Photoresist with Ultrasonic Atomization Allows for High-Aspect-Ratio Photolithography under Atmospheric Conditions

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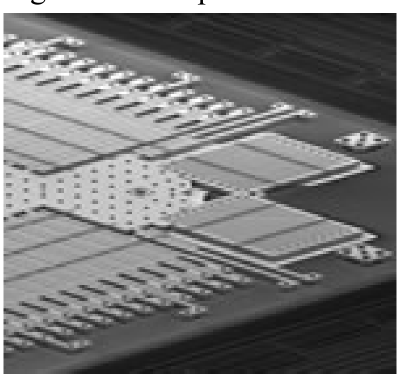
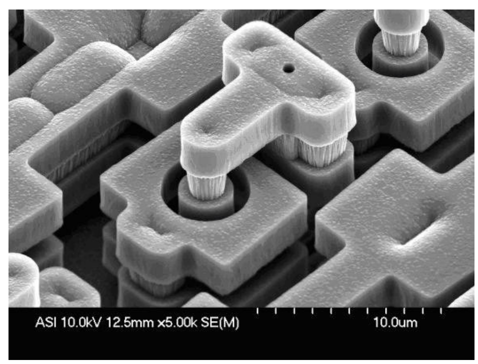
As the demand for faster, smaller micro-electro-mechanical systems (MEMS) on cell phones, tablets, autos, robots and even the potential Internet of Things increases, current traditional spin coating methods have demonstrated a lack of ability to uniformly coat high-aspect ratio devices where the depth to width ratios are 1:1 or greater at dimensions of 100 microns and smaller (IE features that are 400 microns deep and 100 microns wide). MEMS as commonplace as accelerometers on modern phones are common. But advances in medical applications allow extreme precision location of medical instruments used in emerging technologies.

Figure 1: Complex MEMS



(Photo Credit: Electronic Specifier, 2013)

Figure 2: Complex MEMS sample



(Photo Credit: Shanghai Senodia Semi, n.d.)

It has been demonstrated that the advantages of ultrasonic atomization can effectively be used to spray coat these difficult features under atmospheric conditions with high yields and stable performance It is possible to process more challenging features without the need for next-generation-lithography or expensive ALD because the droplets created by ultrasonic atomization are of a fundamentally uniform size, because of the process engineer's ability to control droplet wetness through the nozzle distance variable and because of the independent control of both gas flow that shapes the plume and flow rate of photoresist.

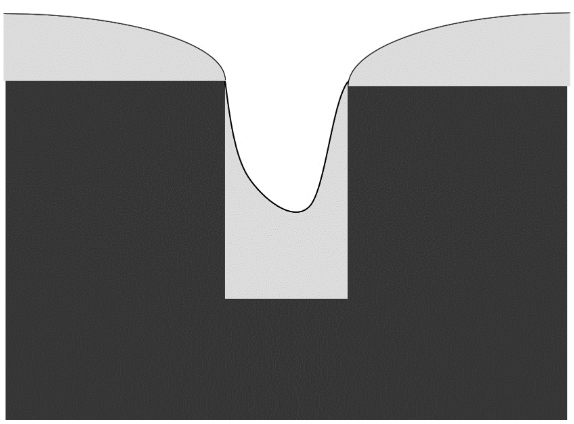
Photoresist Process

The photoresist etching process of MEMS wafers involves the deposition of a photoresist onto a wafer, the exposure of the resist, developing the resist, chemically etching the wafer, and stripping the remaining resist away. The photoresist serves the function of a barrier for the chemical etching process by allowing its partial removal depending on the area exposed to UV light. The exposed area can be for removal or to stay in place depending on if the resist is a positive or negative. Once developed, a chemical etching process can be performed on the substrate surface and the entire process repeated until the desired features have been etched to the desired depth. Thickness of the photoresist in this process is an important part as it affects the resolution and quality when developed.

Challenges of using traditional Spin-Coating when aspect ratios are higher than 1:1 (Depth to Width)

Spin coating became the preferred method of applying photoresist during the 1980's because of its key advantages at the time, which were: In a very short amount of time (typically less than a minute), a uniform layer of photoresist (+/- 10% uniformity) could be deposited at a thickness with which the industry could work (around 10 microns). But in order to keep up with Moore's law, the feature size on the silicon has continued to shrink where the rheology of the resist formulas will no longer be functional. Inevitably the deep wells suffer one of two process failures. The resist either flies over the well, leaving a void air pocket, or it fills the well to an undesirable level and leaves thin coatings on vertical walls.

Figure 3: Illustration of Spin Coated Photoresist (Credit: Sono-Tek Corp)



Droplet Uniformity and Droplet Size

Spray coating of photoresist is successful based on a number principles. The spray must be consistent over time and therefore the spraying device must not clog. In addition, in order to ensure the coating is uniform in its thickness, it is imperative that the spray droplet size be as uniform as possible. Additionally, where feature size gets smaller and smaller (below 50 microns in width), smaller droplet sizes become crucial.

