

# CONFORMAL PHOTORESIST COATINGS FOR HIGH ASPECT RATIO FEATURES

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## ABSTRACT

The recent proliferation in advanced packaging and MEMS applications has created a need for high aspect ratio lithography processes. This paper will explore some of the alternatives for coating photoresists and dielectrics onto such structures, including conventional spin coating, electrodeposition, and more recently, spray coating. Data will be presented and discussed regarding the relative merits of the competing coating technologies, with real-world application examples for spray coating. This novel technique will be shown to deliver highly conformal resist coatings not only over etched v-groove structures commonly found in the MEMS world, but also over deep trenches and wells with high aspect ratios. The paper will emphasize recent improvements to both hardware and process methodology in an effort to broaden the scope of structures and materials suitable for spray coating. Practical extensions of this new technology will be explored and discussed, along with an assortment of new structures and applications that spray coating has enabled.

Keywords: lithography, photoresist, conformal coatings, MEMS, wafer-level packaging

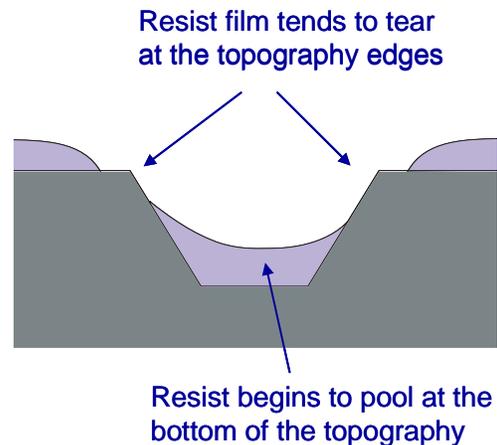
## INTRODUCTION

The fabrication of microelectronic devices has typically involved the lithographic patterning and etching of relatively planar substrates with topography less than a few micrometers in height. Lithography for these planar substrates has been and still is primarily carried out by spin coating a photosensitive resin onto the substrate to form a thin, uniform film which is subsequently baked, exposed and developed to form the desired circuit patterns.

While this historical spin-coating method is still a viable technique for many or most applications, it is not without its challenges or limitations, including inefficient utilization of the photoresist and difficulties in coating various degrees of

topography. So inefficient are most dispense methods that Curtis, et al have wryly noted that “the probability that a molecule of resist will proceed from the bottle to softbake is unacceptably small.”<sup>1</sup> In his paper, he goes on to outline a novel method of photoresist dispense dubbed “reverse radial dispense” which has been shown to greatly reduce resist consumption, particularly for certain resists and dielectrics.

Spin coating is governed by several physical phenomena, including the rheology of the resist, the spin dynamics and the dynamics of solvent transport. These phenomena have been outlined by Curtis, et al to describe the typical behavior of a photoresist or other such material in a spin coating cycle. In general, a photoresist spin coating process can be expected to process good uniform coatings on relatively planar surfaces largely due to the spin mechanics and the tendency of the resist in its fluid state to minimize the surface area. But these same flow characteristics will likely cause the film to poorly coat a non-uniform surface, primarily in response to effects from spin dynamics, gravity



**Figure 1:** Sketch of topography with insufficient coating uniformity

and the surface tension of the resist.<sup>2</sup> When spin coating a wafer with topographical steps such as trenches, grooves or mesas, the photoresist will tend to draw back from edges and corners as shown in Figure 1. This result is highly detrimental and cannot be tolerated in lithography processing.

The need for coating high topography has grown substantially over the last several years primarily due to the proliferation of applications for wafer-level packaging, 3-Dimensional Integrated Circuits, MEMS devices, and many others. Within these varied applications, many topographical steps exist in the form of v-grooves, mesas, cantilevered structures, deep trenches and cylinders, bumps, and tall multi-level metal structures, just to name a few. The need to perform lithographic patterning on and over these structures has created the demand for conformal resist coatings which protect the underlying layers from subsequent etch, deposition, or any other follow-on processing step.

One way of creating conformal photoresist coatings is by means of electrodeposited resist. With this process flow, the user creates a conductive film on the wafer, often through sputtering a seed layer such as chromium or other metals<sup>3</sup>, then electroplates the photoresist onto the wafer surface using a bath setup. While this method produces conformal photoresist coatings even on severe steps, the need for a conductive underlying layer and the inefficiencies and therefore high costs associated with this method limit its application.

