Design Rule Study of Transfer Molding Process on Polymer Cavity Packages

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Abstract

The advantages of polymer cavity package in compound semiconductor devices and MEMS applications are to achieve ultra-low cost and ultra-low profile. The use of DFR lamination for SAW/BAW cavity packages offers weight and size advantages. The cap thickness can be made very thin to significantly lower the overall device thickness. This is particularly desirable for low-profile smartphones and tablets. In this report, we demonstrated polymer cavity fabrication with SU-8 dry film resist using a Teikoku DXL fully automatic laminator. In addition, molding tests with various cavity dimensions were also conducted. We successfully fabricated extremely wide cavities up to 500µm width with excellent wall and cap profiles and also obtained important data to determine design rules in molding processes.

INTRODUCTION

It is commonly cited that packaging accounts for 80% of the cost of a MEMS device, and a lot of wafer level package (WLP) processes are being developed to address the issue. Amongst those, polymer cavity package has been identified as a way to reduce package cost [1, 2]. In these applications, epoxy dry film resist (DFR) is one of the most promising materials to fabricate cavity structures. The simple procedure, consist of laminating a wall DFR structure, followed by a photolithograph step. This is followed by a second laminating step, in which a DFR cap layer is attached to the wall layer, and then completed with a photolithograph step. In addition to the cost advantage, another advantage is low device height. Silicon or glass wafer caps are typically in the 200-400 µm thickness range. DFR on the other hand, is usually 15-50 µm thickness. Thus, thinner DFR thickness contributes to a lower profile cavity package. However design rule of the cavity package has not been determined at this point since dimension of the package include cap thickness, cavity width, wall height and wall width, which all vary depending on designs and devices.

IMPLEMENTATION

To better understand the design rules, the cap lamination process and the transfer molding process were demonstrated. These two processes were believed to have the most effect on the cavity shape.

1. Fabricating Cavity Structures with DFR

We used SU-8 3000CF DFR (Produced by Nippon Kayaku / MicroChem) as a permanent epoxy DFR for both wall and cap layer and DXL Series (Produced by Teikoku Taping System) as a full automatic laminator. The process flow is shown in Fig. 1. All lamination conditions and process condition were consistent (Table I). On a wafer, we fabricated 10 sets of wall structures first, and then fabricated cap structures on the wall structures. The wall height was 20 µm, wall widths were 4.5 mm and cavity widths were 50 µm, 100 µm 150 µm, 200 µm, 250 µm, 300 µm and 500 µm as shown in Fig. 2. On the other hand, we used 20 µm and 45 µm thick cap layer to understand the relationship with cap sagging or doming during the lamination and photolithography processes.

