NEW PHOTORESIST COATING METHOD FOR HIGH TOPOGRAPHY SURFACES

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ABSTRACT

A novel technique of photoresist coating, Dynamic Surface Tension (DST) coating, is presented. This technique is particularly well suited for surfaces with pre-existing topography, which is often the case in micro-electro-mechanical systems (MEMS) and integrated circuits packaging. A simple setup is employed and several resist solutions are tested. Promising results are obtained using a commercial photoresist Shipley SPR 220-3.0. Uniform coverage on micromachined surfaces with high topography is demonstrated. Successful pattern transfer at the bottom and on top of silicon trenches as deep as 15μm with different width from 1μm to 100μm was achieved with 1.5μm resolution.

INTRODUCTION

With the development of MEMS and the growing use of three dimensional microstructures, new techniques are required to fulfill the demand for uniform photoresist coverage over non-planar surfaces with high topography, like trenches, V-grooves, and cavities. Thus, the conformal photoresist coating of wafers with 3D microstructures becomes a critical step in the integration process. In the MEMS fabrication process of devices, there are three main different photoresist coating techniques: spin coating, electrodeposition (ED) coating, and spray coating [1-5]. Several efforts to obtain a conformal coating layer by using spin coating have been reported [1, 2]. Although spin coating is an established technique for resist deposition, it is often not suitable for applications with high topography on silicon or glass surface because of defects generated in the resist layer during the process. More specifically, the photoresist flows down along the sidewalls of trenches due to gravity, gathers at the bottom corners, and is detached at the top corners, as shown in Fig.1. This figure shows an array of trenches, that were created in silicon by using deep reactive ion etching (DRIE) process, and were further coated with commercial photoresist shipley SPR 220-3.0 using spin coating method. Electrodeposition of photoresist has been reported as a useful method for 3-D stacks of chips [3] but it requires a conductive layer. As a result, electroplating of photoresist is restricted to the backend processing. In the case of spray coating, no commercial photoresist exist that could be used without being diluted. Also the diluted photoresist is thick (9μm) not allowing to get a good resolution, the thickness of photoresist is not uniform and depends on the geometry. For instance, if coating an array of cavities, only those cavities having the same size would be covered with the same thickness of photoresist [3]. Here we report a novel technique using a commercial photoresist (Shipley SPR 220-3.0) to achieve uniform photoresist coverage not only on planar surfaces, but also on a micromachined surface with high topography. Photoresist has the same thickness (1.5μm) everywhere independent of the geometry of the patterned surface. Table 1 shows a comparison of this new technique with the three other existing ones.

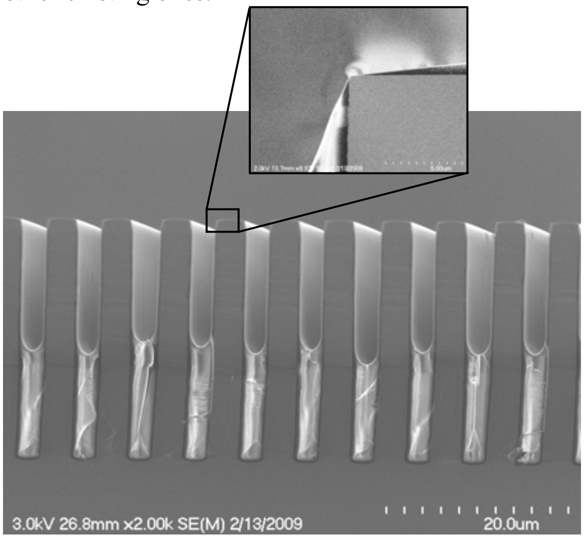

Fig. 1. An array of trenches with resist coated by spinning method.

DYNAMIC SURFACE TENSION COATING

Dynamic surface tension process

Consider a solution (here polymer) poured on the surface of a liquid that has a greater surface tension (called carrier liquid) in the presence of a gas. At the triple contact point P (Fig. 2), which is the junction of gas, carrier liquid and solution, interfacial forces pull the dispensed solution to spread out, covering the entire region of the carrier liquid that is exposed to the gas phase [6].

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Table 1 A comparison between DST technique and three others techniques.

