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Spray Coating of Photoresist for 3D Microstructures with Different Geometries

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Abstract. This paper presents the advantages of spray coating technique as compared to the conventional spin coating method for photoresist coating of 3D microstructures. An optimized mix of photoresist AZ4620: MEK: PGMEA (1:1.5:0.5) was used to achieve good coverage and uniformity of photoresist not only on planar surface, but also along the trenches' sidewall. In order to achieve the ideal coverage of photoresist layer, the effects of the geometries of the microstructures were also considered. Then, we implement this technique for our application in a MEMS device to prove the viability and potentiality of spray coating of photoresist for fabrication of 3D microstructures.

Keywords: Spray Coating;Photolithography; MEMS

1. Introduction

Since the development of microelectromechanical systems (MEMS) and the increasing use of three-dimensional (3D) microstructures, new techniques and processes are required to fulfill the demand for nonuniform photoresist layer over non-planar surfaces with high topography, like trenches, V-grooves, and holes. The process of spin coating, the conventional technique for photoresist coating on flat wafers, was optimized for coating on nonplanar surfaces too [1] [2]. However, it does not perform well for 3D MEMS devices with high topography. High topography in this paper defines the depth of 3D structures to be more than 50 μm. In spin coating, the non-planar surfaces such as trenches, V-grooves, and cavities impede or prevent the flow of photoresist from the centre to the edge of the wafer as the wafer spins. As photoresist coating of high topography surfaces is basic in MEMS applications, recent efforts for the development in photoresist coating were discussed [2]. Of all, one favorite method of photoresist coating is the spray coating technique. This approach is economical, simple and reproducible [2], and can, potentially, substitute conventional spin coating techniques and other methods.

In this paper we report the challenges encountered as a result of spin coating of photoresist for 3-D microstructures. Also, we will present how the spray coating technique can overcome such problems. With the optimized photoresist mixture used in spray coating, we prove that uniformity of photoresist coating is achieved not only on the planar surface, but also along the edges and side of slopes within the trenches. Next, we study the effects of microstructures geometries on the quality photoresist

coated. With the optimized spray coating technique, we were successful in developing a photolithography process for patterned metallization of Cr/Au in our MEMS application.

2. Photoresist for spray coating

To date, there are no commercial photoresist for spray coating techniques. Hence, we often have to mix the conventional photoresist with solvents such as MEK (methyl-ethyl ketone) and PGMEA (metoxy-propyl acetate) to adjust the evaporation rate and the solid content of the photoresist. Photoresist mix and dilution is a critical factor in ensuring the quality of a spray coating process. A practical optimization approach for photoresist mix and a reliable method to qualify the photoresist coated, not only on the planar surface, but also at the edges and side of slopes within the trenches has been proposed [4].

From our experiments, it is observed that the dilution of PGMEA to photoresist AZ4620 makes the solution more mobile, producing a thinner coating along the slope of trench with increase in percentage in PGMEA. However, in coating microstructures with high topography, having PGMEA in the mixture is insufficient in producing quality coatings. This is because dilution of photoresist in PGMEA will result in accumulation of photoresist along the bottom surfaces of microstructures due to the reduction in viscosity. The effect is poor coverage of photoresist along the sidewalls of the microstructures. Thus, MEK is added to the mixture of PGMEA and AZ4620 to adjust the evaporation rate of mixture. Since MEK evaporates faster than PGMEA, the solution quickly evaporates and the flow of photoresist to the bottom of microstructures can be prevented. However, exclusion of PGMEA in the mix will have a tendency of producing a rougher coating. Thus the two main challenges in the optimization of photoresist mix are to produce quality uniformity of photoresist coating and to ensure coverage along the sidewalls of microstructures.

