Low-k Underfill Using Spray Coat Technology

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Abstract

The purpose of this extended abstract is to present a new application of spray coating process which greatly improves the process of performing underfill of suspended structures (air bridges) with low-k polymer. By using spray coating, it is possible to realize as much as a nine-fold materials savings, plus a three fold time savings. This article describes the spray coating process, and how it applies to the underfill process.

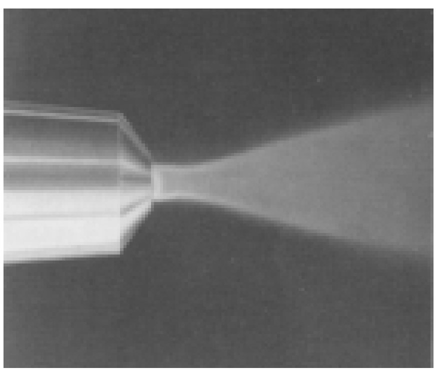

Figure 1: 30° Spray distribution

INTRODUCTION:

Suspended interconnect pathways are a common structure found in many devices requiring high power applications. The reason that the structures exist is to reduce the parasitic capacitance [1]. By filling the space underneath with a low-k dielectric material, this reduction is maintained, while reducing the chance of damage to the fragile structures, effectively increasing yield. However, filling this space can be time consuming and expensive.

This is a process that could be performed by spin coating. However, there are some distinct disadvantages to doing this. First of all, in many cases, the path from the top of the substrate to the area under the suspended region is relatively small (sometimes just a few micron). This requires the use of a low viscosity material (<20 cSt), in order for capillary effects to draw the substance under the bridge. However, a significant amount of material needs to be placed under the structures, as, oftentimes, the structures are suspended 5 μm or more above the bulk surface of the wafer.

Since a material with a viscosity of 20 cSt will result in a film ~1 μm thick when spun on a blank wafer at ~2000 RPM, it takes multiple coats to deposit sufficient thickness of material to completely fill in under the suspended structure. This translates into lost resources, both in the form of material lost and time spent.

Another method would be to use a photopatternable low-k dielectric, such as Benzocyclobutene (BCB, marketed by Dow chemical as Cyclotene®). Then, each level of the suspended structure could be patterned individually in the BCB, with successive layers stacking one atop another. This method is used frequently for redistribution layers in wafer level packaging.

The problem with this method is that, again, multiple coats are being performed. Additionally, the resolution capabilities and, in particular, the sidewall profile in this case is less desirable than that found in other patterning and layering methods.

In contrast, spray coating will make this a much simpler process.

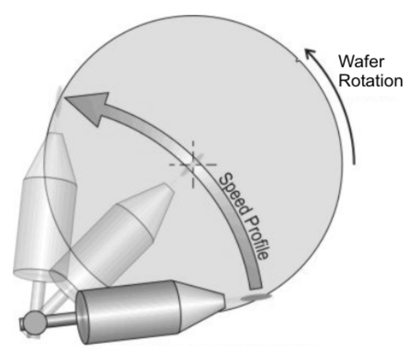

Figure 2: Spray Coating Process Dynamics

SPRAY COATING

The key to this spray coating technology is the ultrasonic spray nozzle. This nozzle oscillates to produce microscopic resist droplets. The mean distribution of the droplets' diameter is typically around 20µm. In order to achieve the proper droplet size distribution, the viscosity of the material introduced to the nozzle must be below 20 cSt (centistokes)[2]. Most commonly used photoresists can be diluted with resist compatible solvents with the following properties:

– Same or similar chemistry as mean resist solvent
– No chemical reaction with the resist before or during the exposure
– High vapor pressure

Table 1 shows a sample of materials that have been used for spray coating processes:

Once the droplets have been produced by the ultrasonic nozzle, they are accelerated toward the surface of the substrate via a stream of clean, dry air (CDA) or nitrogen, which can be adjusted directly within the software preset. During the spray process, the substrate rotates with a very low spinner speed (50 to 100rpm), which minimizes the centrifugal forces on the outer substrate area. These coating dynamics prevent coating defects and non-homogeneous areas on the final coating layer. The dynamics of the process are shown in Figure 2.

