REDUCED WAFER WARPAGE AND STRESS IN JSR DIELECTRIC FILMS

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ABSTRACT

The addition of polymer dielectric films to silicon wafers is useful in producing stress reduction layers and interconnect structures for chip-scale packaging as well as 3D wafer stacks. The use of lower cure temperature materials offers several advantages including a lowered thermal budget on devices that are sensitive to electrical performance change with temperature. Unfortunately, enough stress remains from the difference in the coefficients of thermal expansion of the polymer and the silicon to cause significant wafer bow and handling problems. This warpage problem increases as the wafers are thinned for 3D stacking, TSV, or are used in embedded system packaging. This work describes substantial stress and warpage reduction of positive- and negative-acting photo-dielectric films from JSR Micro, Inc.. Multi-step cure profiles using variable frequency microwaves (VFM) that include low temperature steps and very fast ramps were evaluated with statistical designs. The same materials were cured to the same extent (as measured by TMA and solvent resistance) using a standard convection oven for comparison. Large reductions of wafer warpage does not come at the expense of longer processing times but just the opposite. Substantially lowered cure temperatures and much faster cycle times are reported for these films. The results are discussed in terms of molecular and bulk curing mechanisms.

INTRODUCTION

The use of dielectric films after the last passivation layer on wafers has a long history [1]. The primary purpose of this additional organic film was as a stress buffer layer (SBL) between the high modulus silicon nitride (or oxide) and the high modulus epoxy molding compound or encapsulant that would be the typical covering to a wire-bonded die. This layer both planarizes and provides mechanical and alpha-particle protection. The SBL would typically be a low modulus polyimide coating of 2-5 micron thickness and be fully cured to obtain optimal mechanical and chemical protection of the die.

At the end of the '90s, integrated passive devices produced at the wafer scale, introduced the addition of a second layer of dielectric film to re-distribute the die bond pads to peripheral bond pads [2]. This use of a re-distribution layer (RDL) has expanded to memory devices and grown in thickness to as much as 20 microns. Since most DRAM memory devices have two internal rows of pads, the new, larger, peripheral pads have enabled the stacking of thinned dice with overlapping or staggered wire-bonds (Figure 1).

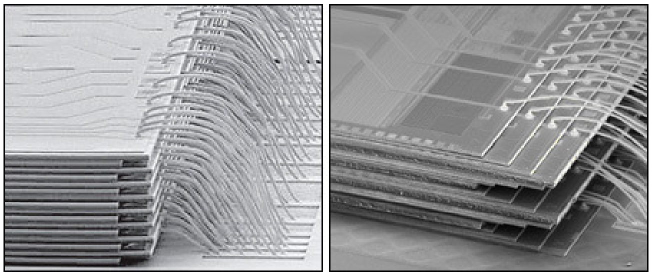


Figure 1: RDL layers leading to peripheral wire bonds

An additional use of dielectric films is the direct application of at least two re-distribution layers to an array of dice that have been embedded in a thermoset base. The dielectric films are patterned to bring the signals up to pads or bumps that can be spread out to an area larger than the die [3]. Stacked die, stacked packages, and stacked array modules are increasing in production volumes due to the potential improved reliability and lowered costs.

Through-silicon-via (TSV) technology has recently become a serious contender for stacked die in a very small form factor. In most versions of TSV there is a need for polymer films for dielectric isolation or for temporary or permanent adhesion.

In all of these applications there has been an increasing concern about the warpage produced by the difference in thermal coefficient of expansion (CTE) of polymers (18-60 ppm/°C) and silicon (3 ppm/°C) during cure processes. In the case of polyimide SBL, the warpage from this one step accounts for a 100% increase over all previous processing [4] and causes serious handling problems especially for 300 mm wafers. That study also found increased warpage with larger numbers of dice per wafer and thicker dielectric layers. In addition, they found that reduced cure temperature, wait periods, and additional cure steps were not successful at reducing warpage. With increasing numbers of polymer layers in the applications described above and the thinning of wafers from 750 µm to less than 50 µm for stacking and TSV, warpage has become a serious issue.

