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Single-Cycle Gas Panel Assembly

Abstract: A single-cycle process has been developed in which the two halves of a gas panel are assembled, sealed, and filled in a continuous, automatically sequenced, controlled-ambient furnace. The entire fabrication operation, including seal, degas, backfill, and tip-off, may be accomplished in a single thermal cycle. During heat-up, the panel parts and furnace chamber are degassed in a programmed cyclic fill (to 20 mm of Hg) and pump-down (to 100 μm of Hg). The panels are sealed in a clean-air ambient at a temperature of 495 ± 5°C. Prior to backfilling with a purified Penning gas mixture and tip-off of the panel, the same gas is used in a cyclic fill and evacuate process to remove air and other contaminants. The entire panel fabrication program takes about 8 hours. Details of equipment construction and operation are presented, as well as advantages of the process compared to conventional gas panel fabrication processes.

Introduction

In separate processes, the two halves of a gas panel structure are metallized, electrode patterns are delineated photolithographically, and the requisite dielectric and secondary-electron emission layers are e-beam deposited sequentially, as described by K. C. Park and E. J. Weitzman [1]. Final assembly of the device involves sealing of the two halves together to form an envelope, degassing of the envelope, filling it with an appropriate discharge mixture, and then tipping off a fill tube. The entire assembly operation, i.e., seal, degas, backfill, and tip-off, may be accomplished readily in a single thermal cycle in an automatic fashion. The resultant advantages are: minimized handling of parts and exposure to contamination, fewer process operations and processing hardware requirements, cleaner active surfaces, easier panel filling and sealing at desired temperatures, and potential for filling to above one atmosphere pressure.

A critical feature of gas panel assembly, especially when the memory attributes inherent in the secondary-electron emission characteristics of the emitter are to be used, involves generation of clean interior surfaces prior to filling of the active region with a Penning mixture. The dependencies of emission characteristics on surface characteristics, amongst other things, have been discussed previously [2]. A procedure for obtaining clean interior surfaces might involve attachment of a sealed, tubulated panel to a high-vacuum system, and subsequent heating of the structure under vacuum for many hours at a temperature below the deformation temperature of any of the glass constituents. However, the panel plates might nominally be spaced only a hundred or so micrometers apart, and the attachment to the vacuum manifold is via a relatively small-bore tube, e.g., 10–20 mm i.d. For large panels especially (let us say 30 cm on a side), and to a degree even for much smaller panels, the pumping resistance is high. Following the initial pump-down, when the chemical potential driving force is large, i.e., α ln 760 mm/10^{-6} mm, subsequent degassing occurs with only minimal driving force, in the form of gradient-assisted diffusion of desorbed molecules. Mean free path considerations dictate a low probability of escape of such molecules through the tubulation. The problem is compounded further if spacer rods are employed in the panel interior to prevent panel sag when the backfill pressure is less than one atmosphere.

Because of such considerations, it was decided in evolving a single-cycle design to dispense with "constant" pressure vacuum degassing approaches and to use instead a viscous cleaning technique in which clean gas is admitted to and evacuated cyclically from the panel interior, providing both dilution and pressure-differential assisted cleaning of the interior surfaces. A windfall with such a procedure is that one can dispense with high-vacuum equipment and rely solely on liquid-nitrogen baffled mechanical pumping. The only caution that need be observed is that the pressure range chosen for cyclic fill and

evacuate procedures must not perturb unduly the temperature and temperature gradient in the furnace in which it is conducted. For the equipment to be described, the range used, except for a final pump-down to 1–2 μm prior to filling with the Penning mixture, was approximately 100 μm–20 mm of Hg. Thus, in each automatically controlled cycle, an effective dilution of approximately 200/1 was achieved. In two cycles, therefore, a 40 000/1 dilution occurs, etc., with the relationship 200^n representing the general case for n cycles. Since the pressures involved are small, the usage of clean gas is also small, e.g., 0.03 atm-liters/cycle. This usage, while not of particular concern during the portions of the cycle in which air is used, is of some importance during system cleanup with the more costly Penning mixture prior to final fill. In the apparatus to be described, gas usage during cycling involves only twice the chamber volume, or about the same volume that might be employed in a conventional manifold design system.

