

## II-5 Sealing Behaviors of Composite Materials for Packaging Semiconductor Devices

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Three types of composite materials, which were designed for use in packaging semiconductor devices, were investigated concerning their viscous behaviors towards balanced setting at temperatures around 200~500°C. The specimens took a form of plate consisting of two or three layers (alumina-glass, Kovar-glass and alumina-glass-Kovar). For each setup two kinds of glass component were tested; one devitrifiable and the other non-devitrifiable solder glass. Setting in the specimens was examined by measuring their deflection which was accompanied with a cyclic heating.

In the case of the composites which have the non-devitrifiable solder glass as a component, setting always occurred when the specimen were cooled from 500°C down to about 370°C, that is, close to the deformation point of the solder glass. "Equivalent setting points" were also found at temperatures around 370°C with any type of the composites.

On the other hand, in the case of the composites which have the devitrifiable solder glass as a component, both the setting temperatures and the equivalent setting point changed in the range between 370~500°C, depending on the type of each particular composites. These results were interpreted as an effect caused by non-Newtonian viscous flow in devitrified glass.

### 1. Introduction

In a certain type of integrated circuit, a semiconductor wafer is sealed hermetically between two ceramic plates (Fig. 1). The plates are cemented through a low-melting solder glass layer. The Kovar terminal plates, which are sealed in the glass layer, form an electrical lead-in between the wafer and external circuits.

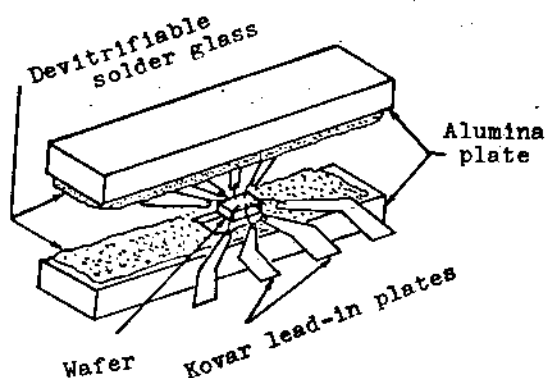


Fig. 1. Expanded view of an integrated circuit showing the construction

For cementing the plates, devitrifiable (or thermo-setting) solder glass is usually employed because it improves the mechanical strength and thermal shock resistance of such com-

posites as a whole. This glass, however, crystallizes in the process of heat treatment necessary for sealing, and this may result in the irreversible increase of glass viscosity in the softening range of temperature.

Thermal expansion characteristics of constituting materials should be compatible to each other, in order to form mechanically stable, strain-free seals. A setting temperature and an equivalent setting point in a seal are the factors which affect this compatibility. The "setting temperature" in this context means the temperature near which the viscosity of heated glass becomes so high ( $10^{10}$  poise or more) on cooling, and it raises strain and stress in the seal, whereas the "equivalent setting point", is featured as follows: in the temperature range below this point strain and stress in the seal can be regarded as aroused solely by the difference of thermal expansion among the component materials.

Since the layer of crystallized (or "devitrified") solder glass has relatively high viscosity and small area of free surface, the viscous flow of the glass may be prevented in some degree. These effects are expected to result in higher setting temperature and higher equivalent setting point.

For the manufacture of integral circuits, the selection of sealing materials is an important problem. To obtain a good measure

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of selection, the viscous behaviors of devitrifiable glass in its softening temperature-region must be clarified. This is the grounds on which the present work was conducted.

## 2. Specimens and Experimental Techniques

A kind of devitrifiable solder glass was used together with alumina ceramic plates ( $10 \times 40 \times 1$  mm) and Kovar metal plates ( $10 \times 40 \times 0.27$  mm) to constitute the seal relevant to the present tests. This solder glass devitrifies by soaking at  $500^\circ\text{C}$  for 5–10 min. Non-devitrifiable solder glass (batch composition: PbO 65, ZnO 13,  $\text{B}_2\text{O}_3$  14,  $\text{SiO}_2$  2,  $\text{Al}_2\text{O}_3$  3 wt %) was also used as a glass component for comparison.

