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Socket with built-in valves for the interconnection of microfluidic chips to macro constituents

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Abstract

This paper reports a prototype for a standard connector between a microfluidic chip and the macro world. This prototype demonstrate a fully functioning socket for a microchip to access the outside world by means of fluids, data signals and energy supply. It supports up to 10 channels for the input and output of liquids or gases, as well as compressed air or vacuum lines for pneumatic power lines. The socket has built-in valves for each flow channel. It also contains 28 pins for the connection of electrical signals and power. Built-in valves make it possible to control the flow in each channel independently. A chip (11.0×11.0×0.9 mm) can be mounted into or dismounted from the socket with one touch. The fluidic connectors of the socket are designed to contact vertically on the top of chip. And the electrical connectors (the spring array) of that physically support the chip and contact lead pads at the bottom of chip. No adhesives or solders are used at any contact points. The pressure limit for the connection of working fluids was 0.2 MPa and the current limit for the electrical connections was 1 A. This socket supports both serial and parallel processing applications. It exhibits great potential for developing microfluidic systems efficiently.

Keywords: Chip technology; Instrumentation; Microfluidics

1. Introduction

With the development of micro-electro-mechanical systems (MEMs), microfluidic applications have increased in importance since the 1990s. A great deal of effort has been devoted to integrate the functions of sample pretreatment, separation and detection onto one chip. Methods for creating networks of microchannels are well established in silicon, glass and polymeric substrates, using etching or molding processes. PZT-actuated micropumps and micromixers have achieved excellent performance and various microsensors have also been reported. These have been well reviewed by Reyes et al. [1] and Auroux et al. [2].

As commercialization of MEMs and microsystems gains momentum, product packaging has also gained increasing attention within the industrial and research communities. Packaging of a MEMs device generally takes up 50–90% of its cost, with 80% the norm [3]. Not surprisingly, packaging has been a major stumbling block in capitalizing the full market potential of microengineering products.

Generally, there are four steps: design, fabrication, packaging and testing, for proof-of-concept prototype development. In our experiences of mi-

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crofluidic device developments, packaging is the lowest efficient step. We have presented our first packaging solution [4]. It concerns process visibility greatly. The top of chip is totally opened to microscopic observation. However, the dicing dusts in flow channels are difficult to avoid. Because dicing process is for not only separating each chip but also the finally forming of fluidic connecting ports on the sidewall of the chip. For ordinary microchannels or micromixers, dicing dusts make tiny effects on their performances. Dicing dusts do not clog micro flow channels. For microvalve application, however, it needs extremely particle-free environment to avoid leakage. Therefore, the flat fluidic connection socket is not suitable for microfluidic devices with built-in microvalves.

In this paper, another type of interconnection socket was reported. This socket was designed for the microfluidic chip that needed vertical fluidic connections. With its built-in valves, this socket supplies a way to control the flow in each channel independently. The socket is shown in Fig. 1.

2. Materials and methods

2.1. Design of the module for working fluidic connections

For the input/output (I/O) of working fluids, a dual inline structure is formed on a transparent acrylic plate. It consists of two five-channel linear arrays. Thus 10 channels are available in total and the pitch is 2.2 mm (Fig. 1). Silicone tubes were chosen as the wetting material. Each silicone tube has an inner diameter of 0.5 mm and an outer diameter of 1 mm. The silicone tubes are designed to extend 0.6 mm above the surface of acrylic plate. The extended tubes work as O-rings to make reliably fluidic connection to microfluidic chip (Fig. 2).

The valves are realized using the screws on the top of the socket. These screws are in a diameter of 1.6 mm. A ball in a diameter of 1.2 mm is inserted between each screw and the silicone tube beneath.

