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Wafer Protection With Screen Printable Polyimide

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Applicability

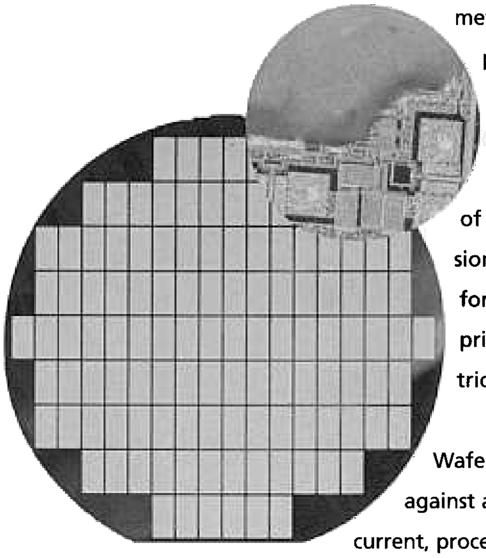

FIGURE 1

A screen printing method for applying a polyimide coating for wafer surface protection has demonstrated significant advantages in efficiency and cost over conventional spin-etch methods. Only two steps (print and cure) are required to screen print wafer surface protection, as opposed to seven or more steps for spin-etch techniques.

The screen printable polyimide EPO-TEK 600 can be used as a passivation coating for mechanical and environmental protection on any type of device. The quality of the surface protection achieved is exceptional, especially during thermal excursions. The screen printing method also creates highly effective alpha particle barriers for memory devices, and it enhances electrical properties for power devices. Screen printing may also be used as a more efficient method of applying interlayer dielectric coatings.

Wafer surface protection is required for virtually all semiconductor devices to protect against alpha emissions from packaging materials, moisture, surface leakage of electrical current, processing damage during wafer fabrication, contamination and handling during test-probe assembly, cracking of die caused by mold compound induced thermal stress, and other conditions and eventualities that may impinge upon the integrity or functionality of the device.

Comparison of Methods

While screen printing the passivation layer is a totally additive process, the widely used spin-etch technique is a subtractive technique that requires chemical etching to selectively remove the spun-on polyimide from the bond pads. Residual etchants remain on the chip surface, necessitating additional cleaning steps, which can cause more contamination. Two applications of the polyimide are needed to achieve the minimum alpha protection coating of 40 microns. A minimum of seven additional process steps are required: spin coat, gel polyimide, spin coat, gel polyimide, expose to light source/mask, etch away uncured polyimide, and remove chemical etchant.

The screen printing technique utilizes a polyimide densely filled with a low CTE (Coefficient of thermal expansion) filler material. This results in a low shrinkage, low stress coating and a flat wafer. By contrast, the unfilled polyimides used for high RPM spin techniques result in high shrinkage during cure, high stress due to CTE mismatch with the silicon wafer, and wafer "bowing."

The screen printing method requires less polyimide solution per wafer, and the material is substantially lower in cost than spin-etch polyimides, resulting in an order-of-magnitude difference in combined materials and process cost. While spin-etch polyimide solutions are typically 85 percent solvents, the printable polyimide EPO-TEK 600 is 73 percent solids. In addition, 70 percent of spin-etch solutions are discarded during the high RPM spin process.

In addition, the screen printable polyimide allows memory IC protection; spin-etch polyimides do not, because the applied layers are typically too thin.

Passivating polyimides may also be dot dispensed or sprayed onto the wafer surface. As in the screen printing technique, dispensing and spraying polyimides requires only two additional process steps. Dispensing and spraying techniques also have the advantages of selectivity – only good die are coated – and the capability of coating the sides of die. This alternative also has significant drawbacks, including: CTE mismatch between silicon die and polyimide, causing wire lift or broken wire; planarity difficulties, caused by the need to raise the height of the dome to increase edge coverage, which exacerbate wire problems; and shifting rheology of the polyimides, due to high vapor pressure. Solvent must be added during production, which changes percent solids and leads to shrinkage and expansion problems.

Another alternative, the use of alpha particle free mold compounds, requires no additional process steps. However this method does not protect against die cracking due to high stress induced by the curing of the mold compound. In addition, the mold compound typically contains "tramp metal" from metal wear on grinding blades during manufacturing, on steel die during preforming, and in the encapsulation mold (due to abrasive fillers). The cost of low alpha-mold compounds is typically five to seven times greater than the cost of standard mold compound.

