[1]Electrical and Fluidic Packaging of Surface Micromachined Electro-Microfluidic Devices

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ABSTRACT

Microfluidic devices have applications in chemical analysis, biomedical devices and ink-jets[1]. An integrated microfluidic system incorporates electrical signals on-chip. Such electro-microfluidic devices require fluidic and electrical connection to larger packages. Therefore electrical and fluidic packaging of electro-microfluidic devices is key to the development of integrated microfluidic systems. Packaging is more challenging for surface micromachined devices than for larger bulk micromachined devices. However, because surface micromachining allows incorporation of electrical traces during microfluidic channel fabrication, a monolithic device results.

A new architecture for packaging surface micromachined electro-microfluidic devices is presented. This architecture relies on two scales of packaging to bring fluid to the device scale (picoliters) from the macro-scale (microliters). The architecture emulates and utilizes electronics packaging technology. The larger package consists of a circuit board with embedded fluidic channels and standard fluidic connectors. The embedded channels connect to the smaller package, an Electro-Microfluidic Dual-Inline-Package (EMDIP) that takes fluid to the microfluidic integrated circuit (MIC). The fluidic connection is made to the back of the MIC through Bosch[2] etched holes that take fluid to surface micromachined channels on the front of the MIC. Electrical connection is made to bond pads on the front of the MIC.

Keywords: microfluidics, packaging, electro-microfluidic interconnection, MEMS.

1. INTRODUCTION

Microfluidic devices have potential uses in biomedical[3,4], chemical analysis[5], power[6], and drop ejection[7] applications. Typically the use of microfluidics in these applications requires the integration of other technologies with microfluidics. For instance: optical means may be used to sense genetic content[3], electronics may be used for chemical sensing[5], electro-magnetics may be required for electrical power generation[6], or electrical power may be required for thermal drop ejection[7]. The already difficult task of packaging the microfluidic device is compounded by the packaging required for electrical, optical, magnetic or mechanical interconnection. In addition, the full potential of microfluidics can not be realized until many microfluidic devices can be effectively integrated into microfluidic systems. This integration requires effective microfluidic interconnections as well as electrical, and/or optical and other types of interconnections. Of special importance for the application of microfluidics is the integration of electronics with microfluidics. This integration will allow the use of already well developed and extremely useful electronics technology with the newly emerging microfluidics technology.

Surface micromachining of microfluidic devices allows the integrated microfabrication of monolithic chips that contain both electrical and microfluidic devices. Integrated fabrication of surface micromachined Micro-Electro-Mechanical Systems (Integrated MEMS or IMEMS) with electronics has been used to fabricate air-bag accelerometer systems[8]. However, integration of microfluidics and electronics on a single

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chip has lagged behind IMEMS development at least partly because of the difficulty in packaging microfluidic devices in a leak tight, efficient, inexpensive and reliable manner.

Several different techniques have been used to package microfluidic devices. These techniques do not typically address the problem of making electrical connection as well as fluid connection to the microfluidic devices. The simplest way to make fluid connections is to epoxy or otherwise adhere glass or capillary tubes over holes in the on-chip microfluidic channels. This method is very difficult to implement consistently at the very small scales involved without plugging the holes with adhesive. If one is making many connections, the tediousness and the sensitivity of this method to the amount of caffeine in ones system make this a very unattractive packaging option. Essentially one is performing very small scale, very meticulous, hand assembly work.

More efficient microfluidic connection techniques have been proposed. Jaeggi et. al.[9] utilize tight fitting fluidic couplers for standard capillary tubes. These couplers are created using Deep Reactive Ion Etching (DRIE) to fabricate cylindrical or annular access holes in a mounting wafer that is fusion bonded to the silicon module containing the microfluidic channels. Capillary tubing fits tightly into these access holes. After fitting the capillary tubes into the couplers, epoxy is applied to the outside of the tubing to seal the connection between the tubes and the couplers. In the most developed version of this technique[9] a plastic fluid coupler fits into the access holes for better alignment and sealing.