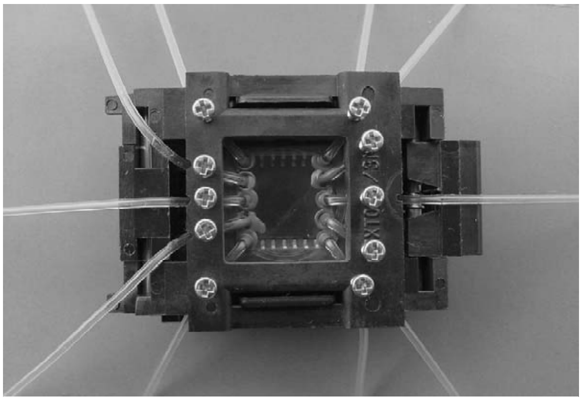

Fig. 1. Photo of the socket. The silicone tubes for fluidic connection are in dual-in-line structure with a pitch of 2.2 mm. There are 10 channels available for I/O of working fluids. The screw over each silicone tube works as a valve. This socket is for the fluidic chip in the size of 11.0×11.0×0.9 mm.

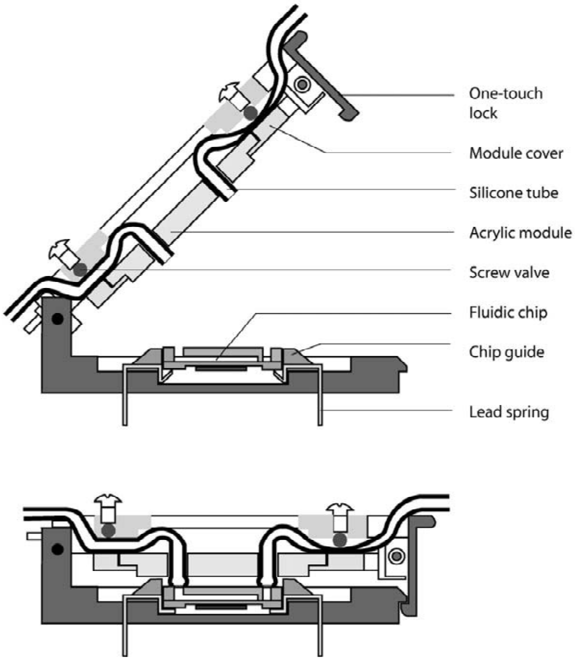

Fig. 2. Schematic drawings of the cross-section of the socket mounted with a fluidic chip (not scaled). The upper part shows the structure of the socket. The silicone tubes are extended a little out of the acrylic plate. In the screw valve, a ball is inserted to avoid the damage directly from screw to silicone tube. The chip for testing is aligned easily following the guides and is supported by the lead spring array. The bottom part shows the state for testing. The extended silicone tubes are deformed and serve as O-rings to seal the flow channel ports on fluidic chip. The spring array for electrical connection is contacted firmly to the lead pads formed on the backside of the chip. Both working fluidic and electrical connections are adhesive/solder-free. These structures made it efficiently to mount or dismount a microfluidic device.

2.2. Design of electrical interconnections

For the electrical I/O, the design of leadless chips and chip carrier sockets were chosen, as shown in Fig. 2. A standard IC testing socket (228-4960-00-1102, Sumitomo 3M, Tokyo, Japan) was modified for this purpose. Twenty-eight pins are located at the bottom of the socket, to make contact with the backside electrodes of the chip. The pitch of the spring is 1.27 mm. The current limit rating of each pin is 1 A and the contact resistance is less than 20 mΩ.

3. Results and discussion

For the R&D proof-of-concept, a convenient, reliable and multichannel interface is required. The socket presented here shows one solution for these requirements. Our socket supports electrical and working fluidic I/O. The physical protection of microfluidic chips, such as wire bonded connections, were also considered. It supports both serial and parallel processing applications.

Here we present a socket vertically connected the ports on the top of chip. A 100-mm diameter glass wafer with through-holes was used to fabricate microfluidic devices as the top wafer. The thickness of the glass wafer is 0.5 mm and the pitch of through-holes is 2.2 mm. Each hole is in the diameter of 0.5 mm. The glass surface with holes is protected by a dicing film during dicing process. Therefore, particle-free microfluidic devices are realized. A microvalve fabricated in this method is shown in Fig. 3.

