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IN SITU INVESTIGATION OF DISTORTION OF MULTILAYER STRUCTURES AT ELEVATED TEMPERATURES

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A modified dilatometer was used as the basis of a measuring method for investigation of the distortion of multilayer structures at elevated temperatures.

The bowing of thick film substrates unilaterally covered with copper paste was measured from room temperature up to 700 °C. The bowing did not, as expected, decrease uniformly with increasing temperature up to the softening point of the glass, but a change occurred in the curvature of bowing at about 100 °C. With increasing temperature, the character of the bowing of the sample changed from linear thermo-elastic behaviour to non-linear behaviour, caused by plastic flow within the metallic copper layer.

Multilayer structures as used for microelectronic systems, for instance, consist of layers of materials with different properties which are deposited on substrates. The heat treatment in the manufacturing process leads to a distortion of the layer system as a result of mismatch between the thermoelastic properties of the individual layers (coefficient of thermal expansion α, Young's modulus E). A simplified model of such a structure is shown in Fig. 1 for a sample with the dimensions h (thickness), a (length) and b (width).

On the basis of such a model, calculations were carried out [1] by using the place theory. The results show more or less good agreement with the bowing measurable

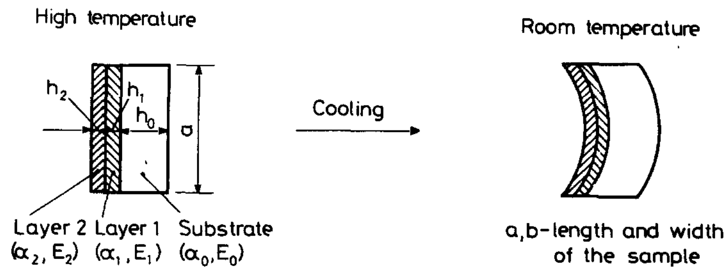

Fig. 1 Model for the description of bowing of multilayer structures

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at room temperature, which depends on the materials of the different layers and their thermoelastic properties. Measurements of the bowing above room temperature have not been performed previously. For investigation of the influence of the layer properties on the resulting bowing of a multilayer structure at higher temperatures too or as a function of changes of temperature ΔT, a measuring method was developed on the basis of the dilatometer principle [2].

Experimental data

Measuring method

The investigation of the degree of bowing of a layer system was carried out by means of a Netzsch 402 E dilatometer, which was adapted for this particular problem by incorporation of a special measuring system. The measurements were made under an inert atmosphere (N_2 or Ar) at a heating rate of 10 deg min^{-1}. The value of the effective bowing degree Δd_{eff} was estimated by taking into

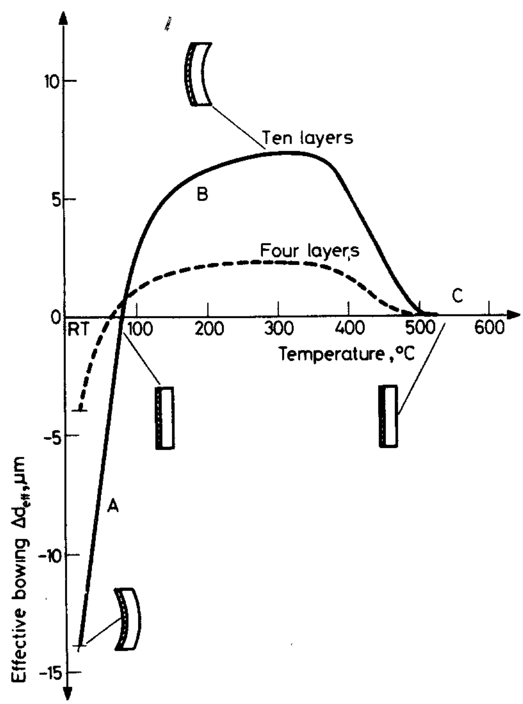

Fig. 2 Effective bowing of thick film substrates unilaterally covered with DuPont DP 9924 copper paste

consideration the correction for the thermal expansion of the measuring system and the sample itself.

