# Glass-Metal Joining in Nuclear Environment: The State of the Art

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*Abstract*—**This article presents an overview of the different joining technologies that can be used to join glass to metal in a severe nuclear environment. Three different types of joining are discussed: fastening, liquid phase joining and solid phase joining. The article will conclude with a discussion on the best choices for the specific examples of windows in the vacuum vessel of ITER and the use of embedded optical fibres sensors in nuclear reactors.**

*Keywords*—**Joining technologies, Glass, Nuclear**

## I. Introduction

TWO important nuclear applications of glass-metal joining are the fixation of the optical fibres to perform diagnostics in a material testing reactor and the optical windows in ITER (see figure 1). These glass-metal joints are a serious problem since they must be able to withstand a high neutron fluence and a high temperature, while keeping a good mechanical strength. The optical windows must also remain leak tight because of the tritium in ITER.

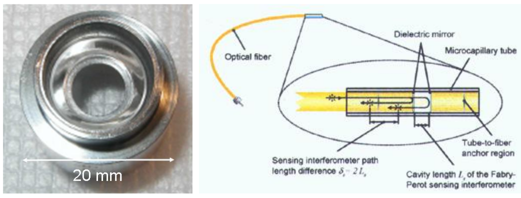


Fig. 1. An optical window made by diffusion bonding (UKAEA) (left) and a Fabry-Pérot sensor (Opsens Inc.) (right).

## II. An Overview Of The Different Glass-Metal Joining Technologies

### A. The Different Technologies

Three types of joining technologies exist: fastening, liquid phase joining and solid phase joining. Fastening is a mechanical attachment technique that does not produce hermetic seals because no real bond is formed. Thus it is not a suitable technique and so it will not be further discussed.

The most important technologies of liquid phase joining are adhesive bonding, brazing and fusion welding. In the case of the solid phase joining the choices are diffusion bonding, electrostatic bonding and ultrasonic torsion welding.

### B. Adhesive Bonding

The first liquid phase joining technology is adhesive bonding. This is an assembly technique where two materials are joined using an adhesive. The bond is created by surface tension forces or mechanical interlocking of the adhesive in pores and valleys of the solid [1]. This is a very easy technique, but it is difficult to assess the durability of the bonded structure.

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### C. Brazing

Another liquid phase joining technology is brazing. Brazing is the joining of pieces of material by fusing a braze layer between the adjoining surfaces. So this process requires first melting of the braze and afterwards wetting of the braze on the material [2]. Brazing is performed above 450°C and in a controlled atmosphere (nitrogen, argon) or in a vacuum better than $10^{-4}$ N.m$^{-2}$. If the temperature is lower than 450°C, then the process is called soldering.

There are two types of brazing alloys: active and non-active. The active brazing alloys contain reactive elements like Ti that will react with the material to enhance wetting. The non-active brazing alloys require a surface treatment to encourage wetting like metallisation.

An advantage of brazing is that it's suitable to join large areas and thin pieces, but on the other hand the surfaces require some preparation to have a good wetting and the thermal stresses can become very big.

### D. Fusion Welding

The last method of liquid phase joining is fusion welding. Here heat is applied at the connection points of the material to fuse the pieces together. After hardening of the mixed components a solid joint occurs. The heat can be applied by different heat sources like fuel-gas flames, electron beams, plasma arcs and lasers. These heat sources have different heat intensities, the spectrum of the heat intensities is presented in figure 2.

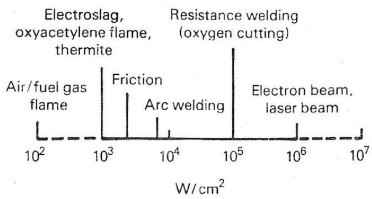


Fig. 2. The intensity spectrum for different heat souces.

### E. Diffusion Bonding

Diffusion bonding is a solid phase joining technology that occurs at atomic level. By applying a pressure at an elevated temperature during a certain time the surfaces of the materials to be joined will deform locally. This deformation will make sure the surfaces come in close contact with each other, so the atoms can diffuse across the interface to form a bond [4], [5].

The mechanism of diffusion bonding can be divided into some stages as shown in figure 3. First there is an initial point contact with residual oxide contaminant layers (a). Then the applied load will cause plastic deformation and creep of the surface asperities to reduce the interfacial voids and to make the contaminant layers thinner (b). Afterwards the final yielding and creep, so that only some voids remain with a very thin contaminant layer (c). The continued vacancy diffusion will eliminate the oxide layer, leaving very few small voids (d). Finally the bonding will be completed (e).

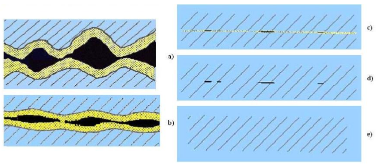

Fig. 3. The mechanism of diffusion bonding.

