

Fluidic Multi Chip Module: Modular Micro Assembly

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1 Introduction

With the advent of micromachining technology, microfluidic devices have proliferated and are now widely applied in environmental and biological analysis. A practical limitation of efficient, reliable and economic use of such devices is the cost associated with design and manufacturing of these microdevices. An assembly method has been developed that provides micro fluidic applications that are suitable for low cost mass manufacturing.

In this article a technology based on conventional flip-chip technology to manufacture micro fluidic systems on an industrial scale is described. This technology uses an interconnection technology that enables combined electrical, mechanical and fluidic interconnections.

To demonstrate the technology a micro gas chromatograph has been developed, which compares favorable against today's leading suppliers with respect to the combination of separation quality and separation time.

1.1 Micro Assembly Technology

Depending on the required production volume and system complexity fluidic Microsystems can be build up in various ways. For high volume applications it may be economically feasible to develop a dedicated monolithic or integrated realization process. Here the whole fluidic functionality is realized in one chip. If the required production volume is lower or if the integration of the different functions in one chip is too complex the system should be built up using separate components. The basic approach to assemble such a fluidic system is to connect the individual components using metal or glass-capillary tubing. The internal volume of such a "spider web assembly" construction is not ideal thus affecting the main advantages of using microfluidics. Although this is a labor-intensive manner of realizing a micro fluidic functionality, it remains the most viable construction for low volume products. For medium volume applications hybrid designs using standardized parts are more cost effective [1].

The positioning of hybrid integration for some typical mid volume and relatively complex micro fluidic systems is given in figure 1. The universality and the possible level of mechanization determine the width of the application field of a hybrid assembly technology. The most universal technology is capable to assemble all different fluidic chips with no or just minor adjustments to the process and equipment. The level of mechanization determines the assembly time and cost. A higher level of

mechanization might increase volume at which total integration starts to be reasonable.