	SPIN COATING	ED COATING	SPRAY COATING	DST COATING
Process	Simple Geometry dependent	Complicated	Simple Geometry dependent	Simple Geometry independent
Substrate material	Conductor or Insulator	Only conductor	Conductor or Insulator	Conductor or Insulator
Photoresist	Commercial	Specific ED resist	Not commercial 8µm resolution	Commercial 1.5 µm resolution
Resist uniformity	Not uniform on pre-existing topography	Uniform	Depends on geometry	Uniform

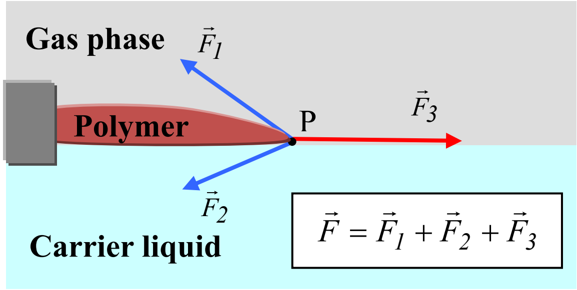

Fig. 2. The driving force $\vec{F}$ for spreading comes from the resultant of 3 surface tension vectors at the interface of 3 different media.

Let's define $\mathbf{F_1}$ as the surface tension between the gas phase and the solution, $\mathbf{F_2}$ the surface tension between the solution and the carrier liquid, and $\mathbf{F_3}$ the surface tension between the gas phase and the liquid carrier. At the moment of the injection, the presence of solvent (polymer) makes $\mathbf{F_1}$ and $\mathbf{F_2}$ to decrease, making $\mathbf{F_3}$ greater than the sum of the two others, driving the solution to expand so as to cover the maximum surface possible. The spreading dynamics is described by the vector equation (1):

$$\mathbf{F} = \mathbf{F_3} - (\mathbf{F_1} + \mathbf{F_2}) \qquad (1)$$

If $[\mathbf{F}]_x > 0$, where $[F]_x$ is the scalar of $\mathbf{F}$ in the direction of the x axis, parallel to the horizontal gas-liquid interface, the solution will spread out over the entire free surface of the carrier liquid until $[F]_x$ reaches zero or becomes negative due to solvent evaporation / miscibility affecting the concentration and viscosity of the material cast during the spreading. Over time, the solvent dissipates, which causes $\mathbf{F_1}$ and $\mathbf{F_2}$ to increase. As a consequence, the illustrated droplet will reach an equilibrium point and beyond, stopping the spreading phenomena. By controlling the interaction between these interfacial tensions, it is thus possible to control the thickness of the film. While the polymer thins down due to solvent evaporation or immersion (dilution of the solvent in the liquid), the quasi gel-solidified polymer film is transferred at a predetermined rate to a substrate forming part or carried by the transferring unit. The thickness of the thin film or layer is generally governed mainly by 1) the concentration (the relative content of solvent and polymer in the injected solution), 2) the rate of injection, and 3) the dynamics of evaporation and/or miscibility of solvent in the carrying liquid.

EXPERIMENTAL SETUP

The deposition is realized by pouring photoresist on the surface of carrier liquid in the presence of air. Photoresist solution is injected from an injection unit while the carrying liquid and the gas phase (air) are controlled for proper conditions. Figure 3 shows the DST process that takes place inside a cartridge at the gas-liquid interface. Polymer spreading is driven by the surface tension differential. The solidifying polymer is continuously taken from the cartridge to the substrate that we want to coat. The substrate is placed on a movable handle called wafer handling unit (WHU). Transfer is guaranteed by the presence of the capillary bridge between the cartridge and the substrate.
Key parameters that influence the thickness, uniformity and quality of the photoresist layer are:

- Solid content of the solution
- Solvent evaporation rate and miscibility
- Temperature
- Gas pressure
- Speed of WHU
- Injection rate of the solution

The first two parameters are related to the resist solution while the other four are related to the DST setup. The first three parameters control viscosity of the polymer and spreading factor at P junction. In other words affect on driving force **F** (Fig. 2). During the process, vapour of solvent content changes the gas pressure and modifies the smoothness of the coated layer. Therefore a good control has to be accomplished during the process of coating. For proper and uniform coating, the WHU needs to have the same speed as spreading process. Also a dynamic balance between the solution injection rate and thin film coating rate is required.

