Study of Spin Coating Properties of SU-8 Thick-layer Photoresist

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ABSTRACT

In this paper the coating properties including film thickness, thickness uniformity and variation of viscosity of SU8 photoresist were investigated by using a spin coater and rheometer. Experimental results indicate that the coating qualities of SU8 are affected by several factors including the spinning speed, the photoresist viscosity, the initial acceleration and the duration. Some recommendations are presented for increasing the quality of SU8 spin coating in thick-film processing.

Keyword: thick-layer resist, SU-8, thickness uniformity, spin coating

1. Introduction

Microelectromechanical system (MEMS) technologies have been developed in the last decade following traditional integrated circuit (IC) manufacturing technology. Thick-film lithography is one of the processes used for fabricating high aspect ratio microstructures of MEMS devices [1,2]. In this process, the formation of organic films, such as photoresist, by centrifugal spinning from solution on rotating disks is the simplest technique, which is widely used. A thick layer of photoresist is initially applied to the disk. During rotation, the resist flows outward radially. Moreover, the film uniformity of the photoresist coating will affect the exposure uniformity and development quality in later steps. It is thus important to accurately control both the photoresist thickness and film uniformity. Emslie et al. [3] investigated the flow of a viscous liquid on a rotating disk. Results showed that, for a Newtonian fluid, the solution of the hydrodynamic equations leads asymptotically to a layer of uniform thickness, independent of the liquid profile at the start of the rotation. The thickness, of course, decreases continuously with time as the material is spun away. Further, the non-uniformity reducing effect is more pronounced when the surface of the liquid is highly non-uniform than that is slightly non-uniform initially, which was demonstrated in thin-film lithography process. Acrivos et al. [4] extended this calculation to non-Newtonian liquids and showed that a specific initial distribution of film thickness must exist for obtaining a uniform thickness by spin coating. However, the non-uniformity reducing effect in thick-film process, which is sensitive to the viscosity variation during processing, is not well understood. In this work, several key factors including the reason and declining process on the non-uniformity of film thickness, the spin coating properties and the viscosity characteristics of NANO^{TM} XP SU8-10 photoresist were investigated by experiments. Finally, recommendations concerning the spinning quality of SU8 thick-film are presented.

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2. Experiments

2.1 Spin Coating Experiments

Many photoresist-processing problems can be attributed to the dirty or contaminated surface. Thus, it is important to clean the silicon wafer before coating the photoresist. Here, the RCA clean process is used in our cleaning process. Following the cleaning process, the wafer was normally primed with a pre-resist coating of a material designed to improve adhesion. The most widely used priming substrate is hexamethyldisilazane (HMDS). In the current study, HMDS was applied to the substrate by vapor priming. The advantages of vapor priming include: (a) wafers can be batch primed; (b) since only vapors come in contact with the wafer surface, potential contamination from particles present in HMDS solution is avoided; and (c) less HMDS is used per wafer, thus providing a cost savings. Then, spin coating experiments were performed under conditions by varying the spinning speed, the initial acceleration, and the duration of using a spin coater with a cover, which is rotational (Gyrset system, Karl Suss Inc.), and the resulting film thickness were measured. The Gyrset system comprises a bell-shaped cover placed over the chuck and the substrate. All the parts involved in Gyrset system rotate synchronously as does the confined air inside the cover. Turbulence, which can cause excessive thickness variation in the corners of the substrate, is thus eliminated.

On the other hand, wafers are coated with photoresist; they are subjected to a temperature step, call softbake. The softbake temperature is often below the glass transition temperature of the photoresist. But for some photoresist the softbake temperature is above the glass transition temperature, such as SU8-10. Adhesion of the photoresist is a function of softbake temperature. Under-softbaking will result in poor photo-oxide bonding and will lift off the photoresist images in the developer. However, over-softbaking will induce film stress and brittleness and can reduce adhesion. Table 1 lists the coating process conditions of SU8-10.

Properties concerning photoresist coating were measured. The film thickness can be measured by a surface profilmeter (α -step system) and dial indicator. Surface profile measure instrument (formtalysurf system) was used to measure surface conditions in current research.

Table 1 Coating process conditions of SU8-10.