There are two factors for consideration in the optimization of a photoresist for spray coating. First is the solid content of the photoresist mix or the photoresist to solution (MEK + PGMEA) ratio. Increase in this ratio results increases the solid content, thus increasing the viscosity of the mixture. Photoresist mix with higher viscosity increases the roughness of the coating, as well as the thickness of the coated photoresist. Also, accumulation of photoresist at the bottom of the trenches and other microstructures is reduced. In our experiments, we proved that the best photoresist to solution dilution is 1:2 [4]. With this dilution, we can optimize the mixture of MEK to PGMEA to adjust the evaporation rate of the photoresist solution. The photoresist solution with higher evaporation rate tends to produce better coverage along sidewalls at the expense of roughness of the coating. With a series of investigations, it is observed that the optimum mix for AZ4620: MEK: PGMEA is 1:1.5:0.5. With this solution, good coverage and uniformity of photoresist are achieved not only on planar surface, but also in sidewall of trenches [4]. An example of V groove shape is shown in Figure1.

Figure1. Photoresist coverage of a via-hole

3. Spin coating versus spray coat

Uniformity in photoresist thickness is critical in photolithography. Normally, the allowable variation in thickness is about 20% when using AZ4620. Overly thin photoresist due to variation in thickness may result in overexposure to ultra-violet radiation during the patterning process, and the vice-versa is true for overly thick photoresist. For either case, this is undesirable. Thus, it is critical to have good control over the thickness and uniformity of the coated photoresist so that the exposure parameters under UV radiation can optimized for the process. Herein, we compare the quality of spin coating to spray coating technique by analyzing the thickness and uniformity of the coated photoresist on silicon wafers with chemically etched trenches.

In the preparation process, silicon wafers with cavities of varying sizes and shapes were etched to depths of 100 um. The anisotropic wet-etching process is performed in a potassium hydroxide (KOH) 30% solution at 90°C. The etch depth was time-controlled; with a slope of the acute angle made at 54.7^{0}. The spin coating and spray coating methods have been used to coat the silicon wafers with 100 µm-deep trenches. In the spin coating process, 50 ml of AZ4620 is dispensed on the centre of the wafer. The wafer was spanned at 1000 *rpm* for 1minute with a slow acceleration of 300 *rpmm* As for the spray coating technique, an optimized photoresist mix of AZ4620: MEK: PGMEA of 1: 1.5: 0.5 is used. The equipment parameters like dispensed rate, nozzle pressure is illustrated in [4].

The results of spin coating of photoresist, AZ4620, are depicted in Figure 2 and Figure 3. It is noted that the thickness of photoresist on surface of the wafer is about 14 µm, but the mean thickness at the bottom surface is about 3.5 µm. Although the uniformity of photoresist on the top surface of wafer is about 10%, the uniformity of the resist layer of bottom surface shows great variation, up to 70%. The results for spray coating are illustrated in Figure 4. The thickness and uniformity of the photoresist layer on the top surface and bottom surface of wafer after spray coating are shown in Figure 4. The thicknesses of coated photoresist were uniform for both the top surface and bottom, approximately 10% variation.

