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Fluidic microsystems based on printed circuit board technology

Ansgar Wego, Stefan Richter and Lienhard Pagel

University of Rostock, Department of Electrical Engineering and Information Technology, Graduiertenkolleg, Richard-Wagner-Strasse 31, 18119 Rostock, Germany

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Abstract
In this paper, fluidic microsystems based on an alternative fabricating technology are described. This technology mainly utilizes the manufacturing principles of printed circuit boards (PCBs). Minimal lateral structure dimensions of approximately 100 μm und vertical dimensions of some 10 μm are feasible. By introducing thin polymeric foils (6–13 μm in thickness) into a stack of PCBs, movable parts forming active or passive valves, pumps or sensors can be produced. The first results concerning several fluidic components based on PCB technology are presented.

1. Introduction

Today, most of the fluidic microsystems are fabricated using either silicon micro-machining or LIGA-technology. The possible structural dimensions attainable by means of these technologies are rather small. But in microfluidic systems in normal cases there is no need for such small dimensions. That is why other technologies with less accuracy and therefore lower costs can also be used for the fabrication of miniaturized fluidic components. For that reason, intensive investigations into the manufacturing of fluidic microsystems using the printed circuit board (PCB) technology have recently been carried out.

Sensors, actuators and electronics have to be combined to create microsystems. That is why the system integration is essential. The system approach can improve the quality of products concerning their reliability, performance, volume and cost [1].

In contrast to previous works on PCB-based micro-fluidic systems [2–4] the method described here has the advantage that all the fluidic components arise within the PCB fabrication process as an integral part of the multilayer, that means no separate process steps are required. Furthermore, all the electronics necessary for sensing, analysing or controlling the fluidic properties can be placed onto the same PCB.

2. Principle of fluidic microsystems based on PCB-technology

The basic idea of PCB-based fluidic systems is to modify the well known multilayer technology utilizing conventional double-sided copper-plated rigid base material (FR4). To create fluidic channels the copper of the PCBs is structured (by chemical wet etching) forming the lateral borders of the channel. By stacking one structured PCB upon the other the vertical borders of the channel are created. Figure 1 schematically shows the principle.

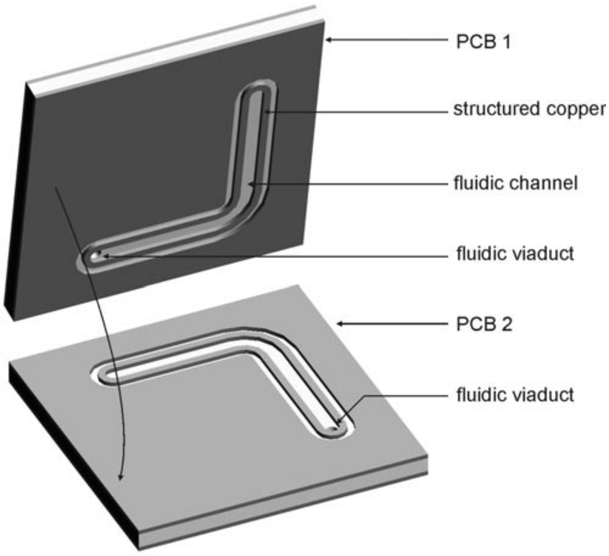

Figure 1. Principle of fluidic microsystems based on PCB technology.

The thickness of the copper and the total thickness of one PCB are selectable (18–105 μm copper 100–1500 μm total, respectively). For connecting the single PCBs, a special

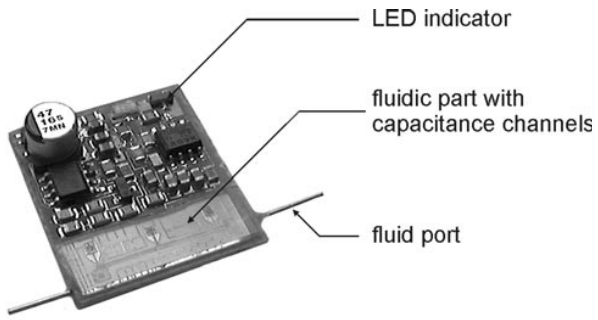

Figure 2. Capacitance bubble detector in PCB technology (dimensions: 22×25 mm^2) [6].

adhesive technique has been used. The single boards are dipped into an adhesive liquid of certain viscosity (epoxy resin solved in ethanol, the viscosity approximately equals 3–6 mPa s) and coated with a thin uniform adhesive film (2–6 μm) by pulling them out of the solution with a constant velocity. Subsequently the adhesive is cured under the application of temperature and pressure. This technique ensures a tight connection of the PCBs and maintains the fluidic functionality of the channels without reducing the channel height significantly (2–6 μm) [5].

