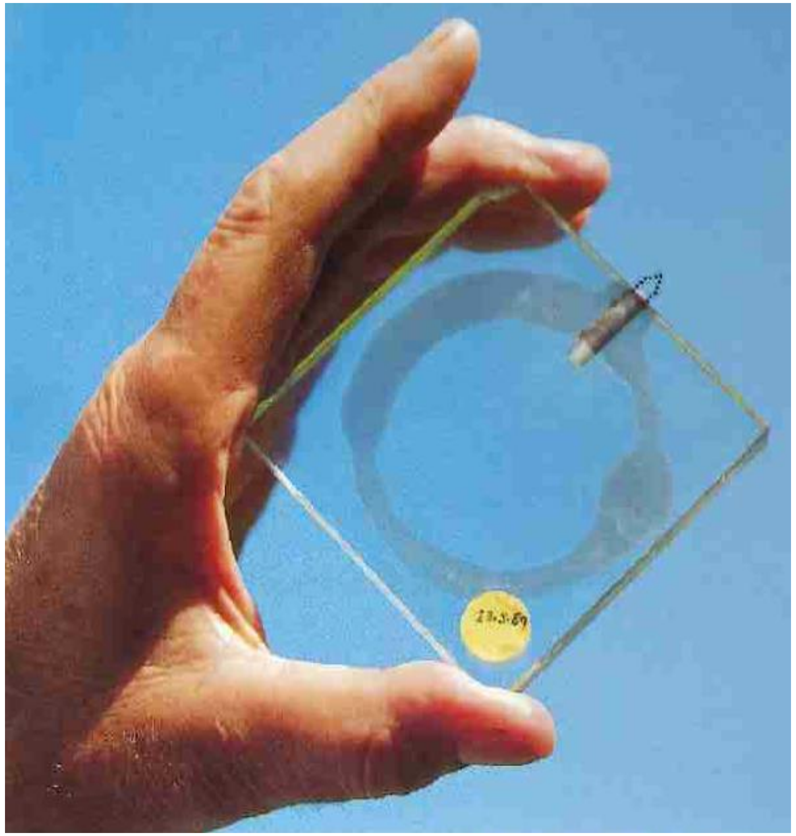
- Support pillars of many different designs and materials
- Pillar arrays of various geometries
- Flexible and rigid edge seals
- Edge seals made with solder glass and metal
- Edge seals made by fusion of the two glass sheets
- Ports and tubes for evacuating the internal volume
- In-vacuum sealing of the edges (“seal the vacuum in”)
- Contoured glass sheets
- Multiple glass sheets
- Internal transparent low emittance coatings

1988: Commencement of VIG research at School of Physics, University of Sydney

- Senior undergraduate project by Stephen Robinson
- In-vacuum sealing of small glass plates with solder glass
- Very narrow gap (no pillars)
- Several evacuated samples made
- Small-area heat flow measuring apparatus developed
- Samples poorly thermally insulating due to:
  - Outgassing after sealing
  - Evanescent field radiative heat flow
- Samples visually unacceptable
  - Interference fringes
- The project pointed the way forward
- Stephen awarded First Class Honours/University Medal