Ultrasonic atomizers provide two key advantages to the process objectives. The size of the droplets are fundamentally uniform in accordance with the formula and data below and the nozzles are self-cleaning and therefore will not clog during the processing.

Figure 4a: Ultrasonic atomization illustration (Credit: Sono-Tek Corp)

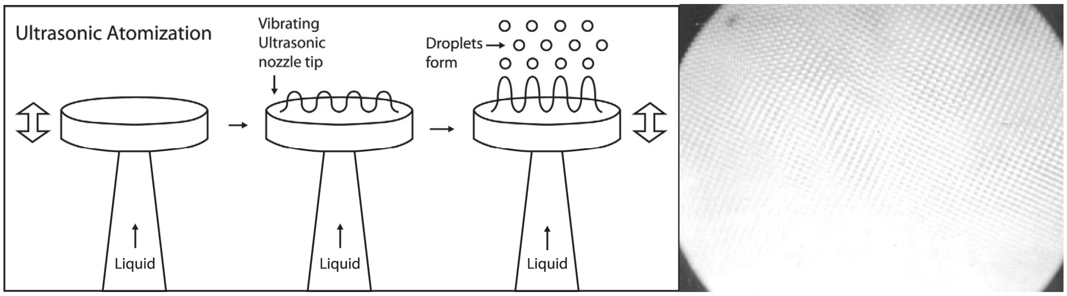


Figure 4b: Drop size calculation formula

$$\lambda_L=((8*\pi*\theta)/(\rho*f^{2}))^{1/3}$$

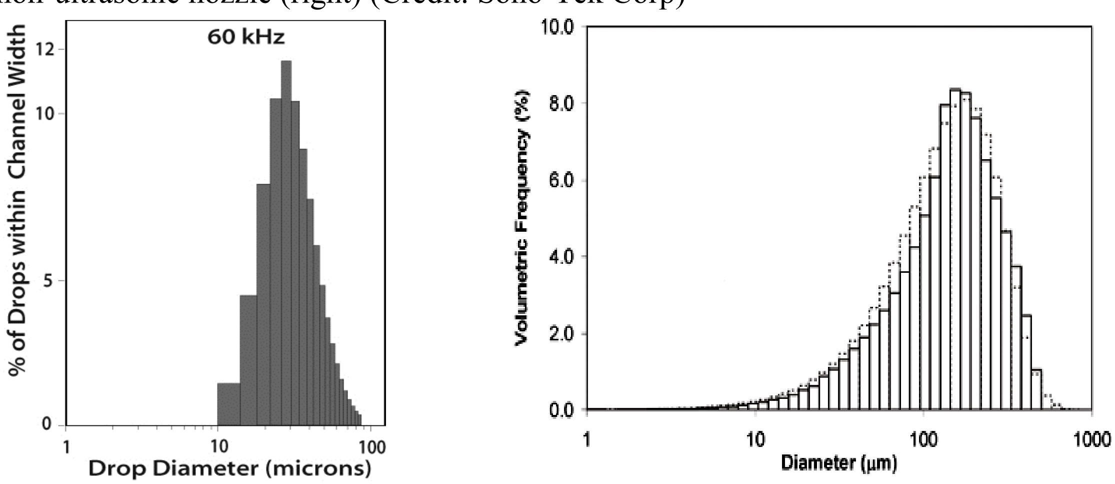
(Rayleigh, "Theory of Sound",1898)

Where:
π = pi
θ = Surface Tension
ρ =Density
F = Frequency of Nozzle

$$D_{N,\,0.5}=.34*\lambda_L$$

(Lang, R.J., 1962)

Figure 4c: Typical Sono-Tek ultrasonic droplet size distribution (left) versus typical non-ultrasonic nozzle (right) (Credit: Sono-Tek Corp)



Process Controls Allowed

Height versus final droplet size and independent control of plume shaping pressure contributes to dryness, wettability and flow on the surface. Because ultrasonic atomization creates the droplets without the use of pressure or gas, the droplets have near zero kinetic energy. The spray plume is then shaped with a low velocity gas. Having control of this gas as a process engineer provides a method to control the dryness versus wetness of the coating created. Another method to control the wetness of the process involves the height of the nozzle relative to the substrate. The droplets will quickly start to evaporate in flight while traveling to the substrate. In controlled environments, this leads to repeatable shrinking of the droplet size and allows fine tuning of the rheology on the substrate surface.

Summary

While this process has competition with more traditional spray and coating methods, it is more consistent and repeatable (ultrasonic nozzles don't clog). Further future expansion may be seen in ALD process, which should allow for a sudden expansion in MEMS capabilities, however this process is prohibitively expensive. Ultrasonic atomization proves today to allow for the most complex MEMS designs and stable manufacturing repeatability.

Figure 5: SEM photo of ultrasonic photoresist coating into 100x100 micron trench
(Photo Credit: Sono-Tek Corp)