Similarly, low alpha emitting ceramic packages, while producing reliable alpha protection with no additional process steps, requires an added expenditure of $10 to $15 per package compared to the use of standard ceramic.

Screen Printing: Processing Characteristics

Highly precise and repeatable printing is, of course, a key requirement for successful implementation of the screen printable wafer coating technique. The polyimide designed for this process EPO-TEK 600 has been carefully formulated to optimize printing in micrometer resolution with minimal post-print flow. High print quality is also promoted by the ability of the material to maintain stable viscosity over time (see "Rheology," under Material Characteristics).

Before the printing process itself, adequate surface preparation (cleaning) must be performed to allow successful adhesion of the coating. A variety of surface preparation techniques have been used with success, including UV ozone treatment, chemical cleaning followed by the use of a silane coupling agent, and plasma cleaning. The EPO-TEK 600 polyimide does not require the wafer surface to be primed with adhesion promoters.

The choice of the print screen or stencil should be made carefully. The screen emulsion selected must be of a type that is not vulnerable to the solvents in the polyimide. A long-lasting metal stencil mask may be used instead of a screen, but this technique has limitations, as complex wafer surface patterns do not lend themselves easily to application via stencil.

The screen printing equipment itself must be equipped with the precision optics and other capabilities necessary to align and print on wafers with micrometer accuracy and excellent repeatability. This requires sophisticated optics. After the printer is selected, the choice of squeegee material should also be made carefully. The squeegee must not be vulnerable to attacks by the solvents in the polyimide, and it must produce sharp print patterns. The precise squeegee shape, material, and pressure will vary according to the precise thickness and viscosity of the polyimide application. The polyimide is printed on the wafer with one pass of the squeegee across the screen, so that the entire wafer is covered, leaving open only the bond pads. A wafer coated with EPO-TEK 600 is shown in Figure 1, along with an enlargement showing the open lands. For bond pads smaller than 5 mil^2, it is necessary to coat the entire wafer area, cure the polyimide, and reopen the bond pad lands using excimer laser ablation techniques.

SCREEN PRINT PARAMETERS

MATRIX I

MASK	325 MESH STAINLESS STEEL: 70 MICRON EMULSION
STROKE	150 mm
SQUEEGEE	100 mm/sec
SCRAPER SPEED	100 mm/sec
CLEARANCE	0.70 mm
SQUEEGEE PUSH PRESSURE	3.1 kg/cm^2
SQUEEGEE PUSH LENGTH	0.50 mm

MATRIX II

MASK	250 MESH STAINLESS STEEL: 85 MICRON EMULSION
STROKE	150 mm
SQUEEGEE	100 mm/sec
SCRAPER SPEED	100 mm/sec
CLEARANCE	0.9 mm
SQUEEGEE SPEED	100 mm/sec
SQUEEGEE PUSH LENGTH	0.2 mm

TABLE 1

The printer setup must be checked to ensure that the squeegee, screen, and print table are parallel. Two sets of printing parameters in the development of the screen printable polyimide wafer coating are shown in Table 1.

Infrared Curing

After printing, infrared curing of the screen printed polyimide may be used to achieve good results. This is because, if the coating is cured in a convection oven, the solvents and other volatiles expelled from the material will recondense on the film, causing sag and loss of resolution. In addition, some of this residue will condense on the open areas of the print pattern, severely compromising wire bonding or soldering. Furthermore, convection curing of the coating will occur from the outside in, so that the cured outer layer of the film will become a barrier to the escape of the volatiles. The result is that it's very difficult to accomplish a complete cure of the material using convection methods. Experimentation with various IR curing systems has indicated that gradient, broadband IR belt systems give the best cure to the polyimide in the shortest period of time (10 to 20 minutes).

Yield

Screen printing passivation has been shown to increase yield, in comparison to both not coating the wafers and other methods of coating. Yield in probe and test experiments at one leading fabricator have demonstrated a 15 percent yield improvement for screen printing compared to spin-etch.

