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Water Uptake of Polymeric Packaging Materials

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1. Introduction

MEMS and microelectronics are very sensitive to water. Ingress of less than 10^{-4} µL water to bond pads in packages is often critical due to galvanic corrosion. Polymeric materials are widely used for MEMS and microelectronics packaging, but they are not water tight (fig. 1).

The general motivation for this work has been to identify optimal polymeric materials and methods for water protective encapsulation of MEMS and microelectronics.

Studies have been made on Compression UnderFill (CUF) for flip chip electrical interconnection of a MEMS pressure sensor and a two-layer combination of materials to glob-top protect a needle shaped MEMS absolute pressure sensor.

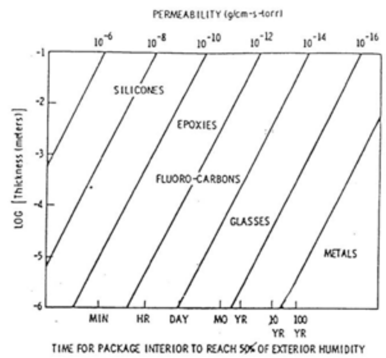

Fig. 1. Tightness of different packaging materials [1].

2. Diffusion theory

Based on Fick's second law of diffusion the amount of water diffusing into a thin square piece of polymer from both sides can be calculated to be [2]:

$$G = \frac{M_t}{M_E} = 1 - \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{\exp\left\{-(2n+1)^2 \pi^2 \frac{Dt}{L^2}\right\}}{(2n+1)^2} \tag{1}$$

where M_t, M_E are the masses of in-diffused water at time t and at equilibrium respectively, D is the diffusion constant, and L is the thickness of the polymer piece. From this equation D can be found.

The flux F of water into a package can then be determined from (2)

$$F = \frac{DS}{d} = PS \tag{2}$$

where S is the water solubility, d is the polymer package thickness, and P is the polymer permeability.

2. Results

2.1 Fit function to determine D

To find D a suitable ($r^2 = 1.00$) fit function G' to G was found:

$$G' = 1 - 0{,}877 \exp\left\{-9{,}18\left[\frac{Dt}{L^2}\right]^{0{,}931}\right\} \tag{3}$$

By fitting this function to the M_t/M_E experimental data D is determined.

2.2 CUF water uptake

Figs. 2 and 3 show measurements on an epoxy based CUF. In one MEMS pressure sensor application where water is supposed to be in direct contact with the CUF d is less than 1 mm. From fig. 3 it is seen that this distance is far too short considering the critical limit of 10^{-4} µL.

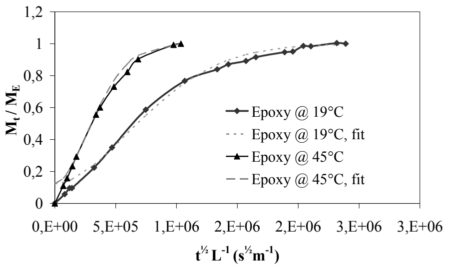

Fig. 2. Sorption curves for epoxy CUF at different temperatures. The sample studied at 19 ºC is 1 mm thick. The sample studied at 45 ºC is 0.85 mm thick. Fitting (3) to the data gives: $D(19\ ^\circ C) = 7\cdot10^{-14}$ m^2/s, $D(45\ ^\circ C) = 5\cdot10^{-13}$ m^2/s.

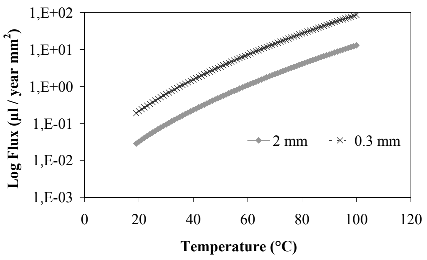

Fig. 3. Flux of water through epoxy CUF of different thickness as function of temperature. Calculations based on fig. 2 data.

2.3 Water uptake of a polymeric bi-layer protective encapsulation for a MEMS absolute pressure sensor

Currently sorption measurements are being performed on a MacroMelt material coated with parylene C (fig. 4). Later measurements on the naked MacroMelt will show the effect of the coating.

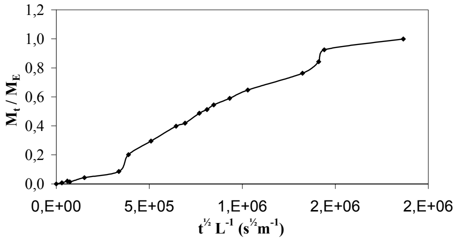

Fig. 4. Sorption curve at 19 ºC for a MacroMelt material coated with 10 µm parylene C. Total sample thickness is approx. 2 mm. Here M_E is not the real equilibrium mass but only the latest measured since saturation has not yet been reached.

4. Discussion

Due to the pre-exponential in the fit function (5) this M_t/M_E estimate is not accurate at short times. If the solubility and therefore M_E are known M_t/M_E can be plotted for short times as a function of $t^{1/2}L^{-1}$ and $D = \pi h^2/16$ where h is the slope.

Note that by water immersion at 45 ºC the 0.85 mm thick CUF sample is saturated after approx. 8 days. At 19 ºC and 1 mm thickness it is saturated after 25 days. I.e. already after these times throughout the polymer the maximum amount of water which can be in contact with e.g. conductors at any time is achieved.

Fragile MEMS components can be moulded with thermoplastic materials like the soft polyamide based MacroMelts which are processed at low temperatures and pressures. However, they are not a suitable choice for water protection due to high P. This problem can be reduced by coating with e.g. 10 µm parylene C which has lower P. In this way the good properties of both materials can be combined. Further simulations show that such a coating barrier will have no influence on the pressure measurements.

4. Conclusion

Generally, the water flux at different temperatures through polymeric encapsulation materials for MEMS and microelectronics can be measured. Design with e.g. materials combinations is important to reduce water attack.

For typical flip chip dimensions the amount of water passing through the studied epoxy CUF in direct water contact by far exceeds the critical 10^{-4} µL within typical required lifetimes.

This is also the case for the studied encapsulation materials separately and in combination. Though, by combining the materials in a layered structure improvement can be achieved.

5. Acknowledgement

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6. References

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[2] The Mathematics of Diffusion. J. Crank (1975), Oxford University Press, Oxford.