

# Plastics for packaging: handle with care

Tests have traced some device degradation to impurities stemming from the plastics or the packaging process. Caution is required, therefore, in cases where high reliability and long life are demanded

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**While transistor and integrated-circuit** manufacturers and users are generally sold on the use of plastics to package devices for commercial applications, some doubt lingers about the reliability of plastics in military and space applications.

Traditionally, plastics have been used to encapsulate or pot electronic assemblies in which the active devices have first been hermetically sealed in protective casings. But the trend now is to apply plastic covering directly to active device chips that are highly sensitive to moisture, contaminants, or stresses.

Unquestionably, some impurities inherent in the plastics or resulting from plastic processing steps degrade the chips. The appeal of the plastic-pack-

aged transistors and integrated circuits currently on the market lies chiefly in their low cost, though sometimes they've been selected because they resist shock and vibration better than their sealed-can counterparts.

The reliability of plastic-cased devices, it should be emphasized, isn't a function of the plastic alone, but also depends on the nature of the device being packaged and on the quality of its passivation layer.

Among the possible drawbacks related to the plastics themselves are permeabilities with respect to moisture and contaminants, dimensional instability that can cause stresses on encapsulated leads, and impurities.

## Minuteman II studies

Signs of potential trouble with plastic packages appeared when transistor surfaces were exposed to gases in physics-of-failure studies for the Minuteman II program.<sup>1</sup> Excerpts from those studies are tabulated on page 102. The table shows how reverse leakage characteristics were affected by contaminants such as benzene and carbon dioxide; contaminants have been detected in device packages by gas chromatography, and their presence has been partially correlated with device performance.

One might guess that other organic solvents structurally analogous to benzene, such as toluene or xylene—also used in the synthesis or processing of plastics—may also be entrapped in device packages during processing. Separate studies indicate that small amounts of ammonia gas and organic amines affect parameters such as reverse current.<sup>2, 3</sup>

In the Minuteman II studies, it was shown that with a microdiode packaged in an inner layer of silicone and an outer rigidizing layer of phenolic

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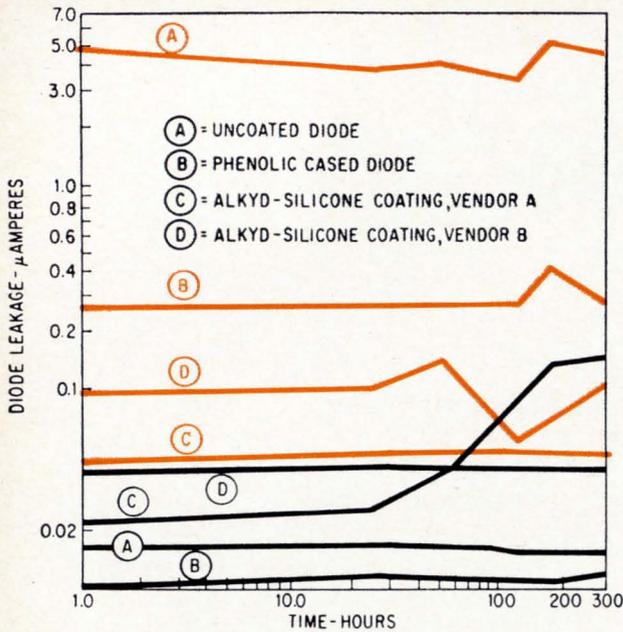
## The authors



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Leakage currents of microdiodes react under exposure to dry ammonia (curves in color). The curves in black represent the same devices in a dry nitrogen atmosphere.

plastic, ammonia could be generated by the degradation of the hexamethylenetetramine present in the outer layer as a curing agent.

The ammonia affected the reverse leakage characteristics of the semiconductor diode after it had permeated the inner silicone barrier coating, as shown in the curve directly above. This problem was solved by substituting a silicone molding compound for the phenolic; no ammonia is generated in curing the silicone.