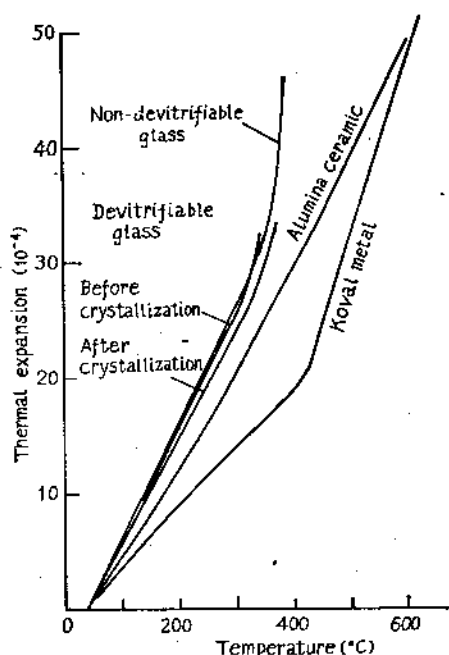


Fig 2 Thermal expansion curves of the materials used

Table 1. Thermal expansion properties of solder glasses

	Devitrifiable solder glass		Non-devitrifiable solder glass
	before crystallization	after crystallization	
Thermal expansion coefficient ( $100^\circ\text{--}300^\circ\text{C}$ ) $10^{-7}/^\circ\text{C}$	95	88	98
Transformation point $^\circ\text{C}$	320	330	340
Deformation point $^\circ\text{C}$	360	370	390
Softening point $^\circ\text{C}$	400	415	419

The thermal expansion curves of these materials are represented in Fig. 2, and some of the thermal properties of the solder glass are shown in Table 1.

Deformation of seals caused by the mismatch of expansion coefficients in the constituting materials was measured by the method described earlier by one of the authors<sup>1)</sup>. The double-layer composites of alumina-glass, double-layer composites of Kovar-glass and triple-layer composites of alumina-glass-Kovar were examined. To form a specimen seal, powders of the solder glass suspended in butyl acetate binder was at first applied on an alumina or Kovar plate, and one end of this plate was clamped by a special holder made of silica glass (Fig. 3). The holder together with the plate was inserted in an electric tubular furnace placed horizontally. In the mean time the furnace was heated up to  $500^\circ\text{C}$ , the glass powder melted into a layer to form a composite. The composite was kept soaking at  $500^\circ\text{C}$  for 10 min. to let the devitrifiable solder glass crystallize. The furnace, then, was slowly cooled. Bi-metallic deflection of the plate was measured by a travelling microscope with an ocular micrometer as a distance of the specimen edge from the needle points of the holder. One division of the ocular micrometer corresponded to  $3.6 \mu$ . The deflection of three-layer composites was similarly measured.

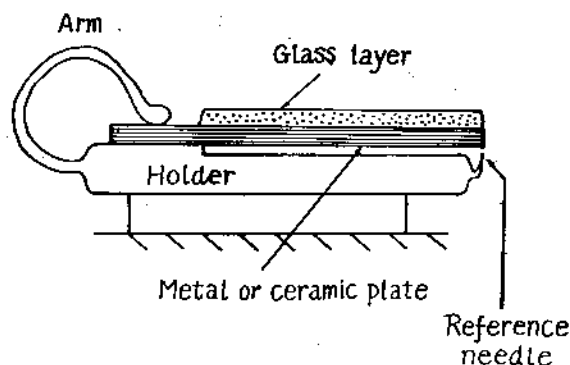


Fig. 3 Assembly for measuring the bending of a composite

## 3. Experimental Results

### 3.1 Non-devitrifiable solder glass

Results are summarized in Fig. 4. It is shown that, either in two-layer or in three-layer composites, their deflection became apparent when they were cooled down to about  $370^\circ\text{C}$ .

