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Active Metal Brazing for Electronic Package Assembly

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Abstract

This paper outlines the two primary technological processes that can be used to produce reliable, hermetic ceramic-to-metal interfaces germane to the production of microwave, rf and photonic package assemblies. The traditional method, called the Mo-Mn process, is a multi-step process that involves premetallization of the ceramic component followed by sintering of the metallization layer, plating of the sintered metallization and a conventional metal-to-metal brazing step to fabricate the assembly. The utility of the Mo-Mn process suffers from several distinct disadvantages. It is confined to applications employing conventional oxide ceramics, and it tends to be time consuming and costly as a result of the multi-step processing. It is also susceptible to yield problems if the assembly is held too long at the brazing temperature. By contrast, the active metal brazing process produces robust ceramic-to-metal joints in a single step. It circumvents the costly premetallization process required by the Mo-Mn method, results in higher throughput, can be applied to non-conventional ceramics and is not prone to yield losses from excessive time at temperature. The active metal process for ceramic-to-metal joining is a viable process alternative for advanced electronic package assembly.

Introduction

The distinct lack of thermodynamic affinity between glasses or ceramics and metal alloys is the primary reason that joining of these materials has historically represented a formidable engineering challenge. The degree to which a liquid phase will wet a solid it is in physical contact with, within a vapor/liquid/solid three phase system, is a direct consequence of the particular conditions of thermodynamic equilibrium. By balancing the horizontal components of the interfacial energies (surface tensions) at the point of contact of such a three phase system (see Figure 1), Young [1] expressed this “mechanical” relationship at the turn of the last century in his now famous equation as

$$\gamma_{sv} - \gamma_{sl} = \gamma_{lv} \cos \theta \qquad (1)$$

where γ_{sv} is the interfacial energy between the solid and vapor, γ_{sl} is the interfacial energy between the solid and liquid, γ_{lv} is the interfacial energy between the liquid and vapor, and θ is the liquid/solid contact angle measured inside the sessile liquid drop. For the case depicted in Figure 1, $\gamma_{sv} > \gamma_{sl} > \gamma_{lv}$ so that the contact angle θ is acute, and by definition wetting of the solid by the liquid occurs. However, for the case where $\gamma_{sv} < \gamma_{sl} < \gamma_{lv}$, the contact angle is obtuse and wetting of the solid by the liquid is thermodynamically unfavorable. This second case is typical of a liquid metal drop in contact with a glass or ceramic substrate.

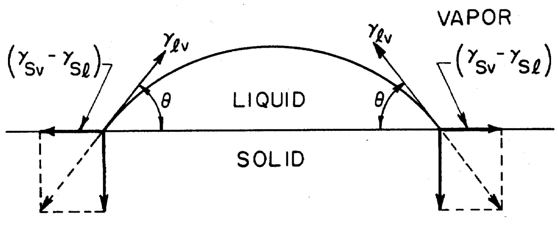

Figure 1 - Sessile drop configuration
(Courtesy J. A. Pask and A.P. Tomsia)

Toward the end of the nineteenth century, Gibbs [2] presented a more rigorous thermodynamic treatment of Young's construction. Although he accounted for the effects of a gravitational field on the system, like Young he assumed the system to be at chemical equilibrium with no mass transport across the interfaces. By now it is well established that the effect of chemical reactions on the relative interfacial energies of solid/liquid/vapor three phase systems, particularly at elevated temperatures where mass transfer effects can be significant, is such that the free energy of the reaction can enhance the driving force for wetting of the solid by the liquid [3] as follows

$$\gamma_{sv} - (\gamma_{sl} + [-dG_r/dAdt]) \rightarrow \gamma_{lv} \cos \theta . \qquad (2)$$

This is true because mass transfer across the interfaces must result in a net decrease of the free energy of the system at any time, otherwise the reaction would not proceed.