Gonzales et. al.[10] describe a snap together method used to connect microfluidic channels at the wafer scale. Finger micro-joints act as springs that hold the channels together after snapping the wafers into place. The connection is a reversible one. Schabmueller et. al.[11] describe a microfluidic circuitboard. In this package several different microfluidic devices are mounted on a circuitboard that contains embedded flow channels connecting the devices in a microfluidic circuit. Finally VerLee et. al.[12] describe a microfluidic manifold that is created in acrylic and contains channels that feed different microfluidic devices. The different layers of the microfluidic manifold are bonded together using thermal diffusion bonding under 45 psi of pressure.

All of these packaging techniques are typically used with bulk micromachined devices. For surface micromachined microfluidic devices the microfluidic device channels scales are even smaller. For instance, a typical bulk micromachined channel would have a channel depth of 50 to 100 microns (0.002 to 0.004 inches). Whereas a typical surface micromachined channel depth would be 2 to 5 microns (0.00008 to 0.0002 inches). The added challenges of connecting to these smaller microchannels, the limitations of current packaging technology, and the necessity of making electrical as well as fluidic connections to make integrated microfluidic microsystems have led us to develop the following packaging scheme.

2. PACKAGING ARCHITECTURE

The goal of our packaging architecture is to make viable fluidic and electrical connections to surface micromachined electro-microfluidic devices, and to package them in a reliable and inexpensive manner. This is a more challenging objective than that addressed by the packaging schemes described in the introduction section in that the size of the microfluidic channels is smaller than that used for typical bulk micromachined channels. Typically our surface micromachined microfluidic devices have channel depths on the order of 2 to 5 microns (0.00008 to 0.0002 inches) while bulk micromachined devices have channel depths on the order of 50 to 100 microns (0.002 to 0.004 inches) – one or two orders of magnitude larger. In addition, we would like to have many fluid connections (typically 10 to 20) to a single microfluidic silicon module. These modules are typically on the order of 5 mm by 5 mm (0.2 by 0.2 inches) in area and are approximately 500 microns (0.2 inches) thick. The volume of liquid that one can easily dispense from a very small micropipette is approximately 1 microliter, while the amount of liquid that is typically used in the shallow (2-5 micron – 0.00008 to 0.0002 inch) microfluidic devices is on the order a 1 nanoliter to 1 picoliter. This large difference in scale (3 to 6 orders in magnitude in volume, 1 to 2 orders of magnitude in length) led us to consider a two stage packaging approach. It would be difficult to go from microliter or standard Swagelok connector (Swagelok, Solon OH) scale (the macro-scale) to picoliter or 2 micron (0.00008 inch) scale (the surface micromachined micro-scale) in one step. Therefore our meso-scale connection is in two stages. The packaging architecture is shown in Fig. 1, and details of internal flow passages are shown in Figs. 2 and 3.

Stage one is an Electro-Microfluidic Dual Inline Package or EMDIP to which the microfluidic silicon module (Microfluidic Integrated Circuit or MIC) is attached. The electrical connection is generally made by wire bonding to bond pads on the surface of the microfluidic module. Other techniques for making the electrical connection, such as flip-chip bonding using solder bumps, are also possible. We are considering the most common connection method, which is wire bonding. The fluidic connections are made through holes in the EMDIP that coincide with holes extending through the MIC from back to front that connect to surface micromachined channels on the front of the module. In the EMDIP a fan-out and scale-up of the fluid passages occurs that is roughly one order of magnitude in length.

The EMDIP then connects to a Fluidic Printed Wiring Board (FPWB) that contains sockets for attachment of the EMDIP leads and fluid channels for connection to the fluid ports of the EMDIP. Standard fluidic and electronic connectors can then be used to feed fluid and power to the FPWB and from there to the EMDIP and the MIC. The sockets in the FPWB allow for some variation in the engagement of the pins from the EMDIP. The EMDIP height off the FPWB surface can vary. This variation allows for the EMDIP to properly seat onto the FPWB to make leak tight fluidic connections. O-rings, gaskets, or adhesive tape may be used at this connection (between the EMDIP and the FPWB) to aid in sealing the joint. Solder may also be used to make the electrical connection.