One of the most important dynamics in the spray coating process is the velocity profile of the resist nozzle as it sweeps over the wafer. Due to the decreasing area of substrate requiring coverage as the nozzle nears the center of the wafer, a constant sweep speed is not appropriate. This would create a resist layer that thickens towards the center of the substrate.

Instead, a varied sweep profile must be used. In order to simplify this process, the sweep path is divided into multiple parts, or indices, each with its own travel velocity.

Material	Comments
Clariant AZ P4620	Positive Photoresist
Shipley S1813	Positive Photoresist
Clariant AZ nLOF 2070	Negative Photoresist
MCC SU-8 2025	Negative tone epoxy
Dow Cyclotene™ BCB	Low-k dielectric
Polyimide	Low-k dielectric
PMMA	E-beam resist
AGI Cytop™	Fluorinated Polymer
GenTak 130P	Spin on adhesive (Bond intermediate layer)
Epic LSF 60	Solder Mask
UV curable adhesives	Bond intermediate layer

Table 1 – Example materials deposited via spray coating

By comparing the relative area of each of these indices, an optimal velocity can be calculated for each index. A general velocity profile can be seen in Figure 3.

In all, the film thickness, uniformity and roughness depend on the following parameters:

– The solid content (resist dilution)
– The angle of the Spray nozzle
– The resist dispense rate
– The scanning speed of the atomizer (velocity profile)
– The Spinner speed

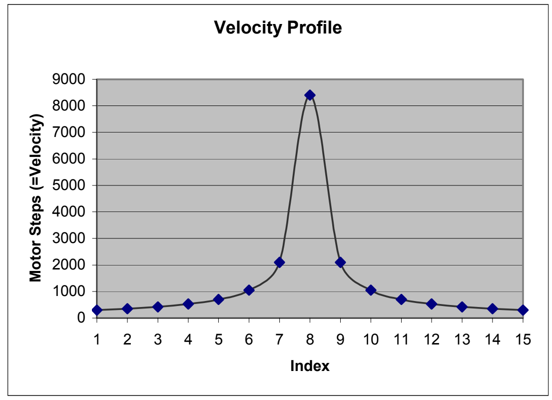

Figure 3: Example of a velocity profile

All critical parameters can be adjusted via the recipe and stored in the preset. The angle of the atomizer and the resist dilution are normally fixed and kept constant for one substrate or experiment. A recipe with optimized parameters has been developed to give a reasonable uniformity of the resist layer across the wafer. With these features it is possible to get good repeatability, and also a very good run to run standard deviation. Table 2 shows the uniformity results of a 4.2 µm spray coated layer on a series of blank 150 mm silicon wafers.

MATERIALS SAVINGS

Spray coating is an ideal process for the application of the low-k underfill. Since this deposition method already requires low viscosity materials, the capillary requirements for underfill are met, and no difficulty is presented in placing sufficient material in a single pass. This results in direct time savings, as only a single coat is required to properly underfill the structure. Material savings are also produced, since only a single dispense is required.

It is well known that in spin coating processes, most of the resist dispensed spins off of the wafer, and into the bowl, eventually becoming waste. Even with the highest level of process optimization, this remains true. Because of the method of deposition used for spray coating, the vast