One further topic merits some discussion, that concerned with the necessity for a fill tube. In a conventional processing approach, where attachment of the panel to a vacuum manifold is required, it is obvious that a fill tube is mandatory. However, in a procedure of the type being discussed in this paper, it is evident that if the panel sits within a vacuum furnace, a fill tube is not necessarily mandatory. For example, prior to achieving the temperature at which the seal glass flows freely and the panel parts become joined, one could have established a pressure of the Penning mixture which at room temperature is the pressure required for the desired position on the Paschen curve. With such a procedure, a fill tube becomes seemingly superfluous. However, a number of factors mitigate against such a decision, notwithstanding the fact that in special instances it might be practical. At the sealing temperature, the glass and active dielectric surfaces are experiencing their maximum process temperature and are likely to be outgassing at a high rate. Such outgassed contaminants would be entrained in the envelope and would in general degrade panel margins and/or long term stability. We have found, for example, that evaporated Schott glass evolves hydrogen at normal seal temperatures, although at lower temperatures such evolution is not measurable with sensitive mass spectrometric techniques. The furnace environment itself contains rather large quantities of H_2O at seal temperatures, and this species would also be entrained within the envelope. Also, as has been indicated in the introductory paper [3], panel hermeticity must be considered, which on a length-of-life basis is keyed to both the absolute leak rates of the electrodes and the volume of the envelope. In general, the tubulation has a larger volume than the rest of the envelope and provides ballast for the structure (a factor of two or so). This can represent a factor of two, e.g., 30 000 as opposed to 15 000 hours, of usable life of the device, a significant contribution.

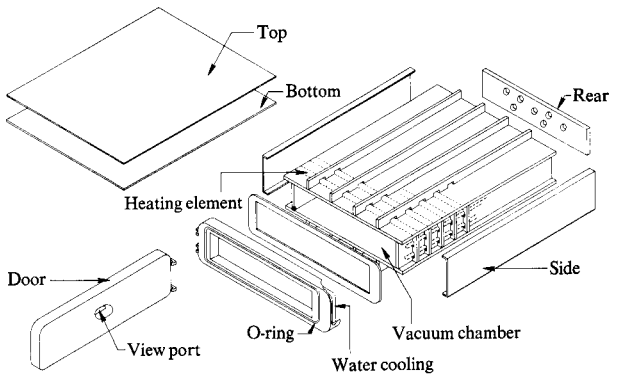

Figure 1 Isometric exploded view of the single-cycle furnace.

Description of the single-cycle system

• *Furnace*

The furnace is constructed of 0.63-cm welded stainless steel (type 304) in the shape of a rectangular box (15 cm × 45 cm × 75 cm inside dimensions), which has 24 strip heater elements (Chromalux, 750 watts each) fastened directly to its exterior surface. The back wall of the vacuum-tight box contains flanged ports through which all services (gas, vacuum, pressure gauges, and electrical power) are connected. The front wall is a hinged door that is sealed via a water cooled O-ring and is held closed by four clamps. In order to prevent chamber deformation under vacuum, the walls are reinforced with steel bands. Figure 1 shows the construction of the furnace including the support ribs, the layout of the heaters (top, bottom, and sides), the hinged door assembly, and the outer sheet metal shell. The furnace volume is approximately 50 liters, and its leak rate was measured to be 1×10^{-4} cc/second.