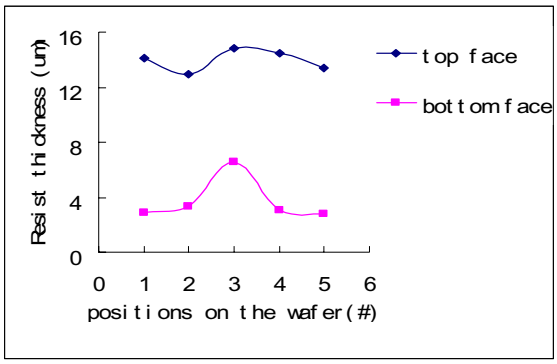

Figure2. Resist thickness of bottom surface and top surface after spin coating

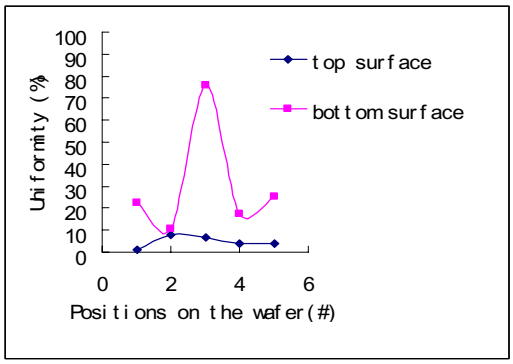

Figure3. Uniformity of bottom surface and top surface after spin coating

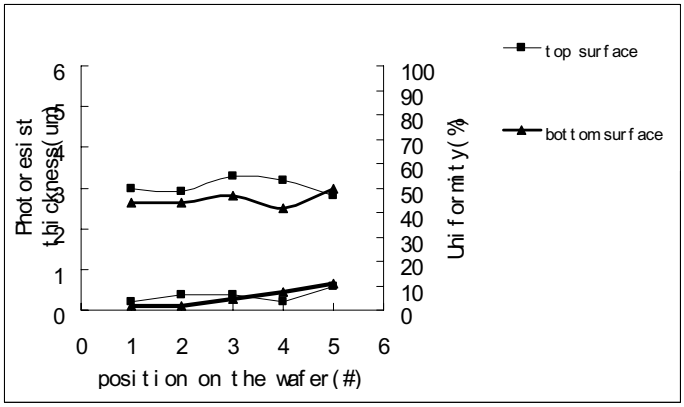

Figure4. Photoresist thickness and uniformity of top surface and bottom surface after spray coating

Besides the uniformity in coating, another problem that arises from using the spin coating is the inconsistency in the thickness along the sidewall of the slope along trenches, Figure 5a. Due to the fluidity of photoresist and centrifugal effect of the spinning chuck (wafer is held by vacuum to the spinning chuck), the photoresist will flow down the slope and be accumulated at the bottom corner. This causes disconnection at the top corner, thus leading to the failure of the device. This problem can be eliminated if the spray coating technique is used. This nozzle of the spray coater oscillates while producing microscopic resist droplets of around 20. The droplets are spray onto the surface of the wafer. The solvent of photoresist evaporates and the solid contents of the photoresist leave on the surface to produce a uniform resist layer along the sidewall of the trench, as depicted in Figure 5b. The evaporation of photoresist droplets minimizes the accumulation of photoresist at the bottom of trenches, and with optimization of the photoresist solution as described above. Overall, spray coating is a more reliable process than spin coating for coating photoresist on high topography surfaces.

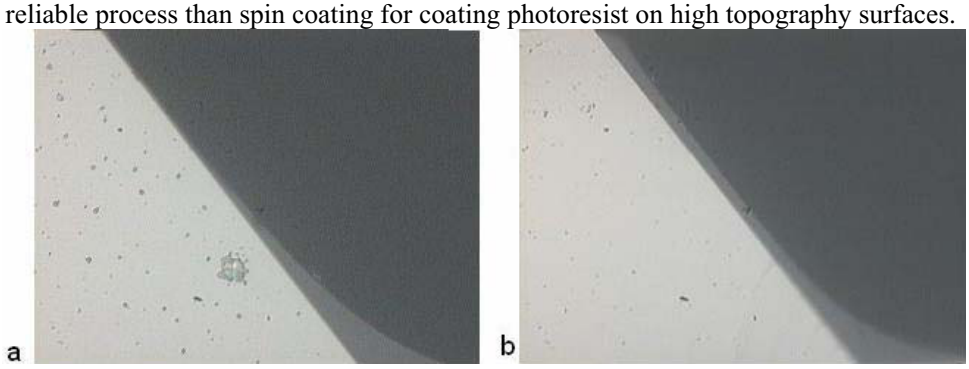

Figure5. Photoresist coverage along the sidewall of trench (a) spin coat (b) spray coat

4. Effect of the geometries of 3D microstructure on the photoresist quality

So far, we have not considered the effects on geometries of 3D microstructures on the quality of photoresist layer. Here, we want to investigate the effects on the area and depth of the trenches to understand the possible limitations of spray coating. 0.5×0.5 mm^2 and a 2×2 mm^2 square trenches of depth 100 μm have been investigated. As illustrated in Figure 6 and Figure 7, the area of the structure has little effect on the uniformity of the bottom surface and sidewall. However, the thickness of photoresist layer on the bottom surface and sidewall of trench with small area is more as compared to one with a 2×2 mm^2 square trench. This can be explained because the trench with large area has larger coating area compared to the trench with small area, thus resulting in a thinner photoresist layer.