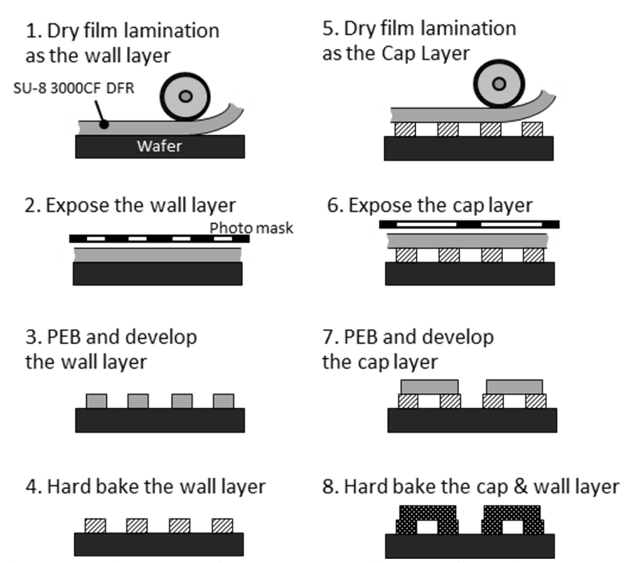

Fig. 1. Polymer package process flow and cavity structure illustration

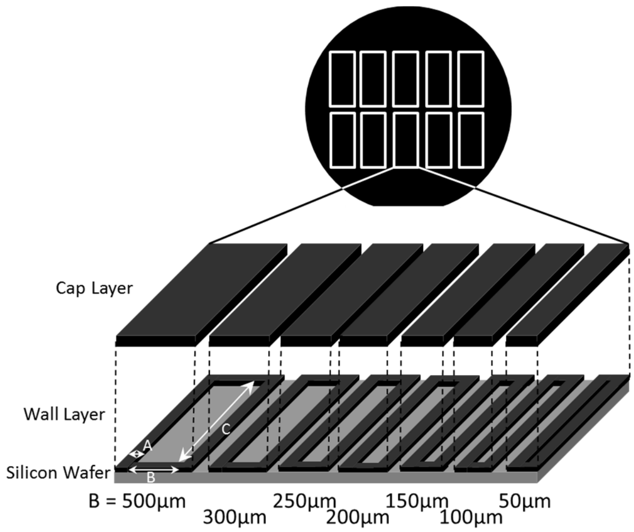

Fig. 2. Wall and cap geometries on a wafer. A=wall width: 4.5 mm. B=cavity width: 50 µm, 100 µm, 150 µm, 200 µm, 250 µm, 300 µm and 500 µm. C=cavity length: 25 mm.

TABLE I. PROCESS CONDITIONS

Process Step	Condition for wall layer	Condition for cap layer
Substrate	4" Silicon Wafer	
Lamination	DXL Series, Teikoku Taping System	
Roll Temp.	60°C	40°C
Stage Temp.	60°C	40°C
Speed	1mm/sec	15mm/sec
Pressure	600kPa	100kPa
Exposure	150mJ/cm² (@ i-line)	200mJ/cm² (@ i-line)
PEB	95°C/6 min on hot plate	55°C/6 min + 95°C/3 min on hot plate
Development	6 min, SU-8 Developer-Immersion	6 min, SU-8 Developer-Immersion
Rinse	30 sec, IPA	30 sec, IPA
Dry	30 sec, Nitrogen	30 sec, Nitrogen
Hard Bake	10 min @ 180°C in oven	60 min @ 180°C in oven

Irrespective of cap thickness (20 µm and 45 µm), we successfully fabricated polymer cavity structures up to 500 µm width (Fig. 3). Upper limits of the cavity width are unknown since we didn't prepare cavity designs greater than 500 µm width. This result exceeded our expectation. Profile of wall layer and flatness of the cap layer were excellent although slight doming of the cap generated by PEB step was observed.

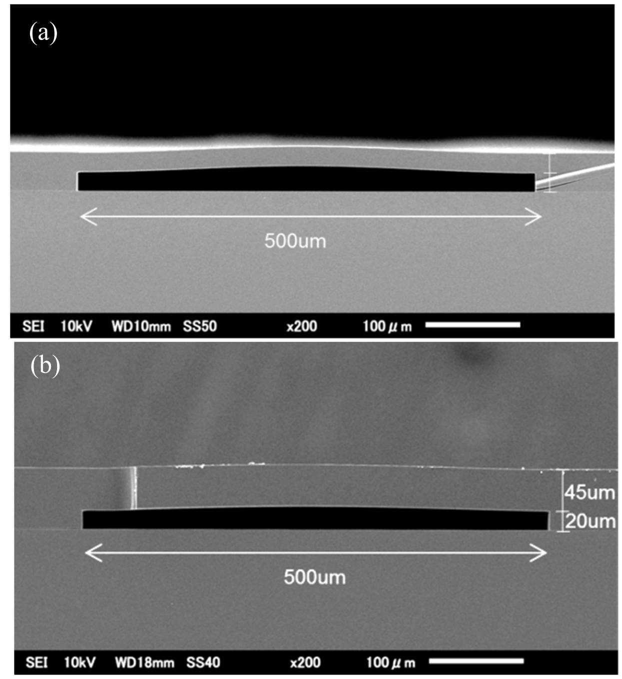

Fig. 3. Cross section SEM image after hard bake. Cap thickness/Cavity width: (a) 20 µm/500 µm; (b) 45 µm/500 µm

