Abstract – This paper presents a new method of photoresist deposition, spray coating, that utilizes the Electronic Vision EV101 system. Several solution of diluted AZ4562 photoresist are used to form a thick layer on flat wafers and to produce sufficient coverage on wafers with deep cavities. A number of parameters that strongly influence the spray process are identified and their influence on resist thickness and uniformity is evaluated. Special attention is paid to the coating process when spraying on wafers with cavities ranging from 75 to 425 µm in depth. A few applications of spray coating are shown to illustrate its possibilities for MEMS.

Keyword – resist spray coating, lithography for MEMS, MEMS for RF, micromachining

I. INTRODUCTION

The continuous development in micro-electromechanical systems (MEMS) and the increasing use of truly 3D microstructures requires new techniques and processes to fulfill the demand for further miniaturization and higher integration density. For several MEMS applications, pattern transfer on wafers with extensive topography requires a uniform resist layer over a non-planar surface. Spray coating of photoresist appears to be a promising technique for coating irregular surfaces as it presents some advantages over other techniques such as spin coating and electroplating.

The Electronic Vision EV101 spray coater [1] and several solutions of AZ 4562 positive resist diluted in PGMEA (methoxy-propyl acetate) with viscosity ranging from 5 to 16.7 cSt have been used for the spray experiments. The experiments are carried out on both flat wafers and wafers with etched cavities from 75 µm up to 425 µm in depth. A number of parameters that strongly influence the spray process are identified. In particular, the dependence of resist thickness and uniformity on dispense volume and solid content of spray solution are investigated. A proper solution for getting a good coverage and uniformity over the cavities wafers is pointed out. The thickness and uniformity achieved is sufficient to pattern contact windows in very deep cavities and rather fine lines across less deep cavities. Several applications for MEMS using the spray coating of photoresist are demonstrated here. These initial results are quite encouraging and well-defined multi-level micromachined structures appear to be feasible.

II. SPRAY COATING

A. Spray coating system

A direct spray coating system has been developed and introduced by the Electronic Vision Group in early 1999. Key to this spray coating technology is an ultrasonic spray nozzle with a patented droplet filter and innovative dispensing method. During the spray-coating process the wafer is rotated at low angular velocity (30-60 rpm) while the swivel arm of the spray-coating unit is moved across the wafer. An image of the Electronic Vision EV101 spray coater chamber is shown in figure 1. This system uses a syringe pump that provides the same precision and repeatability as pumps that automatically dispense out of a bottle while offering the flexibility to use very small quantities of resist. The syringe pump is therefore appropriate for experimental purpose. The EVG Coating System is operated through Windows based software that allows editing of the coating recipes. The resist thickness can be varied by controlling the solid content of the spraying solution and the dispensed volume. Solutions with viscosity up to 20cSt can be employed.

Direct spray coating as compared to spin coating or resist plating offers several advantages. For example, a much smaller resist amount is consumed with the spray coater when thick resist layers are needed. In fact, to obtain a layer of the same thickness generally a resist volume 10-15 times smaller than the one needed for spin coating is used. As compared to resist plating a clear advantage of spray coating is that layers can be sprayed on all type of surfaces, both conductive and insulating. Resist plating,
on the other hand, requires a conductive seed layer, something that can complicate the process when patterning non conductive layers, such as oxide and nitride.

![Image of spray coating chamber](image)

1. Wafer chuck
2. Swivel arm with the spray head
3. Photoresist syringe pump

Fig. 1. The EV 101 spray coating chamber.

### B. Photoresist solutions

Several resist solutions based on diluted AZ4562 photoresist have been used. AZ4562 photoresist has 39.5% solid content and a viscosity of 440 cSt [2]. This high viscosity and high transparency positive photoresist is normally used to form a thick layer by spin coating. Although in our earlier work, we have shown AZ4562 to be a suitable photoresist for coating and patterning wafers with high topography [ref 6] its high viscosity, impedes its use for direct spray coating (the system can operate with solution viscosity up to 20cSt). To overcome this problem we have diluted the resist to create solutions with low viscosity. Methoxy-propyl acetate (PGMEA), a main solvent in the AZ4562 resist, is used to dilute the resist. Three solutions with the solid content of 20, 17 and 15% have been prepared. The viscosity of these solutions, measured by Ubbelohde viscometer PSL ASTM-IP 1C, is 16.9, 10.4 and 5 cSt, respectively. The viscosity of the resist solution decreases rapidly when solvent is added as illustrated in Fig.2.