The holes in the FPWB for microfluidic connection are approximately 0.5 mm (0.02 inches) in diameter and can be fabricated in a standard hole pattern. The holes in the EMDIP can be fabricated such that all or only some of the fluidic connections are used, making it possible to use the same FPWB with many different EMDIPs and MICs. This provides a flexibility similar to that provided by electrical connections where only some of the pins on a standard connector are used. The EMDIP could be manufactured as a molded plastic part – just as standard plastic DIPs are.

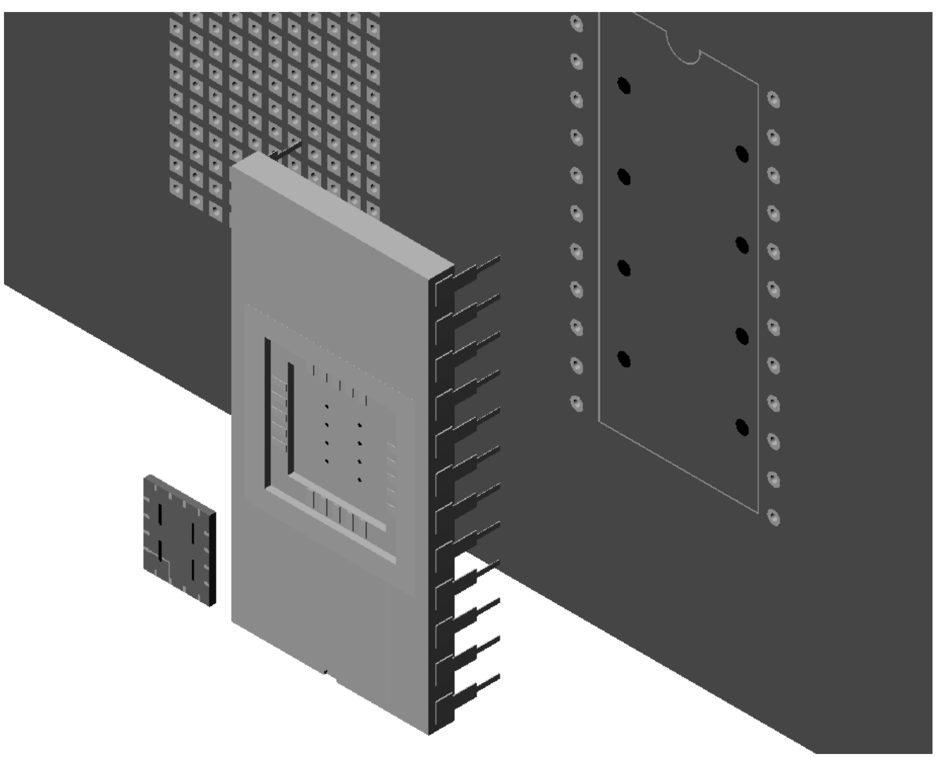


Figure 1. Electro-Microfluidic Packaging Architecture. Fluidic Printed Wiring Board (FPWB) to Electro-Microfluidic Dual Inline Package (EMDIP) to Microfluidic Integrated Circuit (MIC) – largest to smallest scale.

