

# A simple and effective fluidic encapsulation protocol for bioMEMS devices

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**Abstract:** Biomedical micro-electromechanical systems (bioMEMS) and other biochips usually have exposed chip surfaces that interface with fluids containing biological elements. These chips require post-processing for fluidic encapsulation to confine the spreading of fluids during experiments. An effective fluidic encapsulation protocol is reported here that simplifies this encapsulation procedure. The protocol uses tools and components found in a typical fabrication laboratory setting. The procedure encapsulates each edge of the chip working area in one cycle and achieves sharply defined edges with thickness of 1 to 5 mm with boundary tolerance less than 1 mm. The protocol reduces time, complexity, cost and defects for biochip encapsulation with a working area having lengths between 3 to 100 mm.

**Keywords:** bioMEMS, fluidic encapsulation, polyimide, microfluidics

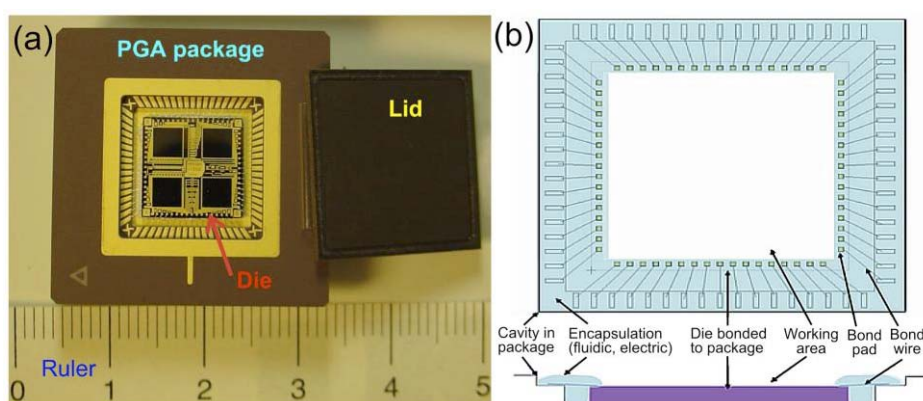
**Classification:** Micro- or nano-electromechanical systems

## References

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## 1 Introduction

Biomedical micro-electromechanical systems (bioMEMS) and other biochips are of recent research interest primarily due to the ability of miniaturization and on-chip operation of macro-scale biochemistry procedures [1, 2]. One of the challenges in testing these devices is the required post-processing for fluidic confinement, specifically for a precisely defined restricted area of operation [3]. Without proper confinement, the working fluid might spread over the chip surface in an uncontrolled manner and might contact with exposed wires or sensors causing malfunction of the device. In this paper, we compare a commonly used procedure [4] with our developed procedure and show that the latter is simpler, more effective, and achieves improved encapsulation.



**Fig. 1.** (a) The fabricated bioMEMS device to be encapsulated. (b) Encapsulation scheme for the device showing a top view (above) and a cross-section view (below).

## 2 Material selection

The test device, fabricated using Metal Multi-user MEMS Process (Metal-MUMPS), contains a metal layer of  $20\ \mu\text{m}$  thick on top of the planar oxide layer on the Si-substrate is shown in Fig. 1 (a). The surface area to be kept exposed for the bioMEMS chip was  $9\ \text{mm} \times 9\ \text{mm}$  as depicted in Fig. 1 (b). Commercially available polyimide is one of the best suited materials for such encapsulation, as it is available in fluidic state, can be easily solidified through a heating process called “curing,” has a very high electrical resistivity that is required for such encapsulation, and is able to encapsulate layered structures that are typical for bioMEMS devices. We selected a high molecular weight polyimide, Model: PI-2611 from HD Microsystems, NJ, USA, which is based on biphenyldianhydride 1,4 phenylenediamine (BPDA/PPD) backbone chemistry. This polyimide has the following properties of interest:

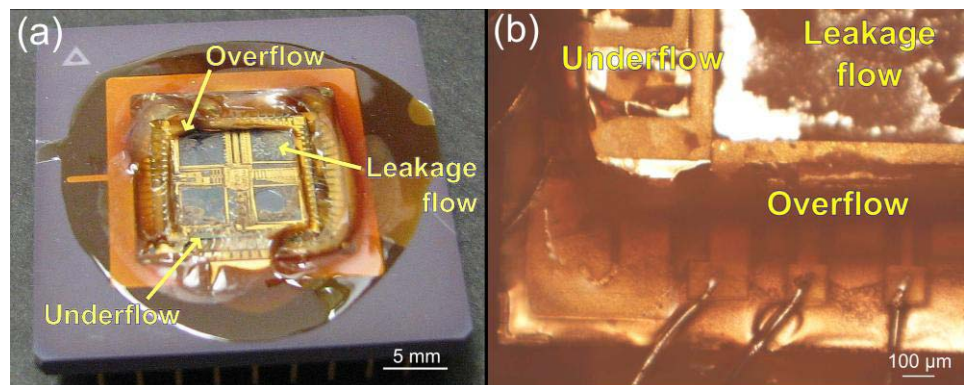
- Viscosity: 110 to 135 Poise
- Density:  $1.082 \pm 0.012$  (fluid),  $1.4$  (cured)  $\text{g}/\text{cm}^3$
- Moisture uptake: 0.5%

- Glass transition temperature: 360°C
- Coefficient of thermal expansion: 3 ppm/°C
- Dielectric constant: 2.9 (at 1 kHz, 50% RH)
- Dielectric breakdown field:  $> 2 \times 10^6$  V/cm
- Volume resistivity:  $> 10^{16}$   $\Omega$ -cm
- Surface resistivity:  $> 10^{15}$   $\Omega$

### 3 Testing with a common encapsulation procedure

A commonly used procedure for fluidic encapsulation uses a metal block to define the active working area [4]. Briefly, the procedure is as follows. (1) The surrounding of the metal block is filled with a fluidic encapsulation material. (2) The encapsulation method is administered by applying the metal block to cover the area that needs to remain exposed, followed by the application of polyimide around the metal-block. (3) Then the device is heated using a heating block to cure or solidify the polyimide. (4) The metal-block is removed once the polyimide reaches a transitional state between fluidic state and solid state. (5) The curing process continues until the polyimide becomes completely solid.

Many attempts to encapsulate the bioMEMS device using this block-metals approach as described above resulted in repeated unsatisfactory encapsulation. Various defects were regularly developed as shown in Fig. 2. These defects can be categorized in three groups as follow:



**Fig. 2.** A photograph is showing various types of defects resulting from the encapsulation attempts with the common encapsulation procedure as observed in a photograph (a) and under an optical microscope (b).

**1) Overflow:** This type of defects resulted from the polyimide being spread into the chip surface when the metal-block is removed during the heating cycle as portion of the polyimide could be in fluidic state due to uneven heat distribution. Polyimide in contact with the metal block hardens quickly and results in a thin shell around the polyimide in fluidic state. This defect caused encapsulation of section of the chip area that is required to remain

exposed.

**2) Underflow:** This type of defects resulted from the polyimide being lifted with the metal-block as it solidified and attached to the metal block. This defect exposed section of the chip surface that needed to be encapsulated.

**3) Leakage flow:** This defect resulted from the fact that the device under test had a working area with an uneven surface, i.e. not coplanar. There were gaps in the metal layer above the planar oxide layer, which is common for many bioMEMS and biochips. For the test device, this resulted in a small gap of 20  $\mu\text{m}$  between the bottom of the metal-block and the surface of the chip. Liquid-phase polyimide flowed underneath the metal-block before it cured to a solid state. This defect resulted in encapsulation of the chip surface with a thin layer of polyimide that was needed to remain exposed.