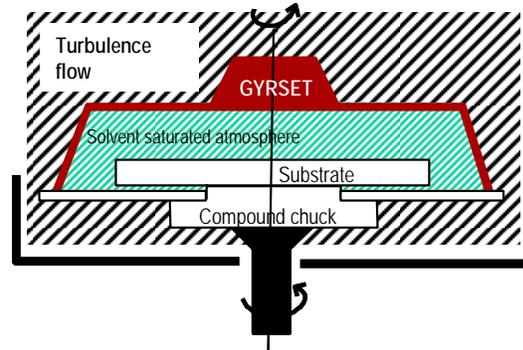
To create alternatives to conventional spin coating and electrodeposition of photoresists, this investigation set out to explore two novel methods of coating the resist: closed-cover spinning with a co-rotating chamber and spray-coating of the materials.

## EXPERIMENTAL

With conventional spin coating of photoresist, the spinning wafer resides in an open, uncontrolled atmosphere. This means that during the material spreading and drying cycle, the carrier solvent in the resist is allowed to evaporate freely into the atmosphere. Depending on several process factors including the volatility of the solvent, the relative humidity and velocity of the vertical laminar flow air, and the rotational velocity of the wafer, this evaporation could be very rapid, creating a skin on the resist surface.

For applications involving relatively planar surfaces, this might not present a problem in coating the wafer uniformly, but for wafers with some topography, the solvent needs to remain in the resist for a longer period of time to avoid creating striations around some of the topographical steps. To avoid this uncontrolled drying of the resist, a closed chamber has been created by means of a co-rotating cover. Dubbed the Gyrset™ coater, the system is depicted in Figure 2 which creates a small solvent-rich environment above the spinning wafer surface. With the chuck and the

Gyrset cover rotating synchronously, air turbulence is eliminated since the air is spinning with the substrate, and the evaporating solvent is captured, creating a solvent-rich environment. With this apparatus, the resist remains in the fluid state for a longer portion of the spread cycle, allowing it to flow more easily around obstructions such as corners of the topography. Avoiding this skin effect also produces an ancillary benefit of reducing the volume of resist material required, especially for materials with highly volatile solvents. Good results are readily achieved on moderate topography up to 10μ in height.



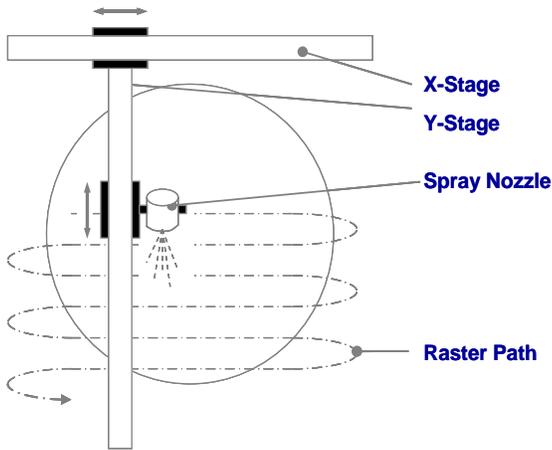
**Figure 2:** Schematic of Closed Chamber coating system

But as the Gyrset system is employed for higher and higher topography, gravity and the surface tension of the flowable resist become the dominant effects, and the feature edges created by the topographical steps are no longer sufficiently covered by the resist. The resist in its liquid state will flow down the trenches, creating open areas on the corners and edges of features. Though the coating results with the Gyrset spinner are superior to conventional open-bowl spin coating, high topography of several 10's of microns cannot be adequately coated by the Gyrset concept, and another method must be used.

To coat high topography, a new method of depositing resist is required which will circumvent the fundamental limitations of spin coating. As long as the resist is in its liquid state, it will flow around obstructions such as topographical features in response to the centrifugal force, and it will flow down inside features in response to gravity.

A new method of coating photoresist onto high topography has been proposed and investigated which does not employ any type of spinning of the substrate. Rather, a spray deposition method is employed which deposits the resist as an aerosol onto the surface of the stationary wafer, avoiding the problems with resist flow described above.

