MICROGASKETING AND ADHESIVE WICKING TECHNIQUES FOR FABRICATION OF MICRO FLUIDIC DEVICES

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ABSTRACT

Microgasketing procedure, developed for MEMS fluidic device fabrication, is described. Planar-processed microdevices of a volume even less than 1 nl can be selectively filled with liquid and sealed at room temperature in a batch fashion. Isolating a liquid within such a small device area by the gasketing and minimizing air traps during sealing by controlled wicking are the key issues addressed. Two unique microdevices made possible by the described technique are presented: 1) a microrelay switched by a liquid-metal droplet (10 μm in diameter), and 2) a highly efficient (e.g., power consumption < 10 μW with driving potential < 10 V) liquid micromotor driven by surface tension force.

INTRODUCTION

Typical micro fluidic devices with closed liquid reservoir contain liquid volumes ranging from μl to ml. The normal practice is to first fabricate the microdevice structures and then fill them with a liquid by capillary action. However, there are situations where the capillary filling approach cannot be used (for example, the liquid may not wet to begin with, or plugging process may not be acceptable). Especially for such devices as presented in the later sections, the difficulty lies with placing liquid-metal droplets on certain locations inside the closed microdevice and filling it with a wetting liquid. Our approach is to place the liquid-metal droplets on desired spots on an open device area, flood the surface with a wetting liquid, dry the liquid outside the device area that is defined by the microgasket.

After isolating the liquid inside the device area, the substrate and the cover should be bonded together. The presence of liquids severely limits how bonding is performed, however. Even a "low-temperature" bonding technique uses temperatures too high for many liquids. Another set of sealing techniques on a chip level (e.g., LPCVD sealing) typically involve vacuum in the process and are of course not acceptable. Spin coating of an adhesive layer is not readily acceptable since the coating covers the whole die area. Our choice is to use the epoxy adhesives, which are curable by ultraviolet (UV) light at room temperature. Although the adhesives can be easily drawn into the gap between the substrate and the cover, trapped air pockets are unavoidable especially near the gasketed device area at the center of the die, where

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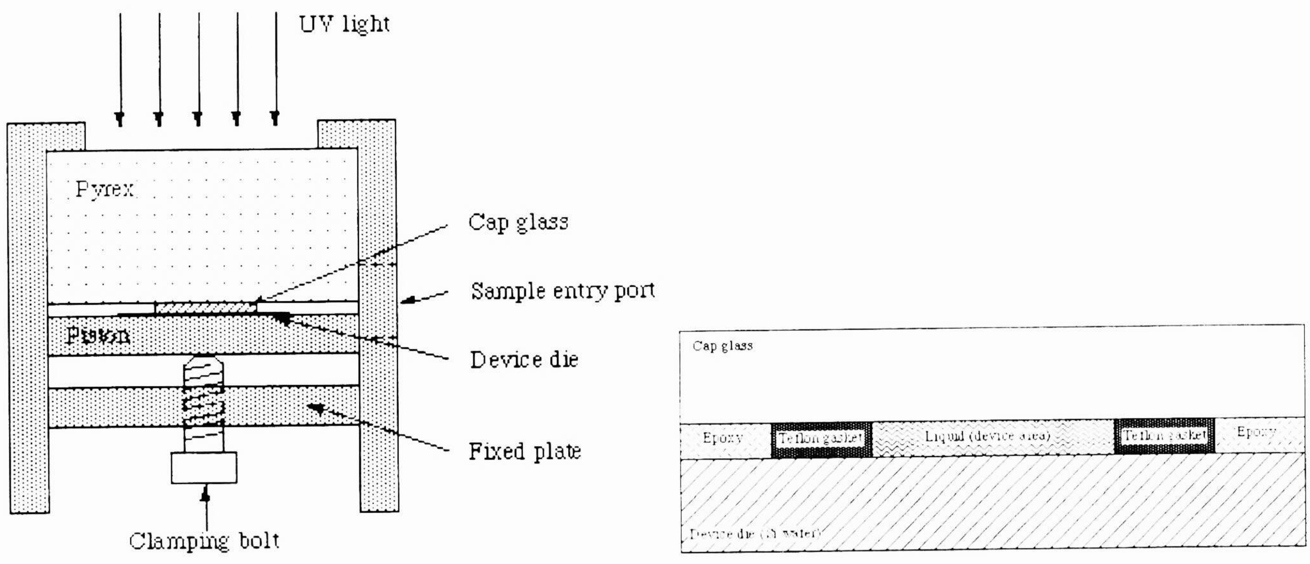
sealing is most important. The idea of wicking microchannels turns out to be critical in obtaining reliable sealing.

