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Carbon Fiber Encapsulation for Packaging Biomedical Lab-on-Chip Components

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Abstract: This paper discusses deflection behaviors of encapsulant material on the packaging of biomedical Lab-on-Chip (LOC) devices. The packaging technology described in this paper represents an important step in developing a first-level packaged LOC from a bare die. This packaging technique is aimed to be applied on analytical and diagnostic biomedical LOCs. The study involves determination of the best material for outer encapsulation, which is required to protect the sensitive elements on LOC during the subsequent high-pressure transfer molding packaging process. The encapsulant material has to have maximum inner surface deflection of 100 μm under 100 atm vertical loading. The encapsulant structure was simulated using CoventoreWare ver.2008 software. The material candidates for the encapsulation were polyphenylene sulfide (PPS) high modulus 55% carbon fiber and liquid crystal polymer (LCP). It is observed that PPS high modulus 55% carbon fiber is a more suitable material for LOC encapsulation due to its high strength, resulting in deflection of less than 100 μm under uniform 100 atm pressure applied for all encapsulation thicknesses tested.

Key words: Lab-on-Chip (LOC) · Encapsulation · Polyphenylene Sulfide (PPS) · Carbon fiber · Liquid Crystal Polymer (LCP) · Coventor Ware

INTRODUCTION

Laboratory-On-Chip (LOC) continues to command the attention of researchers for the miniaturization and automation of biological procedures in chemical analysis [1,2]. LOC devices integrate microelectronics and biological analysis components on one chip, often as small as a few square millimeters to a few square centimeters in size. Biological LOCs often deal with the handling of extremely small volume of fluid, frequently down to a volume of less than a few picoliters [3]. Among the significant applications of LOC are biological analysis, biomedical measurements and micro total analysis systems (μTAS) [4]. LOC possesses the advantages of portability, compact in size and low manufacturing cost. Most LOC components must be isolated individually to protect the bio-MEMS sensors and actuators, as well as to ensure the reliability of the device. A major challenge in packaging LOCs is to develop a standardized packaging technique while maintaining its functionality and performance [5]. As most LOCs do not require, except minute interaction with outside ambient to function, many components of the devices could undergo the standard glob top encapsulation followed by plastic transfer molding packaging process [5]. Hence, numerous LOCs, especially microfluidics, are encapsulated using chemically-inert epoxy to cover the bonding wires, bondpads, sensing electrodes and microfluidic gaps and channels, as shown in Figure 1. Strong glob top encapsulation is needed to keep the mechanical sensors protected before undergoing subsequent transfer molding process [6].

Another aspect to consider is the electrical interconnections within the LOC. In semiconductor industry, it is a common practice to utilize wire-bonding and flip-chip technology to make electrical connections between the dies and the bondpads. However, LOC has to be treated differently as there would be mechanical, chemical and biological interaction between the chip and the environment [7]. For a bio-MEMS die, the exposed sensor elements may increase the parasitic capacitance of the device [2]. The difficulty in finding a suitable interconnection and encapsulation solution is one of the motivations for this work.

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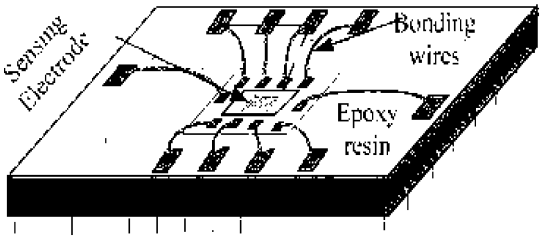

Fig. 1: Biomedical LOC to be encapsulated [1]

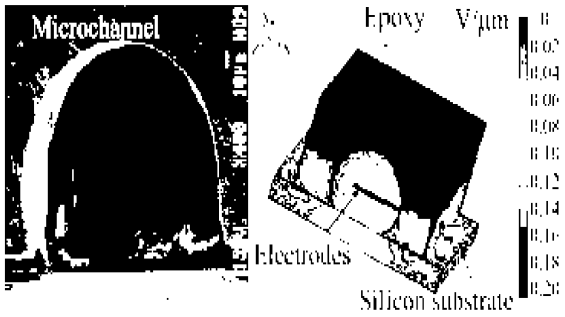

Fig. 2: Illustration of a microchannel on biomedical LOC [1]

Liquid crystal polymer (LCP) and polyphenylene sulfide (PPS) carbon fiber are materials currently used as encapsulant for packaging MEMS accelerometer [6]. The glob top encapsulant protects the movable part during high pressure transfer molding. For this study, both LCP and PPS 55% carbon fiber was considered for lab-on-chip components encapsulation due their extreme strength. For the case of MEMS accelerometer mentioned above, both LCP and PPS deflect less than 5 μm under 100atm loading at a mere thickness of 250 um [6]. LCP and PPS used in this study have Young's Modulus of 27.6 and 62.1 GPa respectively.