The apparatus is depicted in Figure 3 and employs a binary nozzle for creating the resist aerosol, an XY stage, and a chuck to hold the wafer. The binary nozzle is mounted to an arm a certain distance above the substrate, and is

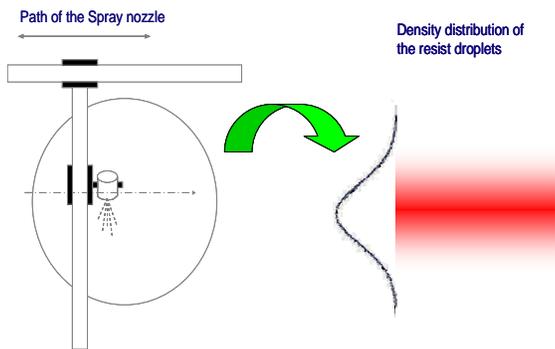


**Figure 3:** Layout of Spray System

supplied with a flow of photoresist and nitrogen pressure. As controlled volumes of photoresist are delivered to the nozzle, the nitrogen is mixed with the resist to create very small droplets as the nitrogen pressure forces the resist through the orifice. Many different materials have been successfully spray coated, and materials are typically diluted down to a viscosity of only a few centipoises.

The binary nozzle is mounted to an arm, which in turn is mounted to an XY translation stage. This stage transports the nozzle at a programmed slew rate to all portions of the wafer. This slew rate and the stepping pitch have been determined by knowing the viscosity of the material to be deposited, the size and shape of the structure, and the desired coating thickness. Round wafers are coated with a truncated pattern to maximize coating efficiency and throughput.

The substrate is fixed by vacuum to an appropriately-sized chuck; a variety of chuck sizes is available, and chucks can be exchanged rapidly. Temperature of the substrate chuck is programmable, with the temperature chosen based on process requirements. By selecting appropriate resist flow rates, N2 dispense pressure and chuck temperature, the resist droplets impinge onto the water surface and dry very quickly, allowing the resist to flow only a desired amount or

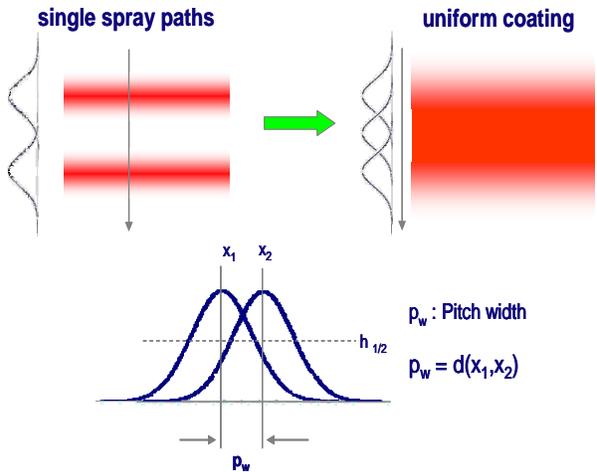


**Figure 4:** Deposition Pattern for Single Pass

not at all.

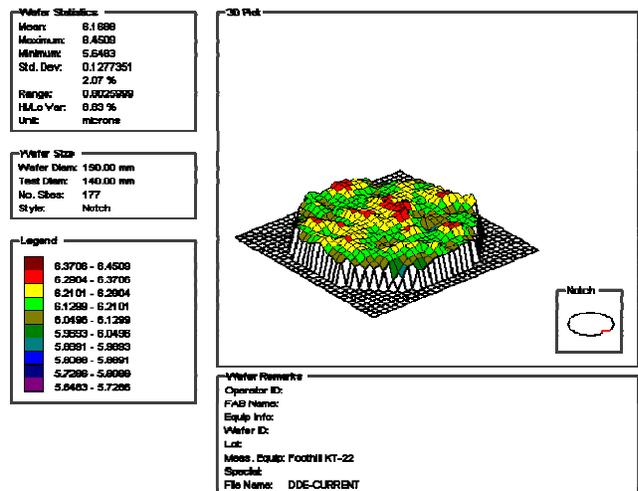
When the spray nozzle is directed across a surface with a single pass, the resulting photoresist distribution will look like Figure 4. Roughly a Gaussian distribution, the spray pattern will have a characteristic width and density depending on the process parameters and the particular material being sprayed.