A specific area where the benefits of screen printable polyimide have been demonstrated is in back-lapping operations. This step typically decreases yields due to the active side of the wafers moving in the wax as the back side is lapped to the desired thickness. This movement can lead to smeared metalization and electrically unstable or nonfunctional devices. The EPO-TEK 600 polyimide barrier serves to protect the active devices from smearing during the back-lapping process.

Figure 2 demonstrates this function of the wafer coating, comparing the average yields achieved after back-lapping with and without the polyimide. While the uncoated wafer yielded 53.7 percent electrically active devices, the yield was 88 percent for the coated wafer.

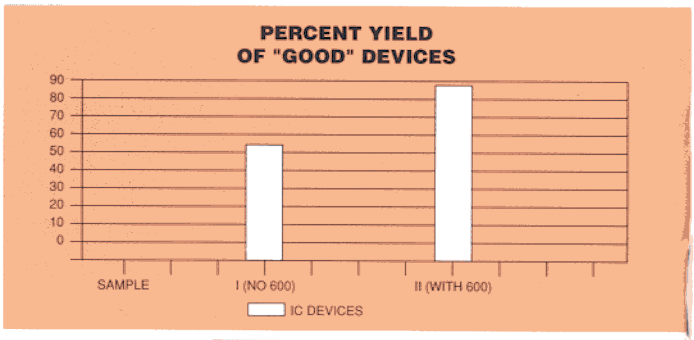

FIGURE 2

Another area where EPO-TEK 600 makes a positive contribution to yield is related to the issue of phase or pattern shift during the transfer mold process. When the molding compound cures, its shrinkage places stress on the metalized lines. This can cause them to shift out of alignment and create electrical discontinuity. The low stress polyimide coating protects the surface of the device from these stresses and thus protects against this source of yield loss.

The EPO-TEK 600 polyimide coating is also effective in reducing surface current leakage and improves the electrical stability of power devices. (See "Electrical Properties".)

Screen Printing: Material Characteristics

Rheology

The high viscosity (> 300,000 cps) and thixotropic index (> 5.0) of EPO-TEK 600 ensure high-resolution screen printing with minimal sag and flow of the polyimide into the open wire bond pads of the device during the print and cure steps. The high thixotropy of the material also prevents filler separation in response to shear forces experienced during printing and curing.

EPO-TEK 600 low CTE filler is highly homogeneous, with small size particles that pass easily through very fine screen mesh and facilitate the application of a uniform, continuous passivation film across the entire wafer surface.

The rheological properties of the polyimide remain stable over time, allowing a screen life in excess of 8 hours, which is necessary to accomplish successful screen printing. If the initial viscosity of the material changed too quickly, achieving consistently satisfactory print quality would prove difficult.

Purity

The use of polyimides and fillers that contain extremely low levels of alpha radiating uranium and thorium as well as ionic contaminants is another essential characteristic of the EPO-TEK 600 wafer coating. The material contains less than 5 ppb (typically, less than 1 ppb) of uranium and thorium, which is the threshold level considered necessary to prevent soft errors in memory cells and enable reliable passivation of memory, logic, and MPU devices.

In one test of alpha particle emissions, a 45 micron thick cured film of EPO-TEK 600 on a wafer was found to emit just 0.001 net α/cm²/hour. Data from testing of a 4 mil thick coating on a ceramic substrate indicated alpha emissions of approximately 0.025 net α/cm²/hour. (Thicker films are generally required for application of EPO-TEK 600 as a passivation material on ceramic, because ceramic substrates emit higher levels of alpha particles than silicon wafers.)

In alpha particle testing by a leading fabricator, memory chips coated with EPO-TEK 600 polyimide and encapsulated in plastic packages recorded 0.05 strikes per hour (for a chip with a 3.0 mil coating) and 55 to 72 strikes per hour (for chips with a 1.2 mil coating). For uncoated chips, alpha strikes in excess of 550 per hour were recorded.

Anion-Cation Analysis of Reflux Solution of Screen-Printable Polyimide

	(ppm)
Na^+	1.710
NH_4^+	0.396
K^+	0.296
Cl^-	0.187

TABLE 2

EPO-TEK 600 also has low levels of ionic contamination. This minimizes the formation of corrosive acids (through the reaction of water vapor and mobile ions) which can attack the aluminum metalization on the surface of the active device. Table 2 indicates the levels of hydrolyzable ions detected in a refluxed solution of EPO-TEK 600. Analytical and performance testing has confirmed that the polyimide contains low levels of ionic contaminants and does not result in corrosive failures.

