Modular Design Approach for MicroFluidic Systems

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ABSTRACT

The possibilities promised by microfluidic systems have not only interested scientists, but also industries, especially in the areas of the Life Sciences (food, medical, biotech) and fine chemistry (pharma, cosmetics). Microfluidics is the part of the MEMS-field in which minute quantities of liquids or gases are manipulated, monitored, analyzed, and even processed. Microfluidics based instruments are capable of synthesizing and analyzing (bio)chemical materials at very high throughputs and against reduced costs. These decisive benefits are enabled by the reduced consumption of reagents, shorter temperature cycling times, faster mixing, and the high degree of automation possible compared to conventional equipment. Referring to the size of microfluidics based systems, they are often called Lab-on-Chip systems.

In this paper a modular design approach for so-called 'true' Lab-on-Chip systems for on/in-line and PoC (Point of Care) applications, and an easy-to-use and potentially on-line Capillary Electrophoresis (CE) analysis system is presented.

Keywords: electrophoresis, lab-on-chip, microfluidics, glass, MEMS

1 LAB-ON-CHIP APPLICATIONS

Roughly, one can distinguish two main areas in Lab-on-Chip based systems. In the first place, there are the so-called biochips of glass or polymer, which have passive fluidic functions and which are being applied in combination with bulky laboratory equipment providing functions such as sample and reagent supply, high voltage control for electro-osmotic pumping, and optical (fluorescence) detection. In the second place, there is the emerging area of true lab-on-chip systems, in which all, or at least the main, functions are combined in a complete (sub) system (Fig.1).

Somewhere in-between are the so-called micro-arrays, having an integrated detection function. These systems can be controlled with a notebook PC and combined with other kinds of desktop apparatus, having functions such as sample preparation and supply.

The micro-arrays are revolutionary and very versatile Lab-on-Chip equipment that are being introduced rapidly. In pharmacy and genomics, for example, experiments can be performed by thousands in parallel resulting in more efficient discovery of new drugs and the accelerated unraveling of the human genome (high throughput screening) [1]. In fine chemistry, the optimization of process parameters and production of small quantities is performed in the very same system, bypassing the expensive up scaling stage (process-on-chip) [2]. Other emerging applications are in medical, clinical and other analysis instrumentation.

The range of possible applications for a quick, cheap and portable analysis of any liquid or air sample is beyond imagination; it can give the information technology world electronic taste and smell, monitor water quality in-line everywhere, check for alcohol or drugs in blood or breath on the spot, and many more.

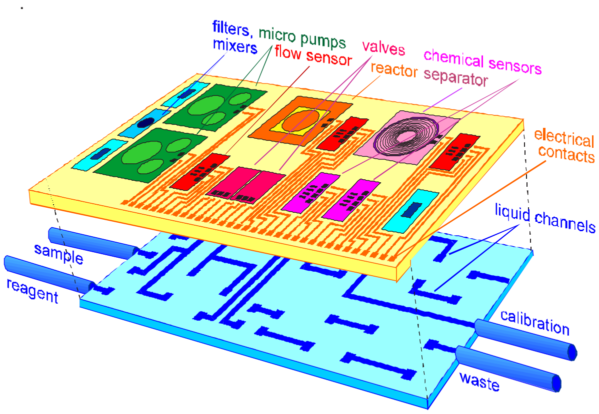

Fig.1 Artist impression of a hybrid μTAS dating from the mid 90's.

2 APPROACH OF MODULAR DESIGN

This chapter will highlight the modular design approach of the emerging area of true lab-on-chips. With help of this approach the potentials and necessity of modular design methodologies which facilitate product development are explained. Also several kinds of application will be given to show the enhanced economical feasibility with the use of modular design.

First the modular and hybrid approach, called MATAS, is defined. MATAS facilitates the realization of complete systems in a flexible and economically feasible way. MATAS is based on established MEMS technology, procedures, and materials and makes short time-to-market possible. Secondly a description is given of an example of MATAS applied to an easy-to-use CE analysis system that became commercially available lately through CapiliX.

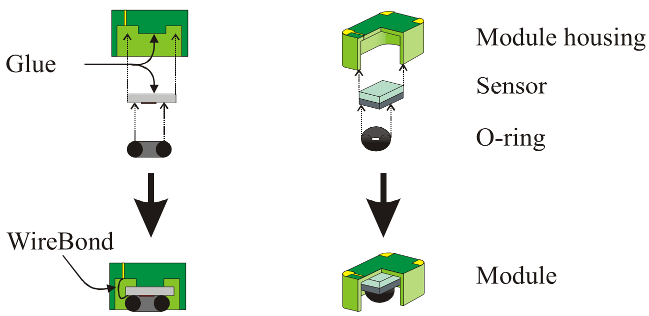

Fig.2 Example of a module for a front sided contact sensor type.