Although there was work about the effects of the depth of cavities on the thickness of the bottom surface [1], no one has critically examined the photoresist layer coated along sidewall of trenches. In our experiment, we further investigate the reliability of spray coating on topography of 2 depths: square trenches of depth 100 μm and 200 μm. Similarly, due to variation in coating area, the photoresist thickness decrease when the etch depth of the trenches increase, as depicted in Figure 8. However, this effect in variation does not result in reliability for future lithography processes.

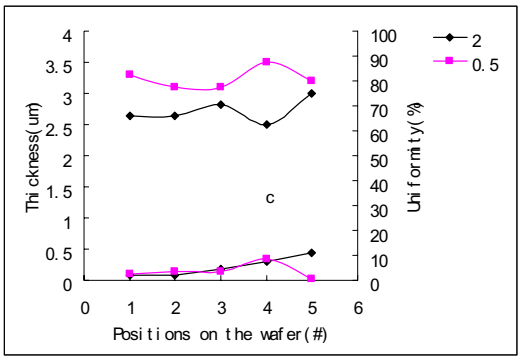

Figure6. Photoresist thickness and uniformity of bottom surface for squares with area 2 × 2 mm^2 and .5 × 0.5 mm^2

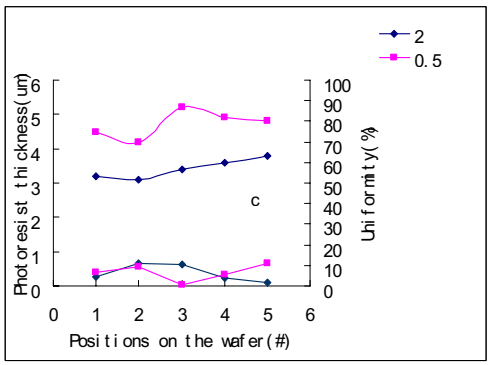

Figure7. Photoresist thickness and uniformity of sidewall for squares with area 2 × 2 mm^2 and .5 × 0.5 mm^2

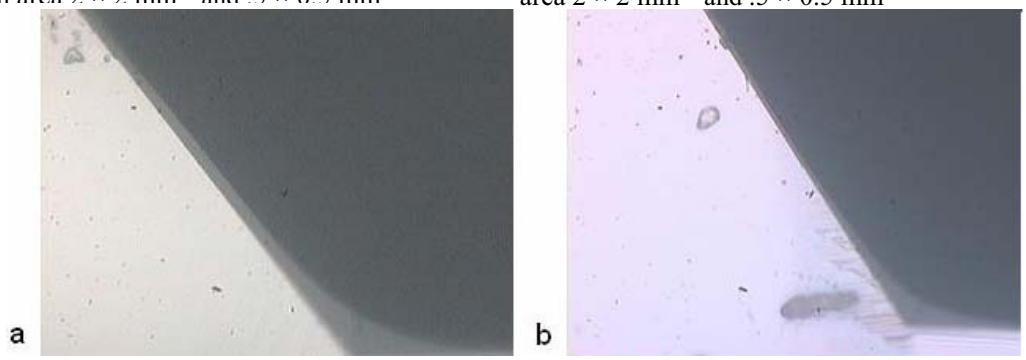

Figure8. Photoresist coverage for trenches with different depth (a) 100 um (b) 200 um