Process Step	Parameters	Equipment
Dehydration bake	150℃ for 25mins use adhesion promoter-HMDS	air-forced oven
Spin Coating	Spread: 300rpm for 10secs Spin: desired speed for 25secs Acceleration: 100rpm/s	Karl Suss Gyrset RC8 (close)
Softbake	Heat ramp: 40℃ to 95℃ for 15mins Plateau: 95℃ for appropriate time	Hotplate
Relaxation	About 3 hours at room temperature	

2.2 Rheological Experiments

SU8-10 is a negative, epoxy-type, near-UV photoresist based on EPON SU8 resin (from Shell Chemical). The photoresist is prepared from commercially available components by dissolving an EPON resin SU8 in an organic solvent GBL (gamma-butyrolacton) [1,6]. The quantity of the solvent determines the viscosity and hence the range of the possible photoresist thickness. In the current study, the photoresist consists of GBL (59wt. %) and solids (41wt. %). The viscosity with respect to shear strain rate characteristics of SU8 photoresist was also studied through the use of a cone-plate type rheometer. Environmental temperature was kept constant to prevent the quality of photoresist from being changed.

3. Results and Discussions

Figure 1 shows the distribution of film thickness in the radial direction at different spinning speeds. The average thickness of coated film increases with decreasing spinning speed; however, the film surface profile becomes less smooth. Especially, locally uneven surface appeared on the film when the spinning speed was lower than 500 rpm. Moreover, when r-value is between 0.7 R and 1.0 R, the film thickness reaches a minimum and then increases rapidly with the increasing r-value. This is due to the position of the photoresist being near the edge of wafer, and the magnitude of the surface tension. In practice, the position of minimum film thickness described here moves inward as spinning speed decreases, which causes the reduction of the effective areas of photoresist-film, as shown in figure 1. Figure 2 illustrates the distribution of film thickness measured along the circumference with radius of 0.5 R. It is clear that the film profiles in the circumferential direction are rugged and rough. Furthermore, the non-uniformity of film thickness is not affected by different spinning speeds. Figure 3, which is derived from figure 1, indicates the relationship of average film thickness and spinning speed. And we find that the average film thickness increases more rapidly with decreasing spinning speed. Figure 4 exhibits the effects of spinning speed on the uniformity of SU8-10 film thickness in the radial direction. The non-uniformity of film thickness increases rapidly when the spinning speed is lower than 500rpm. This represents that the SU8-10 photoresist is suitable for a spin coating process performed at spinning speed higher than 500 rpm. A uniform film with thickness about 30 μm can then be obtained according to Figure 1. Figure 5 shows the relationship between the uniformity of film thickness in the circumferential direction and the spinning speed. Obviously, the uniformity of film thickness in this direction is worse than that in the radial direction, and the situation remains unchanged at different spinning speeds. Figure 6 presents the average film thickness as a function of the initial acceleration. The average film thickness increases abruptly when the initial acceleration of spin coating reaches 1500 rpm/s. Figure 7 shows the relationship between the initial acceleration and the uniformity of the film thickness of SU8-10 photoresist in the circumferential direction. The uniformity of film thickness becomes terribly worse when the initial acceleration is higher than 1300rpm/s or lower than 300rpm/s. Figure 8 shows the spin coating time versus the average film thickness. With longer duration of spin coating, the film thickness decreases gradually and then reaches a definite value. This phenomenon could be due to the change of the viscosity of photoresist during the coating process. Figure 9 shows the relationship between the uniformity of film thickness in the radial direction and the coating time. With increasing spin coating time, the uniformity of film thickness does not decrease monotonously but fluctuates irregularly. This result can be explained by the characteristics of the viscosity of SU8-10 photoresist. The viscosity data measured by the rheometer are illustrated in Fig. 10. The shear stress of photoresist increases as the shear strain rate increases. Fig. 11 exhibits the relationship, calculated from Fig. 10, between the viscosity of photoresist and the shear strain rate. Apparently, the viscosity increases with increasing shear strain rate. Within the current experimental range of the shear strain rate, 0~50 s^{-1}, of the thick-film spin coating, the variation of the viscosity reached 30%. Hence, according to the study of Acrivos et al. [4], we can perceive the results as shown in Fig. 9.

4. Conclusions

The effects of spin coating parameters by using of SU8-10 photoresist, including the spinning speed, the initial acceleration, the coating time on the film thickness, and the uniformity of the film thickness are investigated in this paper. Experiments show that film thickness of spin coating can reach as high as 80 μm. However, if we take into account the exposure quality, which is affected by the uniformity of the whole film thickness, the suitable coating thickness is about 30 μm. Moreover, the variation of the viscosity of photoresist is considered as the basic factor affecting the uniformity of film thickness. As a result, besides decreasing the non-Newtonian characteristic of photoresist as much as possible, the effect of the solvent evaporation rate on the viscosity of photoresust and how to control the uniform distribution of solvent evaporation rate strictly should be studied in the future.

