NEW MATERIAL AND RELIABILITY ISSUES OF RE-DISTRIBUTION LAYERS

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ABSTRACT

With the expansion of wafer level packaging into a wider number of IC designs and multiple die packages, the use of multiple layers of polymer dielectric films has increased. The type and number of chemical resins used to make thin films on wafers has grown as well as options for their cure. Faster cure and lower temperature cure have become priorities but the choice between materials has not always been based on good information about the relationship between cure state and the resultant mechanical and chemical properties of the films. Reliability of films through subsequent processes and into product reliability testing has been adversely affected. Material and process selection criteria are suggested to minimize reliability issues.

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 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 on 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).

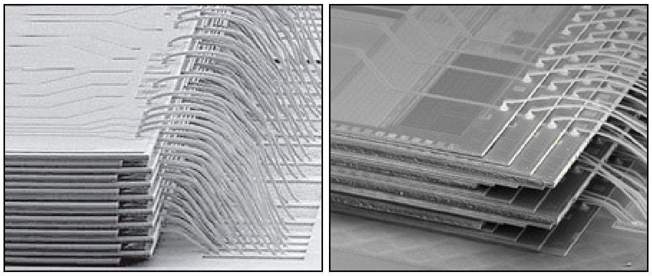

Figure 1. Stacked Dice with RDL

With wafers thinned to 50 microns or less this technology has rapidly produced very dense memory packages in relatively thin formats. At the same time there has been an increase in the use of two or more dielectric films layers in wafer level packages (WLP). Stacked die, stacked packages, and stacked array modules are increasing in production volumes due to claims of improved reliability and lowered costs.

The resurrection of the "die-first" packaging scheme of the early '90s has also increased the interest in multiple dielectric film layers. This package begins with the dicing of wafers followed by encapsulation of the back and sides of the dice in arrays before applying the interconnecting dielectric distribution layers [3]. As many as eight routing layers are claimed as possible for this approach.

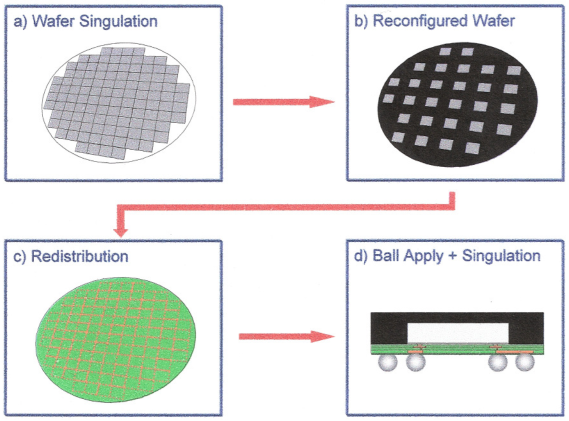

Figure 2. Wafer Level Package (*Courtesy InfineonTechnologies*)

There have been at least two additional requirements imposed on the dielectric films used for RDL and WLP applications. A desire for lower film curing temperatures and shorter cure cycle times would allow for improved yields in DRAM and flash memories. The additional thermal budget required for the dielectric film curing steps causes shifts in data refresh rates. Decreased film curing time is also necessary for higher throughput as the number of film layers increases. Batch wafer curing of only two layers can add 12-15 hours to the process flow. The second requirement is environmental. Water based development is seen as an important direction for many companies and the use of tetra-methyl ammonium hydroxide (TMAH) developer is increasing.

These new requirements have been addressed by the suppliers of dielectric films by the creation of new polymers that cure at lower temperatures and are water developable. Classes of materials not normally considered for die protection are being evaluated and existing materials are being used at lower temperatures and lower times to meet these customer requirements. Alternative curing technologies are also being developed for lower temperatures and faster process times.

The reliability requirements of the final packages are also escalating with increasing functionality and the need for portable consumer product drop testing.

The choice of dielectric film chemistry and processing conditions has a direct effect on product cost and reliability. This choice has become more complex and inter-related.

DIELECTRIC FILM PROPERTIES

There has been a progression from higher to lower temperature stable dielectric materials. Polyimides (Figure 3) continue to be the standard for the most costly and complex die such as microprocessors and logic. There is also not a direct need for lower temperature processing for this die type. Depending on glass transition temperature (Tg), some polyimide films can be cured at lower than 300ºC. Polyimide chemistry is well established and provides the most robust die protection with the least sensitive process conditions.