As with glass-to-metal sealing, the basic requirements for strong, hermetic ceramic-to-metal joints are chemical bonding and minimal stress differentials at and near the interfacial junction. For both cases, these requirements are satisfied by the formation of a thermodynamically stable metal oxide (which serves to act as a chemical "glue") and relatively close matching of the thermal expansion coefficients of the component materials. In general, the specific fabrication processes used to achieve a strong, reliable hermetic seal are more involved for the case of ceramic-to-metal joining.

Mo-Mn Metallization Process

Although patents describing the metallization of electrical porcelains have been issued since the middle of the nineteenth century, the advent of modern vacuum tight ceramic-to-metal seals owes to the invention of refractory metal metallization by Pulfrich circa the late 1930's [4]. His discovery led to the actual production of vacuum tubes during World War II. Later in the 1950's the rise of microwave electronics coupled with improvements in furnace technology catalyzed development of the "moly-manganese" process [5,6], the traditional technique used for the fabrication of ceramic-metal assemblies.

The central feature of the Mo-Mn process is the metallization of ceramic components using a special "paint." This paint is comprised of metal oxides and powders which are mixed with nitrocellulose lacquer and ground in a ceramic ball mill until a suspension having an average particle size of several microns is achieved (twelve to sixty hours). The paint is applied to a ceramic substrate (layer thickness of about 25 microns) and fired under a wet N_2/H_2 atmosphere at a furnace temperature typically between 1400°-1600°C. This sintering process produces reactions between the metal oxides in the paint and the ceramic substrate resulting in a chemically bonded metallization layer.

The surface of the metallizing layer is generally electroplated prior to final assembly with a layer of nickel or copper, which is subsequently, sintered into the metallization layers. This serves to facilitate wetting of the metallized ceramic by the braze alloy that will be used to fabricate the final assembly.

Finally, the metallized ceramic is brazed to a metal member in a hydrogen furnace. This represents a conventional metal-to-metal joining operation, the technical details of which are by now well established. Although many different brazing alloys have been used for this part of the application, the prime consideration in all cases is to allow adequate time for the braze material to wet and flow while avoiding dissolution of the ceramic metallization.

Active Metal Brazing Process

The myriad of process steps for and associated expense of metallizing ceramics prior to ceramic-to-metal joining can be avoided by employing the process of active metal brazing [7-12]. This process takes advantage of the thermodynamic affinity of certain high temperature metals, primarily titanium and molybdenum, for oxygen. By alloying a more conventional braze filler material with one of these "active" metals, it is possible to produce a reliable, hermetic ceramic-to-metal interface using a single step brazing process.

Although active metal brazing alloys can be comminuted into powders and applied in lacquer carriers, the preferred approach is to prealloy the braze filler by arc melting and to fabricate preforms from a cold rolled thin foil of the alloy. The preforms can then be placed between the components to be joined and vacuum brazed in a suitable furnace.

When an active metal braze alloy is taken to temperature during a brazing operation, the oxygen affinity of the active metal constituent provides the driving force for its preferential diffusion to the braze filler/ceramic component interface. It is here that the oxidation reaction necessary for true chemical bonding takes place. The mechanism involves substitutional displacement of cations in the ceramic by the active metal component, in conjunction with an oxidation reaction between the active metal and oxygen in the ceramic. For example, a Ti doped braze filler in contact with sapphire (Al_2O_3) would react as follows:

$$3\,(Ti) + Al_2O_3 \rightarrow 2\,(Al) + 3TiO. \qquad (3)$$

The dynamic equilibrium for this reaction is controlled by the local Ti and Al activities, while the kinetics of the reaction are controlled by Ti and Al diffusion. For most active metal braze alloys, the dissolution of ceramic cations in the braze melt is rather slow so that "wetting" in the traditional sense (liquid melt transported by capillary action) does not occur. For these alloys, wetting is manifested by the appearance of a bluish color at the interface, which is indicative of the formation of a tenacious and desirable oxide. If the ceramic component is transparent, the process provides its own built in metric.