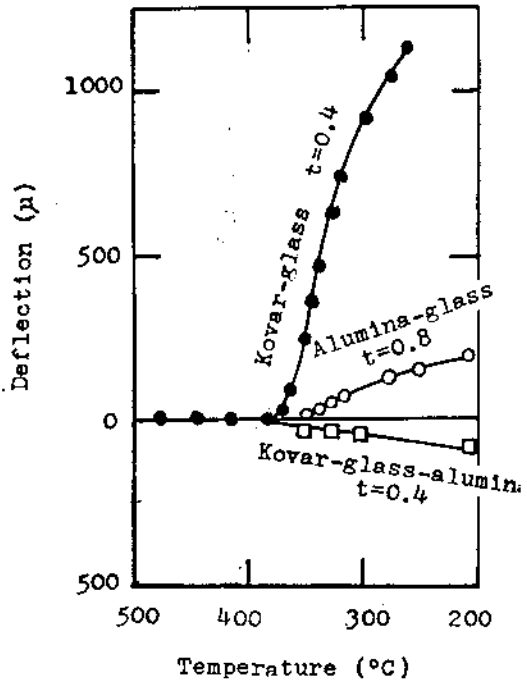


Fig. 4 Temperature-deflection curves on cooling of the composites which have the non-devitrifiable solder glass as a component.  $t$ : thickness of the glass layer in mm

3.2 Devitrifiable solder glass

With respect to the composites which includes the devitrifiable glass as a component, the results obtained show the marked dependence on the other components as well as the types of composites.

3.2.1 Alumina-glass composites

Results are shown in Fig. 5. Though the

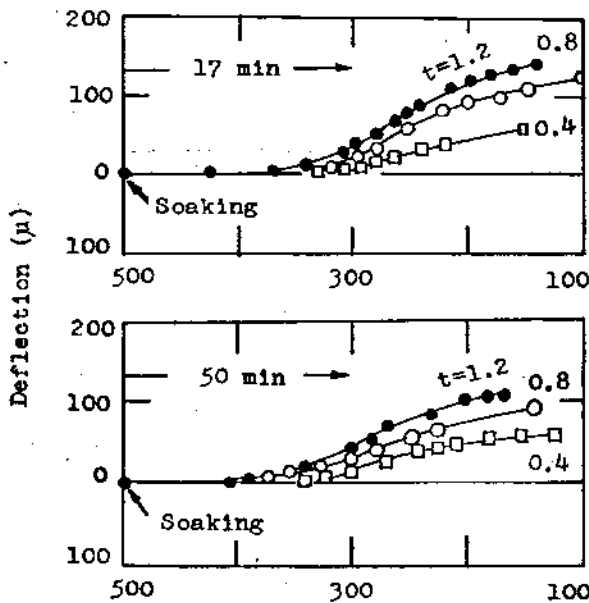


Fig. 5 Temperature-deflection curves on cooling of alumina-devitrifiable solder glass bi-metallic composites showing the effects of glass thickness and cooling rate.  $t$ : thickness of the glass in mm

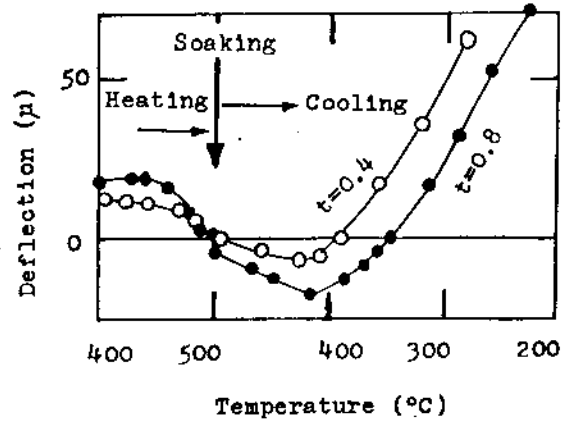


Fig. 6 Temperature-deflection curves on heating-soaking-cooling cycles of the Kovar-devitrifiable solder glass bi-metallic composites.  $t$ : thickness of the glass layers in mm