3.1. Fluidic and electrical connections of the socket

The socket presented was for testing microfluidic device in the stage of prototype development. The flexibility and reusability are the critical properties for testing process. Unlike final commercial products, chip sizes in the reported microfluidic test pieces vary from several millimeters to a whole 200-mm diameter wafer. The chip size, which can be handled directly by hand, is preferred for prototype development. Our socket has two versions to fit for the chip in the size of 11.0 mm square (Fig. 1) and 6.6 mm square (Fig. 3), respectively.

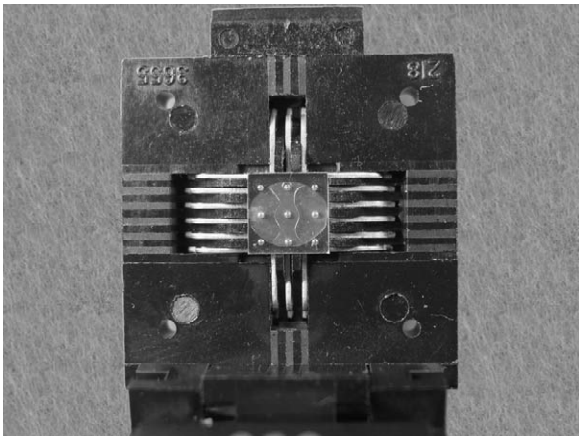

Fig. 3. Photo of a microfluidic valve mounted in a socket. The socket has only eight fluidic channels and 18 springs for electrical connections. The chip size is 6.6×6.6×0.9 mm. The top glass part of the microvalve has through holes with a pitch of 2.2 mm.

The socket was designed for mounted with a bare chip directly. Traditionally, O-rings are widely employed for fluidic leakage controlling. However, handling small O-rings for microfluidic applications are quite time-consuming. Most leakage failures are related with O-rings. The 0.6-mm long extended silicone tubes serve as O-rings in our socket (Fig. 2). Manually handling individual O-rings is not required. With these designs, the chip/socket construct can be assembled with one touch. And no initial failure was observed in either fluidic leakage or electrical mismatching. This structure ensures a reliable fluidic connection to the chip. When 0.2 MPa were applied to each line, no leak of water was observed. Silicone was chosen as the wetting material for its excellent chemical resistances to ordinary acid, alkaline and organic solutions. Physically, it is elastic. It could relieve mechanical stresses during the assembly process. The silicone tubes also worked as flow pulse dampers in a flow circuit.

Comparing with electrical circuits, microfluidic circuit is in the infant stage. The industrially standard interface is not available yet. It is important to have flexibility to be compatible with various microfluidic designs. In our socket, the fluidic connection part is an exchangeable module (Fig. 4). By changing to another module with one touch, the socket will still

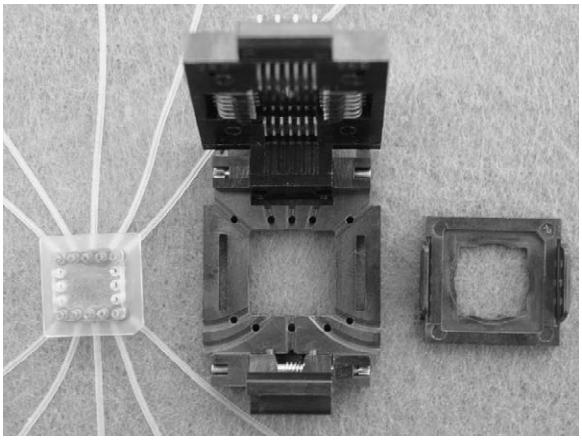

Fig. 4. Photo of the exchangeable module for fluidic connection in the socket. (Left) The fluidic connection module can be various in thickness or pitch to fit for the chip with different fluidic designs. (Middle) The socket frame. The grooves are the guides for silicone tubes and the hole under each groove is for the screw valve. (Right) The cover for the acrylic module.

work for the chips with different thickness or pitch of fluidic ports.