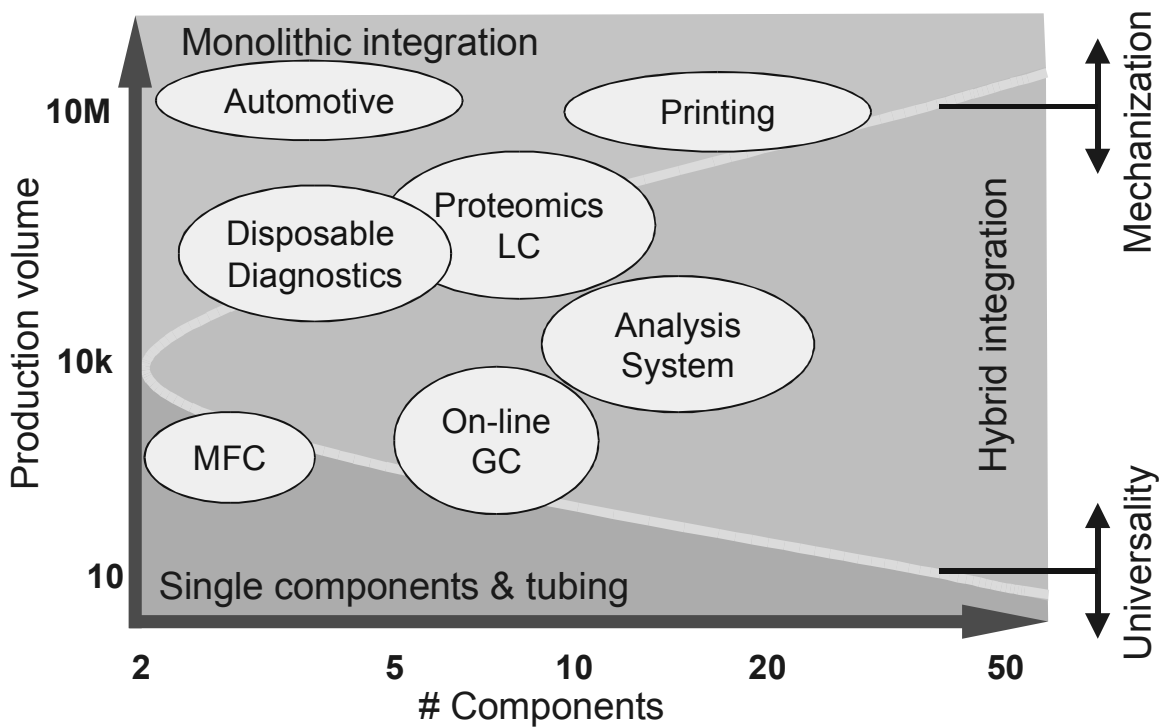


Figure 1: Positioning of Hybrid Integration of micro Fluidic Devices

In packaging of microelectronics Multi Chip Module (MCM) packaging is a standard concept. Here flip-chip technology is used to assemble multiple chips on one substrate. With MCM it is possible to realize a large diversity of electronic functions in a small standard housing. The Fluidic Multi Chip Module (FMCM) technology that has been developed makes it possible to automate the assembly process by (a) using flip-chip technology as the basis for the assembly process and (b) a channel plate with integrated micro channels and integrated micro electrical circuitry. Obviously the main challenge was the simultaneous realization of reliable electrical and fluidic interconnections.

1.2 Micro Gas Chromatography (μ GC)

Gas chromatography is a chemical analysis method that is used to analyze the composition of compounds. The principle of gas chromatography is based upon a difference of passing time of gaseous materials in a separation column. The difference of passing time is measured for example, by measuring the thermal conductivity of gaseous materials that pass a thermal conductivity sensor. By using silicon technology with small detection structure (Micro Electro Mechanical System;

MEMS) it is possible to enable the functionality of a gas chromatograph in a small volume. This size reduction of the gas chromatograph function gives several advantages (1) It is possible to perform an analysis with a smaller amount of material (2) The energy consumption of the gas chromatograph is reduced, this enables stand-alone or wireless gas chromatographs and (3) The small internal volume and the small column diameter leads to a shorter analytical time (to tens of seconds).

The design of other fluidic devices than gas chromatography can be done based upon a catalogue of standard micro components, e.g. several micro valves, thermal sensors, flow sensors, micro mixers, micro capillary interconnects. This modular approach makes it possible to reduce the development time of a new fluidic micro application.

2 Micro Assembly Technology

The basic concept of the assembly technology is to use a base plate, a so-called channel plate with electrical and fluidic functions. The function of the channel plate can be compared with the function of a printed circuit board in electronic assembly.

2.1 Channel Plate

The channel plate consists of fluidic structures (i.e. channels of approximately 100 micrometer width and other functional structures) and electrical circuitry. For purposes of measurement accuracy of the total system, the components are placed with an accuracy of better than 10 microns on appropriate positions on the channel plate using flip-chip technology.

2.2 Components

Accurate switching of small volumes of liquid or gas is essential for most micro fluidic applications. Therefore micro ball valves are used to be able to switch with minimum dead volumes. The requirement of a low dead volume leads to high accuracy demands for the positioning of the components on the channel plate. The footprints of these components are standardized. This makes it possible to design for instance a valve function and have optimum re-use of the already developed valve components and interconnect technology. The sensors used in the demonstrator are thermo-detectors on thin (30 μm thick) silicon membranes. Those membranes are used to thermally isolate the thermo-detector structures. The fragility of the membranes was a major challenge in the development of the assembly technology.

The MEMS components have been designed in such a way that they are applicable with proven packaging and interconnection technology to realize complete system functionality. This is according to the Design for micro Assembly (Df μ A) approach that was developed earlier [3] and that can lead to a reduction in design lead time and product development cost.

With the Fluidic Multi Chip Module technology valves and sensors become 'off-the-shelf' components. Which can be designed easily in new micro fluidic products. A

development lead time reduction of 50 % and a development cost reduction of 80 % are believed to be feasible based upon the experiences with the demonstrator.