Warpage (and stress) can be reduced by lowering the largest temperature excursion from cure soak to ambient of the last process step. With multiple dielectric layer designs, the use of lower cure temperatures for early layers does not relieve the stress of the last high temperature cure. An incomplete cure at a lower temperature will reduce warpage but only if the die does not see any subsequent higher temperature processes such as solder reflow (260°C). Product reliability failures caused by incomplete cure and increased stress by later thermal processing are well known [5]. Very slow ramp rates to final soak temperature and slow cooling ramp rates are commonly used to reduce film stress but the effect is relatively small and the total cycle time increases from 1 hour to 4-10 hours which reduces throughput dramatically.

Less than fully cured PI and PBO films will continue to release water (from the cyclization reaction) as the films are heated during additional processing steps, bonding, and solder reflow during assembly. Less than fully cured epoxies, resists, and other cross-linked polymers will continue to cure during subsequent processing which will change the glass transition temperature (Tg) of the films. The Tg is the point at which dramatic changes in the film's modulus, elongation and coefficient of thermal expansion occur. These films will continue to shrink in the solid phase as they continue to cure during later treatments. Cracks form that are not initially found because they are the result of the additional curing of the layers that are no longer visible in a stack. Of course incompletely cured films will also form cracks with exposure to process chemicals such as acetone, NMP, developers, and strippers (Figure 2) [6].

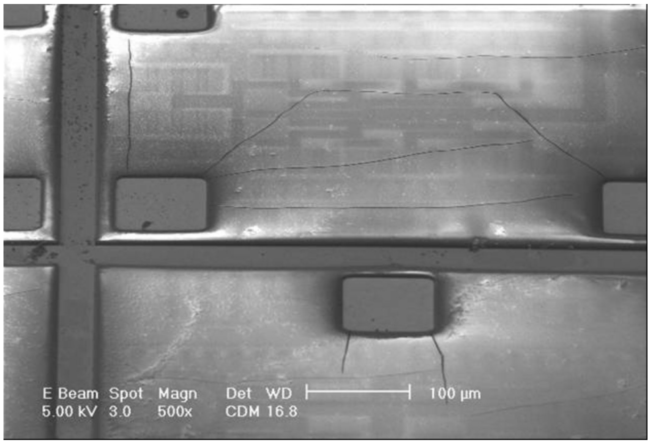


Figure 2: Film cracking from incomplete cure

An alternative curing technology using variable frequency microwaves (VFM) has begun moving to wafer production recently, to provide faster and lower temperature wafer dielectric cure [7,8]. Standard convection heat curing is a sequence of heat transfer from either coils or infra-red emitters to air to the target parts, the oven walls and the fixtures. Even though microwave heating is a thermal process, the fundamental mechanism is based on the excitement of molecular dipoles in the polymer resin and their subsequent dielectric loss to molecular rotations [9]. This direct increase in the entropy of the system at each molecular dipole site causes more rapid collisions of reacting molecules at the proper reaction orientation at a effective lower bulk temperature of the material.

The VFM technology was developed to prevent the arcing of metals and to provide a uniform energy field particularly for use in microelectronics production processes. Many studies by semiconductor fabricators have shown no effect of VFM on the electrical or structural characteristics of semiconductor devices.

It would be expected that VFM curing would provide lower warpage films from the inherent properties of the microwave heating process. Since the entire bulk of the dielectric film layer is heated simultaneously, the uniformity of the cure should be good from top to bottom and center to edge of the wafer. It has been shown that even in batch microwave systems, the uniformity of cure across a 300 mm wafer and from wafer to wafer in the stack is less than 2%. Previously unpublished studies have found the expected reduced warpage from VFM curing compared to standard furnace cures (Figure 3).

	Furnace		VFM	
	X-axis	**Y-axis**	**X-axis**	**Y-axis**
PBO	**71.92**	**66.18**	**31.32**	**31.49**
PI	**56.28**	**46.05**	**24.88**	**23.55**

Figure 3: Warpage of 10 µm films on 200mm wafers

EXPERIMENTAL

VFM curing was done on a Lambda Technologies Microcure 2100-700 system. Ambient gas control or vacuum was not required. Four-thousand ninety-six frequencies were cycled between 5.8 and 7.0 GHz every 0.1 seconds for a residence time of 25 µs at each frequency. Film temperature was controlled in a closed-loop feedback system by measurement with a calibrated non-contact IR sensor focused on the film and adjusted to the emissivity of the film at soak temperature. A fiber-optic contact probe on the bottom of the wafer was also monitored. The wafers were placed into the center of the cavity on a fixture with quartz mounting pins. A ramp rate of 30ºC/min brought the wafer to soak temperature with a control of +/- 1 ºC for the programmed time. The cool time was usually about 2-3 minutes since the chamber and air were at room temperature during the curing.