#### 4 Developed encapsulation procedure

The components used for the developed protocol are: four sticky-note clean-room paper, one clean-room tissue, a machine-cut metal block with a footprint or the bottom surface slightly smaller than the area to be exposed, about 12 mL of polyimide, and about 2 mL of distilled water. To prepare an opening of 9 mm  $\times$  9 mm, a footprint of 8.5 mm  $\times$  8.5 mm of the metal block was chosen, that leaves a clearance of 0.25 mm on each side and produced optimal results. In addition, some commonly used laboratory tools were used, such as a general-purpose cutting blade, a programmable heater, and a flat-head screwdriver or tweezers.

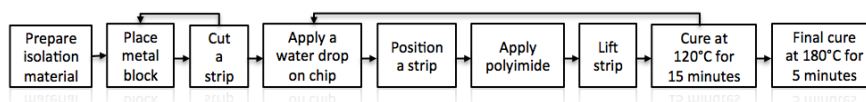
The complete protocol is briefly described below.

- 1) A clean-room stick-on paper and a clean-room tissue are attached together so that the sticky side of the paper attaches with the tissue. These are aligned such that one corner of the sticky edge of the paper aligns with an edge of the tissue.
- 2) The machine-cut metal-block is placed on top of the paper-tissue combination from Step 1 so that the paper layer is at the bottom. The alignment of the metal block is adjusted so that one corner of the block perfectly aligns with a corner of the paper-tissue layer.
- 3) The paper-tissue layer is cut using a general-purpose cutting blade along one of the remaining edges of the metal block. The cutting is continued along the same direction 2 to 3 mm beyond the metal block to have an extension. Then the remaining side of the strip is cut off and is marked on the extended side with a pen for ease of identification of the edges later.
- 4) The procedure outlined in Step 2 to 3 are repeated to prepare four identical strips, one for each side of the encapsulation area.
- 5) After the strips are prepared, a drop of distilled water ( $\sim 0.5\text{ mL}$ ) is applied on the paper side to one of the strips prior to positioning it on the chip. This makes the surface of the strip wet and excess water is

removed by shaking the strip. Then the strip is placed on the chip so that the paper side faces down. The opposite side of the marked strip is matched with one of the edges of the chip area to be encapsulated. A screwdriver or tweezers is used for fine-adjustment of this alignment. The chip surface is protected by the strip that sticks to the surface due to adhesion of water. The bond-wires of the edge to be encapsulated remain exposed.

- 6) After properly positioning the strip, a small amount ( $\sim 3$  mL) of polyimide is applied using a flat-head screwdriver along the edge that is aligned in the previous step. This covers the exposed bond-wires along one edge. Using the flat-head screwdriver, the polyimide is evenly spread-out. The tissue side of the strip absorbs the excess polyimide on top of the strip; however the polyimide cannot reach the chip surface due to paper insulation. At this stage, the liquid polyimide holds the strip in place.
- 7) After the polyimide settles, the tweezers is used to lift the marked edge of the strip upwards so that the strip becomes vertical on the device with the aligned edge touching the chip surface. The strip is then lifted up and discarded. The device can optionally be tilted to  $\sim 30^\circ$  to allow the polyimide to flow outwards. When the polyimide settles, the device is placed on the heater.
- 8) The control of the programmable hot-plate heater is set to heat the device from room temperature to  $120^\circ\text{C}$  with a rate of  $10^\circ\text{C}/\text{min}$ , and allow it to be heated for 15 minutes, and then turn off the heater to let the device cool off to room temperature. After ensuring that the device is at room temperature, it is removed from the hotplate.
- 9) Steps 5 to 8 are repeated for other edges to be encapsulated.
- 10) After encapsulations of all four sides have been completed, a final cure step is performed using the heater by elevating the device temperature to  $180^\circ\text{C}$  for 5 minutes. Finally, the heater is turned off and the device is left to cool off to room temperature.

The complete protocol is depicted schematically in Fig.3.