• *Assembly of panel parts*

In order to minimize the handling of panel parts and disturbing of the assembled pieces while loading into the furnace by hand, a mechanical loader was built, which moves in and out of the furnace on a track. The panel parts are assembled on a pallet which in turn is supported on a movable platform. The pallet, which is left in the furnace during the sealing cycle, is constructed of stainless steel angle. This provides the necessary rigidity to support the panel fixtures, minimizes the mass to be heated, and offers little resistance to gas motion.

The face plate of the panel is placed electrode side up on a bottom ceramic setter plate (1.1-cm-thick, high-density alumina) having locating pins in it which enable sim-

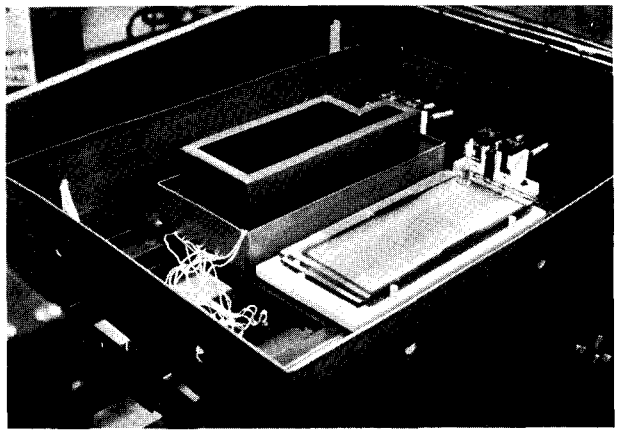

Figure 2 Assembly and weighting of the panel parts.

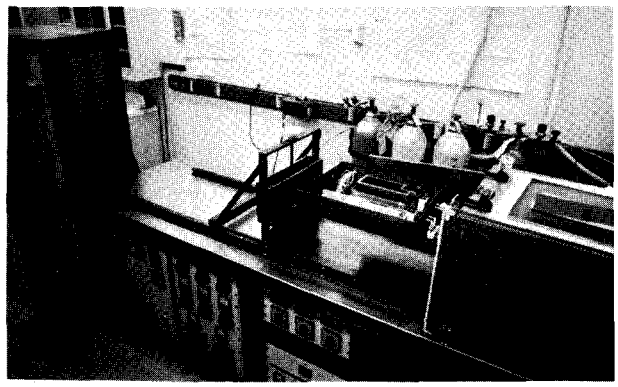

Figure 3 Arrangement of pallet, movable platform, and tracks with respect to the furnace.

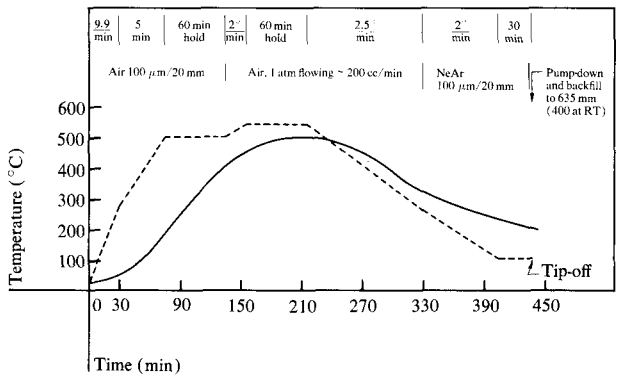

Figure 4 Temperature profile employed during gas panel fabrication process.

ple positioning of the two halves of the gas panel. Spacers, solder glass cane frames, back plate, and a pre-glazed fill tube are stacked on the face plate, and the sandwich is covered with a top ceramic plate and a rectangular shaped steel weight having no top or bottom. The ceramic top plate and the overlying steel weight provide a perimeter load of approximately 5 kg to a panel of approximately 10 cm × 25 cm dimensions. An aluminum box is centered around the entire assembly to improve the thermal distribution. Finally, a resistively heated tip-off coil located on a hinged mount is positioned over the tubulation which protrudes through a hole in the top alumina plate and the heat shield. This assembly is shown in Fig. 2. When this fixturing on the movable pallet is completed, the assembly is loaded into the furnace on the rails and lowered into position; then the fork-lift loading device is withdrawn. Extensions of the tip-off coils make contact to electrical feed-throughs in the back of the furnace in order to enable automatic tubulation sealing at the end of the thermal cycle. Figure 3 shows the arrangement of pallet, movable platform, and tracks with respect to the furnace.