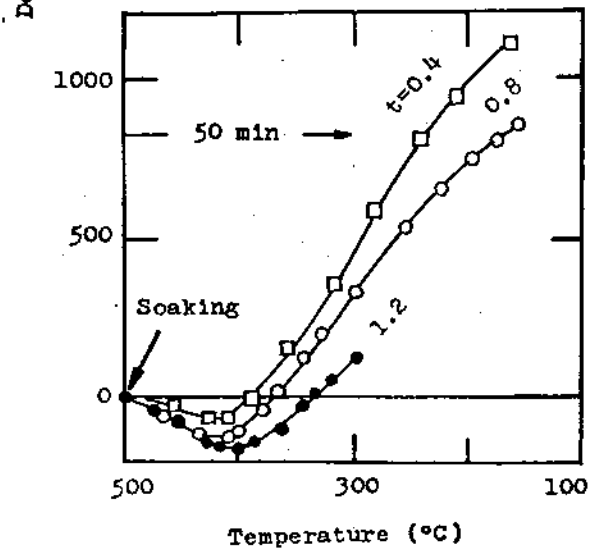
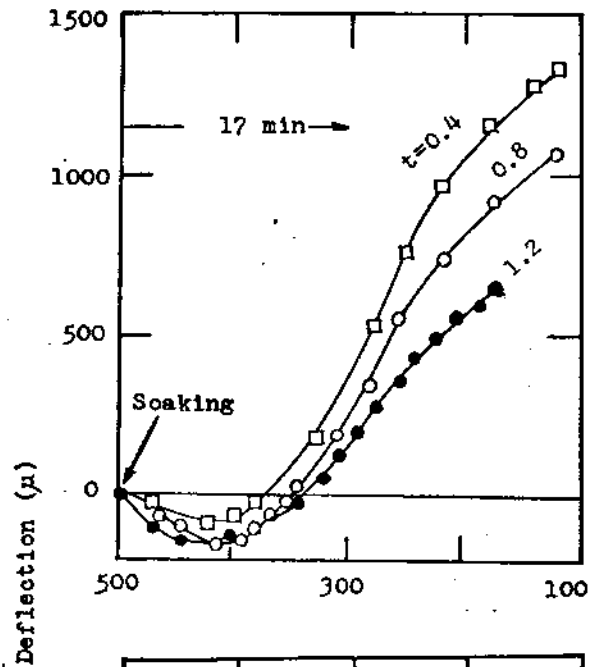


Fig. 7 Temperature-deflection curves on cooling of the Kovar-devitrifiable solder glass bi-metallic composites.  $t$ : thickness of the glass layer in mm

deflection was not detected in the course of heating, it became detectable when the composites were cooled down to about 370°C. In the studied range of the glass layer thickness, the deflection of the composites increased with the increase of that thickness. The effect of cooling rate on the deflection was not distinct.

### 3.2.2 Kovar-glass composites

Results are shown in Figs. 6 and 7. It should be remarked that in this case the deflection was observed in the course of heating near 500°C (Fig. 6). On cooling from the soaking temperature, the amount of deflection began to change immediately (Fig. 7).

### 3.2.3 Alumina-glass-Kovar composites

Results are shown in Fig. 8. No deflection was detected in the process of heating. The specimen began to bend noticeably as soon as they were cooled down from the soaking temperature. The effect of cooling rate on the deflection was not distinct.