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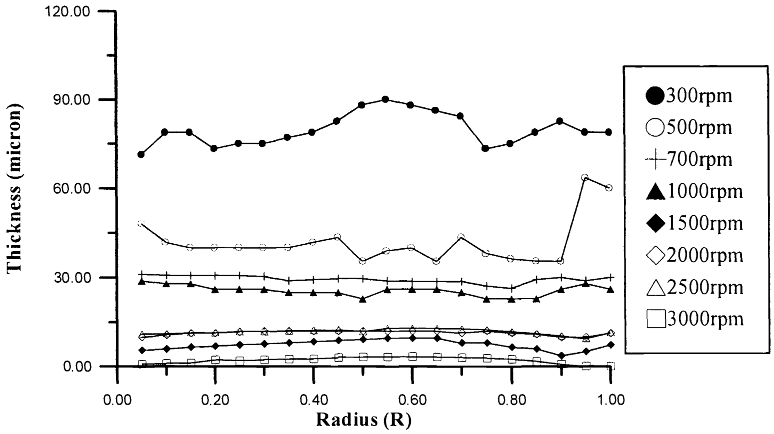

Fig. 1. Film thickness of SU8-10 in the radial direction under different spinning speeds.

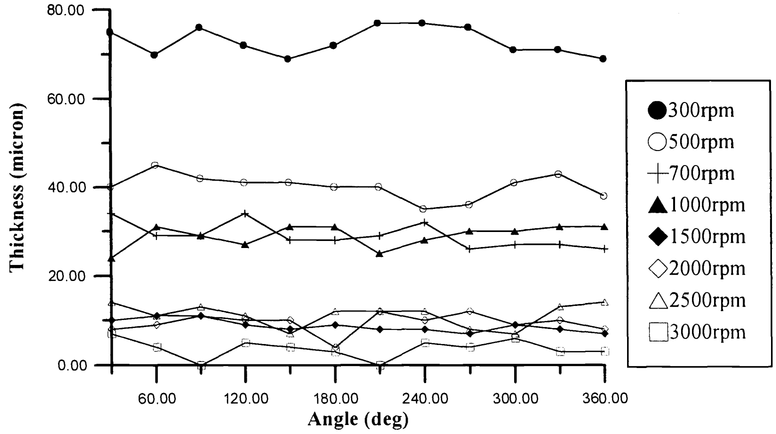

Fig. 2. Film thickness of SU8-10 in the circumferential direction under different spinning speeds. Film thickness at r=0.5R were measured.

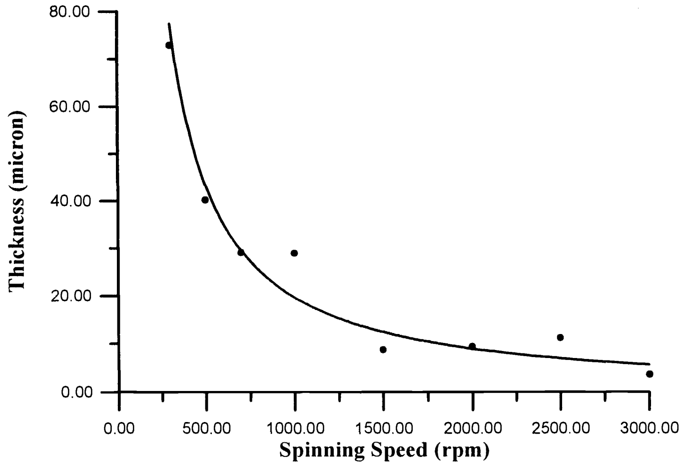

Fig. 3. Film thickness of SU8-10 versus spinning speed.

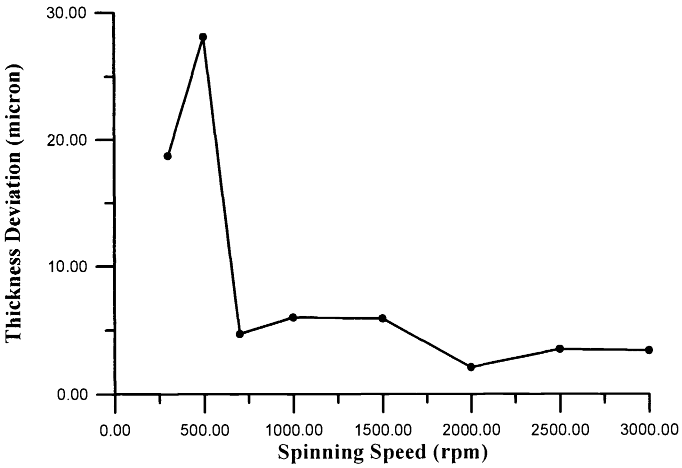

Fig. 4. Film thickness deviation of SU8-10 in the radial direction versus spinning speed.