2. Transfer Molding Test with Various Dimension Cavity Package

To demonstrate transfer molding test, we used cavity structures made of silicon wafers and SU-8 3000CF DFRs, wall height was 20 µm, wall widths were 4.5 mm. Cavity widths were 50 µm, 100 µm, 150 µm, 200 µm, 250 µm, 300 µm and 500 µm, cap thickness were 20 µm and 45µm as shown in the 1st section (Fig. 2). We cleaved the wafer into each die, and then the dies are put into the mold cavity of a transfer molding equipment KTS30-2C produced by Kohtaki Precision as shown in Fig. 4. Transfer molding condition was constant; 9.0 MPa, 175 °C, for 172sec, which is quite standard pressure, temperature and time for epoxy molding compound(EMC) transfer molding process.

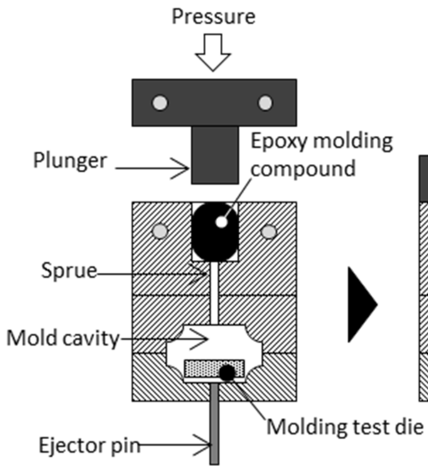

Fig. 4. Transfer molding overview.

In contrast to cap layer lamination, cavity width is very critical to molding resistance. As shown in Fig. 5, the 150 µm width cavity survived the molding process, however, 250 µm width cavity collapsed due to the molding pressure in 45 µm thick cap case. Whilst, the 100 µm width cavity survived, and the 200 µm width cavity collapsed in 20 µm thick cap case.

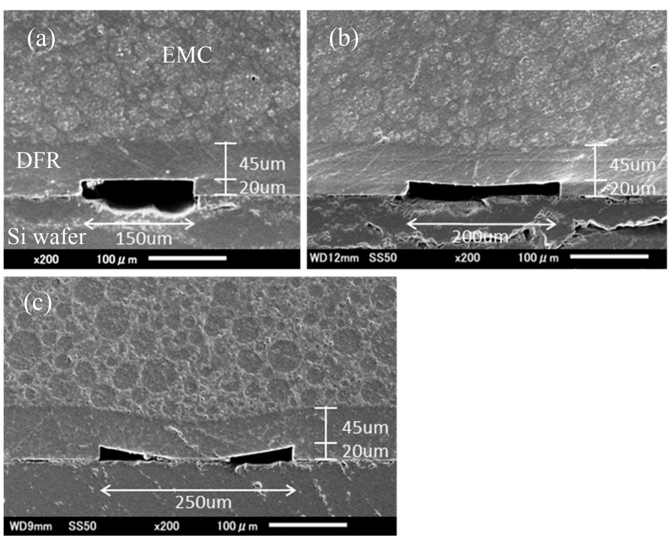

Fig. 5. Cross section SEM image of 45µm thick cap after molding test: (a) 150µm cavity, (b) 200µm cavity and (c) 250µm cavity

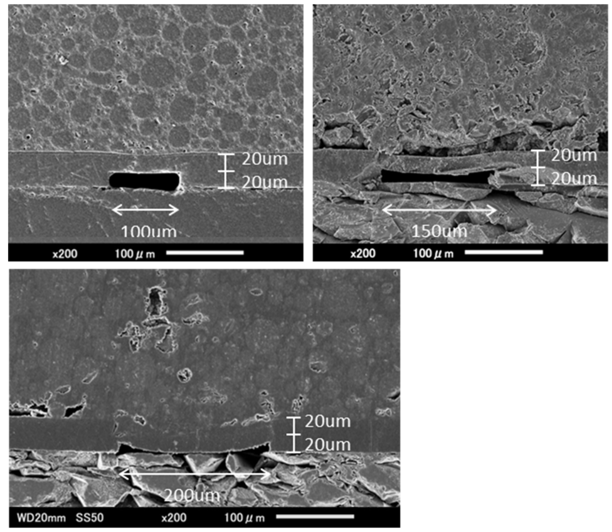

Fig. 6. Cross section SEM image of 20 µm thick cap after molding test: (a) 100 µm cavity, (b) 150 µm cavity and (c) 200 µm cavity.