### III. EXPERIMENTAL AND RESULTS

Direct spray coating is investigated on both flat wafers and wafers with cavities. The spraying on flat wafers is used to identify the relevant process parameters and in particular to select the resist solution more suitable for coating wafers with large topography variation.

![Viscosity vs. solid content of AZ4562 photoresist diluted solutions](image)

**Fig.2. Viscosity vs. solid content of AZ4562 photoresist diluted solutions**

**A. Flat wafers**

Parameters that influence the film thickness, uniformity and roughness of sprayed layers are: angle of the atomizer, spray pressure, solid content of the spray solution, resist dispensed volume and scanning speed of the atomizer. The first two parameters are fixed and kept constant for this experiment. Test depositions using initial settings are performed to study the influence of the resist solution or dispensed volume on the quality of sprayed layer. Three different resist solutions, 20%, 17% and 15% in solid content, prepared as mentioned in previous section of above, are used. For all three solutions, the dispensed volume of resist is 70 µl/s, spin rate of wafer is 60rpm and the scan speed ranging from 600 to 2000rpm across the wafer.

Silicon (100) wafers, 100mm in diameter are used as substrates. Normally, spray coating forms a thicker layer than spin coating. So there will be a flowing effect of photoresist if the layer is thick and not drying fast enough. As PGMEA is not a highly evaporating solvent, a heated chuck has been added to the system to accelerate the drying process. In this case a temperature of 60°C (set-point) has been set for the chuck. After the deposition of resist, wafers are baked on a hot plate at 90°C for 3 min. The resist thickness is then measured by Leitz MPV-SP using reflectance spectrometry technique.
Measurements are carried out at ten positions on the wafer. The final value is averaged over these ten points. The uniformity of the sprayed layer is defined as:

\[ \text{\%1} = \frac{\sigma}{\text{average}} \]

where: \( \sigma \) is the standard deviation of the measurement values and \( \text{average} \) is the average thickness over ten measurement points.

The resist thickness and uniformity on the wafer for the three solutions with different solid content are depicted in figure 3.

The resist thickness increases with increasing solid content of the solution. However, the 15% solid content solution gives a better uniformity than the other solutions. Although quite thick resist layers can be obtained when using a 20% solution, the uniformity is not as good as for the lower solid content solutions. Furthermore, as the sprayed layer is formed by a continuous layer of droplets [3], high solid content solutions produce very thick resist droplets, causing a high roughness surface.

The thickness of photoresist for each spraying solution can also be varied by changing the dispensed volume in a single spraying. (see [4]).

The roughness of the sprayed resist layers is measured using the Tencor alpha step 200. In Figs 4a and 4b, surface profiles over a 10mm length for two solutions are shown. The roughness for a 17% solution is 225 nm while for the 20% solution is 2.9 \( \mu \text{m} \). These results obtained on flat wafers suggest that for wafers with large topography variations, where uniformity is difficult to achieve, low solid content solution should be employed as they produce more uniform layers. The thickness can then be increased by using multiple coating steps.

\[ \text{Uniformity} \]

\[ \text{Resist thickness} \]

Solid content of solutions (%)  

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<th>Solid content (%)</th>
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B. Spray coating on wafers with cavities

Spray coating is suggested as a suitable method to get a conformal coating resist layer over wafers with cavities of various size and depths, as employed in a post-process module for the integration of RF device [5]. Wafers with deep-etched cavities ranging from 75\( \mu \text{m} \) to 425\( \mu \text{m} \) are used. The preparation of these wafers is described elsewhere [6].