	Wafer						
Point	1	2	3	4	5	6	Wafer To Wafer
1	4.201	4.307	4.307	4.021	4.412	4.066	
2	4.177	4.298	4.324	4.128	4.369	4.402	
3	4.088	4.321	4.329	4.218	4.309	4.386	
4	4.180	4.269	4.316	4.326	4.245	4.392	
5	4.160	4.207	4.189	4.342	4.245	4.390	
6	4.051	4.202	4.077	4.217	4.344	4.132	
7	4.148	4.155	4.062	4.150	4.390	4.084	
8	4.151	4.147	4.225	4.258	4.206	4.089	
9	4.128	4.163	4.232	4.229	4.304	4.369	
Average	4.143	4.230	4.229	4.210	4.314	4.257	4.230
Range	0.150	0.174	0.267	0.321	0.206	0.336	0.171
%Unif	1.81%	2.06%	3.16%	3.81%	2.39%	3.95%	2.02%

Table 2 – Spray Coating Uniformity Data

majority (typically >90%) of the material dispensed remains on the substrate.

While this material savings is a good thing in any situation, it becomes very important when applied to precious material. A good example of this is BCB. This material is finding a high degree of utilization as a material for advanced packaging, due to both its mechanical properties, and its utility as a low-k dielectric. Spray coating can allow the use of this material to be extended to cost sensitive devices, where standard coating methods are too expensive to be justified.

A study was performed to determine the amount of

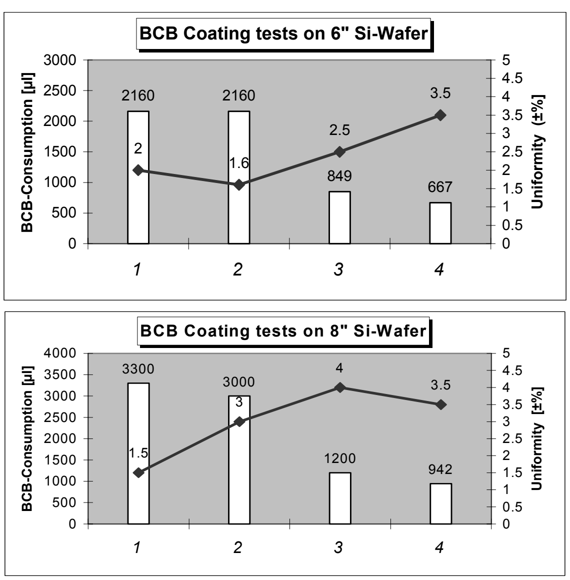

Figure 4 – BCB Consumption and Uniformity on 6" and 8" wafers – 1 - 10µm 4026-46 spin; 2 – 5 µm 4024-40 spin 3 – 10 µm 4026-46 spray; 4 – 5 µm 4024-40 spray

material savings that could be achieved when using spray coating, as opposed to an optimized spin coating process, as well as the resulting change in uniformity (see Figure 4 below).

For both 6" and 8" wafers, and for both resists and film thicknesses, the amount of material savings was approximately the same, at ~1:2.5. This can actually be improved even more, considering that materials such as BCB must be diluted prior to spray coating (the viscosity of either Cyclotene® material used is greater than 300 cSt). Because the thickness of film produced is a direct function (linear) of the solids content of the diluted material, rather than of the viscosity, it would be possible to use a higher solids content material to create a thinner film, just by diluting it more. Thus, using the Cyclotene® 4026-46 to make a 5 µm film would result in requiring even fewer µl of BCB to create the 5 µm film.

Furthermore, when used in conjunction with a syringe dispense system (see Figure 5), the material savings are improved even further. By using the syringe system, several benefits are realized. First, the amount of "dead volume" (the volume of material between source and dispense point) is greatly reduced, and can even be as low as a single milliliter. Additionally, the syringe allows the use of smaller volumes of material at one time, since many