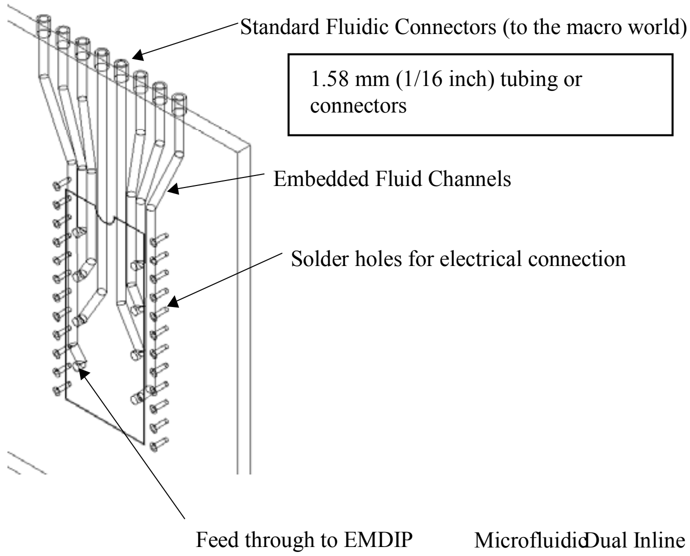


Figure 2. FPWB (Fluidic Printed Wiring Board) internal flow passages. Flow passages fan out to small fluidic connector ports, similar in size to RF (Radio Frequency) electrical connectors.

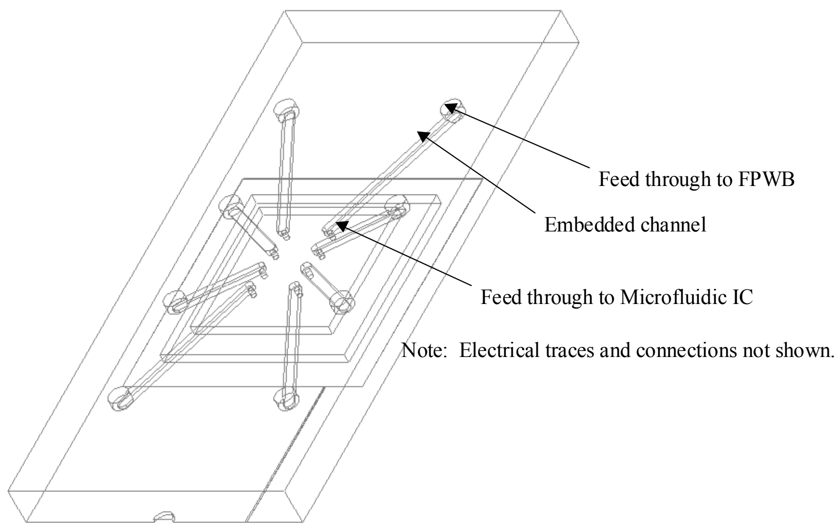


Figure 3. Electro-Microfluidic Dual Inline Package (EMDIP) internal flow passages. Flow passages fan out and enlarge in the EMDIP.

The architecture shown in Figs. 1-3 is based on electronics packaging. It is electronics packaging adapted to include flow passages and fluidic connectors. Microfluidics packaging technology is just beginning to be developed. By emulating electronics packaging we hope to facilitate the transition from electronics packaging to combined electronics and microfluidics packaging.

4. SURFACE MICROMACHINED MICROFLUIDIC MODULES

In order to understand the packaging requirements it is important to have some familiarity with surface micromachined electro-microfluidic modules. Fig. 4 is an image taken from the AutoCAD file used to generate the masks used to fabricate a surface micromachined electro-microfluidic device. Fig. 5 is a cross-section through the device design showing the layers of polysilicon as they are deposited and patterned. Fig. 5 was generated using the 2D cross-section visualization tool developed at Sandia National Labs[13].

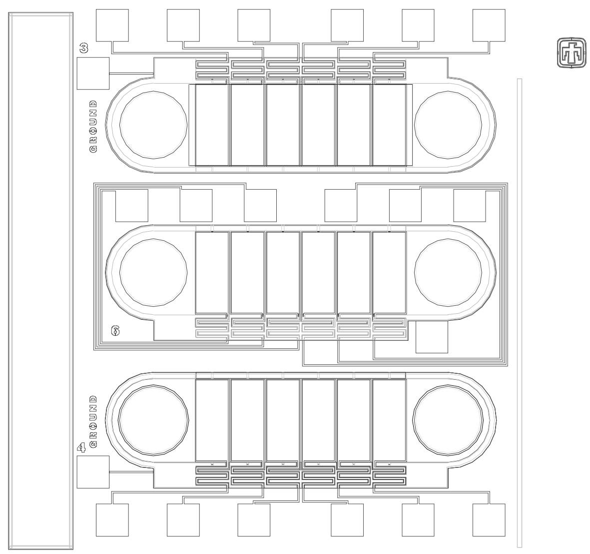


Figure 4. Electo-Microfluidic device (MIC) design.