As mentioned earlier in section II.A, parameters that largely influence the resist uniformity and thickness are defined. The values resulting in good uniformity layers on flat wafers are used as starting points for the wafers with cavities. However, when spraying photoresist on wafers with large topography, the resist will tend to locally flow, resulting in the accumulation of photoresist at the bottom and reduction at the top corners of cavities. The 15% solid content solution does give the better uniformity on flat wafers but its high PGMEA solvent content poses a problem. The solvent does not evaporate sufficiently fast and a severe flowing effect will take place. Therefore a solution with a higher solid content should be used. As the 20% solid content solution results in rough surfaces and very thick layers (difficult to
expose and develop for pattern transfer in and across deep cavities pattern) the 17% solid content solution seems to be the better candidate. To minimize the flowing effect, the drying of the sprayed layer should be accelerated. This can be achieved by using the heated chuck. Wafers are placed on the heated chuck (80º set-point) for about 4 min before the spraying starts. After spraying, the wafers are baked on a hot plate at 90ºC for about 3 min. A lithography step is applied to pattern structures in and across the cavities. The patterning of photoresist at the bottom of the cavities is also used to evaluate the thickness and uniformity of the resist layer. Exposure is carried out in EV-420 Contact Aligner with UV light source for 25 s (about 625 mJ/cm²). In order to open the structure at the bottom of cavities, high exposure energy is needed. Immersion development is performed using a potassium-based alkaline developer (AZ400K) diluted by 1:4 in deionized (DI) water. The resist thickness for these wafers is the thickness at the bottom of the cavities measured by a Tencor alpha step 200 profilometer. At each cavity five measurement points are taken and averaged in a similar way as for flat wafers. Wafers with cavities of 75, 150, 250, 375 and 425 µm deep are investigated. For the spraying process the same values of dispensed volume, spin speed and scan speed as in the experiment with flat wafers are used. The average thickness and uniformity for wafers with cavities is illustrated in figure 5.

The resist thickness decreases and the uniformity worsens as the etch depth of the cavities increases. In most cases the uniformity 1σ % is around ±12%, and for wafers with 425µm-deep cavities is >20%. However, for several MEMS applications, where the dimensions of patterned structures are often in the range of tens to hundreds of microns, this uniformity can be acceptable.

IV. APPLICATIONS

A. Spray coating resist for metal electroplating

As the spray coating technique can provide a thick resist layer on the wafer, it can be used to form the photoresist mold for metal electroplating. At DIMES, copper plating has been used for several purposes such as integration of RF devices and high-density interconnect [7,8]. We have used the 15% solid content spray solutions for copper plating.

![Fig. 6. SEM photograph of a photoresist pattern of an inductor structure (magnification 170X)](image)

Figure 6 is a SEM image of a photoresist pattern of a spiral inductor structure. The patterned resist line width is 3 µm and the spacing is 10 µm. Spiral inductors after copper electroplating and removal of resist are shown in figure 7.

![Fig. 7. SEM photograph of two copper electroplated inductors](image)

B. Spray coating for pattern transfer in deep-etched cavities

Although the coating of wafers with deep cavities still needs some improvements, these initial findings are
sufficient to transfer patterns to wafers with up to 400 µm-deep cavities. Several contact windows can be opened at the bottom of these deep cavities as illustrated by the SEM picture in figure 8.

Fig.8. SEM photograph of patterned contact windows at the bottom of a 375 µm deep cavities (magnification 28X)

Due to the flowing effect, the resist tends to accumulate at the bottom corner of cavities. In order to pattern the lines running over these cavities higher exposure energy is needed to remove the excess photoresist at the bottom corner of a cavity.

Fig. 9. Lithographic pattern of several lines across 375-µm deep cavity (magnification 75X)

Figure 9 is a SEM picture showing several lines patterned across the 375-µm deep cavity. In order to further improve the layer uniformity, other type of resists and solvents will be investigated.

V. CONCLUSIONS

The spray coating of AZ4562 photoresist has been investigated on both flat wafers and wafers with cavities. Three AZ4562 diluted solutions have been used for the experiments reported here. The proper resist solution for coating wafers with cavities is proposed. The thickness and uniformity of spray-coated resist layers is sufficient for some MEMS applications such as thick layer resist for metal electroplating and patterning in and across the deep-etched cavity wafers. The spray process has been employed for the fabrication of RF-MEMS devices at DIMES. Further development can result in opportunities for higher integration of MEMS components and three-dimensional (3D) structures that cannot be realized by conventional spin coating technique.

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