### Why leakage increases

Temperature-voltage inversion is the label often applied to the mechanism by which reverse leakage current increases. It is postulated that contaminants such as  $NH_4^+$  ions on the surface are positioned in an orderly fashion in the region of a reverse-biased junction by the fringing electric field that extends through the oxide.<sup>4</sup> This positioning is abetted by either high humidity or high temperature. The ordered ions attract oppositely charged carriers in the underlying semiconductor material, thus effectively inverting that region from its majority carrier status to that of a minority carrier layer. The inverted region provides a much greater junction area and thus increases the leakage current of the original junction. If the device is heated for a time at zero bias, the ions once again assume a random arrangement.

A second mechanism, space-charge buildup within an oxide layer, may also be susceptible to unwanted chemicals from plastics and may also degrade device performance. The sources of contamination relevant here are usually attributed to the device processing.

As an example, space-charge buildup resulting from the migration of ions under the influence of

an electrical field is thought to occur in the insulating oxide under the gate of an MOS device when potential is applied to the gate. It's easy to see how such a space charge could influence the performance of the MOS device, since it affects the electrical field the gate exerts in modulating the channel in the silicon under the gate oxide. Indeed, the space charge itself can act as a gate field when the external gate voltage is removed. No exact mechanism for this effect has yet been defined. It has been attributed variously to alkali ion, hydrogen ion, and oxygen vacancy migration.<sup>5, 6</sup>

### Permeability factor

The plastic package's permeability is perhaps its most important characteristic. Impurities exert their influence as a function of this permeability whether they are gases and vapors outside the package or chemicals generated internally. The permeability of typical plastic coatings with respect to moisture is tabulated on the opposite page. Note that cellophane, cellulose acetate, and Neoprene are included in the table for comparison purposes. It is unlikely that any of these materials would be used in packaging devices. Coatings most likely to be used are epoxy-anhydride, epoxy-aromatic amine, silicone-alkyd, with or without microdiode coating, polytetrafluoroethylene (PTFE), PTFE dispersion coat, fluorinated ethylene propylene (FEP), polyvinyl fluoride, polyvinylidene fluoride (Teslar), p-polyxylylene (Parylene C and N).

Another important factor is dimensional stability, since shrinkage can lead to induced stresses. Epoxy will decrease in volume during curing, for example, and other plastics will shrink when solvents evaporate. Unexpectedly large forces can result when plastics are solidified from a gel or colloidal state.

### Reverse current leakage of dual pnp signal transistors shifts with gas ambient

Conditions	Leakage current, $I_{CBO}$ (anoamps) @ 20 v reverse bias	
	Transistor A	Transistor B
Before vacuum bakeout	3.0	2.5
After exposure to benzene vapor and reverse bias on transistor A only	2,400	—
After exposure to water vapor and reverse bias on transistor A only	10,000	—
Vacuum bake at 300°C and no bias	2.5	2.5
Bias on transistor B in vacuum	2.5	3.0
After exposure to carbon dioxide and bias on transistor B only	3.0	650
Vacuum bake at 300°C	3.0	3.0

If it were feasible in all cases to remove the solvent at its critical temperature, there would be practically no effects from surface tension as the solvent was withdrawn.

Shrinkage stresses produced in a coating formed by solvent removal can be serious enough to fracture an integrated circuit's interconnection wires. In a typical example, several 0.7-mil-diameter wires with individual breaking strengths of several grams were broken in a single IC. The solvent in this case was removed by evaporation from a non-elastic silicone coating on the IC.

### Typical test results

The varieties of plastic tested by the Autonetics division of the North American Aviation Inc. fall into four categories: epoxies, phenolics, silicones, and fluorocarbons.

In the case of the epoxies, a variety of chemical and ionic species can be formed during their degradation, as shown in the table on page 104. Carry-over and retention of many of these chemicals in the final cured plastic is highly probable. Yet only limited tests have been performed and there is no indication of which impurities are critical to device performance, or of what the threshold levels of impurities are.

Emission spectrographic analysis has been found to be a good technique for determining kinds and relative amounts of metallic constituents down to 0.5 ppm (based on ash content). In tests, plastic samples were deposited and cured directly onto the graphite electrodes, since it was previously determined that curing in glass or aluminum dishes introduces additional impurities from these receptacles. A large variety of metallic impurities were found in the samples tested (see table on page 105), especially in the case of epoxies and highly filled molded compounds. Other silicone coatings, and fluorocarbons such as Teflon, displayed a relatively low metallic content.