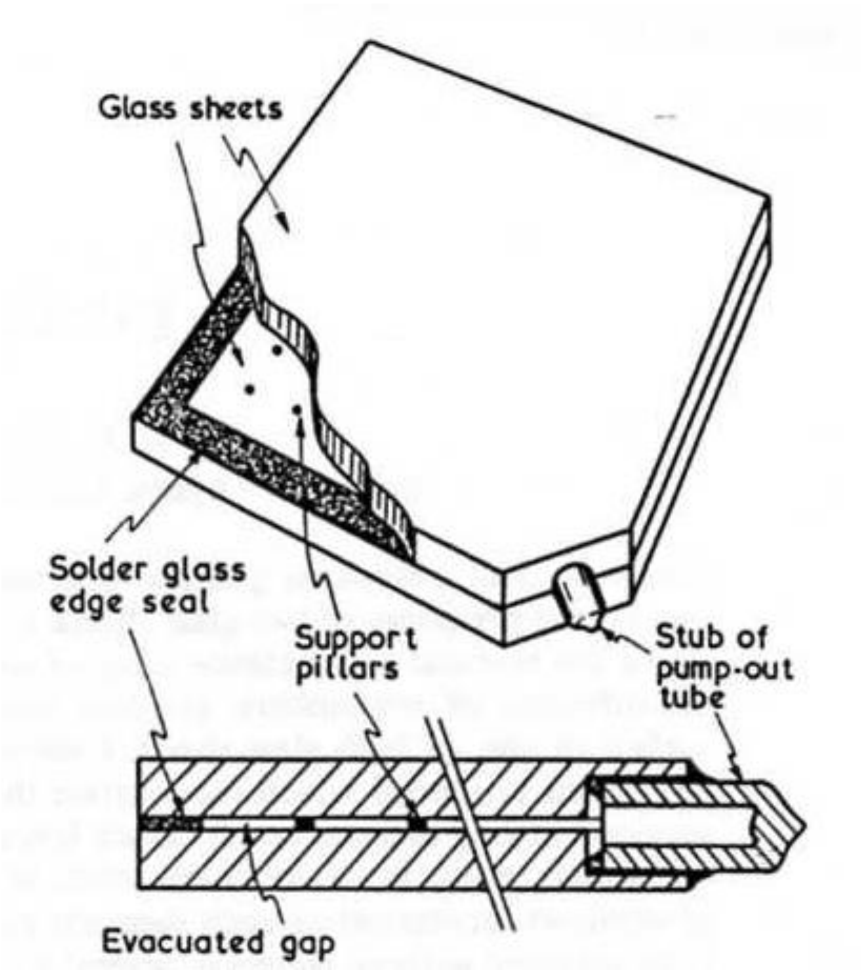
2 June 1989: First thermally insulating sample





Two months later: A4 sized sample

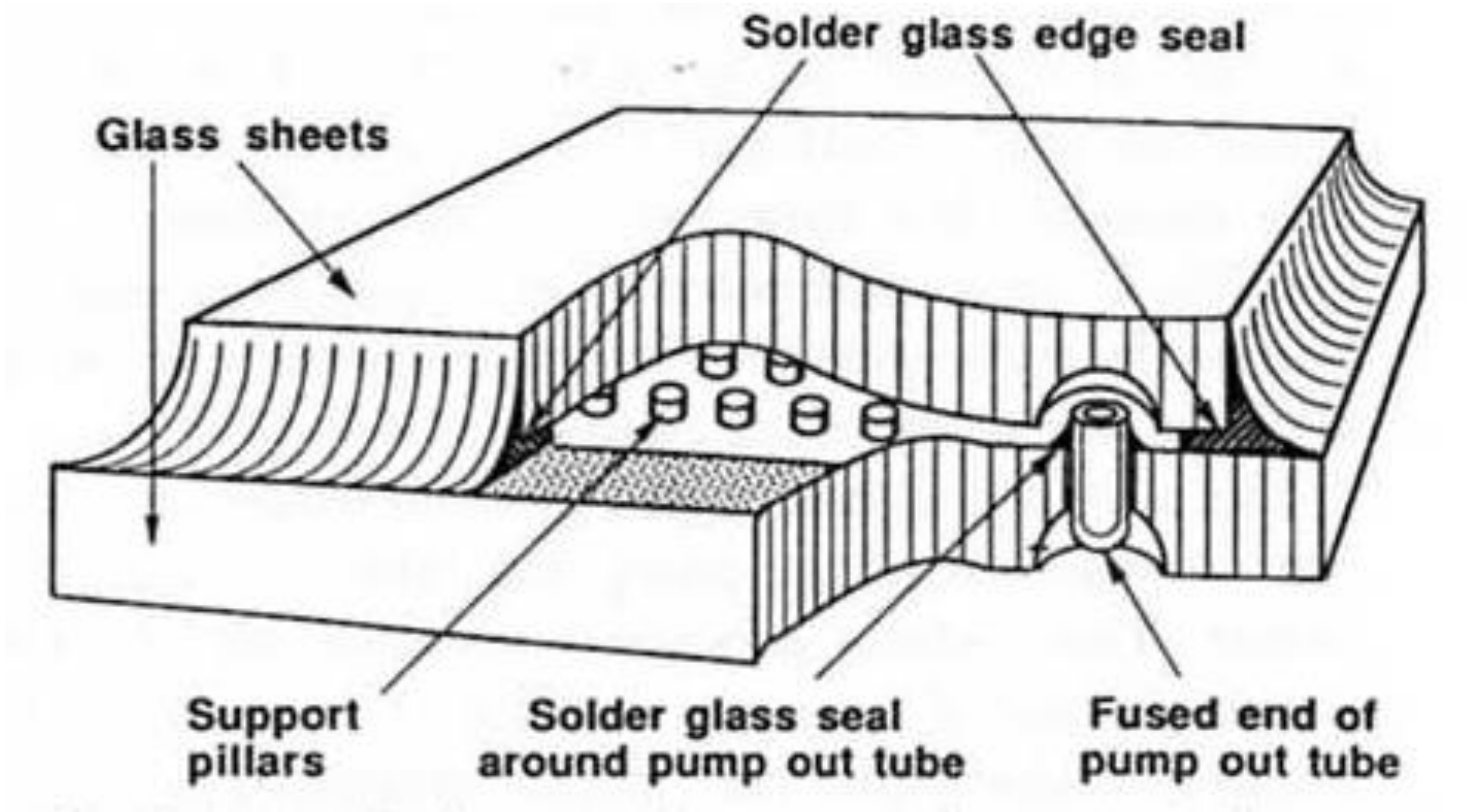
- Solder glass edge seal
- Solder glass pillars
- Pillar height ~0.1 mm
- Pillar separation: 50 mm
- 4 mm thick glass sheets
- No low E coating
- Vacuum stable in laboratory
- Reported at ISES Congress, Kobe, September 1989 (Robinson and Collins)