MICROGASKETING

Adhesive bonding is generally convenient if implementable for the given device [1], since it uses relatively low temperature and does not require the two mating surfaces to be completely flat or in perfect contact. The critical issue for our situation is process compatibility due to the fact that we wish to have liquid inside the device and adhesive outside the device. Furthermore, the process should be carried out at room temperature or at least well below the boiling point of the filling liquid. These requirements severely limit the ways in which adhesive can be applied and therefore calls for a new approach.

We have developed a successful process for permanently sealing the liquid-filled devices using an adhesive bond combined with a patterned Teflon gasket as part of the device fabrication. Teflon is spin coated onto the wafer and patterned by oxygen plasma to form a gasket. The microgasket defines the area to be filled with liquid. After the device is flooded with liquid and covered with a glass cap, the die and cap glass are placed in a clamp, which compresses the Teflon gasket and creates a seal. Sealing with the clamp is shown schematically in Fig. 1(a). The clamp is cylindrical in shape and made of machined aluminum. The sample (cap glass placed on a soaked device die) is loaded through a milled entry port in the side of the cylinder and clamped by movement of a central aluminum piston. The clamping bolt is tightened, pressing the die against the cap glass backed by a thick (1") Pyrex glass block, which provides both mechanical rigidity and optical transparency.



(a) (b)

Fig. 1. (a) Clamping setup developed for device sealing using UV curing epoxy.
(b) Liquid-filled gasketed area sealed with epoxy (cross section view).

The liquid outside the gasketed area is dried (typically in 4-5 hours) in air, while the area inside the gasket remains wet (even for weeks). The dried area outside the gaskets is to be filled with an optically curing adhesive, which is an epoxy or acrylic resin that is cured at room temperature by exposing to a high intensity UV source. The epoxy is cured by exposure to a 0.3 W UV source for several minutes. Figure 1(b) shows a schematic cross section of a sealed die.

Figure 2 shows a photograph of a sealed test gasket. Water (A) is inside the gasket, while the outside area is filled with epoxy. The presence of bubbles in the epoxy (outside the devices) is not desirable since we would like the maximum bonding surface possible. To help minimize this problem, we have added wicking channels around the perimeter of the die. Sealing was not successful before the wicking channels were devised due to the large air pockets trapped at the center of the die. These wicking channels will be discussed in more detail in the following section.

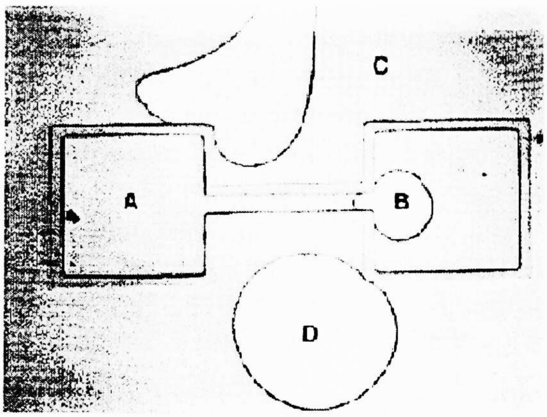


Fig. 2. . Sealed test gasket with water inside (A) and epoxy outside (C). Air pockets (B and D) are trapped inside and outside the structure. Outside the gasketed area would have been completely surrounded by a large air pocket if no wicking has been used. More elaborate wicking would reduce the air pocket further.