3. Fluidic components based on PCB technology

3.1. Capacitance bubble detector

Many technical, medical and biological systems respond very sensitively to gas bubbles in fluids. It is quite common to obtain incorrect experimental results. At worst, the systems fail to function. A bubble detector can give a warning if gas bubbles are detected.

The bubble detector was the first realized fluidic component [6]. It consists of two capacitance channels in a row. If a bubble appears in a fluid current, the first value of capacitance will change while the second value will remain constant. When the bubble leaves the first channel and arrives at the second channel, the relations will be reversed. The electronic circuit of the bubble detector compares both values of capacitance. If they are different, a LED indicates a detected bubble. Figure 2 shows a photograph of the bubble detector.

3.2. Microfluidic pH-regulation system

The microfluidic components for a pH-regulation system based on PCB technology are presented in [7]. A pH-regulation system can be used for biological cell culture systems. It basically consists of a fluidic and an electronic part. A chamber contains cultured cells for optical and electrical monitoring. A micropump allows the nutrition of the cultured cells. For long-term cultivation, a stable physiological environment is necessary. Therefore, the pH-value of the nutrition medium must be controlled. This is realized by an optical sensor and a CO_2-diffuser (see figure 3). The signal analyses are done by a micro-controller in the electronic part of the system.

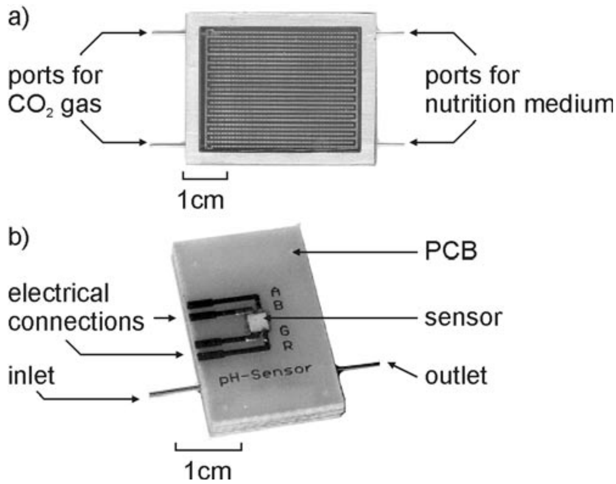

Figure 3. Fluidic components of a pH-regulations system [7]: (a) CO_2-diffuser; (b) optical pH-sensor.

3.3. Micropump

A new quality of fluidic components in PCB technology has been achieved by introducing thin flexible polymeric foils into the PCB stack. These foils consist of polyimide (Kapton®) with a thickness of 8 μm. To build the pump, four double-sided 70 μm copper-plated PCBs (with a total thickness of 800 μm) were mechanically and wet-chemically structured. The foil was clamped into a special handling system (structured rings) to allow the processing (structuring, coating, cleaning and positioning) of the foil. After mounting the heater into the actuator chamber, all parts were cleaned. Subsequently the PCBs and the foil were coated with adhesive and stacked into a positioning system. Finally the PCB stack is put into a thermopress to cure the adhesive. Figure 4 schematically shows a cross section of the micropump.

By switching on the heater, it dissipates electric power and causes an increase of temperature in the chamber. That forces the chamber pressure to rise and subsequently leads to a movement of the membrane decreasing the pump chamber's volume. The resulting over-pressure closes the inlet valve and opens the outlet valve simultaneously driving the fluid out of the chamber to the outlet. Cooling down the heater lets the actuator membrane return to its initial position. The volume of the pump chamber increases closing the outlet valve and sucking in an amount of fluid through the inlet valve. Periodical repetition of these processes induces a pulsating fluid flow from inlet to outlet.

A typical measured flow versus back pressure curve of a PCB micropump delivering water is depicted in figure 5. The pump shows a linear dependence of the flow on the applied back pressure. The maximum flow rate of approximately 470 μl min^{-1} is achieved without back pressure. The flow stops at a back pressure of approximately 135 hPa. The driving frequency and the mean power consumption of the pump averages 0.9 Hz and 900 mW, respectively.