In this work, encapsulation materials and design are studied to protect LOC components with microfluidic channels as shown in Figure 2. A dome shaped model is used to predict deflection of the encapsulation material under uniform loading. Parameters considered are mechanical properties, namely Young's modulus and Poison's ratio of the material, as well as the design of the structure. The two materials are compared to select for the best encapsulant under 100 atm pressure. The encapsulant would cover the sensing electrodes, fluid channels, as well as bonding wires and pads, so that the LOC could be subsequently packaged using standard plastic molding process.

MATERIALS AND METHOD

CoventorWare ver.2008 was used to simulate the deflection behaviors of the candidate encapsulant materials. In order to isolate the channels and sensing electrodes from outside ambient, a 100 μm air gap is allocated on top of the microfluidic, movable and sensor elements. The allocated dimension of the inner gap is 2950 μm × 2950 μm × 100 μm. The encapsulation layer is then built with a bottom cavity of the aforementioned dimension, as depicted in Figure 3. Thus, the defection value must not exceed 100 μm to avoid any contact or squishing of sensitive elements by the encapsulant material itself. The initial glob top encapsulant is 250 μm thick, with an outer diameter of approximately 5286 μm. Next, both materials are re-simulated for encapsulation thickness of 150 μm and 200 μm to study the effect of thickness variation.

The glob top encapsulation simulated has a spherical dome shape, as shown in Figure 4. The shape is selected due to its capability to endure high external pressure applied on its surface. A 100 atm pressure was applied on the top surface, simulating pressure from transfer molding

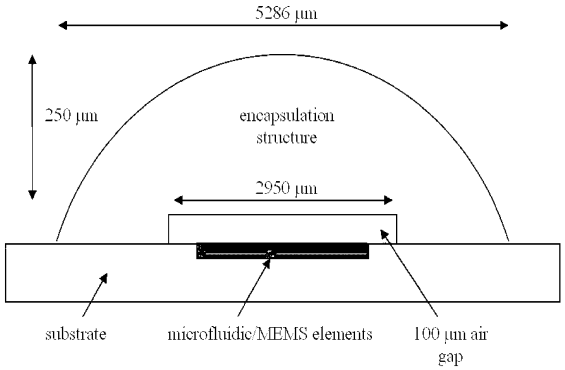

Fig. 3: Schematic diagram of the encapsulation structure

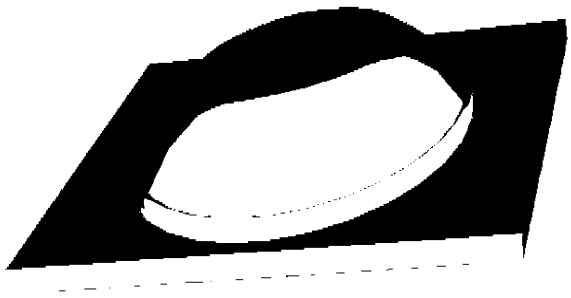

Fig. 4: 250 μm thick PPS 55% and LCP encapsulation modeling

Table 1: Young's modulus and Poison's ratio values for the encapsulant materials [10,11]

Material	Young's modulus (GPa)	Poison's ratio
PPS 55%	62.1	0.4
LCP	16.46	0.4

process. The pressure applied on the top surface is distributed in meridional direction [8]. Due to the small shell thickness to shell radius ratio, the encapsulation shell would behave according to shell bending theory, as described in our previous work [5,9].

The material selected must be capable of handling the applied pressure with net deflection of less than 100 µm. RTP 1390 HM polyphenylene sulfide (PPS) high modulus 55% carbon fiber (RTP Company, Winona, MN, USA) and RTP 3499-3 liquid crystal polymer (LCP) (RTP Company, Winona, MN, USA) were selected for this study. Mechanical properties for both materials are summarized in Table 1.

RESULTS AND DISCUSSION

Deflection simulation results for 250 µm thick encapsulation for both materials are summarized in Table 2. The shape of the deflected dome is depicted in Figure 5. For both PPS 55% and LCP, the deflections occur in both positive and negative directions of all the three axes. Results tabulated in Table 2 are portrayed as initial and deflected encapsulant structures in Figure 6. From Figure 6(a), it could be observed that the encapsulant displaces evenly in all directions on the *x*-*y* plane. This indicates uniform deformation of the perimeter of the dome as pressure is applied on the top surface of the dome. An interesting phenomenon is observed when the deflection is viewed from the vertical plane (Figure 6(b)). The dome is mainly deflected in the *–z* direction. However, the structure simultaneously slightly bulge up in the *+z* direction around the perimeter of the dome as top surface pressure is applied. This is the smudging of the structure as a mean to disperse the applied pressure because the material could not smudge further in the *x*-*y* direction, since the base is affixed on that plane.