Since the goal of the coating process is to have a uniform, conformal layer of material on the topography, the spray head is directed across the entire surface of the substrate



**Figure 5:** Deposition Pattern for Multiple Passes

using the slew rate and stepping pitch determined above, depicted in Figure 5. After the substrate has been coated in this first pass, the wafer is rotated to a programmed angle, and the process is repeated until the desired coating results are achieved.



WAFERMAP 2.1

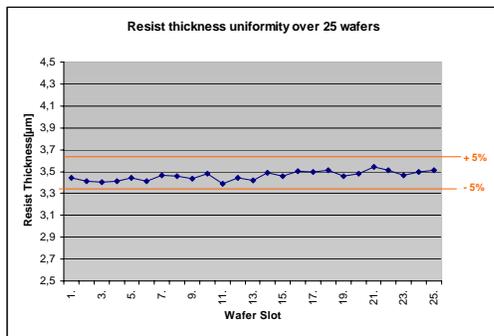
**Figure 6:** Resist Uniformity on Planar Wafer

## RESULTS AND DISCUSSION

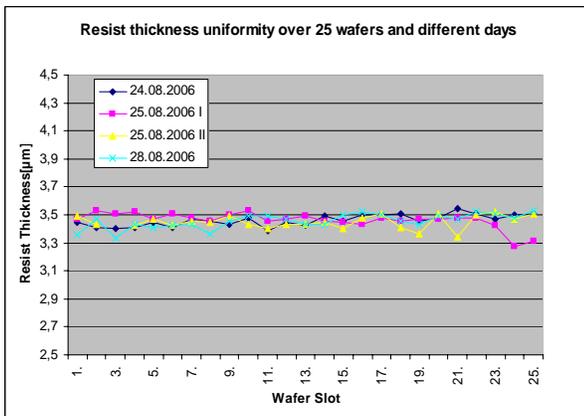
To baseline the coating performance, a series of tests was

carried out on 150mm planar silicon wafers. As noted earlier in this paper, planar wafers are not the intended substrate for spray coating, since the simpler and incumbent spin coating method can normally achieve good results on these substrates. As seen in Figure 6, the resist thickness was about  $6.2\mu$ , with a standard deviation of about 2.1%. Though this uniformity is not ideal and is not as tight as a normal spin coating process on a planar wafer, it demonstrates the ability of the spray coater to deliver consistent results on all portions of the wafer and expands the realm of photolithographic printing into technologies with high topography.

To characterize the coating repeatability, a batch of 25 wafers was coated with a similar process, but with about  $3.5\mu$  as the target thickness. Coating uniformity within the batch and from batch to batch was very good, as seen in Figures 7 and 8.



**Figure 7:** Resist Uniformity Wafer-to-Wafer



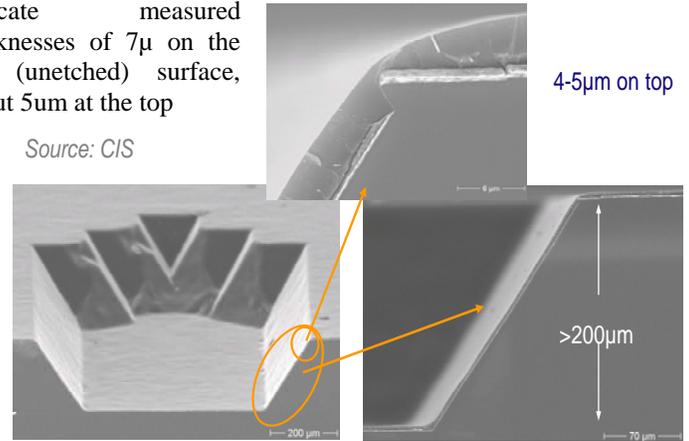
**Figure 8:** Resist Uniformity Batch-to-Batch

As emphasized in the introduction to this paper, high topography is the intended application space for spray coating, so a number of test wafers and customer samples were coated to explore results on challenging structures, including v-grooves, etched trenches, micro-lenses, vertical trenches, and actual device structures such as through-