RESULTS AND DISCUSSION

Irrespective of cap thickness (20 µm and 45 µm), we successfully fabricated polymer cavity structures up to 500 µm width (Fig. 3) with excellent profiles. However, 500 µm width was too wide and therefore it could not survive at the molding process. As can be seen from the Fig. 7, when the criterion of cap layer displacement is set 0 µm, the design rules of the cavity width are 100 µm for 20 µm thick cap and 150 µm for 45 µm thick cap under the general molding condition. Also, if you can accept 10 µm cap layer displacement, it will be 150 µm and 200 µm respectively.

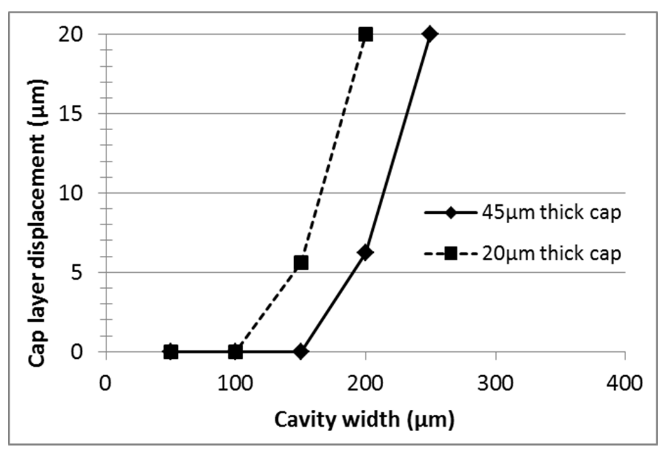

Fig. 7. Cap layer displacement vs cavity width on 20 µm and 45 µm cap thickness.

This result is also strongly supported by the theory of both ends fixed uniformly distributed load as shown below. $\delta_{max} = WL^3/384EI$, where δ_{max} is displacement at the center(mm), W is total load(N), L is length of the material(mm), E is young modulus of the material(N/mm^2) and I is moment of inertia(mm^4).

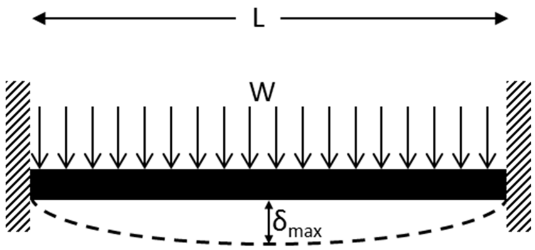

Fig. 8. Both ends fixed uniformly distributed load model.

As you can see in the formula, cap layer displacement (δ_{max}) is proportional to cube of the ratio of material length (L). So it could be said that cavity width has the greatest impact to molding resistance. Also, reducing molding pressure and increasing young modulus of the material, which can correspond W and E respectively, are promising when improving mold resistance. Furthermore, low temperature molding is also suggested to improve performance since young modulus of the DFR is higher at low temperature.

Additional molding test data with different parameters will be generated and presented, and supporting results on design rule determination will be discussed in detail.

CONCLUSIONS

We successfully fabricated extremely wide polymer cavities up to 500 µm width with excellent wall and cap profiles by using SU-8 3000CF DFR and a laminator DXL series. We also obtained important data to determine design rule for the molding process. According to the results, cavity width was the most critical parameter and when we set the criterion of the cap layer displacement 0 µm at transfer molding, design rules are 100 µm width cavity with 20µm thick cap and 150 µm width with 45µm under the common transfer molding condition; 9.0MPa at 175°C.

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