The most important parameters of diffusion bonding are:

- Bonding temperature: Typical 50 % to 80 % of the melting temperature of the most fusible material
- Bonding pressure: It can range from a few MPa to even 200 MPa
- Bonding time: It can be some minutes, but also several hours depending on the bonding temperature and pressure

Diffusion bonding has some benefits like it produces joints of very good quality, the properties of the parent materials are generally unchanged and it produces no harmful gases. On the other hand the surface preparation stage is very important because excessive oxidation or contamination of the faying surfaces decreases the joint strength drastically and the bonding of materials with stable oxide layers is very difficult. Other limitations are that it is difficult to make large joints and the ratio of the contacting area to the faying area is very low.

### *F. Electrostatic Bonding*

Another solid phase joining technique is electrostatic bonding (also called field assisted or anodic bonding) [6]. By applying a voltage between the materials, ionic migration will occur. This migration will lead to chemical reactions till a joint is formed. For this technique the glass must contain mobile ions.

### *G. Ultrasonic Torsion Welding*

The last solid phase joining technology is ultrasonic torsion welding. Here joining is achieved by using high frequency torsional shear oscillations and a static pressure perpendicular to the oscillation direction. This will disrupt the oxide layers on the materials, so that the surfaces come in close contact with each other. The atoms can diffuse then from one part to the other to form a bond at the interface [3].

## III. Some General Limitations And Problems For Joining

### *A. General Limitations*

There are two main limitations for joining: the surface roughness and the surface contamination [1], [8]. Any surface exposed to the atmosphere will adsorb oxygen, water vapor, carbon dioxide and hydrocarbons very rapidly. A monolayer of gas will even strike a surface in $10^{-8}$ atmosphere-seconds and contaminate the surface. This is too small to permit cleaning of the surfaces before joining in anything other than an ultrahigh vacuum. There is one exception for the contamination, namely adhesive bonding. With this technology the contamination is not removed, but merely buried under the adhesive.
When materials are placed against each other, the real contacting area is much less than the apparent contact area because of the roughness and nonplanarity of a surface on an atomic scale. To overcome this roughness and to make the real contacting area bigger, the solid phase technologies rely on deformation or diffusion. The liquid phase technologies on the contrary use a liquid to have a close contact between the mating surfaces.

### *B. Problems For Joining Dissimilar Materials*

The main problems for joining dissimilar materials are the differences in physical properties and undesirable metallurgical interactions such as brittle intermetallic formation [7], [8]. Differences in physical properties that can cause problems are the melting point, the elastic modulus and especially the coefficient of thermal expansion (CTE). Mostly glass has a lower CTE than metal, this will lead to thermal residual stresses when the materials are cooled down from the joining temperature to room temperature. These stresses will weaken the mechanical strength of the joint.

## IV. Conclusion

So the technologies that might be useful for these applications are: fusion welding, adhesive bonding for high temperature, brazing and diffusion bonding. Adhesive bonding for high temperature and fusion welding are more suitable for the application of the optical fibres, the other two techniques (brazing and diffusion bonding) are better for making leak tight optical windows.

## Acknowledgments

The author gratefully acknowledge the suggestions of the following people: G. Van Oost, J. Degrieck, M. Decréton, B. Brichard, J. Linke and T. Koppitz.

## References

[1] T.W. Eagar, *Processes of Joining Materials*, http://mit.edu/3.37/www/chapter.shtml.
[2] J.A. Fernie and K.I. Ironside, *Ceramic brazing*, Materials World, 7(11):686-688, November 1999.
[3] H. Kuckert, C. Born, G. Wagner, and D. Eifler, *Residual Stress Distributions in Glass/Metal Joints Produced by Ultrasonic Torsion Welding*, Mat.- wiss. U. Werkstofftech., Vol 34, 2003, p 30–33.
[4] G. Çam and M. Koçak, *Progress in Joining Advanced Materials*, International Materials Reviews, Vol 43 (No. 1), 1998.
[5] G. Wittenborn, *Diffusion Bonding*, 1st Annual KU Aerospace Materials and Processes 'Virtual' Conference, University of Kansas, 2001.
[6] A. Balagopal, *Epoxyless Fiber to Submount Field Assisted Bonding for Optoelectronic Applications*, PhD Thesis, University of Cincinnati, 2005.
[7] R.M. do Nascimento, A.E. Martinelli, and A.J.A. Buschinelli, *Review article: Recent Advances in Metal-Ceramic Brazing*, Cerâmica, Vol 49, 2003, p 178-198.
[8] T.W. Eagar, A.A. Baeslack, and R. Kapoor, *Joining of Advanced Materials: An Overview*, In Encyclopedia of Advanced Materials, Pergamon Press, 1994.