ADHESIVE WICKING

Simple application of a sealant around the edges of the die pair was found to be problematic. Devices sealed in such a manner tend to leak after the clamp is removed. Bonding quality is compromised by the existence of large air pockets randomly formed at the center of the die. An adhesive needs to penetrate uniformly throughout the die, including the area near the devices, to maintain good bonding and gasket seals. Although low viscosity of the adhesive helps penetration, it alone does not solve the problem of air trapping. To achieve penetration of the adhesive in a controlled manner, we introduced the idea of wicking channels. A series of Teflon lines are patterned around the edge of the die, fabricated in the Teflon gasket layer, resulting in about 2 μm tall, 80 μm wide channels which aid in drawing the adhesive into the center of the die. They also function as a spacer so that a more constant gap between the device die and cap is maintained across the die. A drop of adhesive is wicked into the die by the long narrow channels to the desired central portion of the die and leaves few air pockets. The main goal of designing wicking microchannels is to direct adhesive flow from the central area to the die edges, not the usual case of from edge to center. Many elaborate designs of wicking channels have been employed, including the one in Fig. 4.

EXAMPLE 1: MICRORELAY FABRICATION

A micromachined mercury relay of an extremely small (< nl) volume filled with a dielectric liquid (see Fig. 3) has recently been reported [2]. The device consists of a bulk-etched throat connecting two reservoirs with suspended heaters. A small droplet (10 μm diameter) of a liquid metal (e.g., mercury) is placed in the center of the throat near a set of disconnected electrodes, and the device is operated by heating one reservoir, which grows a bubble and forces the mercury drop onto the electrodes, completing a circuit. The circuit can be opened by activating the other reservoir. Operation of the relay has been first demonstrated using temporary sealing with a glass cover pressing on the wafer in [2]. However, the device tended to leak, and a more reliable and permanent sealing method was eventually obtained when wicking channels were added [3].

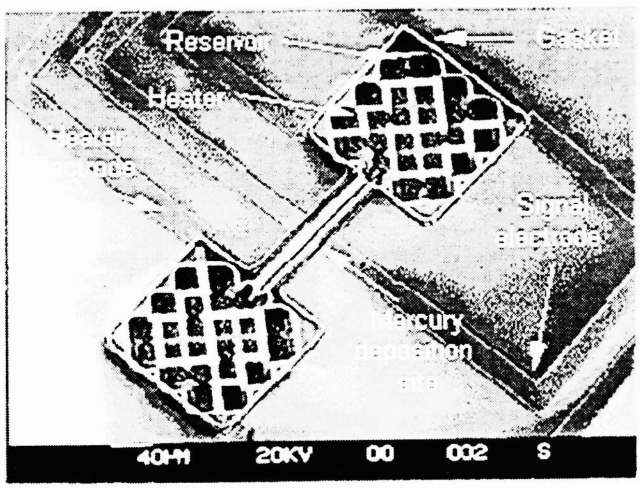


Fig. 3. SEM of microgasketed relay before sealing.

EXAMPLE 2: MICROACTUATOR BASED ON SURFACE TENSION DRIVING

The first MEMS device that employs the so-called "continuous electrowetting" phenomenon has been realized as a liquid micromotor by the microgasketing process [4]. The continuous electrowetting uses local variation of surface tension to generate motion. The liquid micromotor implemented this concept and demonstrated a continuous travel of mercury drop along the circular channel. The mask layout of the device reveals the design of adhesive wicking path in Fig. 4.

The maximum speed of 9.4 cm/s was achieved at below 10 V (currently less than 2 V) with favorable characteristics such as smooth and wear-free motion. This active use of surface tension has advantages for micromachines compared with other types of actuation mechanisms. First, the surface tension dominates other types of forces in microscale. Secondly, the created motion is continuous liquid motion, innately eliminating the problems of friction and wear, which often limits the long-term operation of many other microdevices. Applications include memory device, microrelay, optical switch, and inertia devices.