Many of these metallic impurities aren't inherent in the resin polymer itself. For example, silicones after synthesis are extremely pure materials. The impurities may be introduced in mixing or in formulating with fillers, or may stem from metal storage cans or drums.

### Measuring ionic material

To detect and measure ionic material in plastics, samples of the plastics can be pulverized and then digested in distilled water at 160°F for eight days. The electrical conductivity of the water extracts is then measured.

Although there is uncertainty about the extent of hydrolysis that occurs during the digestion period, the results are useful as a relative indication of the amounts of ionic and ionizable species in the sample, as well as of the hydrolytic stability of the plastic under these conditions. Of the materials tested, the epoxies and phenolics had rather low resistivity values, as shown on page 106. This isn't surprising considering the types of probable

### Moisture resistance of plastic coatings

Plastic coating	MVTR*	Source
Epoxy-anhydride	2.38	Autonetics data
Epoxy-aromatic amine	1.79	Autonetics data
Neoprene	15.5	Baer (Ref. 11) (39° C)
Polyurethane (Magna X-500)	2.4	Autonetics data
Polyurethane (isocyanate-polyester)	8.72	Autonetics data
Silicone-alkyd	6.13	Autonetics data
Silicone-alkyde (microdiode coating)	7.9	Autonetics data
Olefane, polpropylene	0.70	Avisoun data
Cellophane (type PVD uncoated film)	134	du Pont
Cellulose acetate (film)	219	du Pont
Polycarbonate	10	FMC data
Mylar	1.9	Baer (39°C)
	1.8	du Pont data
Polystyrene	8.6	Baer (39°C)
	9.0	Dow data
Polyethylene film	0.97	Dow data (1 mil film)
Saran resin (F120)	0.97 to 0.45	Baer (39° C)
Polyvinylidene chloride	0.15	Dow data (1 mil film)
Acrylonitrile co-polymer		
Polytetrafluorethylene (PTFE)	0.32	Baer (2 mil sample 40°C)
PTFE, dispersion cast	0.2	du Pont data
Fluorinated ethylene propylene (FEP)	0.46	Baer (40°C)
Polyvinyl fluoride	2.97	Baer (40°C)
Polyvinylidene fluoride (Teslar)	2.7	du Pont data
p-polyxylyene (parylene N)	14	Union Carbide data (2 mil sample)
p-polyxylyene (parylene C)	1	Union Carbide data (2 mil sample)

\* (Moisture vapor transmission rates in grams/mil/100 sq. in. in 24 hours)

contaminants and the emission spectrographic results. The silicone and fluorocarbon extracts, on the other hand, had comparatively low conductivities.

It has also been demonstrated (curves, p. 105) that the deviation from stoichiometry of the epoxy system affects the water extract conductivity. By stoichiometry is meant the exact proportions in which the resin and hardener will combine according to molecular equations.

### Electrical effects

In one experiment, plastic coatings were applied to bare microdiodes. To study surface inversion, the diodes were then reverse biased at elevated temperatures. Because of the high insulation resistance values for most plastics (see graph on page 105), ohmic leakage through the plastic coating was assumed to be negligible compared to the reverse conduction current exhibited by the device. With some plastics, however, such as the cast epoxy