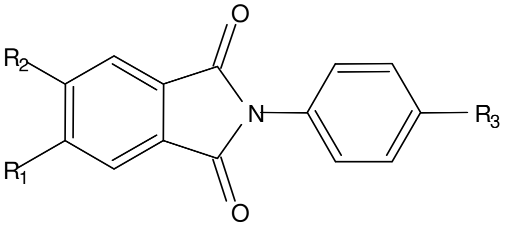

Figure 3. Polyimide (PI)

Polybenzoxazoles (Figure 4) are rapidly becoming popular for their aqueous development [4] while retaining most of mechanical advantages of polyimides. Cure temperatures for PBOs remain well above 300ºC to retain those advantages. Elongation is often higher in PBO films than PI films and they have somewhat lower tensile modulus as well. PBO films offer half the moisture uptake of a PI film. On the other hand, compared to polyimides, PBO materials usually have lower thermal and chemical resistance and adhesion is sometimes not as strong. The shelf-life and process windows for PBOs are shorter and more narrow, respectively, as well. The advantage of a positive tone, aqueous compatible process has made PBOs very attractive for current use.

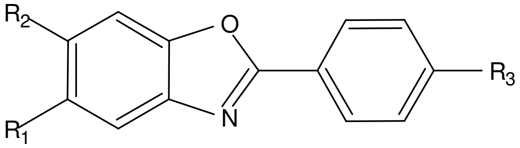

Figure 4. Polybenzoxazole (PBO)

There have been several applications that have employed BCB materials and there are several photo-resist based mixtures being evaluated as well. These resists and epoxy materials are higher modulus and have lower Tg but can be processed at lower temperatures. The general category of highly cross-linked materials includes the latter two groups in Table 1.

	Tg	Diel. Const.	Elongation	Modulus
PI	350	3.4	40-100%	2-4 GPa
PBO	310	2.9	80-120%	2-3 GPa
BCB	250	2.7	6-8%	3-4 GPa
Epoxies	165	2.8	3-6%	4-8 GPa
Resists	210	3.6	4-8%	2-3 GPa

TABLE 1. Dielectric Material Properties

The cure profiles of all these dielectric materials are usually listed by the time at the maximum soak temperature. This soak time is usually around an hour but the total cure cycle time includes slow ramps up to the maximum temperature and cooling ramps back down. The total cure cycle times are actually 4-7 hours or more. This is partly due to the necessity of heating the air and the chamber uniformly as the material takes on the heat inductively. The other reason for slow ramp cycles is the relief of stress as the films are heated from the top down to the wafer. Table 2 lists cure cycle times and maximum temperatures for typical examples in each chemical class.

An alternative curing technology using variable frequency microwaves (VFM) has begun moving to production recently [5]. The time and temperatures for VFM cure are listed in Table 2 as well. If standard temperatures are chosen for VFM curing of polyimides for example, the cycle time drops to 15 minutes.

	Temp	Time	VFM Temp	VFM Time
PI	350ºC	4 hrs	175ºC	1 hr
PBO	380ºC	5 hrs	190ºC	1.5 hr
BCB	250ºC	5 hrs	200ºC	1 hr
Ep./Resist	220ºC	7 hrs	190ºC	0.5 hr

TABLE 2. Film Curing Condition Comparisons

PROCESS RELIABILITY ISSUES

From Table 1 it can be seen that higher Tg materials will obviously have higher resistance to mechanical and chemical breakdown. This is more of an issue with microprocessor dice than with memory dice which see fewer packaging process steps.

It is necessary to fully cure these materials to obtain the desired mechanical and chemical properties. If the materials are only partially cured they will have lower Tg, higher modulus, lower strength, and reduced adhesion to surfaces. The modulus figures in Table 1 listed for resists and epoxies are literature values and not necessarily the fully cured values, which tend to be much higher. Cracks in films that were not completely cured are shown in Figure 5. These cracks are the result of exposure to acetone or other chemicals during subsequent process steps [6].

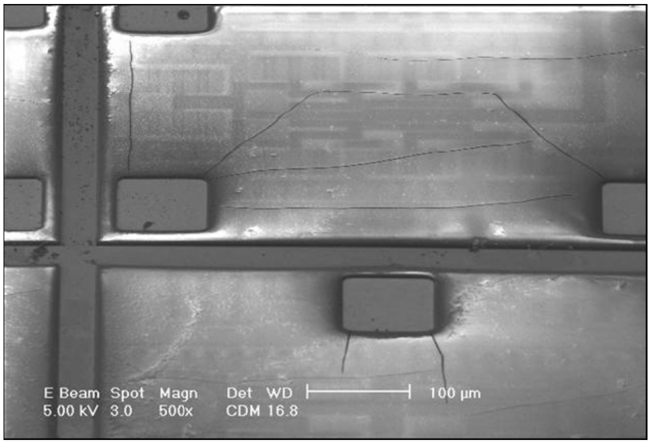

Figure 5. Cracks in un-cured dielectric films.

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. Some of these cracks are not initially found because they are the result of the additional curing of the layers that are no longer visible in a stack.

PRODUCT RELIABILITY ISSUES

When there are problems found in the process flow it affects yield and of course costs. Worse is the situation where changes due to temperature, handling, or environment cause products to fail in the field. No manufacturer likes surprises. Reliability should be predictable and stable. Preconditioning tests are designed to find early failures and part reliability tests are designed to find failures over time.