Nonvolatile Solvents

To allow a long screen life, EPO-TEK 600 is formulated with nonvolatile, high boiling point solvents. The result is a screen life of greater than one day, and the elimination of pinholing or skimming over the surface of the wafer coating.

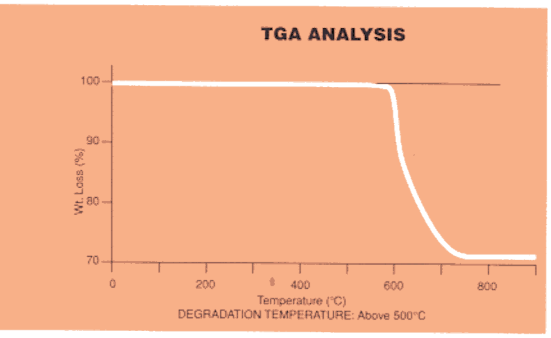

FIGURE 3

Thermal Stability

EPO-TEK 600 demonstrates exceptional thermal stability at high temperatures. Post-cure thermogravimetric analysis (see Fig. 3) indicates a decomposition temperature in excess of 600°C, with no outgassing taking place below 500° C.

In one set of experiments, wafers with cured polyimide coatings were exposed to a belt furnace CERDIP seal temperature profile of 20 minutes duration, with 5 to 8 minutes of exposure to the peak temperature of 450° C. No degradation of the polyimide coating, outgassing, or adverse effects on the electrical performance of devices were observed, nor was there any bowing of the wafer as a result of thermal stress.

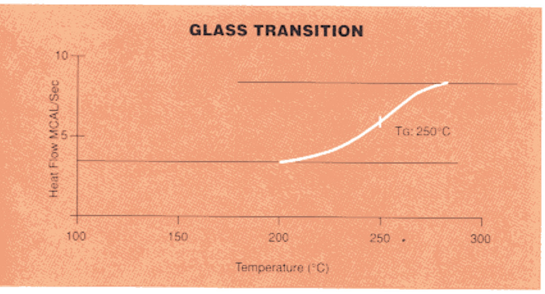

FIGURE 4

The glass transition temperature of EPO-TEK 600 is 250° C (Fig. 4), which is high enough to allow thermocompression wire-bonding at temperatures in excess of 300° C.

Assembled plastic packages die coated with EPO-TEK 600 have been subjected to thermal cycling and thermal shock tests. Temperatures ranging from –50° C to +125° C caused no adverse effects on the coating or the performance of the assembled devices.

Low CTE Filler

Larger IC devices accentuate the need for wafer passivation polyimides that exert the lowest possible amount of thermal stress. Because unfilled polyimides shrink volumetrically up to 85 percent during the curing process, they result in a great deal of stress on the device. Large wafers coated with unfilled polyimides exhibit considerable "bowing" after cure. In addition, the high coefficient of thermal expansion of unfilled polyimides may cause cracking of devices during post-mold thermal excursions.

To eliminate this problem, EPO-TEK 600 is densely filled with a low CTE filler. This results in a polyimide film that demonstrates low shrinkage during cure and an extremely low post cure CTE (10×10^{-6} ppm/°C) that minimizes the CTE differential with silicon. This minimizes the potential for wafer stress and cracking in response to thermal challenges.

Testing of filled and unfilled polyimide films on plastic sheets has demonstrated a bowing effect on the sheets coated with the unfilled polyimide. Wafers protected with EPO-TEK 600 demonstrate perfect flatness after cure, with no bowing whatsoever.

Moisture Resistance

Test results have indicated that wafer coatings formed by the EPO-TEK 600 polyimide are highly effective as moisture barriers. Plastic packages containing chips screen-printed with EPO-TEK 600 were subjected to THB (85° C, 85 percent RH, 1000 hours) and PTHB (121° C, 15 psi steam autoclave, 250 hours) conditions. No electrical failures from polyimide delamination or degradation occurred, nor were there any corrosive failures. The absence of corrosion under PTHB conditions is a result of the exceptional adhesion of the coating to the wafer surface, which prevents capillary flow of water and ionic particles along the interface of the device and the coating.