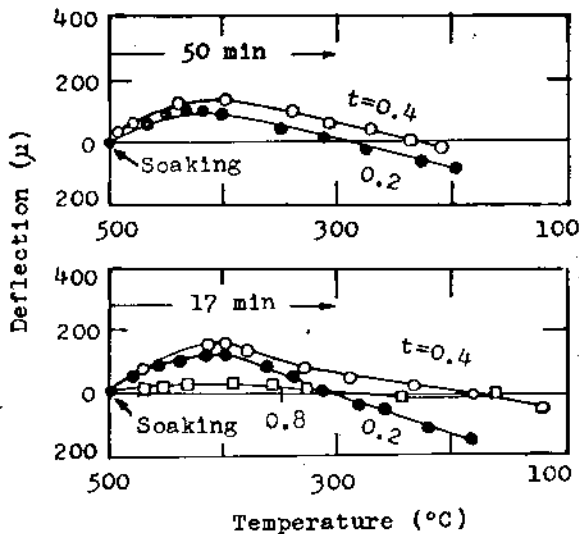


Fig. 8 Temperature-deflection curves on cooling of the alumina-devitrifiable solder glass-Kovar sandwich-shaped composites.  $t$ : thickness of the glass layer in mm

## 4. Discussion

The thermally induced deflection of layer composites, as well as their strain and stress, can be calculated by following the theories of bi-metals<sup>2-7)</sup> or of multi-layer composites<sup>8)</sup>. According to such theories those quantities as linear functions of expansion difference between or among the component materials. In the case of two-layer composites, deflection is proportional to the expansion difference between two materials. By a graphical super-

position of a theoretical and experimental temperature-deflection curves in the range of relatively low temperature, an equivalent setting point may be obtained as the temperature at the intersection between the theoretical curve and temperature axis. Although the thermal expansion curve of glass above its transformation point cannot be firmly determined, it is possible to make an approximate evaluation of the equivalent setting points.

In the case of the non-devitrifiable glass (Figs. 4, 9a and 10a), setting temperatures and equivalent setting points were estimated to be about 370°C with any kind of composites studied.

In the case of the devitrifiable glass, results are rather complex. Setting temperature was about 370°C for alumina-glass composites (Fig. 5) and about 500°C (soaking temperature for crystallization treatment) both for Kovar-glass (Fig. 7) and alumina-glass-Kovar composites (Fig. 8). On the other hand, equivalent setting point was about 370°C in alumina-glass (Fig. 9b) and Kovar-glass composites (Fig. 10b) and about 500°C only for alumina-glass-Kovar sandwich-shaped composites (Fig. 8 and refer also to Fig. 11).

The causes of such various behaviors mani-

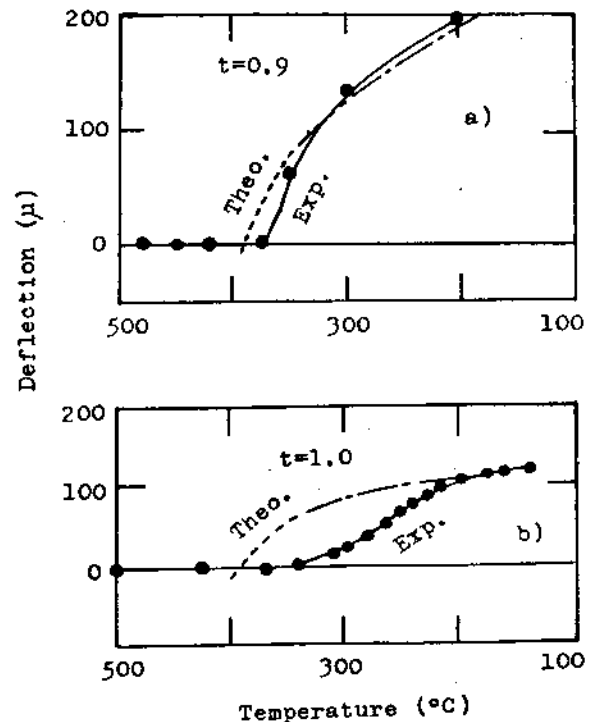


Fig. 9 Experimental and theoretical temperature-deflection curves on cooling of the alumina-glass bi-metallic composites. a) non-devitrifiable and b) devitrifiable solder glass