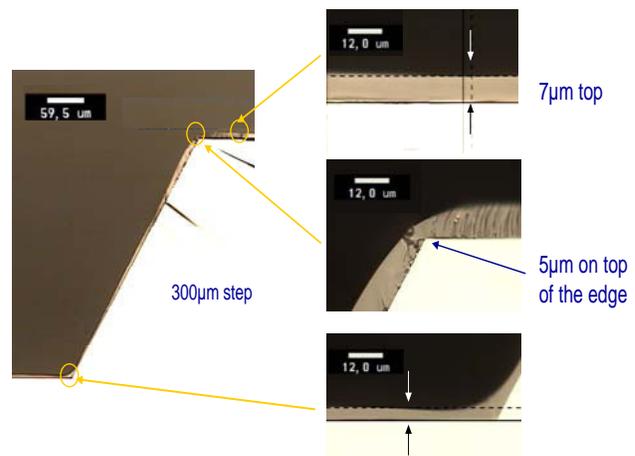
silicon-vias (TSV'S).

The first structure to be coated was a test structure with groove-like structures. This structure was selected because it is representative of the high topography commonly encountered in wafer level packaging, micromechanical systems (MEMS) and optoelectronic applications. These structures were created by preferentially etching the Si surface with a liquid etchant, creating the approximate 54 degree sidewall angle. The structured wafer was held by the vacuum chuck as the pre-diluted photoresist AZ4999 from AZ Electronic Materials was sprayed onto the surface with multiple passes until the desired thickness of about  $4.5\mu$  was achieved, as shown in Figure 9. As can be seen in the higher magnification insets in the photo, good coverage was achieved despite the cusping or lip at the top of the structure. Note also the lack of pooling of the resist at the bottom of the structure.

Similarly, a dielectric material (Cyclotene 4000 series from Dow Chemical) was diluted and spray-coated onto a v-groove structure, shown in Figure 10. Insets in the photo indicate measured thicknesses of  $7\mu$  on the top (unetched) surface, about  $5\mu$  at the top

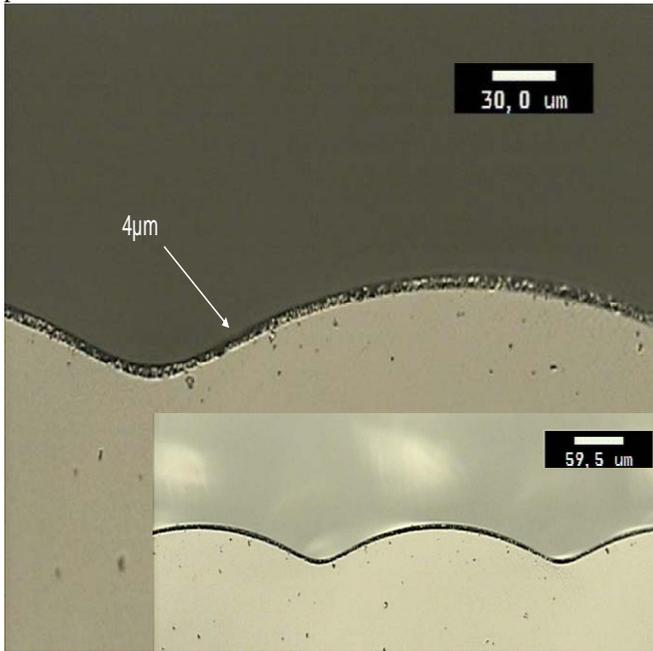


**Figure 9:** Conformal Coverage on an etched Multifaceted Structure with AZ4999 resist

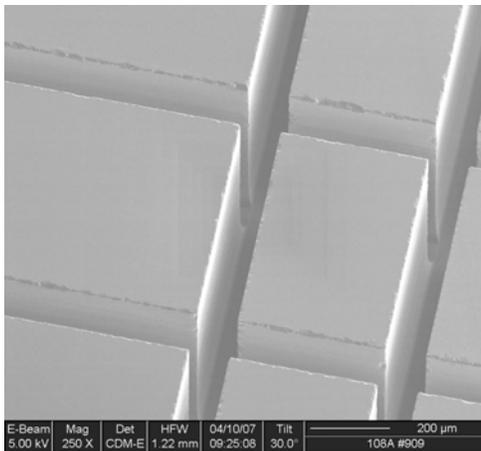


**Figure 10:** Modified BCB4024 coated on v-groove

corner, where surface tension would normally tear the material away, and about  $3\mu$  at the bottom of the trench, where gravity would normally pull a liquid material into a pooled state.