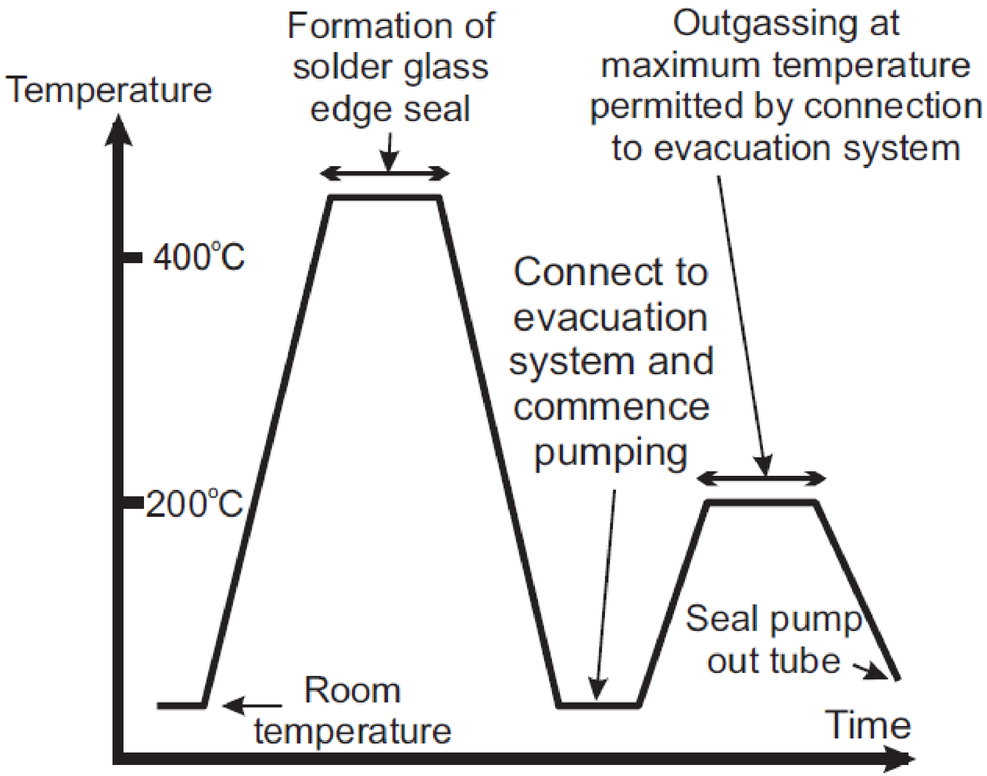
VIG research program at U of S

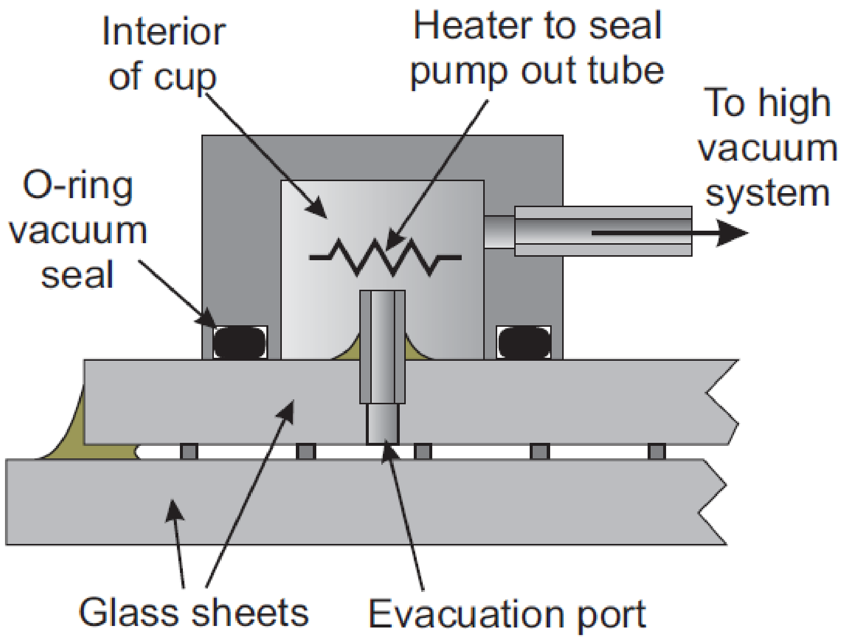
- Production methods
- Heat flow: physical mechanisms & measurement
- Stresses due to temperature difference, pressure
- Support pillars: design, materials
- Design tradeoffs for pillar array (heat flow/stress)
- Evacuation time of large area, small gap interior
- Pump out tube: design, sealing
- Vacuum stability and degradation mechanisms
- Impact strength
- Validation of results by independent laboratories
- Cost
- Prior art

1990: University of Sydney VIG



Two-step manufacturing process





Strategy of U of S VIG research program

- Combination of applied and basic research
- Involvement of students