The films for this study were provided by JSR Micro, Inc., and were prepared for cure as shown in Figure 4. The WPR-1201 and WPR-S206 are negative tone resists while the WPR-5200 is positive acting.

Sample type	Films preparation on 8 inch Si wafers
WPR-1201	1) Spin-coat : 300 rpm (10 s) + 850 rpm (30 s) 2) Prebake : 110 °C (3 min) on the HP in the air 3) g,h,i-line exposure : 2000 mJ/cm^2 4) PEB : 110 °C (3 min) on the HP 5) Each curing treatment conditions
WPR-S206	1) Spin-coat : 300 rpm (10 s) + 850 rpm (30 s) 2) Prebake 110 °C (3 min) on the HP in the air 3) g,h,i-line exposure: 2000 mJ/cm^2 4) PEB : 110 °C (3 min) on the HP in the air 5) Each curing treatment conditions
WPR-5200	1) Spin-coat : 300 rpm (10 s) + 850 rpm (30 s) 2) Prebake : 110 °C (5 min) on the HP in the air 3) Each curing treatment conditions

Figure 4: Film preparation

To make sure that the extent of cure in a furnace/oven was equivalent to the cure in VFM, Tg measurements were made with TMA (pressure probe method). Extent of cure was also measured by dipping tests using n-methyl-pyrolidone (NMP) and THB-S2. If the sample retains none of the chemical/solvent as measured by film thickness after water wash and drying, then the cure is considered equivalent between samples. In some cases the tests were made at elevated temperatures as well. Wafer warpage was measured by profilometer in microns.

RESULTS

Low warpage can be produced with insufficient cure so the equivalent cure for convection oven and VFM were determined by the glass transition point (Tg) as measured by TMA. An example for WPR-1201 is shown in Figure 5 for cure soak times at 190°C. It can be seen that the VFM cure time is much shorter to equivalent Tg than the oven cure.

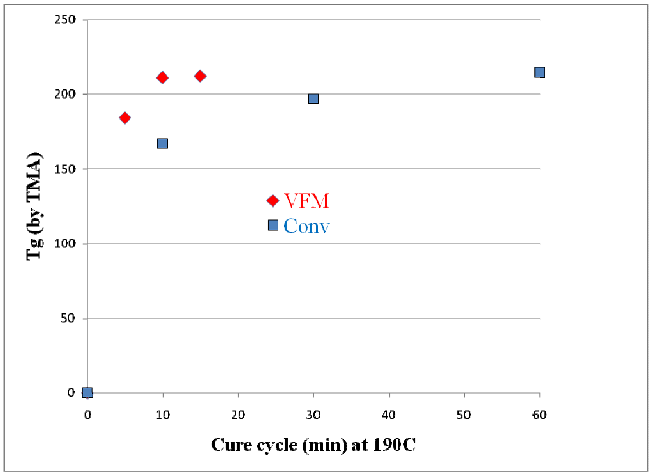


Figure 5: Equivalent cure of WPR-1201 at 190°C

VFM cure times were determined by this method to correspond with standard oven cure times from JSR Micro. It was determined that an easier comparison of extent of cure was chemical resistance. Film thickness measurements were used to compare the cures of VFM and convection oven for WPR-1201 and WPR-S206 (Figure 6).

Sample		Dipping test THB-S2		
		after cure (um)	after 10min dip (um)	FT change (%)
WPR-1201	VFM	19.39	19.24	99
	Conv	20.82	20.88	100
WPR-S206	VFM	20.68	21.38	103
	Conv	20.29	21.38	105

Figure 6: Comparison of cure by chemical resistance

In the same manner, all three materials were compared to equivalent cure but with different cure profiles. The intent was to determine if the WPR materials could be cured at temperatures as low as 160°C with VFM while producing full cure film properties (Figures 7-9). Note that the convection cure data in each figure is marked with a "C".