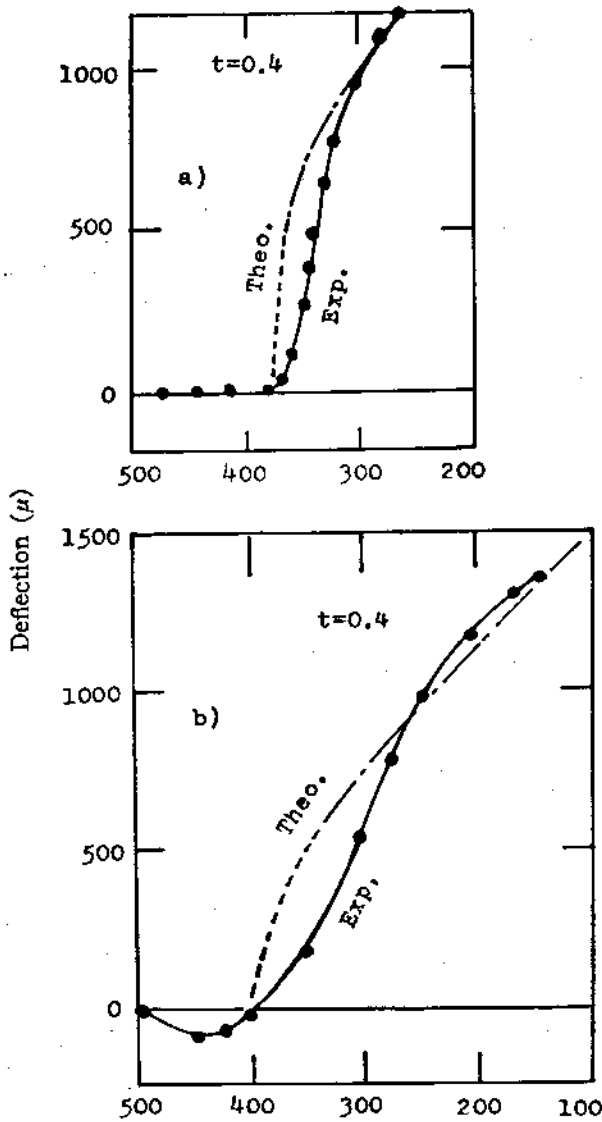


Fig. 10 Experimental and theoretical temperature-deflection curves of the Kovar-glass bimetallic composites. a) non-devitrifiable and b) devitrifiable solder glass

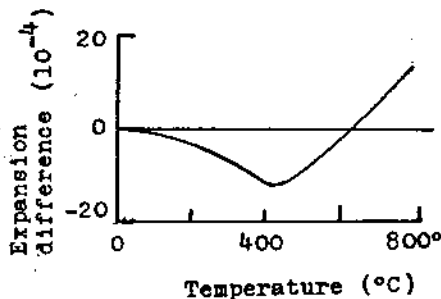


Fig. 11 Thermal expansion difference between alumina and Kovar

festated in the setting of each particular composite are presumed as follows:

A). Viscosity of non-devitrifiable glass near the deformation point decreases rapidly with the increase of temperature, i.e., from about

$10^{13}$  poise at transformation point to about  $10^{10}$  poise at deformation point. In consequence, even if the shape and dimension of a composite, also its constituting material other than glass have some effects on viscous flow of the glass, these effects may be readily compensated by small change of temperature. Therefore, the change in setting temperature is very small, and the equivalent setting point is apparently unchanged.

B) In devitrifiable solder glass after crystallization many minute crystalline particles are suspended in a glassy matrix. The viscosity of such a system is expected to be non-Newtonian. Although the viscosity of the glassy matrix decreases rapidly with the increase of temperature, the decrease of apparent viscosity of the system is much slower.