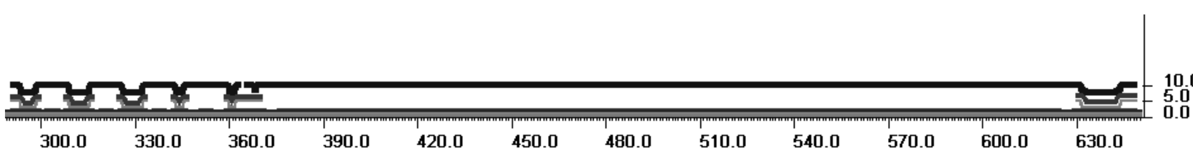


Figure 5. Electro-Microfluidic device (MIC) cross-section.

Fig. 4 shows a top view of three microfluidic channel designs with electrostatic actuation. Each device design has one exit port and one entrance port (circles). A Bosch etch process[2] is used to etch through the wafer from the back side. The Bosch etch stops on the bottom layer of sacrificial oxide deposited on the front surface of the device. Cuts through the bottom layer of insulating Silicon Nitride are used to define the Bosch etch entrance/exit ports. The entrance/exit ports are 200 microns (0.008 inches) in diameter and are approximately 1 mm (0.040 inches) apart. The fluid can flow from either left to right or right to left in Fig. 4. The squares around each channel are bond pads where electrical connections are made for actuation of the fluidic channels.

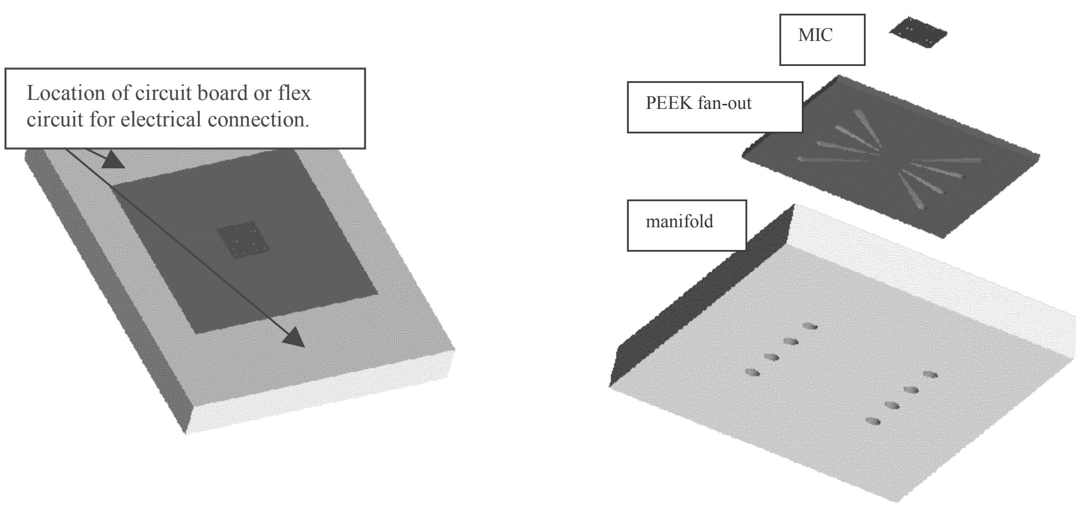
The channels are covered using the top layer of polysilicon (poly3) available in the SUMMiT IV process[13] (see Fig. 5). Channel side walls are fabricated using the other layers of polysilicon (poly1 and poly2). The cross-section shown in Fig. 5 is through the middle of the bottom channel in Fig. 4 and is a vertical cut. The channel depth is approximately 5 microns (0.0002 inches) and is defined by layers of sacrificial silicon dioxide[13]. The final step of the fabrication process is the release etch that removes all of the sacrificial oxide between layers of polysilicon. After the release etch the polysilicon channels are hollow and ready for fluid to flow through them.