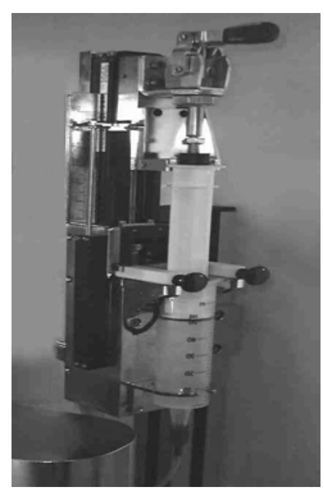

Figure 5 – Syringe Dispense System

		Units	Cost per Unit	Units per Wafer		Cost per Wafer	
				Spin	Spray	Spin	Spray
Prime	AP3000	ml	$ 0.05375	3	3	$ 0.16125	$ 0.16125
BCB Coat	BCB4024-40	ml	$ 1.60000	1.4		$ 2.24000	$ -
	BCB4026-46	ml	$ 1.60000		0.4	$ -	$ 0.64000
Spray Diluents		ml	$ 0.02939	0	3.2	$ -	$ 0.09405
EBR	T1100	ml	$ 0.05046	15	0	$ 0.75690	$ -
Develop	DS2100	ml	$ 0.04575	30	30	$ 1.37250	$ 1.37250
					Cost per wafer - Coating	$ 2.9969	$ 0.7340
					Cost per wafer - Full Process	$ 7.5276	$ 2.2678
					= 76% savings per wafer for coating only = 70% savings per wafer for full process		

Table 3: Chemical costs for 4µm BCB film

materials (BCB included) have a sharply reduced lifetime at room temperature. (BCB expires within 5 days when stored at room temperature.) Finally, the syringe system allows rapid changeover between resists (or different dilutions), when used in an R&D environment.

Cost data from work with a major power devices manufacturer shows the benefits of spray coating (Table 3)

UNDERFILL COATING

In contrast to spin coating, spray coating will make the underfill process much simpler.. It also allows great economic benefit, both from reduced process time and reduced materials usage.

As mentioned above, spray coating already requires low viscosity materials, thus satisfying the requirement to allow for capillary effects to draw the material under the structures. Since there is no concern with the low-k material flowing off of the wafer, no difficulty is presented in placing sufficient material in a single pass. This results in direct time savings, as only a single coat is required to properly underfill the structure, while in the case of spin coating, at least three coats are usually required..

Material savings are found in two ways. First of all, the amount of material required to fully coat the substrate via spray coating is less than the material required for a single spin coat (already over 70% savings). Since multiple spin coats (~3) would be necessary to match a single spray coat process, the material savings would multiply (>90%). In addition, the spin coating process tends to leave the top surface of the material (above the suspended structure) with limited planarity, while the spray coating method has demonstrated a high degree of planarization (see Figure 6).

CONCLUSION

This article has described a new process for the deposition of dielectric material. This process is very effective a creating a layer of low-k material sufficient to serve as effective protection for the fragile structures that are encapsulated. It was shown that spray coating can be used to not only provide a superior quality of coating as compared to spin coating, but at a great reduction in materials cost and process time.

By performing this underfill process, the power performance benefits of air bridges can be realized at high yield with minimum cost per wafer

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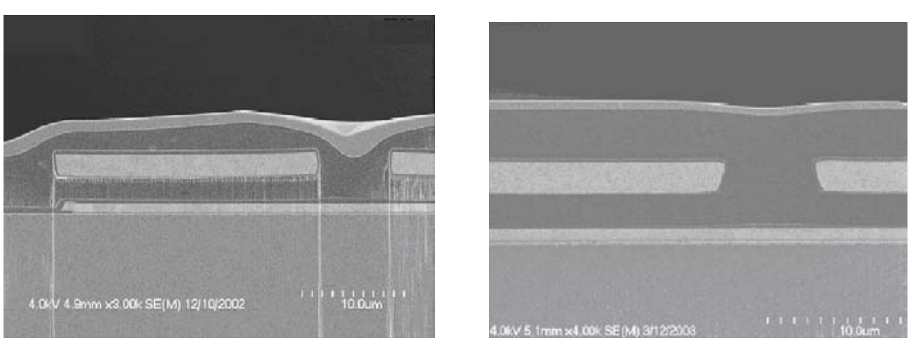

Figure 6 – Underfill Process a) with Spin Coat b) with Spray Coat. Images courtesy of Agilent Technologies