Generally, a relatively small percentage of the active constituent is preferred in active metal braze alloys (often < 2 wt. %) to minimize or avoid the formation of brittle intermetallic phases in the brazement. Since the active metal component readily getters oxygen, the process requires vacuum processing so as to avoid oxidation reactions anywhere except the ceramic-metal interface. This usually means vacuum better than 5×10^{-5} torr, depending on the braze alloy.

The active metal brazing process is attractive because it promotes chemical bonding between the ceramic and metal members of an assembly without the need for costly and time consuming premetallization of the ceramic component. In addition, active metal brazements offer excellent reliability for special applications involving resistance to high temperature corrosion. It is important to note that this process can also be used to join metals to non-traditional ceramics for which metallizations are not available, such as Si_3N_4, AlN, SiC, Y_2O_3, TiB_4 and graphite.

Case Study

Measurement requirements used to characterize digital communications in the time domain have driven development of the HP 83480A Digital Communications Analyzer. Integral to the success of this optical telecommunications analyzer is a set of optical-to-electrical (O/E) plug-in modules that allow specific measurements at the various transmission rates currently employed by telecommunication systems [13]. The modularity of these O/E components benefits customers because they can configure an instrument to best meet their current needs, then easily modify it as their needs change with evolving fiber-optic technology and standards.

The heart of the O/E plug-in modules is a custom InP/InGaAs/InP p-i-n photodiode, which converts the incoming photons of light to a proportional electrical current. To protect the photodiode, it is mounted (along with attendant amps, filters and samplers) inside a hermetic package assembly. A single-mode fiber is attached outside of the package. The lid of the package has a sapphire window, which allows light photons to pass from the fiber into the package and illuminate the photodiode.

The sapphire window is joined to an ASTM F-15 alloy package lid using active metal brazing (see Figure 2). This process eliminates the necessity of premetallization of the sapphire window by employing a quaternary active braze alloy of 63% Ag, 34.25% Cu, 1.75% Ti and 1% Sn, with a liquidus of 806°C. The hermetic ceramic-to-metal interface is developed *in situ* by taking the lid/window assembly to approximately 830°C in a vacuum ambient between 2 and 5×10^{-5} torr. By means of this relatively simple and robust joining process, the cost savings realized in fabrication of the lid/window assembly is about 70% compared with the conventional Mo-Mn process.

The sealed hybrid package and hermetic lid/window assemblies were subjected to strife testing that involved temperature cycling from -50°C to +85°C, random vibration at 8g rms, and mechanical shock to 1800g while maintaining their hermetic leak rate specification of $< 10^{-9}$ std cc He/sec. In addition, lid/window assemblies survived a severe thermal shock test where the units were plunged into liquid N_2 from room temperature without failing specification.