5. Application of spray coating for 3D microstructures

With the optimized spray coating process, we then fabricate a 3D dielectrophoretic MEMS device for separation of cells as shown in Figure9a. In this experiment, we etch a series of 100 µm-deep trenches on a Pyrex glass wafer using HF acid by using Cr/Au mask. To complete the selective metallization of these trenches and via holes, we use spray coating described to pattern a new Cr/Au for metallization and electrical contact for the device. Figure 9b shows the results of the metallization. Alternatively, we prepared another wafer of the using the same technique, only to replace spray coating with spin coating at 500 rpm. It is observed that the metal layer at the top edge of the trenches is not protected by photoresist, resulting unwanted exposure of the metal layer to etchant. This is the main reason for device failure when using spin coating for MEMS devices. However, when we use spray coating for the same application, we do not observed the same problem. In another experiment shown in figure10a, 6 × 6 mm^2 squares have been etched through in a 1mm thick glass wafer. The Au/Cr electrode has been selectively patterned on the etched glass (Figure 10b). This could not have been achieved using the spin coating technique.

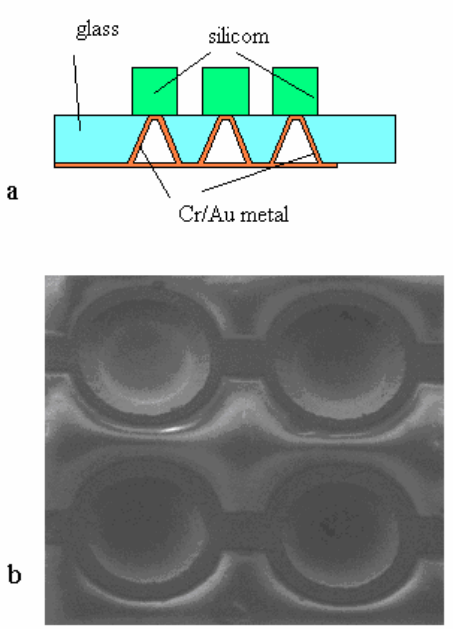

Figure9. Cr/Au metallization on a via-hole with a depth of 100 um

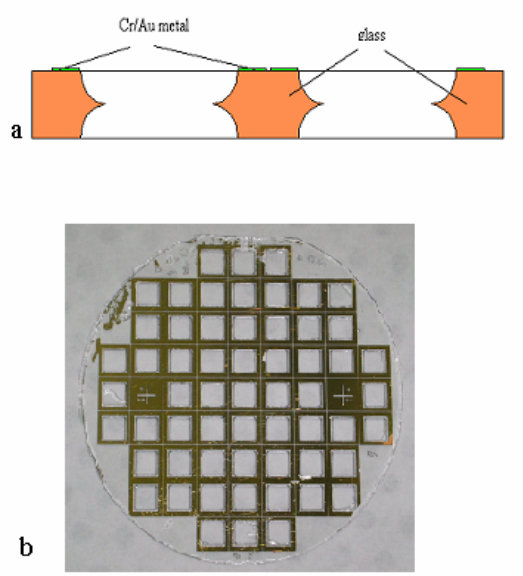

Figure10. Cr/Au electrodes fabricated on a wafer with 6 × 6 mm^2 areas and 1mm depth

6. Conclusions

This paper presents the advantages of spray coating technique as compared to the conventional spin coating method for 3D microstructures. An optimized mix of photoresist AZ4620: MEK: PGMEA (1:1.5:0.5) has been illustrated. With this solution, good coverage and uniformity of photoresist are achieved not only on planar surface, but also along sidewall of trenches. In order to achieve the ideal coverage of photoresist layer, we have considered the effects of the geometries of the microstructures for special applications. We prove that area and depth of trenches has little effects on the uniformity of the coated photoresist. With the technique developed from spray coating, we successfully demonstrate selectively metallization of Cr/Au for our MEMS device. Hence, we prove that spray coating is a viable approach to photoresist coating for different types of 3D structures.

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