The outer dimensions of the PCB pump without electronics measures $14 \times 17.5 \times 3.2$ mm^3. A photograph of a delivering pump with integrated electronics is shown in

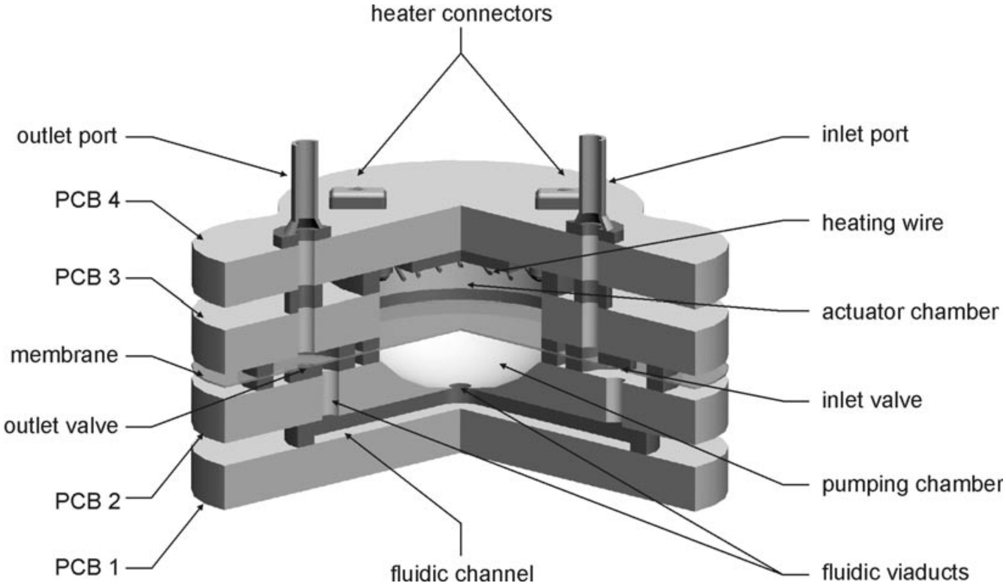

Figure 4. Cross sectional scheme of the micropump built with four PCBs.

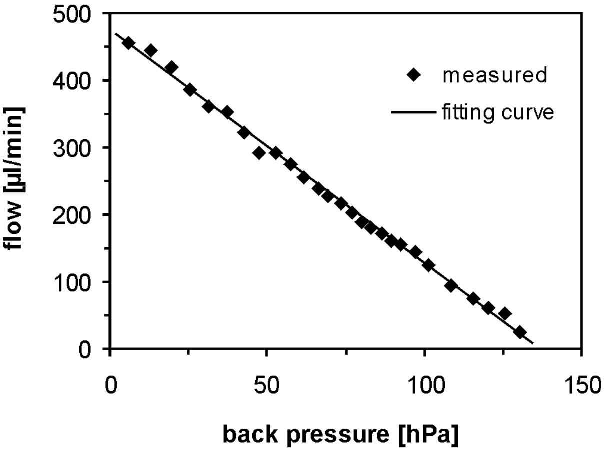

Figure 5. Typical flow versus back pressure curve of a (water) delivering PCB micropump.

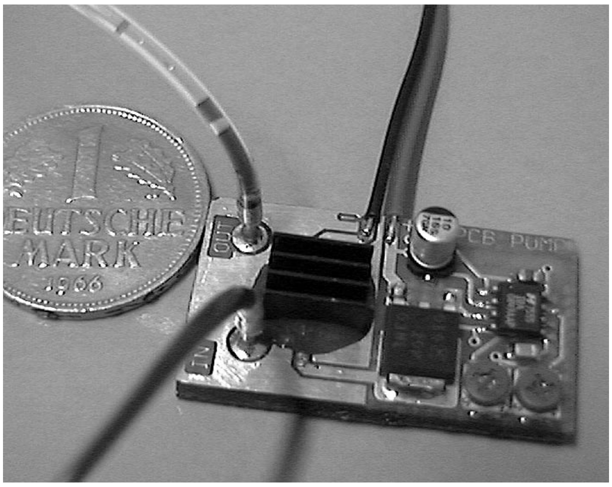

Figure 6. Photograph of a micropump with integrated electronics built in PCB technology.

figure 6. The pumps reach a compression ratio of up to 30% and thus are tolerant of gas bubbles in the liquid and capable of self-filling.