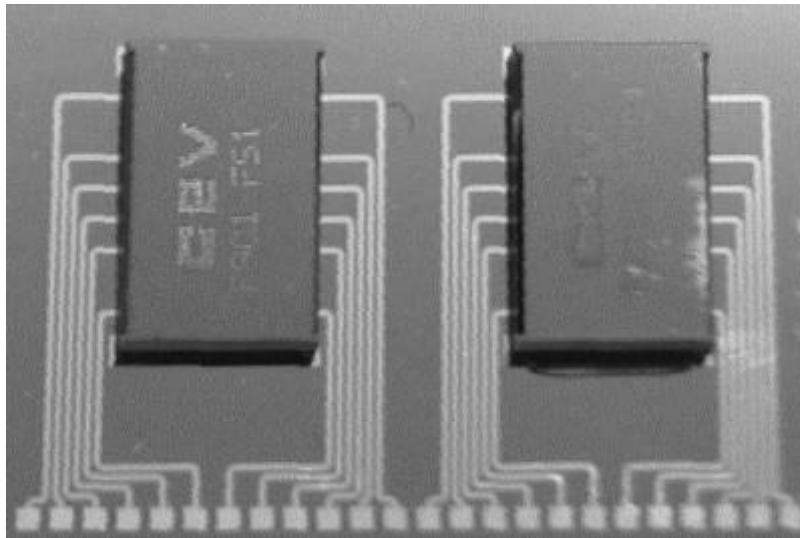


Figure 2: FCM Sensor assembly

2.3 Interconnection issues

The interconnection provides the interfacing between the channel plate and the assembled components in three domains: 1) Fluidic 2) Electrical and 3) Mechanical. The demands for the interconnection are severe. For instance, the fluidic interconnection needs to be leak tight over a temperature range of - 40 to 100 degrees Celsius as well as chemically inert, and has to be able to withstand pressures of 10 to 300 k Pa. At the same time, the electrical connections and mechanical stability must be maintained. To address all these demands, the different functions of the interconnection have been decoupled. This allows individual optimization of each function and avoids the need for unwanted compromises to meet contradicting demands.

Several interconnection technologies, for different application areas, have been investigated, such as soldered interconnection and adhesive interconnection solutions. Examples of all solder solutions for establishing both electrical and fluidic interconnection have been reported by the Universities of Minnesota and Illinois in Chicago [4] and by Fraunhofer (IZM / IPA) and VDMA [5, 6]. However the use of all solder solutions for the interconnection problem have potential problems with corrosion, creep and fatigue of the interconnection. The adhesive interconnection that is used in the demonstrator does not show these problems.

A very robust method to solve issues with degradation of the interconnection is the use of a sealing between the fluidic channels and the interconnection material. This way both issues of leakage and wear down of the interconnection can be addressed. Also chemical inertness can be addressed by proper choice of the sealant material.

The electrical connections are established between flip-chip pads, arranged on the opposing sides of the assembled parts, using a conducting adhesive. The mechanical interfacing is accomplished using an underfilling adhesive.

The chosen interconnection technology provides a flexible, reliable and high performance platform for the cost-effective development of complex fluidic micro devices. Initial reliability tests have shown that the technology can operate for more than 150.000 switchovers at elevated temperatures without leakage or functional degradation.

3 Micro Gas Chromatography

By size reduction of a gas chromatograph to a micro gas chromatograph several advantages can be realized. Smaller sample volumes are sufficient to perform an analysis. The energy consumption of an analysis is reduced. Because of the reduced system volume and column length a faster separation of components takes place and therefore a shorter time of analysis becomes possible.

3.1 Demonstrator μ GC

The demonstrator of choice, shows: (1) The ability to assemble micro fluidic parts with an accuracy better than 5 micron (2) The ability to process fragile components (3) The ability to assemble fluidic interconnects that are inert for chemicals (4) The ability to assemble a thermal stable device, as the gas chromatograph operates at elevated temperatures and (5) The ability to realize a creep resistant fluidic interconnection.