Adhesives or solders are avoided from all fluidic or electrical contact points. A testing sample could be mounted into or dismounted from the socket with one touch. These structures greatly increase the efficiency for testing microfluidic devices.

With the help of this socket, a complete fluidic circuit (containing various functional components, for example: micropumps, microvalves, flow-rate regulators and micromixer) could be assembled easily. More importantly, these fluidic circuits showed great freedom for changing flow channel connections or to add/remove any functional components. Trail and error cycles are unavoidable at the stage of prototype development.

3.2. Built-in valves for each flow channel in the socket

In general, functional elements are integrated into chip and the socket only supplies interface to connect outside. With the development of microfluidic research, flow controlling in microfluidic devices will depend on microvalves. At the present of time, however, microvalves, especially the valves for liquid applications, are still under development. There are successful pneumatic driven microvalves [5] but they are basically microfabricated sealing structures. The on/off of pneumatic lines are still controlled by normal size valves. Therefore, screw valves are built-in our socket. They are simply, well-integrated and easy to control. The most important, they are reliable. To avoid the damage of silicone tube by screw, a ball is inserted between each screw and silicone tube beneath.

3.3. Considerations of visible flow channels

Visible fluidic channels are important to check the positions of clogging, leakages or gas bubbles. Unfortunately, process visibility is not fully supported with this socket. Geometrically, the silicone tubes shutter part of the top area of chip. The visible area is restricted only in the center part of the chip. Because the fluidic connection module covers the top of chip, it is also difficult to observe the chip below with ordinary microscope in high magnitude. The working distance of the lens is just not longer enough. The objective may even interferences with the screws on the top of socket. Furthermore, there is a gap of hundreds micrometers between chip and acrylic plate due to the existing of the extended silicone tubes (Fig. 2). Visibility decreases because of the reflection at the gap.

However, optical observation is still possible because transparent acrylic plate is used. Visibility will be improved by filling a liquid into the gap. Using optical fibers is an alternative. There is also enough space for fixing optical fibers.

3.4. Design considerations for testing chip

The fluidic connection module we used was designed for the chip in anodic bonded structure of glass (0.5 mm thick) with silicon (0.4 mm thick). Because of the difficulties to open through holes in glass or quartz using microfabrication techniques, the wafer with through holes drilled by traditional ultrasonic method was used. PDMS or plastic substrates have better compatibility with our socket for fluidic connection. However, electrical circuits are not easy to be formed on such flexible substrates.

Electrical circuits could be formed on silicon or glass using standard photolithographic processes. However, the design of our socket restricted the final electrical lead pads to be formed on the backside of the chip. This restriction made it difficult to use our socket directly for the electrophoretic or electroosmotic applications. Those applications need the electrodes to be formed inside flow channels, rather than on the surface of microfluidic chip. These problems could be overcome using through-hole technique. With the development of ICP technologies, through holes can be formed easily on silicon substrate. The method to metallize through holes in silicon has been reported [6]. A low melting point alloy (indium alloy, melting point: 90 °C) is heated up to 120 °C in a vacuum box. After glass/silicon bonded wafer is put onto the melted alloy, the vacuum box is vented and the alloy casts into through holes naturally to make the interconnections between the electrodes in the layer of fluidic channels and the circuits on the backside of wafer. It is a relatively low temperature process and is compatible with the polymer structures using silicone or polypropylene. The alignment marks for dicing processes should also be specially concerned. They should be formed on the side with electrical lead pads. Therefore, the fluidic connection ports can be protected by dicing tape. Dicing dusts would not be a problem for fluidic circuits any more.

4. Concluding remarks

Currently, microfabrication processes are highly productive but packaging of microfluidic devices is hindering faster prototype development and market applications. Large numbers of test chips are discarded, without packaging or testing, because of a lack of an efficient packaging solution. A standard interface for fluidic MEMs prototype development has been investigated. It supplies multiple I/O channels for working fluids as well as electrical signals and power supplies. Built-in valves supply an easy access to control the flow in each channel. Besides testing applications, the socket may also be embedded into final products which use disposable microfluidic chips. The socket presented here was not autoclavible.

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