## Contaminants originating in epoxy plastics

Ingredient	Types	Synthesis ingredients	Potential contaminant
Epoxy resin	Epon 828 815 (etc)	Epichlorohydrin Dichlorohydrin Allylchloride Propylene NaOH Bisphenol-A  Acetone Benzene HCl or HBr catalysts Phenol  Sodium orthosilicate	Cl <sup>-</sup> HO Cl  Na <sup>+</sup> , OH <sup>-</sup> —C <sub>6</sub> H <sub>4</sub> —OH, Na <sup>+</sup> , OH <sup>-</sup> (CH <sub>3</sub> ) <sub>2</sub> C=O C <sub>6</sub> H <sub>6</sub> H <sup>+</sup> , Cl <sup>-</sup> , H <sup>+</sup> , Br <sup>-</sup> C <sub>6</sub> H <sub>5</sub> O <sup>-</sup> , H <sup>+</sup> CO <sub>2</sub> H <sub>2</sub> O, Na <sup>+</sup> , CO <sub>3</sub> =Na <sup>+</sup> SiO <sub>4</sub> <sup>-4</sup>
Curing agents	Ethylene diamine Diethylene triamine Polyamides (Versamids)  Acid anhydrides	Dichloroethylene NH <sub>3</sub>  Polymerized vegetable Oil acids Polyalkylene amines Polyalkylene chlorides Carboxylic acids	NH <sub>4</sub> <sup>+</sup> , Cl <sup>-</sup>  NH <sub>3</sub>  RCOO <sup>-</sup> , H <sup>+</sup>  Cl <sup>-</sup>  R(COO <sup>-</sup> , H <sup>+</sup> ) <sub>2</sub>
Fillers	Alumina Cabosil Silica	— — —	Al <sup>+3</sup> Si <sup>+4</sup> Trace metal ions
Pigments	Titania Carbon blacks Calcium carbonate	— — —	Ti <sup>+4</sup> C Ca <sup>+2</sup> , CO <sub>3</sub> =
Solvents	Ketones Esters  Ethers Halogenated hydrocarbons Toluene Xylene Alcohols Cellosolves	— —  — — — — — —	(R) <sub>2</sub> C=O R COO <sup>-</sup> , H <sup>+</sup> , RO <sup>-</sup> H <sup>+1</sup> ROR Cl <sup>-</sup>  C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub> (CH <sub>3</sub> ) <sub>2</sub> ROH
Flow control agents	Beetle resins  SR-82 Butvar	Urea  Silicone Polyvinyl butyral	NH <sub>4</sub> <sup>+</sup> , NH <sub>3</sub> , CO <sub>2</sub> H <sub>2</sub> O, CO <sub>3</sub> =H <sup>+</sup>
Fire retardants	Antimony trioxide Arochlors  Brominated or chlorinated resins	—  Chlorinated polyphenyls	Sb <sup>+3</sup>  Cl <sup>-</sup>  Br <sup>-</sup> , Cl <sup>-</sup>

This table should not be construed as a complete list of ingredients and contaminants. Potential contaminants are those constituents inherent in the material or, under some conditions of temperature, hydrolysis, or other stress, derivable from the material. Unreacted or excess synthesis ingredients due to nonstoichiometry may also act as contaminants. A listing of fillers and reinforcements is given in reference 9; solvent and solvent combinations commonly used with epoxies are given in reference 10.

listed in the graph, ohmic leakage could be a factor. Polyethylene is included in the graph for comparison purposes; it is not a candidate for packaging semiconductor devices.

In the diode experiments, technical-grade and specially purified epoxies (employing molecularly distilled reactant materials), epoxies with stoichiometric and nonstoichiometric ratios of resin to hardeners, and fluorocarbons (TFE and FEP Teflons) were applied to devices and cured according to vendors' recommendations. The devices were then subjected to 150°C heat for varying periods of time, with a reverse bias of 75 volts. After this, they were cooled to room temperature with the voltage removed. Changes in reverse current observed under these conditions are tabulated below.

Similar plastic-coated microdiodes were exposed to 95% relative humidity at 160°F with a 75-volt reverse bias. Typical values of reverse current measured after the diodes were removed from this atmosphere are shown on page 108.

The fluorocarbon-coated and silicone-coated diodes generally exhibited smaller changes in reverse current than did the epoxy-coated diodes. However, large changes in reverse current—from nanoamperes to microamperes—indicate that the commercial-grade epoxies tested contained sufficient amounts of ionic or other contaminants to affect the semiconductor. Also, the epoxies with nonstoichiometric resin-to-hardener ratios displayed high values of reverse current. One or more high values or electrical opens occurred in each category; the latter were probably due to stress or mechanical damage rather than to impurities.