Through the use of modular assembly technology it becomes easy to test small design changes and improvements. Especially changes in the design of the channel plate where flow of gasses has to be optimized, become relative simple. Just changes in the lay-out of the channels have to be done.

3.2 Results obtained with the μ GC

Tests with the realized μ GC have demonstrated the performance and reliability of the developed assembly technology. For the analysis standard gas chromatograph columns were used. From these tests high quality chromatograms were obtained from natural gas (see Figure 3), showing very low dead volume in the system compared to a conventional gas chromatograph. As a result, peak broadening is low and high-resolution separations can be obtained with a relatively short column, thus reducing the analysis time for natural gas.

This very accurate switching of gasses and liquids which is demonstrated in the micro Gas chromatograph is also applicable in other microfluidic areas.

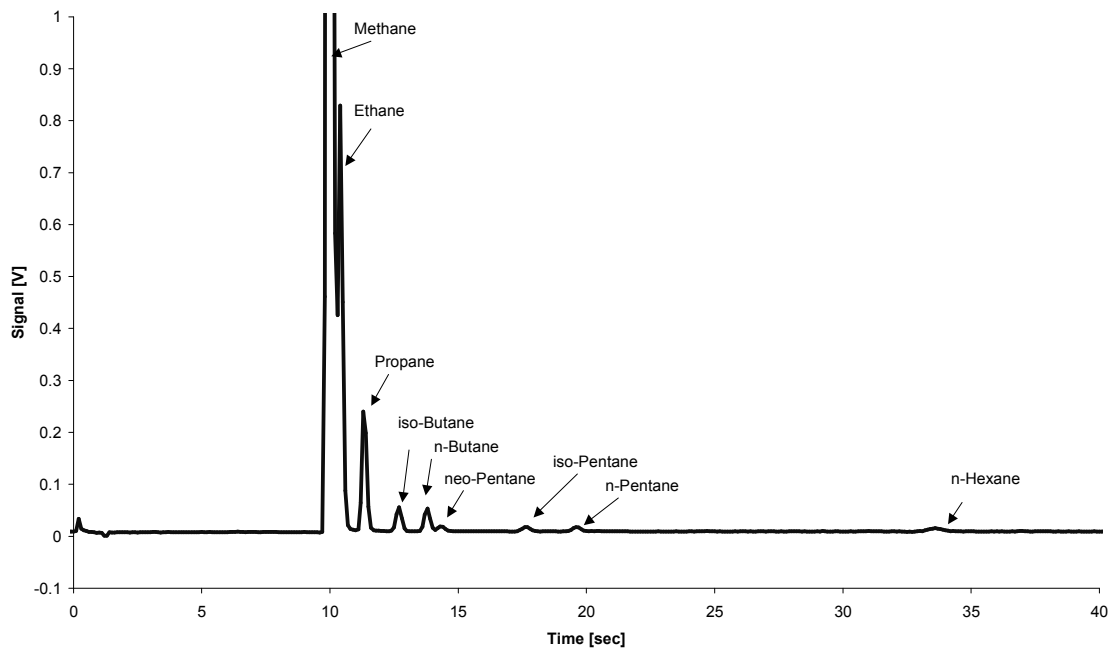


Figure 3 Natural Gas Chromatogram made with a micro Gas Chromatograph

4 Conclusion

A modular assembly technology has been developed where fluidic MEMS components with standard foot-prints can be assembled in such a way that simultaneously electrical and fluidic interconnections are achieved using standardized assembly (flip-chip) and interconnection processes.

With the Fluidic Multi Chip Module technology micro valves and micro sensors become 'off-the-shelf' MEMS components. Which can be designed easily in new micro fluidic products. A development lead time reduction of 50 % and a development cost reduction of 80 % are believed to be feasible based upon experiences with the demonstrator.

5 Literature

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