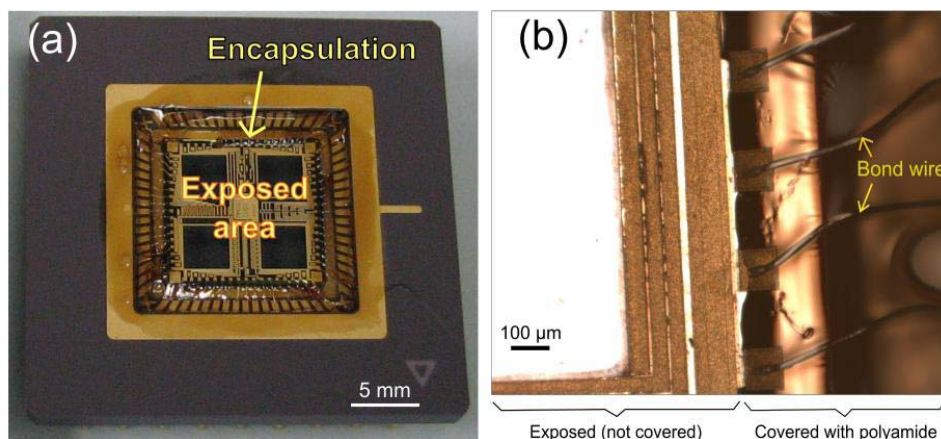


**Fig. 3.** A schematic representation of the developed encapsulation procedure.

## 5 Observations with the developed protocol

The encapsulation obtained from the proposed protocol is superior compared to the previous attempts with the conventional procedure. A photograph of the encapsulated device using the developed protocol is shown in Fig. 4(a).





**Fig. 4.** A photograph (a) and an optical microscopic picture (b) of the device after encapsulation with the proposed protocol show the exposed area to be free from the defects with sharply defined boundaries.

Sharply defined boundaries within mm tolerance between the exposed and the encapsulated regions were observed under a microscope as depicted in Fig. 4 (b).

The developed procedure has minimized all types of defects resulting from overflow, underflow and leakage flow, as compared with the common procedure for fluidic encapsulation. Through observations under optical microscope such as Figure 4 (b), it was found that the maximum misalignment in the boundary of the encapsulation was  $\sim 1$  mm and typically within 0.1 mm. Note the distance between the bond pads where the bond wires are connected and the nearest metal layer is  $20\ \mu\text{m}$  as shown in the figure. Comparing these results with the conventional procedure, a ten-fold or more improvement was achieved. 100% of the encapsulated chips using the proposed procedure showed no leakage flow ( $N = 5$ ), whereas 67% of the chips encapsulated with the conventional procedure were unusable due to leakage flow ( $N = 3$ ). This demonstrates the improved encapsulation ability with low defects. The rationales for low defects with the developed protocol are as follows.

**1) Overflow and underflow:** Due to the ability of fine adjustment of positioning of the covering strip before applying polyamide, the boundaries of the encapsulation could be fine-tuned. Furthermore, as the covering strip is removed only when the polyimide is settled, the procedure resulted in less unwanted flow or removal of polyimide and a sharply defined boundary of encapsulation.

**2) Leakage flow:** The distilled water drop that is added before the covering strip is positioned on the chip causes water surface tension to stick the covering slip tightly with the uneven chip surface. Thus, most of the gaps between tracks of the metal layer are temporarily blocked so that polyimide

does not leak to the chip working surface that should remain exposed.

Since the protocol is conducted manually, the minimum length for working area to be exposed should not be less than 3 mm. The maximum length can be as large as 100 mm, which is sufficient for any practical biochip. The thickness of fluidic encapsulation is estimated to be between 1 mm to 5 mm.

## 6 Conclusions

The encapsulation with the developed protocol was superior and resulted in less defects compared to the commonly used procedure for encapsulation of the bioMEMS device under test. This simple and effective protocol leads to a less complex encapsulation process, fewer defects, lower cost, and improved confinement of fluids. The protocol is applicable to many bioMEMS and other biochips where fluidic encapsulation is required.