5. TEST FIXTURE

In order to test this packaging scheme a fixture is being manufactured. The test fixture is shown in Fig. 6. The test fixture simulates an EMDIP with the fluidic and electrical connections separated. In the test fixture a manifold (steel, aluminum, Lexan (acrylic) or glass) allows fluid to be introduced into a fan-out part from standard 1.6 mm (1/16 inch) tubing. The manifold has a small circuit board or flex circuit mounted on top of it that allows electrical connection using wire bonding to the microfluidic IC.

The fan-out part of the test fixture is fabricated from PEEK (Polyetherether Ketone) using standard tooling. A 0.2 mm (0.008 inch) drill is used to drill a hole through the PEEK in a hole pattern that matches the hole pattern in the MIC. The holes in the PEEK are therefore 200 microns (0.008 inches) in diameter and are approximately 1 mm apart. On the opposite side of the PEEK a 250 micron (0.01 inch) diameter end mill is used to create channels that are approximately half the thickness of the PEEK part deep. These channels fan out to 1 mm (0.042 inch) diameter holes that mate up with the test manifold ports (see Fig. 6). The channels are closed and sealed by the top surface of the test manifold when the PEEK part is attached to the test manifold. In a production device the EMDIP would probably be produced as a molded plastic part that would combine the PEEK part, the manifold, and the flex circuit or circuit board into one part. The EMDIP would be fabricated in a manner similar to that in which plastic DIP's are now produced. This part would be very similar to current plastic DIP's but would contain flow passages.

The MIC is attached to the PEEK part using 0.05 mm (0.002 inch) thick double sided VHB transfer adhesive tape from 3M (3M, Minneapolis MN). The same hole pattern drilled in the PEEK part to mate up with the MIC is drilled in the tape. This is accomplished by attaching the tape to the PEEK prior to drilling the PEEK. The paper backing is left on the opposite surface of the tape until the MIC can be attached to it. A flip chip alignment system (Research Devices Inc., New Jersey USA) is used to align the MIC with the PEEK and then attach the MIC to the PEEK. The flip chip alignment system allows very tight tolerance alignment – down to 1 micron (0.00004 inches). This method of assembly (utilizing flip chip alignment) could be used in a production device.



(a) assembled

(b) exploded view

Figure 6. Test Fixture.

6. CONCLUSIONS

We have presented a candidate scheme for use in packaging surface micromachined electro-microfluidic silicon modules. This method borrows heavily from electonics packaging in order to make multiple fluidic and electronic connections to the microfluidic integrated circuit. A two stage packaging architecture takes the fluid from macroscopic volumes (microliters) to microscopic volumes (picoliters). Going from largest to smallest, a standard small fluid connector is attached to a fluidic printed wiring board that contains embedded fluidic channels. The embedded channels converge and shrink such that the channel exit is significantly smaller that the channel entrance. The second stage of packaging is an electro-microfluidic dual in-line package that attaches to the fluidic wiring board and the microfluidic integrated circuit. It is the intermediate packaging part and contains flow passages that further shrink the fluid volume down to the level of the microfluidic integrated circuit. Very thin double-sided adhesive film is used to attach the microfluidic integrated circuit to the electro-microfluidic dual in-line package and to attach the fluidic printed wiring board to the electro-microfluidic dual in-line package. The electrical connections are made using wire bonding between the microfluidic integrated circuit and the electro-microfluidic dual in-line package, and using pin in socket or between the electro-microfluidic dual in-line package and the fluidic printed wiring board. We plan to demonstrate that this packaging method will provide a reliable and inexpensive method for getting fluid and electrical signals to wide range of surface micromachined electro-microfluidic on-chip devices that are being developed as part of the MEMS revolution.

7. ACKNOWLEDGEMENT

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