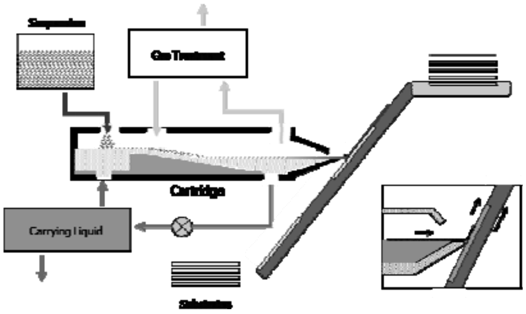

Fig. 3. DST setup.

Photoresist type

Most conventional photoresists cannot be used directly for DST coating because of their high viscosity. Therefore they have to be diluted with solvents in order to lower their viscosity. Basically the DST coating system can be operated using solutions with viscosity lower than 470 cP. Using too viscose photoresists cause small driving force and therefore create non uniform layer. Several photoresist solutions have been investigated in order to find the most appropriate one for the purpose of coating high topography surfaces.

We have investigated AZ9260 resist solutions that are diluted from the original photoresist by adding solvents. Also SPR 220-3.0 resist was used without dilution.

EXPERIMENTS AND RESULTS

Several <100> silicon samples containing an array of trenches with different widths etched by DRIE, are prepared for the DST coating experiments. We used water as the carrier liquid and air as the gas in the experiments. Unlike the other methods of coating, in DST coating, photoresist is coated on top (stacked) of the trenches making it interesting and useful for some special application where fabricating a cavity inside the structure is desired.

Figure 4 shows SEM pictures of a sample coated with AZ9260 resist using DST method. We used butyl alcohol as solvent with a solid content of 17%. The speed for WHU was 8 mm/s. As seen in Fig. 4, the coating is not uniform. The thickness of photoresist at the top of steps are 4μm whereas at the corners is almost zero, meaning the deposited film is not planar. For surfaces with topography, the extent of planarization is defined as [7]:

%Planarization = (H-h)/H,

where H and h are the depth (or height) of the topography on the uncoated and coated surface, respectively, as shown in Fig. 5.

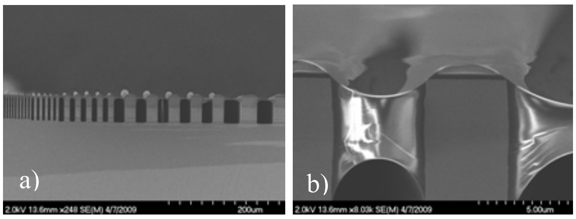

Fig. 4. a) Coated AZ9260 resist diluted with butyl alcohol (solid content of 17%), b) zoom on one trench.

The degree of planarization increases with decreasing distance between trenches (or steps) and with increasing film thickness (high viscosity photoresist) when spin coating method is used [8]. In DST method, planarization is independent of trench (or steps) height which is a great advantage over other methods. Instead, planarization is proportional to h′/h where h′ is the thickness of photoresist at the corner of steps. As the coated film flow deeper, h increases and therefore the thickness at the corner of steps decreases, leading to poorer planarization. As seen in Fig. 4, the thickness at the corners is almost zero meaning zero planarization. Figure 6 shows a more uniform coating realized with AZ9260 photoresist diluted in acetone with a solids content of 33%. The speed for WHU was 8 mm/s.

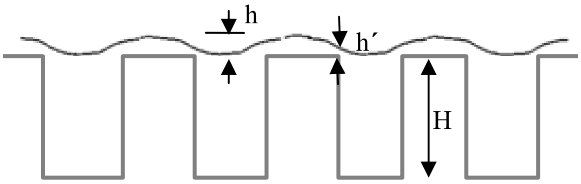

Fig. 5. Schematic of the coated film profile.

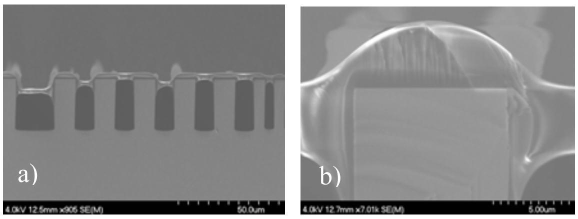

Fig. 6. a) Coated AZ9260 resist diluted with acetone (solids content of 33%), b) zoom on one trench.