- In early years, seek highest thermal insulation
- Do NOT try to create spin-off manufacturing, but ….
- Develop production-relevant designs & techniques
- Generate know-how and patent protection that will assist commercialisation
- Seek a commercial partner

Finding a partner was difficult

- Unconventional approach to insulated glazing
- Many technical uncertainties and unknowns
- Nearly 80 years of unsuccessful attempts
- Doubts about the validity of U of S results
- “Not Invented Here” syndrome
- Perceived high product cost
- No existing technology for some critical steps, such as pillar placement
- A high cost, high risk commercial enterprise

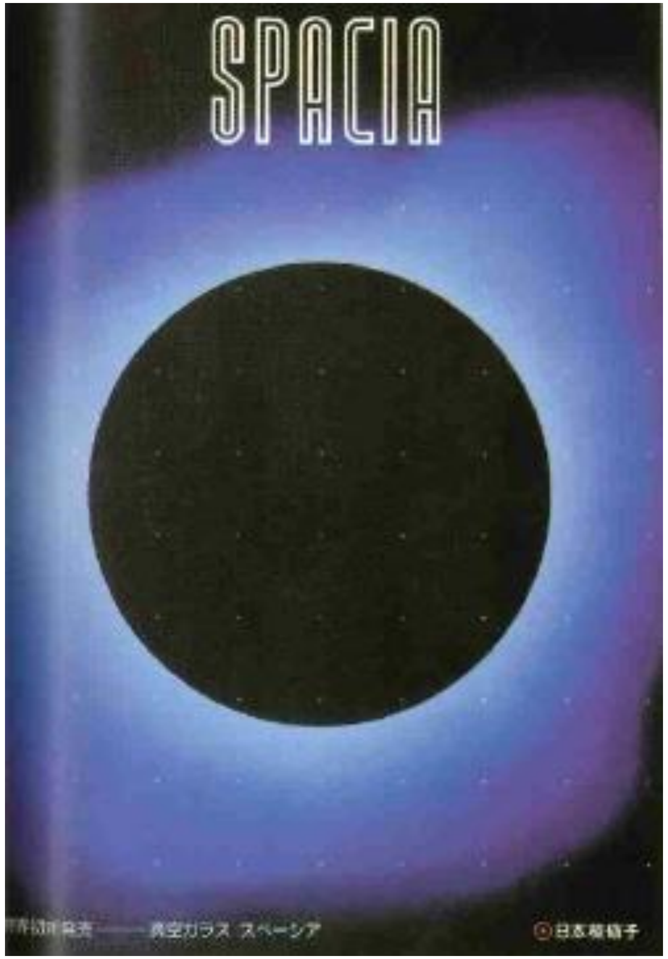
Nippon Sheet Glass (NSG)