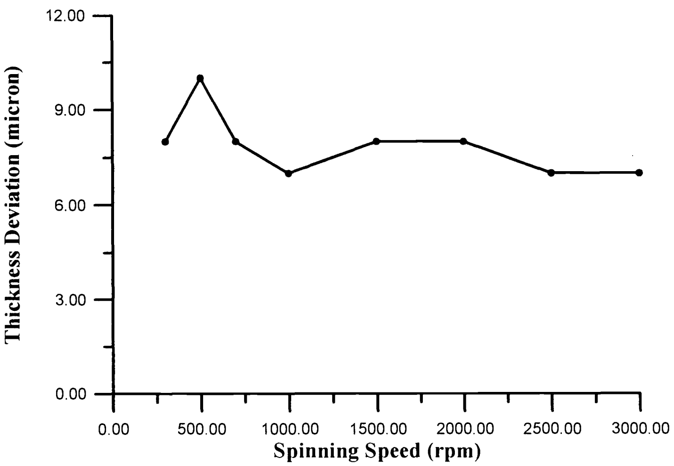

Fig. 5. Film thickness deviation of SU8-10 in the circumferential direction versus spinning speed.

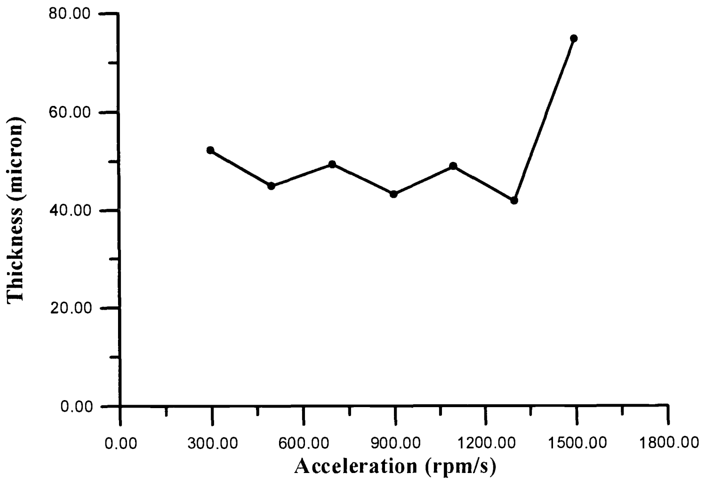

Fig. 6. Film thickness of SU8-10 versus initial acceleration. The spinning speed used is 1000rpm.

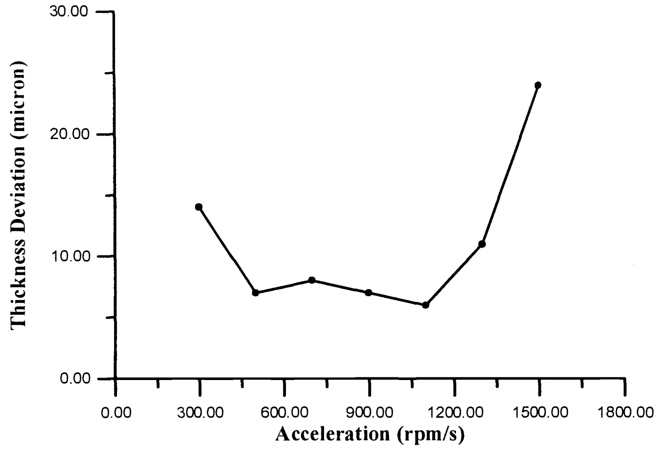

Fig. 7. Film thickness deviation of SU8-10 in the circumferential direction versus initial acceleration. The spinning speed used is 1000rpm.