Table 2: Deflection results for 250 µm thick encapsulation for both PPS 55% and LCP

	PPS 55%		LCP	
	Max (µm)	Min (µm)	Max (µm)	Min (µm)
Node *x* displacement (+*x*, -*x*)	1.79	-1.79	6.76	-6.76
Node *y* displacement (+*y*, -*y*)	1.79	-1.79	6.76	-6.76
Node *z* displacement (+*z*, -*z*)	0.03	-14.24	0.08	-53.74

Fig. 5: A simulation capture showing 250 µm thick PPS 55% with maximum deflection of 14.24 um under 100 atm pressure

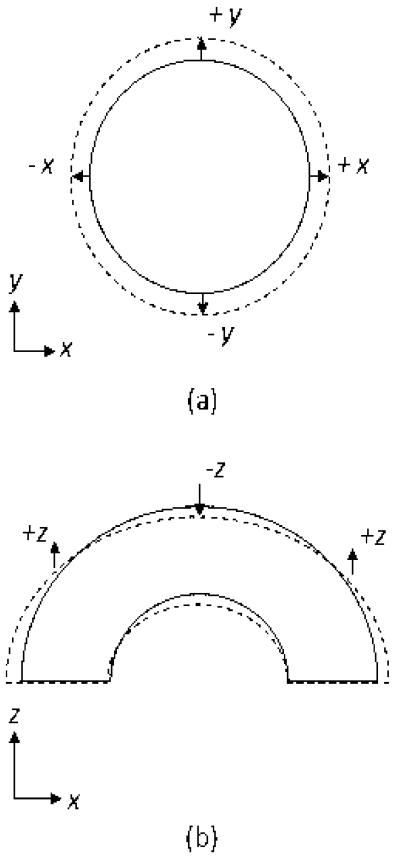

Fig. 6: Initial dome shaped (solid) and deflected encapsulant (dotted line). The encapsulant deflections are observed from (a) top view and (b) side view. Note that the deflections occur in all directions of the three axes.

Table 3: Deflections of PPS 55% and LCP at various encapsulation thicknesses

	Deflection (μm)	
Encapsulant thickness	PPS 55%	LCP
150 μm	54.88	153.08
200 μm	25.80	92.72
250 μm	14.24	53.74

Both PPS 55% and LCP are acceptable materials for encapsulating biomedical-LOC due to their deflections of less than 100 μm under 100 atm pressure. An encapsulation layer with maximum thickness of 250 um is sufficient to protect the sensitive elements of the LOC before undergoing SMT packaging. From the 100 atm loading simulation, 250 μm thick PPS 55% and LCP each yield 14.24 μm and 53.74 μm deflection respectively, as summarized in Table 3. It is further observed that the minimum thickness required for PPS carbon fiber and LCP encapsulants are 150 μm and 200 μm respectively, to withstand 100 atm loading without excessive deflection. It is thus concluded that both materials are suitable for encapsulating biomedical-LOCs before the devices are being packaged into a more standardized IC packaging. These results are consistent with findings from our previous work on encapsulating MEMS accelerometer. The variance in strength between the two materials is directly correlated to the values of Young's modulus and Poisson's ratio for both materials.

The simulation results suggest that the glob top encapsulation designed could be successfully used to isolate various components within the LOC, as well as making the elements more robust. Microfluidic interfaces and elements on the LOC could then be well separated from the electrical connections and electronic processing sections of the chip. As a result, the encapsulation ensures a strict separation between the wet sensing area and the electrical elements, thus assisting in robust functionality of the device.

CONCLUSION

Encapsulation material and design for LOC packaging has been simulated using CoventorWare ver.2008 software. Two materials, namely PPS high modulus 55% carbon fiber and liquid crystal polymer (LCP) have been considered based on their Young's modulus and Poisson's ratio values. Dome shaped encapsulation was selected due to its robustness to endure up to 100 atm external pressure during plastic package transfer molding process. Both PPS 55% carbon fiber and LCP are acceptable materials for 250 μm thick LOC encapsulation due to their deflections of less than 100 μm under 100 atm pressure applied. PPS 55% carbon fiber is however a more suitable candidate due to its acceptable deflection for all the encapsulation thicknesses tested. The simulation results suggest that the encapsulant material and the design selected envisage a promising method to generically package biomedical LOC devices.

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