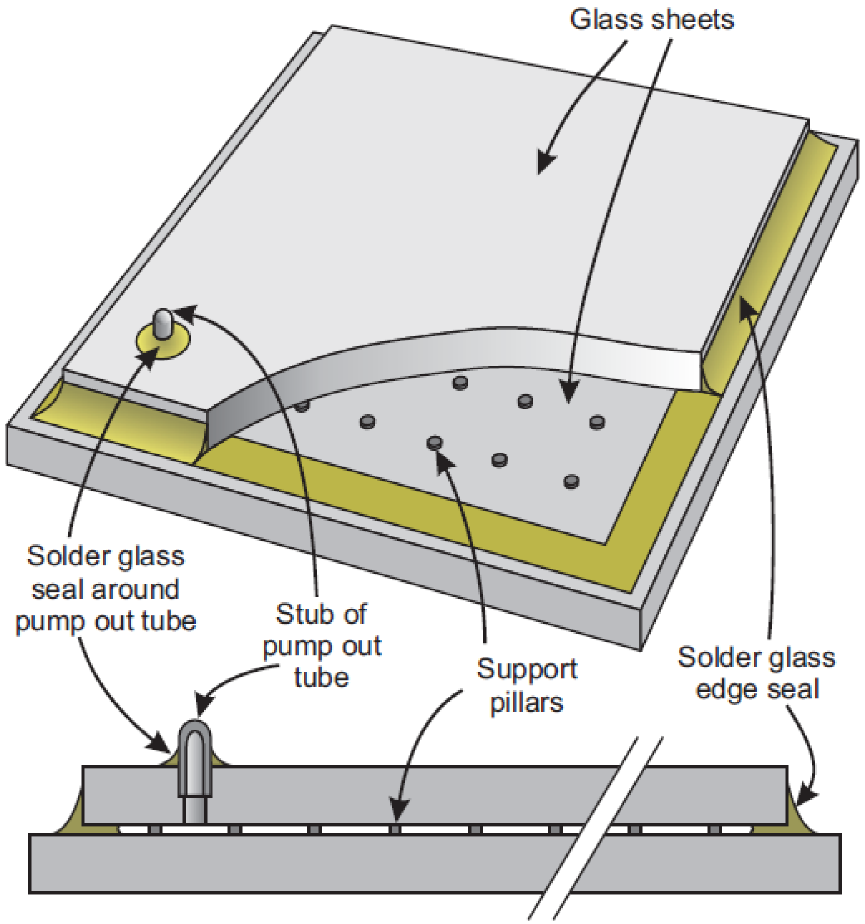
- 1989 – 1993: Many companies were approached, without success
- 1993: Sakae Tanemura introduced U of S to NSG
- Late 1993: Meeting in Japan with Hideo Kawahara, Director of NSG Architectural Glass R&D Division
- NSG interested in a thin (≤6 mm), moderately insulating glazing for the Japanese retrofit market
- Late 1994: Licensing and collaborative research agreement between NSG and University of Sydney

1994 – 1996: Initial product development

- Frequent NSG/U of S meetings in Australia and Japan
- Detailed design: pillar array (diameter, height, material, separation), glass thickness, pump out tube
- Involvement by NSG of specialist companies
- Batch process chosen (more flexible than in-line process)
- Two-step manufacturing process (the only known possibility)
- Process design: glass handling, pillar placement, solder glass dispensing method, evacuation system and bake out temperature, tip off method, testing
- Many decisions had to be made with an incomplete understanding of the relevant science and technology
- Pilot production plant built at NSG Kyoto factory

