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STP Sealing Technique for Surface Micromachined MEMS Stacked on a CMOS LSI

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1. Introduction

Seamless integration of MEMS (Microelectromechanical Systems) devices with CMOS LSIs is a new direction to create high-functionality devices [1]. We proposed a novel fingerprint sensor, a MEMS fingerprint sensor, that has MEMS structures with cavities stacked on sensing circuits as shown in Fig. 1 [2]. It obtains clear fingerprint images regardless of finger surface conditions and environments. In the MEMS structures, the cavities are indispensable; they let the upper electrode move as shown in Fig. 1(c). This is also true of other MEMS devices that have mechanically movable parts like capacitive pressure sensors, radio frequency MEMS, and so on.

To protect the inner parts of the cavities from harsh environments of water, air, and contaminants, sealing of cavities is important. Conventional sealing techniques, which are anodic bonding [3] and chemical vapor deposition (CVD) with sacrificial etching [4], are shown in Fig. 2. In sealing technique of cavities, the thickness of sealing film and the lateral size of the cavities are critical parameters. We classified the conventional sealing techniques by these parameters as shown in Fig. 3. There is a gap region that neither of the sealing techniques can cover. Techniques in this gap region are necessary to integrate LSIs in a sub-micron size and larger MEMS with a size of several microns or more.

In this paper, we propose a new sealing technique that uses STP (Spin coating film Transfer and hot-Pressing), and describe the capability of STP to extend the applicable region of sealing techniques with thicker sealing films. We also present an application of STP for sealing the cavities in the MEMS fingerprint sensor stacked on a CMOS LSI.

2. STP Sealing Technique

STP was originally developed as a planarization technique in multi-level interconnection technology for LSIs [5]. Dielectrics fill the gaps of the interconnections and planarize the surface. Here, we propose applying STP to MEMS fabrication technology. The principle of STP as a sealing technique is shown in Fig. 4. The difficulty lies in keeping the dielectric from flowing into the cavities on the Si substrate, especially during the hot-pressing in the vacuum chamber [Fig. 4(b)]. In using STP in both of the technologies, controlling the flow of dielectrics is the most important issue.

We focused on the viscosity of the dielectric and constructed an analytical model [6]. Based on the model, we investigated the controllability of the dielectric flow for sealing. The simulated result in Fig. 5 shows the effect of the viscosity and external pressure during the hot-pressing step on sealing cavities. When the viscosity is high and the external pressure is low, the dielectric seals cavities. On the other hand, the cavities are filled when the viscosity is low and the external pressure is high. This graph predicts that sealing is achievable by controlling the dielectric flow.

We investigated the possibility of STP as a sealing technique by experiments. Organic dielectrics were hot-pressed against Si wafers with various kinds of gap patterns and sizes. The result in Fig. 6 proves that the large gap-pattern 100-μm wide and 0.5-μm deep is sealed by the 20-μm-thick dielectric film.

3. Application to MEMS Fingerprint Sensor Fabrication

To examine whether STP is a compatible process with CMOS LSIs, we applied it in the MEMS fingerprint sensor fabrication process. Each pixel of the sensor has the MEMS structure and sensing circuits below it as shown in Fig. 1(c). The MEMS structures must be stacked and the cavities sealed without damaging the underlying sensing circuits.

We devised the following surface micromachining process to form and seal the cavities. First, the lower electrodes, grounded wall, and upper electrode were formed by gold-electroplating with a sacrificial layer of polyimide. After that, the sacrificial layer was etched off through the etch-holes to make cavities as shown in Fig. 7(a). Then, the etch-holes were sealed. Conventional sealing by means of CVD would need a thick film to seal the 5-μm-square etch-holes. The deposited film would also invade the cavities and prevent the upper electrode from moving. STP can solve these problems. Figure 7(b) shows the surface micromachined MEMS structures sealed by STP. The 5-μm-square etch-holes were sealed with the dielectric film 1-μm thick as shown in Fig. 7(c).

The cross section of the MEMS structure after completing fabrication is shown in Fig. 8. The MEMS structures with sealed cavities were fabricated on a CMOS LSI without the sealing material flowing into it. The fingerprint image in Fig. 1(b) was obtained with the STP-sealed MEMS fingerprint sensor, which indicates the STP did not damage the underlying CMOS LSI.