Furthermore, it is certain that the stress in the system plays a determining role in enhancing the flow of the whole system. The Kovar plate is a component material more responsible to the bending of the composite than others. The product of Young's modulus and moment of inertia of cross section of the Kovar plate used is about one hundredth of that of the alumina plate used (Young's modulus of Kovar is  $2 \times 10^4 \text{ kg/mm}^2$  and of alumina  $4 \times 10^4 \text{ kg/mm}^2$ ). In Kovar-glass composites, although Kovar deforms readily by the expansion difference between Kovar and glass, stress in the layer will not be raised so high as to lower the apparent viscosity of the glass considerably. Both the apparent high viscosity of glass and the high adaptability of Kovar for bending must be the substantial factors to make the setting temperature as high as  $500^{\circ}\text{C}$ . In the course of cooling, the mismatch of expansion in the constituting materials is enhanced. At higher temperatures, however, the viscous flow in the glass layer is still high and the deflection cannot exceed a certain level. The tendency of the composites for deflection due to the expansion difference at temperatures below and near  $500^{\circ}\text{C}$  is thus mostly released, and the final development of deflection occurs only after the completion of solidification of the glassy matrix. As a result, the equivalent setting point is far lower than the setting temperature.

On the contrary, the alumina plate is very stiff and does not respond readily to bending. In the case of alumina-glass composites, the

expansion difference between the components may cause high stress in the glass layer. This stress serves to increase viscous flow in the glass layer. Furthermore, owing to the high stiffness of the alumina plate, the deflection of the composite, if any, must be very small at the beginning of cooling. The final setting in the composites, therefore, occurs only after the solidification of the glassy matrix is completed. All of these factors should lower the setting temperature as well as the equivalent setting point.

Finally, in the case of alumina-glass-Kovar composites, the lack of sufficient free surface of the glass layer must prevent the viscous flow in the layer. This makes the setting temperature and the equivalent setting point rather high, and may result in the observed setting behavior of this composite which apparently differs depending on the thickness of solder glass layer.

As has been hitherto discussed, stress in the composites which include devitrifiable solder glass as a layer component can be affected by many factors: shape and dimension of the composites, stiffness of the component materials, expansion differences between the components and the area of free surface of glass layer. Also, volume fraction and particle size distribution of crystalline materials in the glass are suspected to affect the setting behaviors of the composites. This behavior was definitely influenced by small changes in chemical compositions, amount of additives, particle size of raw glass powder and the schedule of heat treatment. Details of these effects are hardly possible to be explored without the aid of practical experiments, and the method used in this study is believed very useful for the development, selection and evaluation of sealing materials.

## 5. Summary

The bi-metallic deflection of three types of composite materials was measured at temperatures approximately ranging from 200 to 500 °C. These materials were intended to package semiconductor devices, and were composed of

two or three layers: alumina-glass, Kovar-glass and alumina-glass-Kovar. As a component glass in each setup two kinds of solder glass, i.e., devitrifiable and non-devitrifiable, were used.

In cases of the composites which have the non-devitrifiable solder glass as a component, setting always occurred when the composites were cooled from 500°C down to about 370°C, which is near the deformation point of the solder glass. The equivalent setting points were also in the temperature range near 370 °C in any type of the composites.

Results were rather complex in cases of the composites which have the devitrifiable solder glass as a component. In alumina-glass composite setting occurred, when the composite was cooled from its soaking temperature (500 °C) down to about 370°C for devitrification (crystallization) treatment. Equivalent setting points were also found to be in the temperature range near 370°C. In Kovar-glass composite, setting occurred at once when it was cooled from its soaking temperature (500°C). Equivalent setting point, however, was approximately 370°C, and it was far lower than the setting temperature. In alumina-glass-Kovar composite, both setting temperature and equivalent setting point were as high as about 500°C.

These results can be explained by assuming non-Newtonian viscous flow of the devitrified solder glass and by assuming the effects on the flow in the glass layer caused by the shape and dimension of the composite.

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