1996: Launch of Spacia by NSG





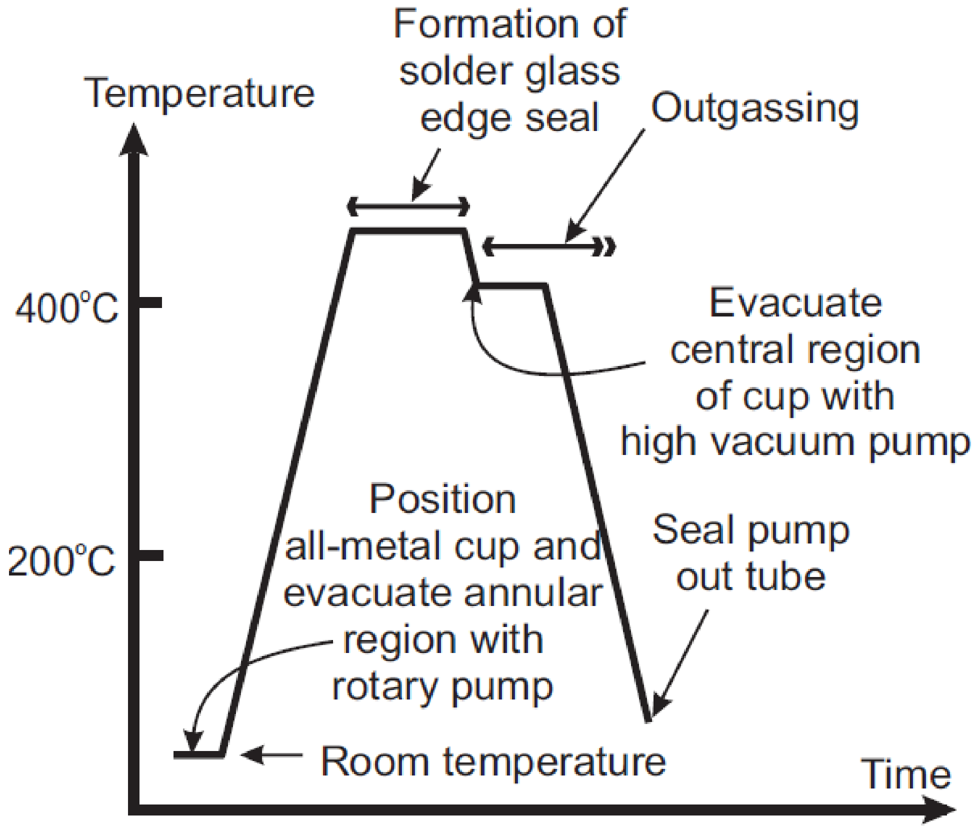
Launch of Spacia followed by:

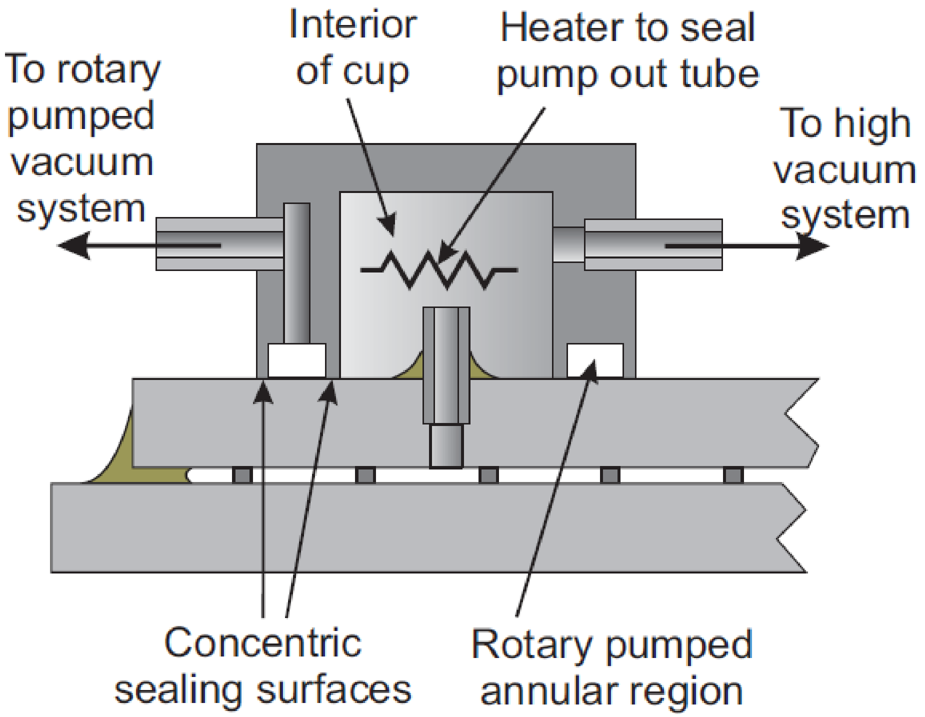
- Intensive marketing
- Demand exceeded manufacturing capacity
- Scale-up of manufacturing capacity at Kyoto
- Steady improvement of yield
- Continuing research and development
- Introduction of LowE coating
- Second manufacturing plant built at Ryugasa