• *Thermal cycle*

The glass sealing and gas filling operations in the furnace are sequenced automatically via variable programmable systems built into the electronics, with separate stages triggered by time, temperature, and pressure sensors in the furnace interior. Heating and cooling rates are also programmed, and these include heat soak periods. Gas ambient atmosphere changes are synchronized with the several phases of the thermal cycle. The panels are sealed in clean air, using a direct seal technique in which the solder glass forms a seal around the electrodes directly to the substrates, with the dielectric confined entirely within the seal region. In order to seal directly to the substrate, in air, it was necessary to develop an oxidation-resistant metallurgy. As discussed in [4], a Cu-Al alloy with a resistivity somewhat higher than that of copper was developed for this purpose. During the final stages of cooling, the clean-air ambient atmosphere cyclic fill and evacuate procedure is replaced with an alternate filling-evacuation technique using the purified Penning mixture. Prior to this changeover, there is an initial pump-down to 100 μm Hg using the Welch model 1397 mechanical pump (pumping speed 8 liters/second). The temperature profile employed during the process for gas panel sealing and filling is shown in Fig. 4. It should be noted that there are two temperature curves as functions of time. The dashed line represents the furnace wall temperature, which follows directly the pre-set program. The solid line indicates the temperature of the glass parts and shows the lag between the furnace and the glass parts. It should also be noted that the lag, and therefore the rate of temperature increase, is very much dependent on the mass (fixtures and panel parts) loaded into the furnace. The gas train for the system, including purification, is shown schematically in Fig. 5. The thermal cycle is divided essentially into three sections keyed to the changes in gas ambient atmosphere. During the first part of the heat-up (glass temperature raised to approximately 400°C), air is admitted to approxi-