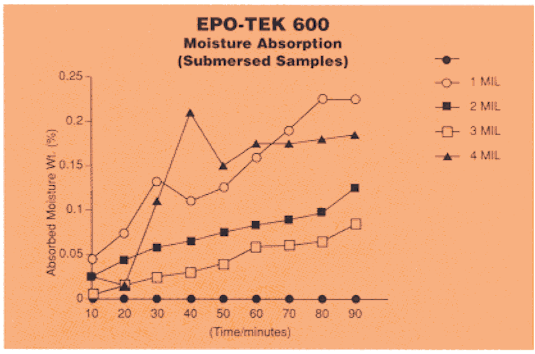

FIGURE 5

In another set of tests, EPO-TEK 600 films of various thicknesses were applied to glass and silicon. The cured films were submerged in water for up to 90 minutes. As Figure 5 shows, these tests showed that the polyimide absorbs low levels of water even when submerged for an extended period. These tests were designed to test the tendency of the wafer coating to absorb water vapor from the air during pre-mold processing. The results indicated that EPO-TEK 600 can promote the reliability of active devices by eliminating surface corrosion and electrical leakage.

Electrical Properties

The screen printable polyimide has demonstrated excellent insulating properties and suitability for protecting power devices. The material's bulk electrical properties include volume resistivity of 10^{15} ohm-cm, dielectric strength of 430 V/mil, and dielectric constant of 2.4.

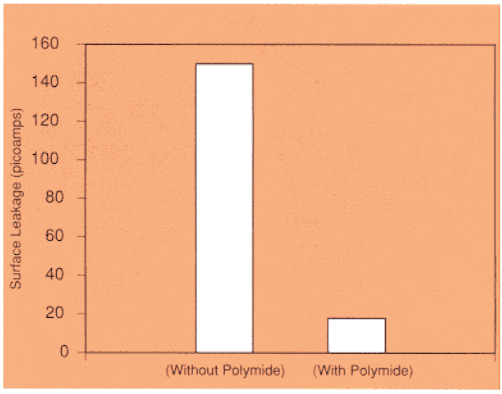

FIGURE 6

In a test of the value of the protective coating on power devices, EPO-TEK 600 was screen printed on the surface of bipolar transistors. Surface leakage current was measured for both coated and uncoated wafers. As indicated in Figure 6, uncoated devices averaged leakage of 150 picoamps, but polyimide-coated devices averaged leakage of only 14 picoamps. This result is attributed to the elimination of moisture from the surface of the

About the authors

Frank W. Kulesza, president of Epoxy Technology, Inc. is a graduate of Northeastern University, receiving a B.S. in Chemical Engineering in 1950. Prior to his founding of Epoxy Technology in 1966 he held positions at Borden Chemical Company and IBM Corporation. Mr. Kulesza has authored and presented a number of technical papers on epoxies and their applications, both here and abroad. Mr. Kulesza was primarily responsible for and is well known as the pioneer in the use of electrically conductive epoxies being employed for die attach in the microelectronic industry. He was presented the Technical Achievement Award by ISHM in 1989 for his contributions to the microelectronic industry in relation to epoxy die attach. More recently, he was granted a patent on PFC, a polymer flip chip processing technology-an efficient and cost-effective method of flip chip assembly without the use of solder. He is a corporate member of ISHM and SEMI and holds memberships in the American Chemical Society as well as the Society of Plastic Engineers.

Richard H. Estes received his degree in Chemistry from the University of Massachusetts in 1975. He was a chemistry instructor for six years prior to taking a position at Epoxy Technology, Inc. in February 1981. Mr. Estes has held the positions of Quality Control Manager, Technical Service Manager, and is currently the Vice President of Technical Operations at Epoxy Technology. Areas of responsibility include technical services and quality control, as well as supervising R&D in the development of new materials and processes for applications in the semiconductor and hybrid microelectronics industries and the optoelectronics/fiber optics industries. Mr. Estes has authored several technical papers on the technology of adhesives, is a member of ISHM, SEMI and IEEE, and holds patents in the field of flip chip technology.

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