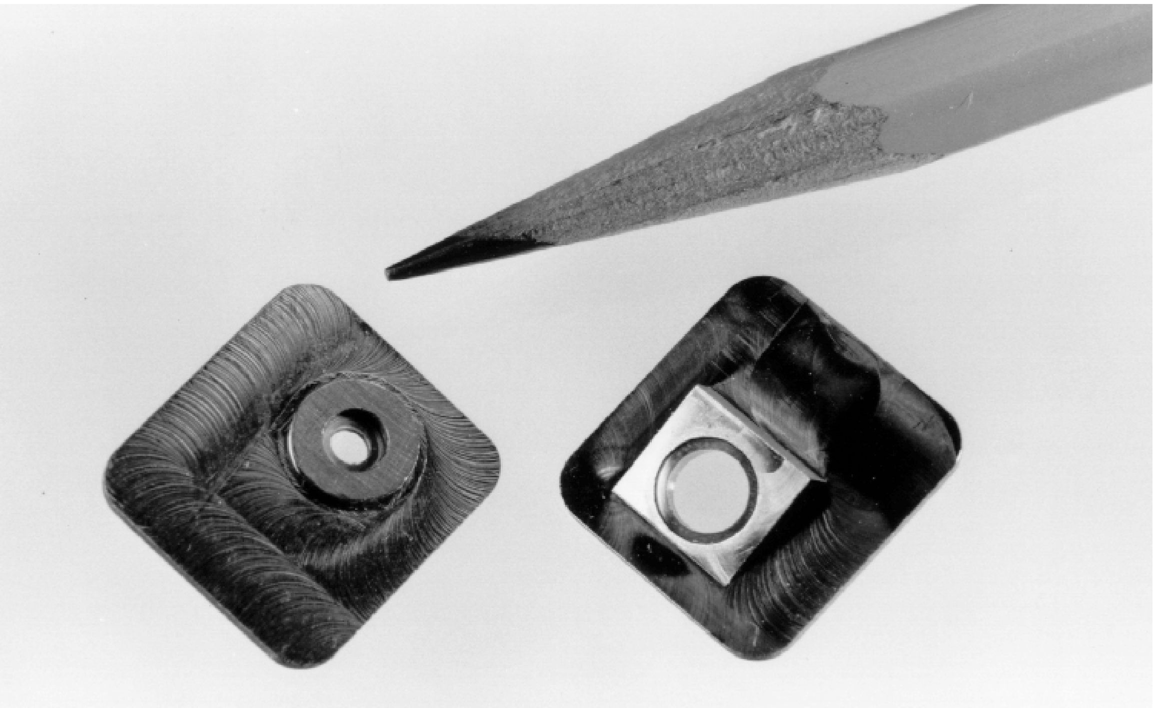

Figure 2 - Two examples of active metal brazed lid/window assembly designs.

Conclusion

Despite its apparent advantages, active metal brazing has not been used as widely as conventional metallize/braze approaches. Recent advances in vacuum furnace technology and the availability of commercial active metal braze alloys have eliminated the standard drawbacks so that currently, the lack of familiarity with the active brazing process among designers represents the primary reason it is not more widely employed in the fabrication of electronic package assemblies.

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References

[1] T. Young, *Phil. Trans. Roy. Soc.*, Vol. **95**, pp. 65-94, 1805.
[2] J.W. Gibbs, *Trans. Conn. Acad.*, Vol. **3**, pp. 343-371, 1878.
[3] J.A Pask and A.P. Tomsia, in Surfaces and Interfaces in Ceramic and Ceramic-Metal Systems, Edited by J.A. Pask and A.G. Evans, Plenum, New York, pp. 441-449, 1981.
[4] H. Pulfrich, U.S. Patent 2,163,407, June 20, 1939.
[5] H.J. Nolte and R.F. Spurch, U.S. Patents 2,667,427 and 2,667,432, January 24, 1954.
[6] A.J. Chick and L.S. Speck, U.S. Patent 2,708,787, May 20, 1955.
[7] C.S Pearsall, *Mater. Methods*, Vol. **30**, pp. 61-62, 1942.
[8] F.C. Kelly, U.S. Patent 2,570,248, October 9, 1955.
[9] H. Mizuhara, U.S. Patent 3,561,099, February 9, 1985.
[10] H. Mizuhara and K. Mally, *Weld. Journal*, Vol. **64**, No. 10, pp. 27-32, 1985.
[11] A.J. Moorhead and H. Keating, *Weld. Journal*, Vol. **65**, No. 10, pp. 17-31, 1986.
[12] H. Mizuhara and E. Huebel, *Weld. Journal*, Vol. **65**, No. 10, pp.43-51, 1986.
[13] C.M. Miller, R. King, M.J. Woodward, T.L. Bagwell, D.L. Faller, J. Straznicky and N.L. Whang, *Hewlett-Packard Journal*, Vol. **47**, No. 6, pp. 22-31, December, 1996.