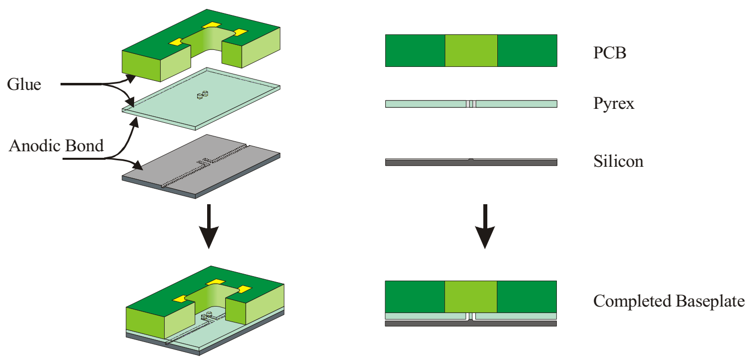

Fig.3 Example of a wet circuit board, where the modules will be mounted.

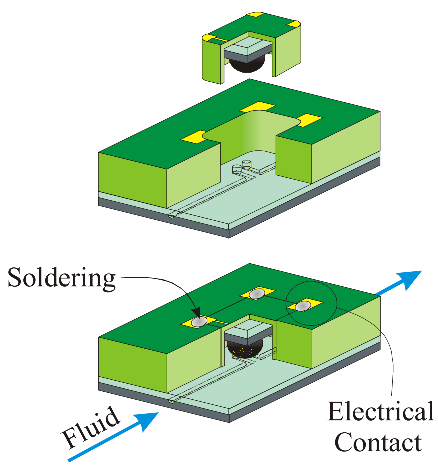

Fig.4 Assembly drawing of the modules and the wet circuit board.

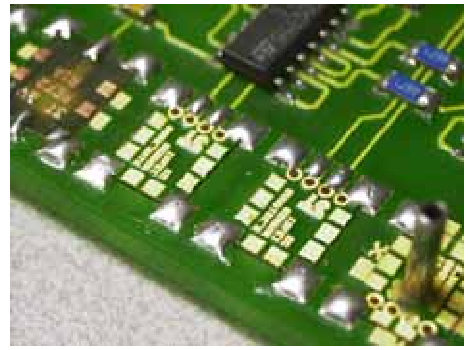
Fig.5 Modules applied in a water hardness detector µTAS [6]. The module on the left is a thick film reference electrode, the two in the middle are a sodium and a calcium module and the right module is an input/output module.

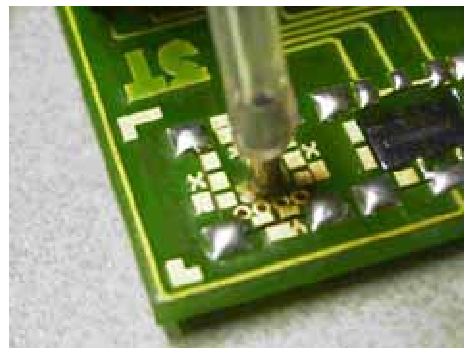
Fig.6 Close up of an input/output module connected to a tube to interface the 'macro world'.


Fig.7 Close up of the fluid side of the water hardness system. The fluidic part is realized in silicon, but it can also be plastic or polymer.

2.1 MATAS technology

MATAS stands for Modular Assembly Technology for micro Analysis/synthesis Systems and is being developed in the framework of a series of projects [3, 4, 5, 6, 7]. The essence of the MATAS technology is a series of modules designed to fit a class of components (micro fluidic functions, sensors and actuators, etc.) that fit into recesses in a surface mounted technology (SMT) based printed circuit board. The board thus becomes a housing for both electrical and the fluidic circuits (Fig.2 and 3 [4]). Figure 4 shows how the modules precisely fit into the circuit board.

Assembling the board involves simply putting the modules in place, as if assembling a simple jigsaw puzzle. Electrical and mechanical connections are made by soldering. The integrity of the fluidic interconnections are assured by small O-rings. All dimensions in the modules are chosen to be easily within the tolerances of the technologies used. The O-rings provide the ability to correct for the different tolerances of the surface mounted technologies used for the layout and the microsystem technologies used for the components.

The electrical layout is situated on one side of the system (Fig.5 and 6). The technology used to interface the components electrically and to fix and align the modules mechanically is situated on this side of the board. The fluidic circuit is situated at the other side of the system, making the total system a planar system (Fig.7). The fluid interconnection between the modules and the fluidic layout is done between the fluidic part and the electrical part; by O-rings inside the system. The fluidic part can be made in any technology of any material, as long as the SMT tolerances are kept.

A first example of a demonstrator system is able to measure the electrical conductivity [7], pH [8], sodium and calcium concentrations [9] of a mineral water solution, while an integrated sensor controls the water flow (Fig. 8). Thanks to the very small volumes of solutions, the system shows a very fast response on variations in e.g. pH and

Fig.8 The water test demonstrator. The different mineral waters enter the pinch valve board on the left, the liquid flows through the cell (attached on the valve board). The sensor signals are entered in the computer and processed on the screen (ACHEMA2000).