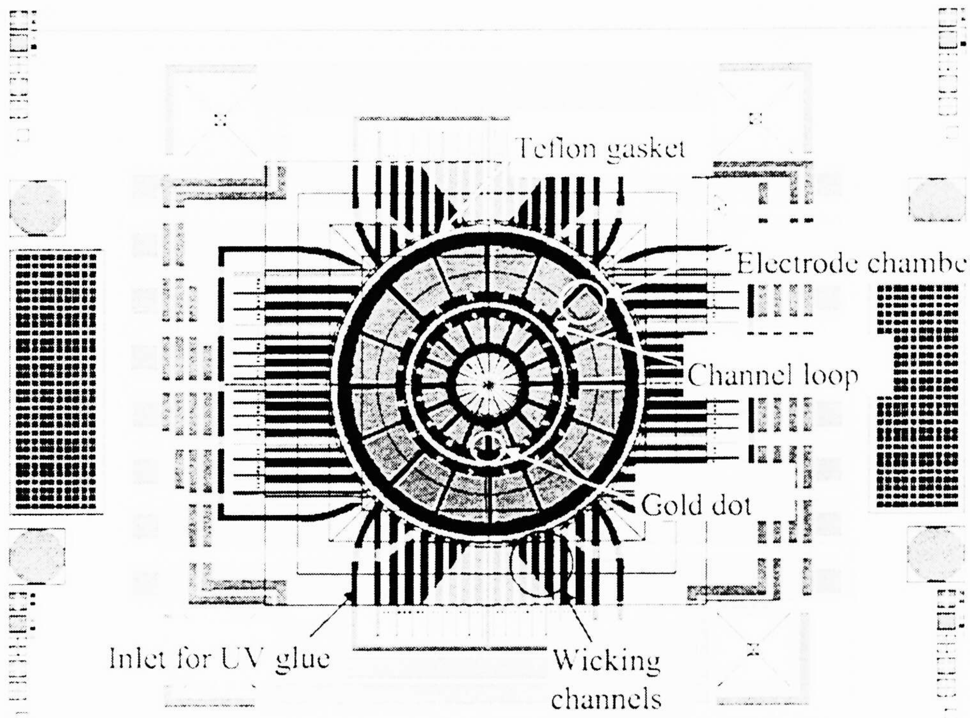


Fig. 4 Mask layout for liquid micromotor. Note the inlet guide for UV glue and wicking channels

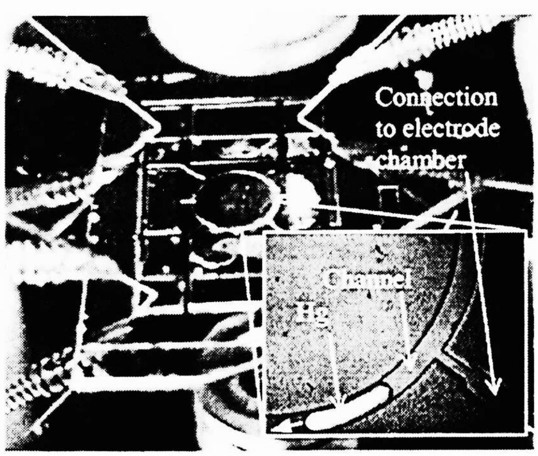


Fig. 5 Test of liquid micromotor (1 cm loop diameter)

SUMMARY

Microgasketing technique, which isolates liquid within planar-processed microdevices, is combined with the adhesive wicking of a room temperature curing UV epoxy to permanently seal a liquid-filled micromachined device. The method is general, as the reservoir area could contain liquid or gas. Planar-processed microdevices of a volume even less than 1 nl can be selectively filled with liquid and sealed at room temperature in a batch fashion. Two examples of shown where microgasketing and adhesive wicking techniques were critical in successful fabrication of devices: a microrelay and a liquid micromotor.

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