Preparation of specimen

Models of thick film modulus were prepared by printing the conductive copper paste of the DuPont base metal system DP 9924 (consisting of copper and glass) in four and ten layers (the average thickness being 12 μm/layer) on thick film substrates from Feldmühle Kyocera, 30 mm × 50 mm × 0.625 mm in size. The layers were fired separately under nitrogen, with the recommended firing profile [3]. These substrates were cut into 20 mm × 9 mm pieces to obtain the samples for the dilatometric measurements.

Results

Figure 2 shows the effective bowing of the investigated multilayer systems as a function of temperature. These curves were reproducible on repeating the experiment. For qualitative discussions, Fig. 2 also contains a scheme of the effective bowing at selected temperatures.

Discussion

The bowing shown in Fig. 2 does not undergo a linear decrease with increasing temperature. It goes down with zero within the softening range of the glass (above 500°), as expected, but changes its sign. The substrate covered with conductive copper paste is bent concavely at room temperature. With increasing temperature, the bowing degree goes down to zero at about 100°, and changes its sign with a further increase of temperature to reach a convex bend.

In the first part of the curve (A), the bowing of the sample shows thermo-elastic behaviour. This follows from the sum of the contributions of the individual layers i *for* $h_i \ll h_0$) according to

$$\Delta d_{\text{eff}} \approx \frac{3}{4} \Delta T \frac{\sum_i E_i(\alpha_i - \alpha_0)h_i}{E_0 h_0^2} (a^2 + b^2).$$

At higher temperatures (B), the bowing shows non-linear behaviour because plastic flow takes place within the metallic, copper layers. Thereby, the stresses within the multilayer structure which would in principle increase with temperature are reduced. Above 500°, the layer system becomes tensionless and planar as a result of glass softening (C).

Conclusion

The represented method for measuring the distortion or bowing of multilayer structures can be applied for the investigation of all layer structures with thermally induced deformation, for instance in thick film and thin film or chip carrier engineering, for the analysis of plasma-sprayed layers or CVD and PVD-produced layers on thin substrates.

The field of applications ranges from the solution of problems in fundamental research to investigations of the influence of technological conditions on the distortion of layer structures. Such distortions can occur, for instance, during the production of the layers (dependent on the thickness of the layers, the impurities, and so on) or during subsequent steps at higher temperatures, e.g. in connection with soldering (for termination) or aging (for testing).

References

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2 I. Storbeck and G. Leitner, Hybrid Circuits, 13 (1987) 30.
3 E. C. Patuelli and R. E. Coté, DuPont Electronic Materials Customer Seminar, Berlin–Waldesruh, 19–20 June (1984).

Zusammenfassung — Eine Messmethode unter Verwendung eines modifizierten Dilatometers wurde entwickelt zur Untersuchung der Verbiegung von Vielschichtstrukturen bei erhöhten Temperaturen. Die Verbiegung einseitig mit Kupferpaste beschichteter Dickfilmsubstrate wurde von Raumtemperatur bis 700 °C gemessen. Abweichend von den Erwartungen nimmt die Verbiegung nicht gleichmässig bis zur Erweichungstemperatur des Glases ab. Stattdessen ändert sich ihr Vorzeichen bei ≈100 °C. Mit steigender Temperatur ändert sich der Charakter der Verbiegung von linear thermoelastischem zu nichtlinearem Verhalten infolge des plastischen Fliessens in der Kupferschicht.

Резюме — Модифицированный дилатометр был использован в качестве измерительного устройства при исследовании деформаций многослоистых структур при повышенных температурах. Изгиб толстопленочных подложек, покрытых с одной стороны медной пастой, был измерен при температурах от комнатной до 700°. Вопреки ожиданиям, не происходило равномерного уменшения изгиба с увеличением температуры до точки размягчения стекла, но при температуре около 100° наблюдалось изменение кривизны изгиба. С увеличением температуры характер изгиба образца изменялся от линейного термоэластичного поведения до нелинейного, что вызвано ползучестью внутри слоя металлической меди.