SINGLE-STEP, INTEGRATED ASSEMBLY AND ENCAPSULATION OF MICROFLUIDIC BUBBLE GENERATOR

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ABSTRACT

This paper describes a single-step method for assembling and encapsulating a microbubble chamber in which injection-molded plastic secures the fluidic and electrical interconnects. All of the necessary components for the chamber are loose assembled in a plastic-injection mold and subsequently packaged, encapsulated, and sealed in one molding step. These components include a silicon/Pyrex® bubble chamber, copper electrical leads, and small-gauge stainless steel fluidic headers. This approach delivers a fully integrated microbubble chamber with 1) zero dead volume, 2) low electrical contact resistance (<1 Ohm), 3) low compliance, in-plane fluid interconnects and 4) small overall dimensions (7.5 mm × 4 mm × 3 mm) conforming to the Dual In-Line Package (DIP) standard, Fig 1.

INTRODUCTION AND MOTIVATION

Current electro-fluidic systems lack standardized geometry and fabrication processes. Additionally, chip level integration – where all components are created simultaneously on one substrate – is the current focus of most microfluidic research [1]. However, forcing all microfluidic components to conform to a single fabrication process can sacrifice performance and increases process complexity.

In contrast, this paper suggests the idea of board level integration where a system is assembled from individual components. Each individual component can be optimized for performance and fabrication without concern with interfering with other components.

1. Electrical Leadframe
2. Fluidic Header
3. Assembled and Encapsulated Device
4. Bubble Chamber
5. Injection Mold

Figure 1 - Process Flow: The leads and headers are aligned with the clearance holes in the silicon/Pyrex® bubble chamber by the plastic-injection mold. The injection molding step secures the leads and seals the fluidic connections, delivering an encapsulated and packaged device.
In this scenario an entire system is built on a board with electric, fluidic, and optical interconnects, similar to modern electronics consisting of discrete components assembled on a printed circuit board.

This paper also looks to address weaknesses in current packaging techniques. The default method of creating fluidic interconnects via backside ports [2,3], though functional, increases the overall volume of the system as space above the chip must be devoted to these out-of-plane tubes. Many times these backside ports are attached by hand, a labor intensive process that is prone to error [4]. Also, there is no standard way to connect these systems electrically, therefore requiring additional processing steps such as wire bonding.

**CHIP DESIGN AND FABRICATION**

A bubble generator was chosen for this project as it is simple to fabricate and still allows the final package to be easily tested for electrical continuity and fluidic integrity; its simplicity allowed us to focus on the packaging aspect of the project without having to be concerned with developing a complex device. The bubble chamber is a straight channel with gold electrolysis electrodes and gold thermo-electric heaters, and was fabricated in the UC Berkeley Microfabrication Laboratory, fig. 2. 100 µm deep channels are patterned into the surface of a silicon wafer forming the fluidic pathway. Clearance holes are etched from the backside of the wafer to provide recesses for the fluidic headers and the electrical lead frames. Gold traces are patterned in relief features etched into a Pyrex® wafer. The Pyrex® wafer is anodically bonded to the silicon, capping the channels and allowing for visual inspection of the fluid in the component. The chip is designed with only one glass cover leaving the channel opening exposed from the backside fig. 3. In total four masks are required for the fabrication of the test chip.

The fluidic headers consist of 25 gauge (500 micron OD, 250 micron ID) stainless steel tubing cut to length (15 cm). A wire EDM was used to fabricate the lead frames. The size of the test chip was chosen such that the final package would conform to DIP standards.

The gold thermo-electric heaters were designed such that the electrical resistance is relatively low (< 10Ω). While this requires that the heaters be driven at high current, it minimizes the occurrence of electrolysis due to high voltage [5].