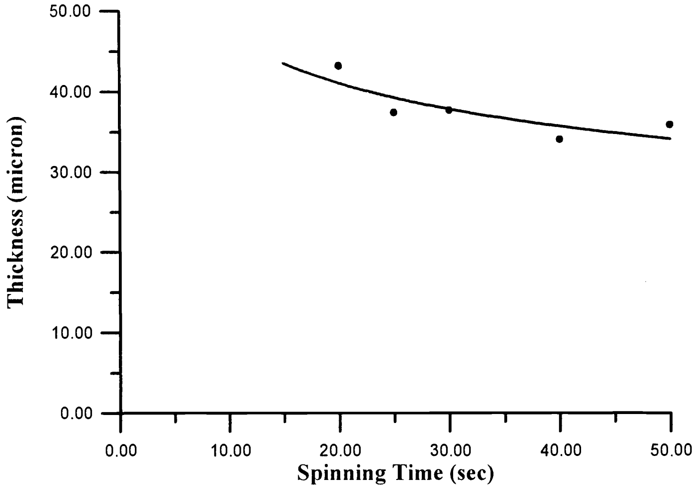

Fig. 8. Film thickness of SU8-10 versus spinning time. The spinning speed used is 1000rpm.

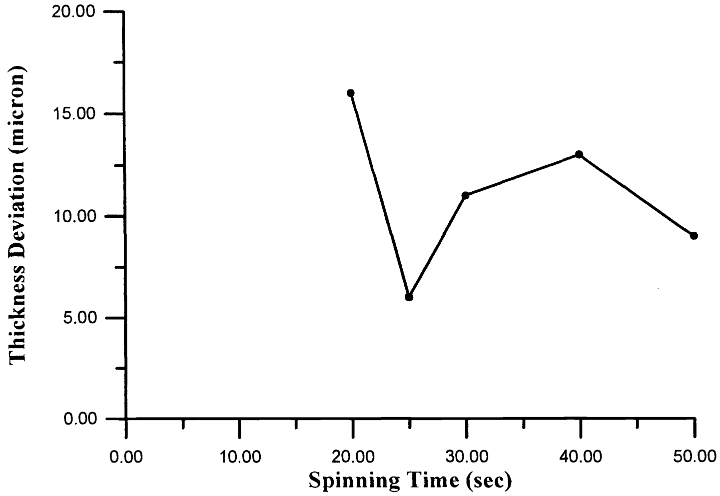

Fig. 9. Film thickness deviation of SU8-10 in the radial direction versus spinning time.

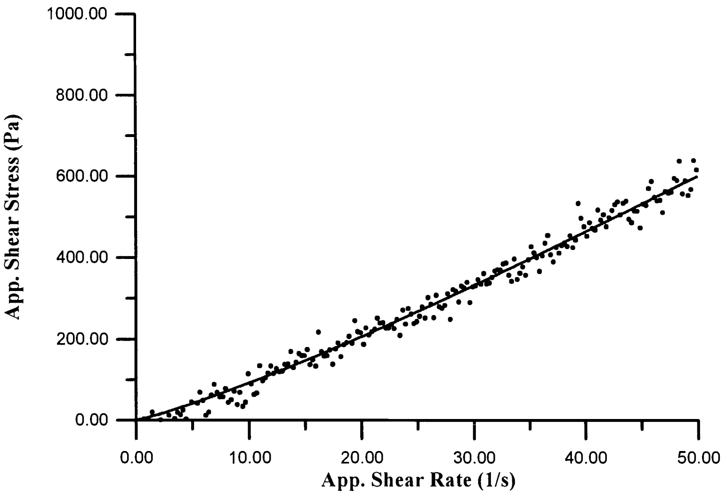

Fig. 10. Shear Stress versus shear strain rate data for SU8-10 photoresist.

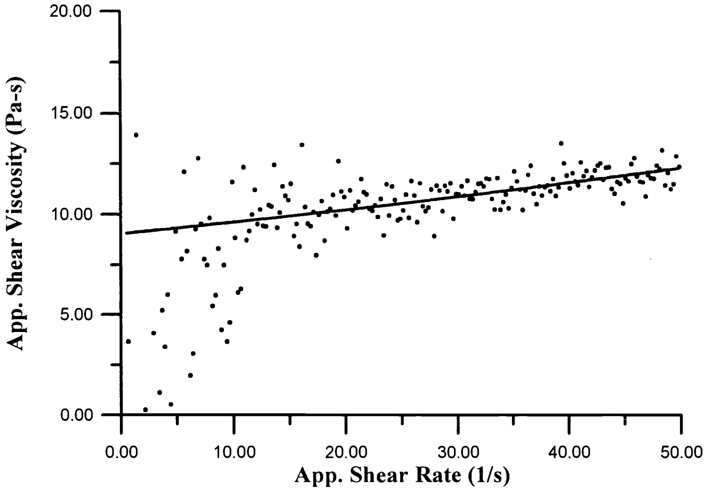

Fig. 11. Viscosity versus shear strain rate data for SU8-10 photoresist.