1996 – 2000: Product and manufacturing development

- Many incremental changes were made to product design and manufacturing method
- Most of these changes were a result of conventional yield improvement activities
- However, one major change was implemented: from a two-step manufacturing process to a single-step process

The single-step manufacturing process was made possible by invention of the all-metal evacuation cup





The need to introduce the single-step process was a direct consequence of the earlier incomplete understanding of important technical issues

NEGATIVES

- Major redesign/rebuild of 2 manufacturing plants
- Costly and time consuming

POSITIVES

- Number of heating steps reduced from 2 to 1
- Post-assembly production time halved
- Simplification of manufacturing process
- Reduction in manufacturing cost
- Enhanced commercial viability of Spacia

The NSG/U of S VIG development was a truly collaborative endeavour

- Shared commitment to success of project
- Both participants highly motivated
- Creative and positive approaches to issues
- Very close interactions
- Mutual trust (no secrets)
- Highly innovative science and engineering
- Top priority given to solving problems
- Evidentiary approach (What do the data say?)

2000 – present: consolidation of VIG technology

- Several million Spacia units manufactured and sold
- Installed units have shown excellent reliability
- U-values as low as 0.6 W m^{-2} K^{-1} in 10 mm thick VIG
- Hybrid glazing and laminated assemblies available
- Major expansion of Spacia production capability
- Several significant VIG research studies undertaken
- Extensive publication and patenting
- Other companies have entered the VIG market, or intend to do so
- VIG Standards are being written

Future developments 1: Design

- Tempered glass (need lower temperature edge seal)
- Innovative pillar designs
  - Thermally insulating materials
  - High strength materials
  - Low friction bearing surfaces
  - Structured pillars
- Improved performance of existing VIG designs
  - Pillar array design
  - Higher performance Low E coatings
- Flexible edge seal (considered unlikely)

Future developments 2: Production technology

- Alternative edge seal materials
  - Solder glass, metal, (adhesives considered unlikely)
- Evacuation port
- In-line manufacturing
  - Cost reductions possible
- In-vacuum edge sealing
  - Challenges include outgassing after sealing, and maintaining geometry in VIG edge seal region

Summary

- History of VIG is unusual for a new technology:
  - 75 years from conception to first experimental device
  - Then only 8 years to first commercial VIG, Spacia
  - Spacia is a highly successful product, but:
  - After 20 more years, still very few VIG manufacturers
  - Strong current interest
- The future is likely to see:
  - More manufacturers entering market
  - Larger sales volumes
  - Design evolution
  - New production approaches
  - Improved performance
  - Reduced cost

Prognosis

- VIG unlikely to be a very low cost insulating glazing:
  - Capital investment for VIG plant, and energy used during manufacture, always greater than for conventional IG
  - However, material costs for VIG and IG are similar
  - Thus, VIG/IG cost differential is not necessarily great
- VIG is very much thinner than conventional IG
- VIG has excellent thermal performance & reliability
- VIG is therefore likely to become an increasingly attractive option as a high performance thermally insulating glazing, and in the retrofit market

Key to success of project: people

I acknowledge with thanks the contributions by my many students at the University of Sydney, and by my colleagues in the University and at NSG

Key to success of project: people

I dedicate this talk to
Stephen Robinson
Hideo Kawahara