A recent study by Lin et. al. [7] found that MSL testing of epoxy flip-chip encapsulants revealed much higher creep strains and severely decreased ultimate tensile strength. Isothermal aging revealed declining elastic modulus and interfacial adhesion to the point of adhesive failures. This data was attributed to incomplete cure of the underfill at the standard cure profile.

INCOMPLETELY CURED DIELECTRIC FILMS

In the course of experiments to determine the temperatures and times necessary to "fully" cure materials with VFM it is necessary to establish a baseline where the measured Tg (by DSC or TMA) of convection cured samples is maximized and stable. If the sample cured with VFM has the same Tg (+/- 2 ºC measurement error) then it is considered to be "fully" cured and will have the same mechanical and chemical stability as the conventionally cured sample. DSC is good for measuring cure up to 90-95% but TMA is better for the last few percent. Figure 6 shows the elimination of the exotherm peak (by DSC) as a material is cured by VFM to better than 90%. The flat line at the top is the trace for a completely cured material by convection.

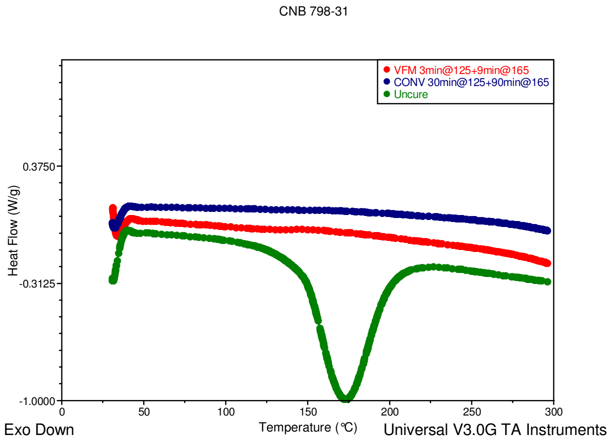

Figure 6: DSC of epoxy cure exotherm

Under-curing of polyimides at 180ºC is a long accepted practice when the application doesn't require full mechanical protection. The problem can arise when a lower temperature cure is recommended without awareness that full cure is not being achieved. For any material, the question is how good is "good enough"? Over the last few years, several dielectric film materials have been found to be incompletely cured by the "standard" cure without this fact being known to the user. In some cases the cure has been as low as 50% or less. The DSC traces of a photo-resist layer are shown in Figure 7. Curing at higher than "standard cure" temperature decreased the peak height but did not result in substantial cure. The mechanical and chemical properties of this material are dependent on the thermal history of the material through processing, assembly and use.

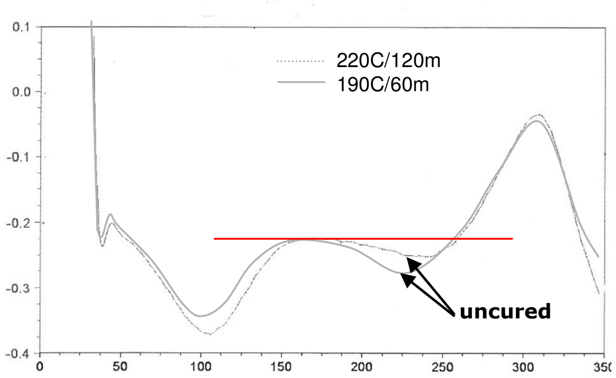

Figure 7: Incomplete resist cure

A recently documented issue with incompletely cured epoxy resin in printed circuit board substrates has resulted in failures that were hard to trace. Microvia epoxy resin layers can be as little as 30-60% cured after board lamination. Cure continues during assembly and reflow operations causing the CTE to change by a factor of two and resulting in cracks between layers and in microvias. High voltages produced arcs between vias and traces across the cracks and failed circuits in the field.

CONCLUSIONS

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. The PBO materials have similar thermal stability and chemical resistance while adding more environmental friendly aqueous processing.

The addition of new resist-based and epoxy-based film materials offer lower processing temperatures at a cost of lower elongation and thermal/chemical stability. Process times for these cross-linked polymers are at least as long as the polyimide types.

Newer cure technologies such as variable frequency microwaves (VFM) offer much faster process times at the same temperatures. For die technologies that require lower thermal budget VFM can be used to lower the cure temperatures of all the materials which allows the combination of lower process temperature with resulting high stability films.

In all cases care should be taken to determine the true cure status of the films after processing and in products. Films that are not completely cured will change with subsequent thermal steps and the mechanical and chemical properties will change as well. Over time the interfacial adhesion and ultimate tensile strength will degrade and creep strain will increase. Re-distribution and wafer level packaging promise higher reliability but due diligence must be taken to be sure "good enough" is truly good enough.

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