**Figure 11:** Shipley 1818 Resist conformally coated onto microlens structure. Photo courtesy SUSS MicroOptics

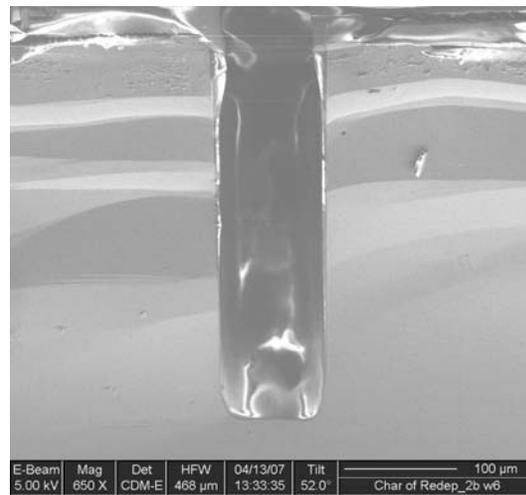


**Figure 12:** Vertical Structures from Seagate Research before Resist Coating

The next structure to be coated consisted of glass substrate which had been selectively etched to form cylindrical lenses. Such structures are used in imaging applications to form microlenses which are applied to manipulate or translate an image or a distribution of light. This structure was spray-coated with a diluted form of Shipley 1818 photoresist from Rohm and Haas chemicals, with the results shown in Figure 11.

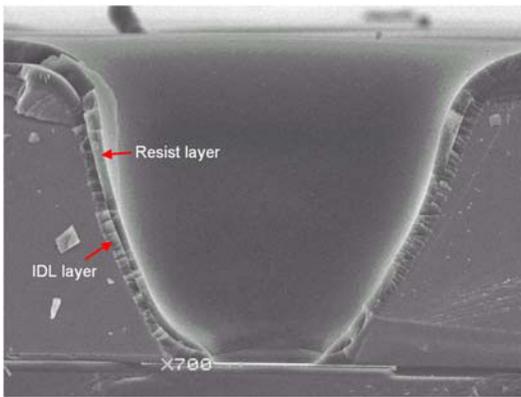
After these tests with relatively shallow angles, a test device with 90 degree sidewalls was prepared using a 150mm Si wafer. These vertical grooves were processed into the wafer, nearly extending the full thickness of the wafer. The uncoated trenches covered the entire surface of the wafer, as depicted in Figure 12. Subsequent processing required that the sidewalls of these trenches be completely coated with photoresist, but without pooling at the bottom. This was considered to be an extreme challenge for photoresist coating.

Using the spray coat tool described, a process was devised using the off-the-shelf AZ4999 resist. Several spray passes were used to coat to the required thickness, and the sidewalls were adequately covered from top to bottom to meet process requirements, as shown in Figure 13.



**Figure 13:** Seagate Vertical Trenches conformally coated with AZ4999 resist

Finally, the spray coating technology was applied to a device wafer for an advanced imaging sensor from Schott Advanced Packaging. This device is highlighted because the shape, materials and Through Silicon Via (TSV) structure utilized is typical of many emerging applications in the realm of wafer level packaging and 3-Dimensional Integration. In this specific case, a tapered via allowed both the Inter-Dielectric Layer (IDL) and the photoresist to be spray coated onto the TSV structure<sup>4</sup>. Tapered vias will likely be used on many devices where the available real estate allows their use due to the cost savings of spray coating over chemical vapor deposition (CVD). The results are depicted in Figure 14 and show excellent coverage on all areas of the TSV, especially at the critical corners.



**Figure 14:** Through Silicon Via conformally coated with dielectric and photoresist. Photo courtesy of Schott Advanced Packaging

## CONCLUSIONS

The problem of coating photoresist onto high aspect ratio features has been investigated. Conventional spin coating, the incumbent technology for relatively planar substrates, cannot produce coatings of sufficient quality for good lithographic results. A closed cover spin coating system produces sufficient results on topography up to about 10 $\mu$  but not significantly higher.

Spray coating has been proposed as an alternative solution to producing conformal coatings over high topographical steps. The method was used with good results on numerous test and device wafers with structures including v-grooves, vertical trenches and through silicon vias. Spray coating is therefore shown to be an enabling technology for these types of structures used in advanced packaging, 3-dimensional integration and MEMS applications.

## REFERENCES

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