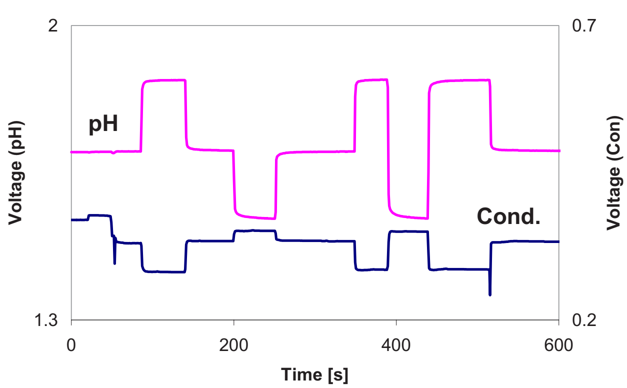

Fig.9 pH and conductivity signals as a function of time for varying step inputs.

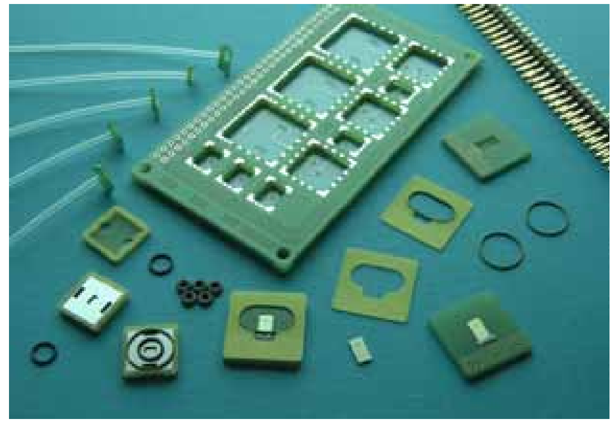

Fig.10 Example showing the parts of a complete system based on MATAS modules with micro components such as temperature, flow and pressure sensors and micro valves.

electrical conductivity reading (Fig. 9).

Another demonstrator system concerns a gas manifold with sensors and valves, applicable in e.g. Flame Ionization Detectors in chemical analysis systems (Fig.10).

2.2 Modular CE analysis system

Based on the previously described MATAS technology, CapiliX developed a completely modular CE analysis system (Fig.11) [10], especially suited for laboratory use. It consists of a microfluidic glass CE-chip that is packaged in a disposable cartridge (Fig.12) and a programmable high voltage supply that can drive 4 separate microfluidic channels.

The system has a modular set-up in the sense it comprises a disposable cartridged CE-chip and a sampling and fluid handling subsystem in the form of a 'docking' station (Fig.13). The CE-chip can also be manufactured having integrated electrodes for electrical conductivity (EC) detection of cations and anions like Na^+, Ca^{2+}, NH^{3+}, PO_4^{3-}, HCO_3^-, etc.

Due to its modular design, the system can be used in combination with commercially available light induced fluorescence detection systems (LIF) as well, making it suitable for any CE-assay application. Also new methods of detection can be integrated on-chip.

The glass chip is fabricated by wet-etching, sand-blasting and bonding technologies using a low-cost mass production foundry. Also the chip cartridge has a low-cost design, making it suitable as a disposable component that facilitates safe and easy handling of this CE-analysis solution.

In the presented form, it is meant for use in R&D laboratories with the main features of being easy-to-use and safe-to-operate compared to the common modus operandi for open chip-based CE-systems. Also the amount of valuable lab bench space is very limited.

With additional (macro) fluidics, developed in cooperation with other OEM, the CapiliX system allows on-line analysis and is particularly useful for monitoring of

Figure 11. Complete CapiliX Capella microfluidic CE system.

Figure 12. CapiliX MCC-1 disposable chip cartridge.

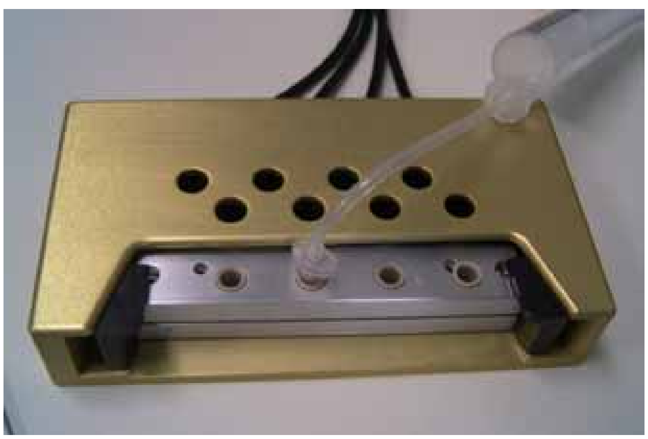

Figure 13. The CapiliX CDS-1 chip docking station holding a MCC-1 chip cartridge (patent pending).

trace elements in continuous-flow production processes in fine chemistry, (waste) water monitoring, etc. The system, being a closed system, is also suitable for applications in a microgravity environment, e.g. for astro- and exobiology.

3 CONCLUSIONS

The market for microfluidic Lab-on-Chip is more and more growing and diversifying. This is economically enabled by modular design methods that make adaptation of existing technology to certain new applications easy, reliable and safe.

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