4. Summary

We have developed a new sealing technique based on STP. An analytical model showed controllability for both filling and sealing. Experimental results with thin and thick sealing films revealed the potential of STP to advance sealing techniques. The application of STP to a MEMS fingerprint sensor confirmed that STP is effective in sealing MEMS devices stacked on a CMOS LSI.

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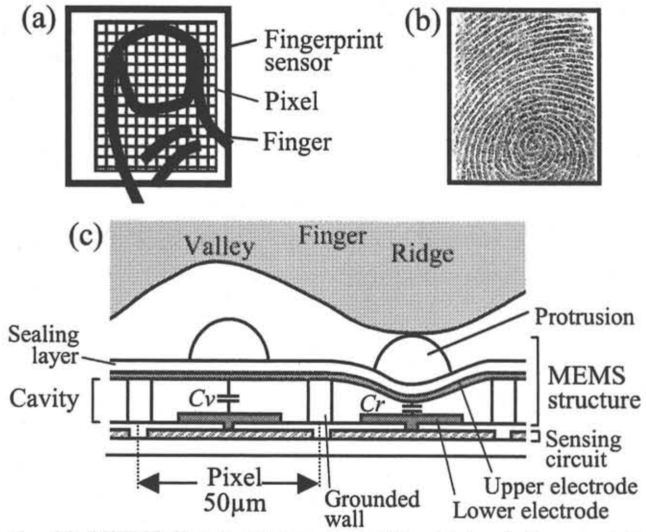

Fig. 1 (a) MEMS fingerprint sensor, (b) obtained fingerprint image, and (c) MEMS structure and sensing mechanism. Finger ridges push the protrusion down and enhance the capacitance between the upper and lower electrodes. The capacitance magnitude relationship *Cr>Cv* is translated by the sensing circuits into contrast in the fingerprint image.

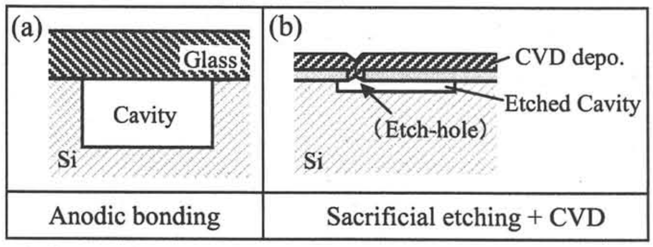

Fig. 2 Conventional sealing techniques for MEMS. (a) A thick glass plate seals a cavity that is large in lateral size, and (b) a sacrificial layer is etched to make a cavity, and a thin film deposited by chemical vapor deposition (CVD) seals the etch-hole that is small in lateral size.

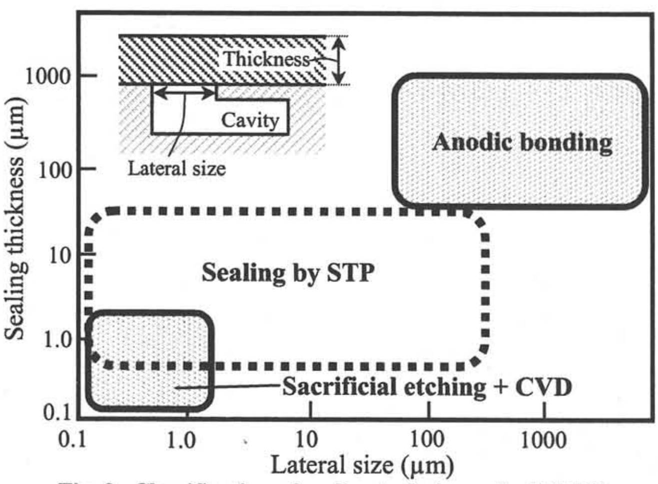

Fig. 3 Classification of sealing techniques for MEMS.

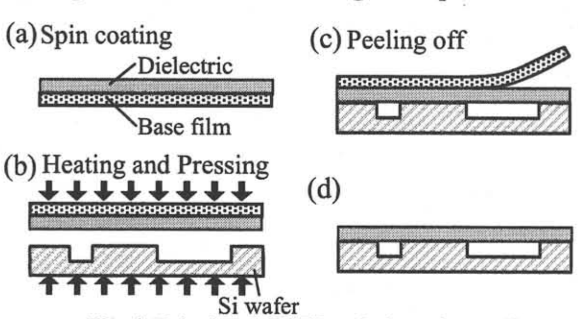

Fig. 4 Principle of STP technique for sealing.