The thickness of photoresist is 4.7μm at the top of steps and is 1.8μm at the corners, providing 38% planarization. Fig. 7 shows another sample coated with AZ9260 photoresist diluted in acetone with a solids content of 17%. The speed for WHU was 12 mm/s. The thickness of photoresist is 1.6μm at the top of steps and is 0.7μm at the corners, providing a better planarization of 44%.

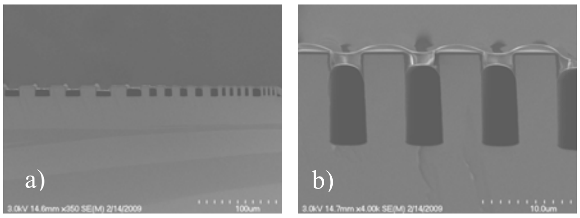

Fig. 7. a) Coated AZ9260 resist diluted with acetone (solids content of 17%), b) zoom on one trench.

Another sample was coated with SPR 220-3.0 photoresist. Since this type of photoresist has low viscosity, we did not dilute it with any solvents. The speed for WHU was 12 mm/s. The resulting coated profile is shown in Fig. 8. The coated photoresist on top of the trenches is uniform and has the same thickness as that at the corners, providing optimal planarization. The thickness of photoresist is 1.5 µm everywhere and is independent of trench (or cavity) geometry. Since the coated photoresist is thin, lithography with high precision (1.5 µm) is feasible. Figure 9 shows the same sample after photolithography and etching. The bottom of trenches and the top of steps have been perfectly etched while preserving the masked areas.

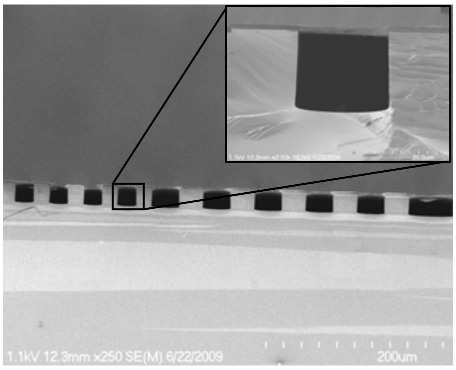

Fig. 8. Coated SPR 220-3.0 resist.

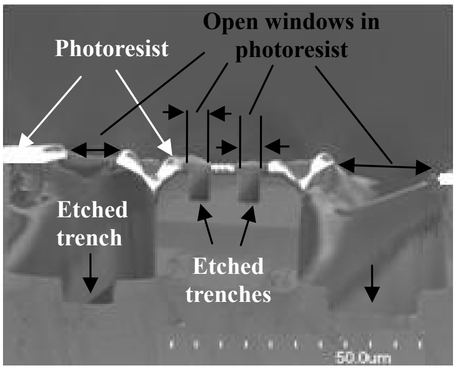

Fig. 9. Etched sample after photolithography and DRIE.

Figure 10 shows the sample after stripping the photoresist. The edges of the trenches are sharp demonstrating the uniformity of the coating.

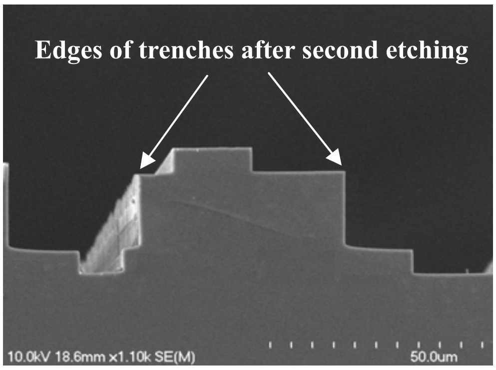

Fig. 10. Sample after stripping the photoresist.

CONCLUSION

In conclusion we have successfully coated uniformly a commercial photoresist on a surface with high topography by utilizing a novel technique. The resist uniformity is independent on position and size of the trenches (or cavity) and a 1.5 µm photolithography resolution was achieved.

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