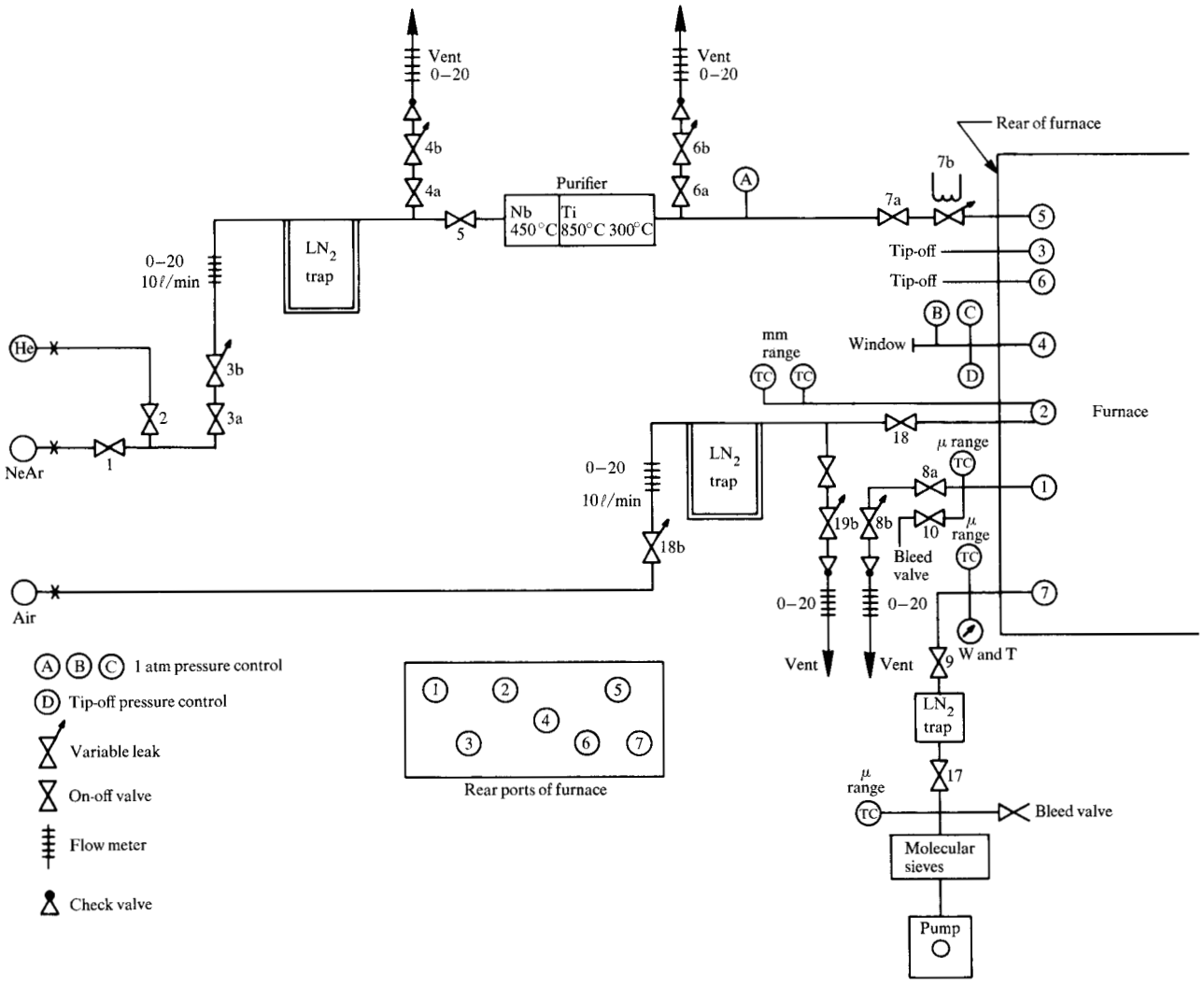

Figure 5 Schematic representation of gas train for system.

mately 20 mm Hg and pumped out to ca 100 μm Hg. The air used is cylinder gas, dried grade, without further purification. At approximately 400°C, the air "tickling" is stopped, and the furnace chamber is backfilled to slightly more than one atmosphere with air flowing at 200 cc/min. Under these gas flow conditions, the temperature is then sequenced to 495 ± 5°C to complete the sealing of the two halves of the panel and the joining of the tubulation. The time at maximum temperature of the glass is approximately 40 min.

The air flow is continued while the furnace is then cooled to ca 300°C. At this temperature in the cycle, air flow is stopped, the chamber pumped out, and NeAr is used to clean the system (and panel) of residual air. In the time required to then cool to 200°C, Ne 0.1% Ar is alternately filled to 20 mm Hg and pumped out to ca 100 μm Hg. At the tip-off temperature, 200°C, the system is pumped out to 1–2 μm and backfilled with the NeAr mixture. The pressure to which the chamber is backfilled is that required to give the desired room-temperature panel pressure (i.e., 635 mm at 200°C is equivalent to 400 mm at 25°C). The panel tubulation is then sealed by activating the platinum tip-off coil (0.5 Ω, 100 watts, 50 seconds total time). The system is then automatically cooled, shut down, and held ready for unloading of the completed panels and for repetition of the process.