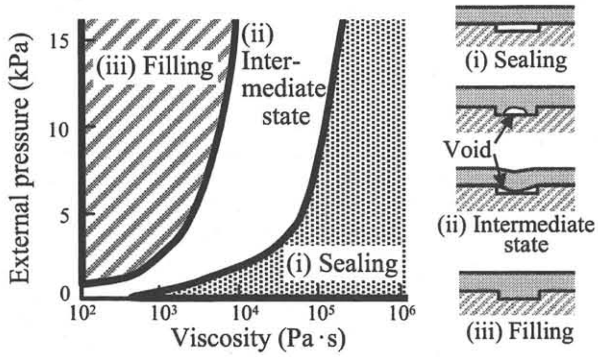

Fig. 5 Simulated relationship between viscosity and external pressure.

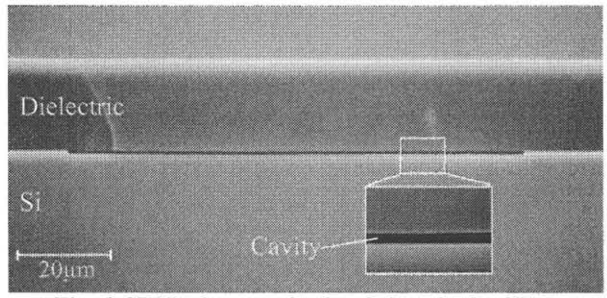

Fig. 6 SEM micrograph of sealed cavity by STP.

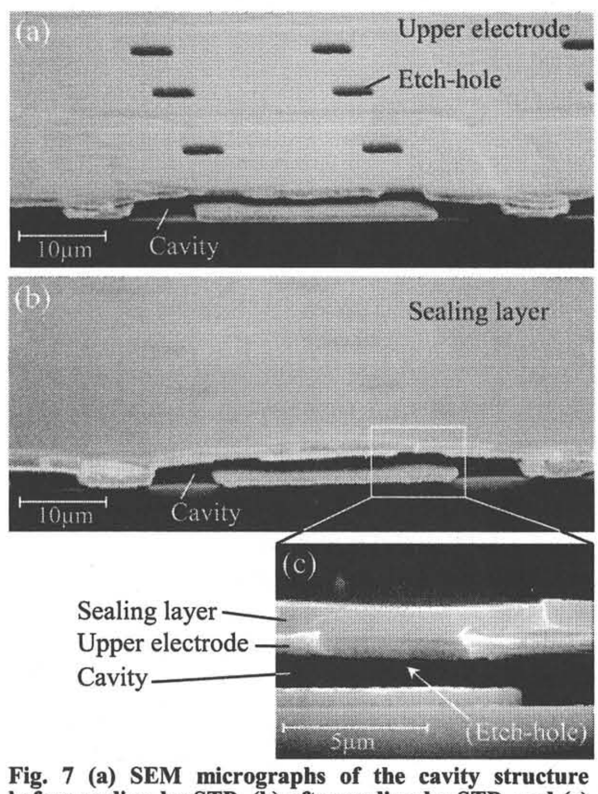

Fig. 7 (a) SEM micrographs of the cavity structure before sealing by STP, (b) after sealing by STP, and (c) magnified image of the sealed cavity.

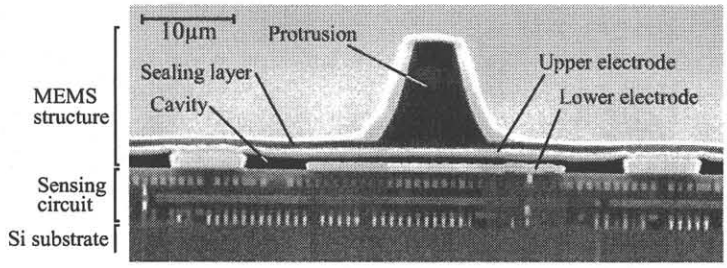

Fig. 8 FIB (Focused Ion Beam) cross section of the pixel.