**INJECTION MOLD DESIGN, FABRICATION, AND PROCESS**

A standard 88 size (200mm x 200mm) mold block was purchased from D-M-E Company. The mold was designed such that all of the pieces (microfluidic chip, tubing, and lead frames) could be loose assembled on the A-side (stationary side) of the mold with the mold cavity on the B-side directly opposite, fig. 4. The vast majority of injection molding machines inject horizontally so that the parting line of the mold is vertical. While this design allows for newly injected parts to fall out upon ejection, it became problematic as the pieces to be packaged tended to fall out as well. Therefore, a small amount of water was applied between the chip and the mold allowing capillary forces to hold the chip in place as the mold closed.

The part is gated from both sides of the cavity. Gate size was chosen intentionally small so that later modification of the gates would be easy if deemed necessary. The mold was designed using SolidWorks and was machined on a traditional CNC machining center.

The package was injected on a 30 ton FANUC Roboshot (Model a-30iA) injection molding machine. Cyclic Olefin Copolymer (Ticona Topas®, COC) was originally chosen as the packaging material due to its optical clarity, biocompatibility, and flow properties. Other plastics were also explored as discussed in the next section.

A typical injection mold process consists of two stages. First the cavity is injected at high speed to fill the majority of the cavity before the plastic cools. This is followed by a packing step which forces plastic at high pressure into the mold, compensating for part shrinkage as the plastic cools. The injection pressure can be monitored on the injection molding machine and a pressure threshold was used to switch the machine from the injection stage to the packing stage. This process was chosen, instead of the typical volume threshold, in order to reduce the chance of the chip cracking during injection.

**Figure 2 - Microbubble generator:** Looking through the Pyrex® cover reveals all of the important features of the microfluidic test chip.

**Figure 3 - Cross Section:** This illustrates where the tubing sits and how the channel opening is exposed.
RESULTS AND FUTURE WORK

Initial results with COC were promising. Figure 5 is an example of the final package. Electrical continuity was demonstrated with both the resistive heaters and the electrolysis electrodes as seen in fig. 6. It should be noted that for this test the lead frames were prebonded to the chip with conductive epoxy. The package was also tested for fluidic integrity by building pressure in the system and measuring the pressure decay over time, fig. 7.

Unfortunately, three main issues were evident. First, the chip often cracked during the injection process. Second, the lead frames were often pushed out of place by the plastic, necessitating the use of conductive epoxy. Lastly, poor adhesion between the tubing and plastic led to a small leak. The adhesion issue was addressed first by exploring new plastic types. Dow PRIMACOR was found to have much better adhesion properties to metal due to polar side groups attached along the length of the carbon chain [6]. However, the plastic also flowed differently than the COC leading to the plastic flowing behind the tube and into the channel, effectively blocking it off. Therefore an easy modification was added to the chip by bonding another Pyrex® cover to the backside of the silicon using SU-8 photoresist as a UV curable adhesive. This created a fully enclosed region for the tube and lead frames to sit, fig. 8. While this protected the tubing and channel, it also allowed for the lead frames to fit snugly against the gold contacts eliminating the need for prebonding with conductive epoxy. This new design is still being tested for fluidic integrity.

Other types of tubing were tested to avoid cracking the chip. It was found that more compliant tubing such as PEEK and fused silica tubing greatly reduced the occurrence of chip cracking. It is believed that as the plastic flows around the tube, the tube presses on the glass creating a stress concentration and subsequently cracks it. Future designs look to minimize or eliminate this stress concentration.
CONCLUSION

This packaging technique involves placing a microfabricated fluidic chip in an injection mold followed by fluidic and electrical interconnects. Plastic is then injected into the mold, flowing around the pieces resulting in a fully assembled package of standard dimensions. At present, a bubble generator has been packaged and electrical continuity has been demonstrated. Research is ongoing to improve fluidic integrity and repeatability. New designs involve different plastic types as well as mechanical changes of the chip to promote sealing.

The work in this paper could easily be extended to package other microfluidic components such as valves, pumps and mixers. With these components in hand, complete systems could be put together at the board lever via a pick and place technique mimicking macroscale fluidic systems and modern electronic design. This provides for more flexibility in individual component design as fabrication process compatibility issues are minimized.

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REFERENCES