Discussion

• *Direct seal*

Gas panels sealed in clean air have exhibited electrical behavior superior to that of those fabricated in an inert gas ambient, as described by O'Hanlon et al. [5] in this issue. As mentioned, the glass parts are sealed directly to the exposed electrodes and the substrate plate, rather than through the dielectric layer. Figure 6(a) is a cross-sec-

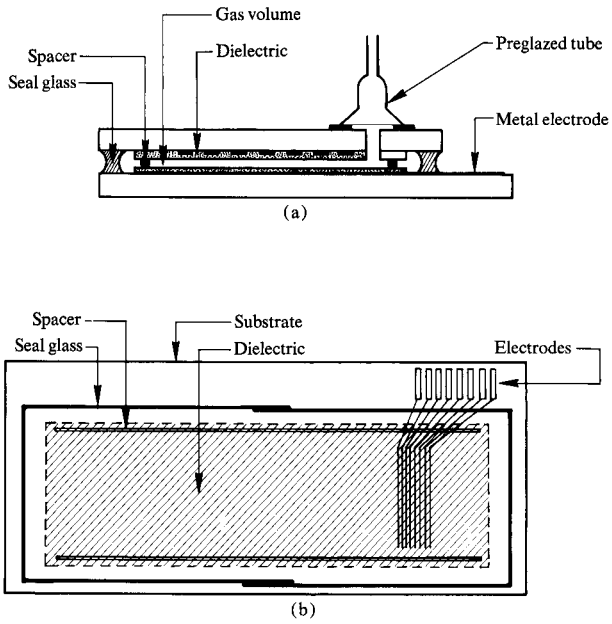

Figure 6 Representation of gas panel showing relative position of its parts.

tional view of a gas panel showing the relative positions of its parts. Several advantages are derived from the direct seal technique. In the case of the evaporated dielectric, the use of a simple mask during deposition confines the glass layer to the active region, compared to a reflow dielectric which must, in general, be applied to the entire substrate surface. Consequently, the direct seal method does not require subsequent etching back of the dielectric, after the panels have been sealed, to expose the electrodes for interconnection purposes. A conventional Cu type metallurgy was found unsuitable for this direct seal approach in air, due to rapid oxidation. The Cu-Al alloy employed (approximately 10–15 at% Al) was found to be quite resistant to the oxidizing environment during the process cycle.

• *Seal glass*

A commercially available solder glass (Owens-Illinois, SG-67) which has been modified via an oxygenation process [6] is used in two forms to join the panel parts. The copper-containing solder glass is first equilibrated by bubbling dry oxygen through a melt in the range 750–850°C. The temperature of the melt is then lowered to approximately 600°C and cane is pulled (approximately 0.8 mm diameter). The cane is bent into L or U sections, and two such pieces are used to form the edge seal. Shown in Figs. 6(a) and 6(b) are the arrangement of the solder glass cane, the shape of the attached tubulation, and the relative position of the spacers needed to set the gap between plates.

The tubulation is flared or bell-shaped at one end and is constricted down to 3 mm diameter at the other end to permit a more rapid closure during tip-off. The flared end (approximately 1.88 cm diameter) must be flat so that good contact will be made with the glass substrate. It is preglazed by dipping into a melt of the same solder glass at 900–950°C.

• *Panel tip-off temperature*

Experimental panels were backfilled initially to 1 atm and tipped off at 457°C. These exhibited a level of H_2 contamination of approximately 100 ppm, as measured by optical emission. It was found that by lowering the tip-off temperature to 200°C, H_2 became undetectable. In order to determine the source of H_2, a Veeco Residual Gas Analyzer was added to the single-cycle system to monitor the evolution of gases during the fabrication process. Panel parts in various combinations were heated in vacuum to 495°C. Samples containing the evaporated dielectric show a gradual increase in the H_2 level with increasing temperature. At approximately 365°C, the H_2 level began increasing rapidly, its level peaking at 385–405°C, and then it dropped to a level comparable to that of the system outgassing at approximately 460°C. This H_2 evolution could be minimized but not eliminated completely by periodic cleaning of the Schott glass e-beam evaporator. Studies of H_2 contamination at various tip-off temperatures (200–475°C) showed that following panel tip-off, H_2 continues to evolve until the panel is cooled to ca 200°C. For this reason, this temperature was chosen for final filling and tip-off.

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