Temp(°C) / time(min)	**Before (µm)**	**After (µm)**	**% change**
200 / 10	20.7	20.71	**0.05**
	20.35	20.35	**0**
185 / 25	20.23	20.22	**-0.05**
	20.53	20.51	**-0.1**
160 / 60	20.88	20.87	**-0.05**
	20.48	20.48	**0**
250 / 60 C	20.17	20.17	**0**

Figure 7: VFM Cured WPR1201 NMP Dip Test

Temp (°C) / time (min)	**Before (µm)**	**After (µm)**	**% change**
200 / 10	20.92	20.91	**-0.05**
	21.09	21.1	**0.05**
185 / 25	21.01	20.99	**-0.1**
	21.16	21.16	**0**
160 / 60	21.21	21.21	**0**
	21.44	21.43	**-0.05**
250 / 60 C	21.56	21.57	**0.05**

Figure 8: VFM Cured WPR S206 NMP Dip Test

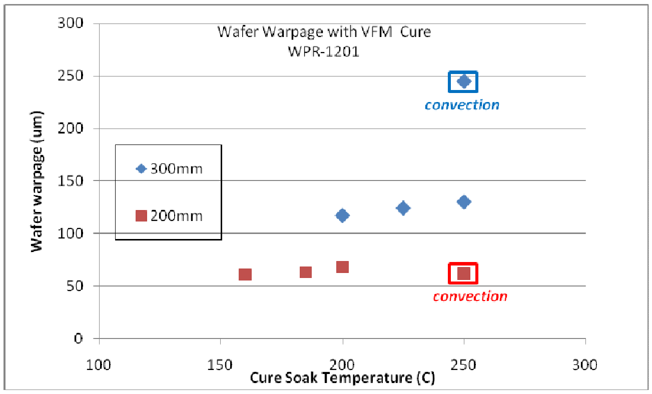
Temp (°C) / time (min)	**Before (µm)**	**After (µm)**	**% change**
200 / 25	20.51	20.5	**-0.05**
	20.52	20.53	**0.05**
180 / 45	20.09	20.1	**0.05**
	20.24	20.26	**0.1**
160 / 90	20.54	20.72	**0.88**
	20.62	20.76	**0.68**
200 / 120 C	20.55	20.56	**0.05**

Figure 9: VFM Cured WPR 5200 NMP Dip Test

As discussed above, lower cure temperatures should be expected to lower film warpage. In the case of low temperature VFM curing, there is no disadvantage of reduced extent of cure or risk of cracking with exposure to chemicals in later process steps. Note that the WPR-5200

which is the only positive acting resist did require slightly longer cure cycles.
In fact it was found that for 200 mm wafers coated with WPR-1201, the warpage with VFM curing was not different from convection cured wafer films (Figure 10). With the larger 300 mm wafer films however, the warpage reduction with VFM cure is seen to be about 50% depending on the temperature of cure. With VFM cure, the warpage of the 300 mm films is not much greater than the warpage of 200 mm wafer films.

At the higher temperatures (200-250°C) the cure times of WPR-1201 are reduced, as would be expected, to even less than 15 minutes but the reduced warpage with VFM cure is maintained at 50%.



. **Figure 10:** Wafer diameter warpage comparisons

DISCUSSION

There is an expanded set of material choices for polymer dielectric layers that can be used for stress buffer layers, re-distribution layers and wafer packaging layers. Previous studies have found that VFM curing can be used to reduce the cure cycles of dielectric films from hours to minutes. The VFM cure profiles can also be reduced for PI and PBO films from 350°C or more to less than 200°C. Lower warpage has been a recognized characteristic of VFM curing of adhesives and more recently of PI and PBO dielectric films.

This work has shown that the thermoset based resists of JSR Micro can also be cured at faster times, lower temperatures and with lower warpage. Making sure that all films were completely cured and resistant to chemical attack, the two negative tone and one positive tone materials were successfully cured at only 160°C. One of the materials is shown to be cured with only a 5 minute cure cycle while all cure cycles were far less than the 4-10 hour cycles commonly used. Warpage reduction of films on 300 mm wafers was typically 50% especially at the lower temperatures.

The initial success of this study is being followed up with additional study of warpage of all three wafer films at a range of even lower temperatures that the 160°C described here. DMA analyses of the final networks at various temperatures (and multi-step temperature profiles) are also planned to determine potential improvements in film properties in conjunction with JSR Micro, Inc..

In a parallel study at the University of Oregon, Department of Chemistry, the mechanism of low temperature microwave cure is being investigated [10]. Besides the uniform nature of VFM curing and the low temperature "effect", there may be changes in the morphology of the thermoset cross-linking only found with microwave energy that allows for a more elastic final structure.

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