3.4. Capacitive pressure sensor

The structure of a capacitive membrane sensor for pressure measurement is schematically shown in figure 7. It consists of three PCB layers with an intermediate flexible foil layer forming the membrane. The first board contains a horizontal fluid channel for connecting the reference pressure port to the sensor chamber located in the second PCB layer. A height difference between the static electrode and the other wires is produced either by milling or by selective electroplating and defines the spacing between the electrodes of the measuring capacitance. The moveable electrode is formed by a membrane made of a polyimide foil of 8 μm in thickness coated with a 20 nm thin film of aluminium by sputtering. A via in the third PCB layer allows the thin film electrode to be contacted. Besides that the board contains the pressure chamber and carries the fluidic and electric connectors.

The metal layer on the membrane surface and the fixed electrode in the sensor chamber form a capacitance. A pressure difference between the pressure and sensor chambers leads to a deformation of the membrane changing the electrode spacing and as a result of this the sensor capacitance.

Figure 8 shows a laboratory sample of the sensor described. The sensor has a nominal capacitance of 22 pF and a nearly linear behaviour in the pressure range of −5 to +15 hPa with an average sensitivity of 1 pF hPa^{-1}. By simply scaling the dimensions the pressure range of the sensor can be changed.

4. Conclusions

In this paper, the first results of fluidic microsystem components based on printed circuit board technology are presented. The capabilities of this technology have been

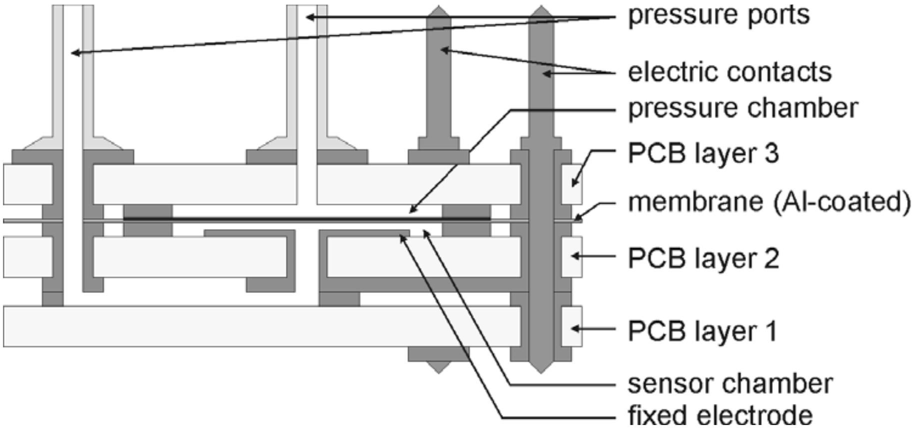

Figure 7. Schematical drawing of a capacitive pressure sensor based on PCB technology.

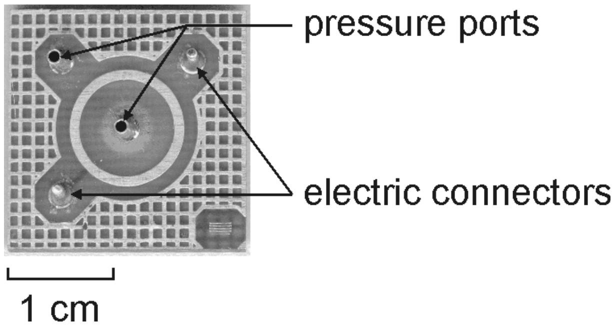

Figure 8. Photograph of a capacitive pressure sensor built in PCB technology.

demonstrated by several examples. A capacitance bubble detector able to give a warning if gas bubbles are detected and two components for a pH-regulation system keeping the physiological environment of cell cultures stable have been described. A micropump with integrated control shows features like self-filling and insensitivity to gas bubbles. Furthermore, a PCB-based sensor for pressure differences featuring a high nominal capacitance and a high sensitivity has been described.

The examples show that this technology provides a potential for the cost-effective production of integrated fluidic systems. Thus, it can be an alternative to traditional technologies in some fields. For instance, a study on the integration of the pump described into the life support system of a tissue sensor is in progress.

Acknowledgments

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