Improvement of Post Exposure Delay of Photo-Patternable and Adhesive Materials for Wafer-Scale Microfluid

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In order to simplify the wafer-scale fabrication of microfluidic devices JSR has developed a photo-patternable and adhesive (PA) material which allows to pattern and bond microfluidic structures in one single process step. Control over the film thickness and excellent patterning properties are crucial for many microfluidic applications. By optimizing the acid diffusion after exposure, improved PA patterning properties were achieved. This in combination with the possibility to pattern 80 um thick structures makes PA an ideal material candidate for many microfluidic and BioMEMS applications.

Keywords: Photo-patterning and bonding, acid diffusion and evaporation, thick PA for microfluidics

1. Introduction

The importance of microfluidic technologies has dramatically increased in recent years since microfluidics is considered as a key technology in the life science field [1]. There is a growing interest in the development and fabrication of microfluidic lab-on-a-chip (LOC) devices for a wide number of applications such as point-of-care and high-throughput screening. Material selection is a very critical step in the fabrication process of microfluidic systems. As summarized in Table 1, each of the traditionally known microfluidic materials has its advantages and drawbacks. When cheap disposable microfluidic devices are required, plastic is the material of choice. On the other hand, when more complex microfluidic devices are envisioned, Si and glass are often selected. However, the process flow of both materials is rather costly and time-consuming. Due to the increased complexity of LOC systems, where bio-sensors need to be integrated into the Si platform and need to be physically interfaced with fluid samples, there is a need for new microfluidic materials and processes which allow the easy integration of microfluidics with CMOS fabricated sensor chips. Within the aca-

Table 1. Devices can be classified by substrate

| Plastic          | Injection molded |
|------------------|------------------|
|                  | Low cost but also low complexity |
|                  | Disposable       |
|                  | Read-out requires separate device or instrument |
| Glass            | Some semiconductor processes |
|                  | Higher cost but also low complexity |
|                  | Important for sensitive fluorescent assays |
|                  | Read-out requires separate device or instrument |
| Silicon          | CMOS compatible processing |
|                  | Perceived as high cost |
|                  | (true for low volume or prototyping) |
|                  | Potential for full integration or read-out |

Figure 1 Material selection in the merging of sensors and microfluidics.
demic world microfluidic channels are often fabricated out of PDMS and SU-8 [2]. Although both materials have shown their value in microfluidics, the material concerns are raised when shifting to more complex, integrated devices or when high volume manufacturing is required. To fill this material gap, JSR has developed a photo-patternable and adhesive material (PA). Using PA, microfluidic structures can directly be fabricated on the Si wafers in a CMOS compatible process flow as shown in Figure 2 [3]. On top of that, a glass cover can directly be bonded to the patterned microfluidic structures. This in combination with the fact that PA is biocompatible opens the door for the wafer-scale fabrication of integrated microfluidic devices. In this paper, the material optimization route will be discussed in more detail. More specifically, solutions to avoid bridging and T-top shape patterning will be presented. Not only the patterning properties but also the film thickness window and the adhesion properties of the new PA material were found to be improved.

2. Materials and Methods

2.1 Materials

PA-001 is a negative tone chemically amplified photoresist which consists of an acrylate type polymer with an alkali soluble unit, a multifunctional epoxy material as a crosslinking agent, triarylsulfonium salt as a photoacid generator. PA-002, PA-003 and PA-004 at the other hand are a mixture of PA-001 with 20%, 10% and 5% of basic compound (BC) which contains nitrogen atom to PAG, respectively.

2.2 Methods

2.1.1 Coating procedure

Accurate thick PA material was coated on a 6-inch wafer in a clean track (Mark Vz by Tokyo Electron) and subsequently baked at 110°C for 3 minutes to remove the solvent. In a next step, PA was exposed at 365nm (NSR 1505 i10D by Nikon) with corresponding photomasks and baked at 110°C for 5 minutes, followed by development with 2.38wt% TMAHaq. for 3 minutes.

2.1.2 Evaluation of patterning properties

The optimum exposure dose was measured with critical dimension scanning electron microscope (CD-SEM, S-9220 by Hitachi High Tech).

2.1.3. Evaluation of bonding strength

A 8mm x 8mm glass wafer die was put on the patterned PA wafer and bonded at 200°C for 2 seconds while applying a pressure of 5 MPa (FTD-1940 by SHIBAURA). The resulting bonding strength was measured with a bond tester as shown in Figure 3 (4000 multipurpose bond tester by Dage).

3. Results and Discussion

As shown in Figure 4, patterning of PA-001 often resulted in bridging around the pattern top area. In order to understand the root cause of this bridging phenomenon, several parameters were changed. It was found that both the delay time after exposure (Figure 5) and the post exposure bake (PEB) temperature played an important role (Figure 6). Possibly, the bridging effect is enhanced by the acid diffusion after exposure and the acid evaporation during the PEB as schematically represented in Figure 7.

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Figure 2. Wafer-scale process integration

Figure 3. Schematic representation of the Bonding strength measurement setup

Figure 4. Pattern bridging of PA-001
In order to control the acid diffusion [4] and the acid evaporation [5], the addition of a basic compound (BC) containing a nitrogen atom was studied.

This new formulation, PA-002, which has an additional 20% of BC compared to PA-001, was evaluated. The comparison of PA-001 and PA-002 is shown in Table 2. In this result, the effect of BC is confirmed and it supports our hypothesis. However, it should be noted that the photo-sensitivity of the PA-002 steeply decreased (Table 2). To check the photo-sensitivity and the bridging margin in more detail, the effect of the BC amount (PA-003: 10% of BC, PA-004: 5% of BC) was further evaluated. These results (Table 2) clearly show that PA-004 has the best patterning performance even at decreased photo-sensitivity (i.e. 50%).

As stated before, not only the patterning properties but also the film thickness is a key factor for many applications. Especially in cell based applications a channel thickness between 30 and 100 μm is desired. In order to achieve this thickness range, a higher viscosity version of PA-001 and PA-004 was tested as well. Based on Figure 8, it is clear that for PA-001H bridging is worse than for PA-001 when applying the same conditions. However, for both PA-004 and PA-004H, no bridging was observed due to the presence of the BC. In addition, the corresponding bonding strength of the different formulations was studied. As can be seen from Table 3, the addition of the BC did not affect the bonding strength. On the other hand, switching to the “thicker” high viscosity formulation significantly improved the bonding strength due to its inherent higher deformation rate. In conclusion, PA-004H is considered the ideal material candidate for many microfluidic applications.

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4. Conclusion

By fine-tuning and optimizing the process margin of our PA material, an ideal material candidate for wafer-scale manufacturing of microfluidic and BioMEMS devices was designed. Control over the acid diffusion by addition of a basic compound was found to be crucial to avoid pattern bridging, especially when thicker microfluidic structures are aimed for. These improved patterning properties together with the intrinsic bonding properties of the material will open the door for a broad window of new wafer-scale based microfluidic applications.

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