In other studies,<sup>2</sup> microdiodes coated with phenolic material exhibited high I<sub>R</sub>; both experimental results and theoretical considerations suggest the presence of large amounts of such impurities as ammonium ions. The table below shows that the reverse-current characteristic decreases after heating for a time without electrical bias, presum-

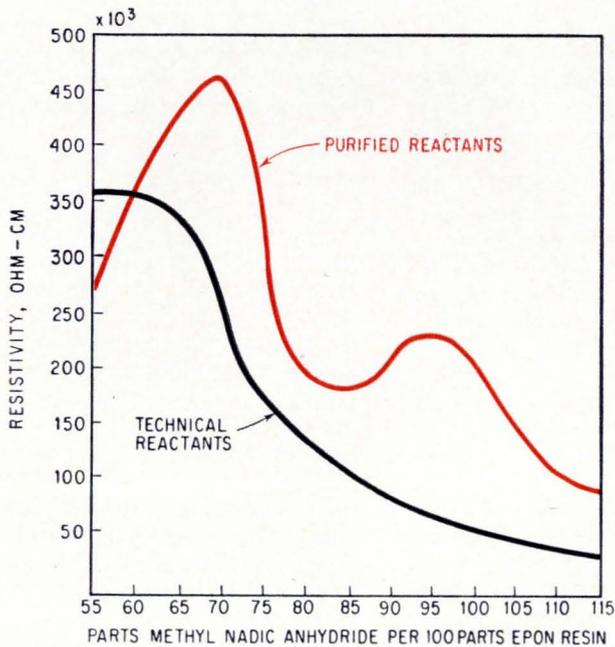
### How temperature affects reverse current of plastic coated diodes

Coating systems	Initial reading I <sub>R</sub> (na) @ 50v	I <sub>R</sub> (na) @ 50v after 20 hours @ 150°C and 75v rev. bias	I <sub>R</sub> (na) @ 50v after additional 20 hours @ 150°C no rev. bias
Epoxy, stoichiometric purified	10	548	14
Epoxy, nonstoichiometric purified	9	10 × 10 <sup>3</sup>	10 × 10 <sup>3</sup>
Epoxy, stoichiometric technical	12	237 × 10 <sup>3</sup>	121 × 10 <sup>3</sup>
Epoxy, nonstoichiometric technical	12	31 × 10 <sup>3</sup>	14 × 10 <sup>3</sup>
Fluorocarbon, resin, FEP Teflon	17	18	16

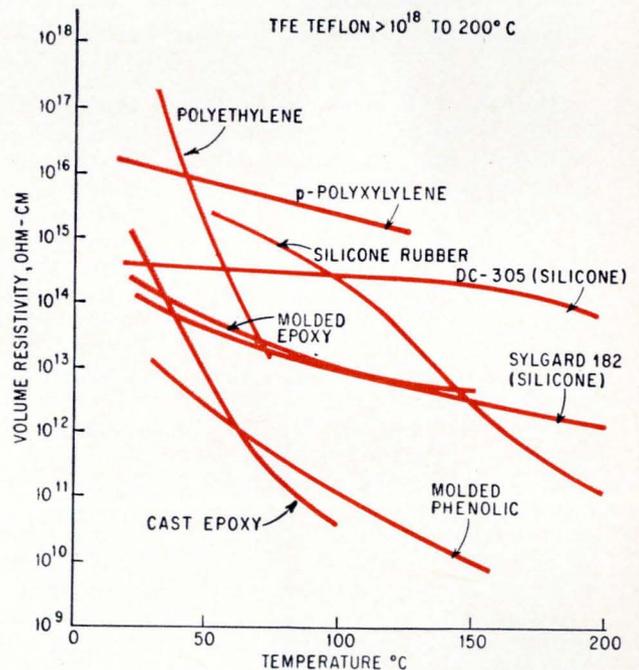
## Spectrographic analysis of plastics

Sample	Condition	Metals detected	Relative amounts*
Epoxy, Epon 828	As received	Copper, aluminum, magnesium silicon, calcium	Traces
Epoxy, Epon 828	Still residue after molecular distillation	Silicon, Magnesium, aluminum, iron copper, chromium, calcium, manganese	Major
Epoxy, Epon 828	Distilled, light molecular weight fraction	Copper	Traces Trace
Silicone, Sylgard 182	Cured	Silicon,** Titanium, magnesium	Major Slight traces
Silicone coating, DC 644	Cured	Silicon Copper, magnesium	Major Slight traces
Silicone molding compound, DC-305	As received and molded	Zinc Silicon, chromium Lead, titanium, nickel, copper, manganese, aluminum and magnesium	Trace Major
Silicone gel coating, DC-51	Cured	Iron, cobalt Silicon	Traces Minor Major
Phenolic molding compound	As received	Calcium Magnesium Iron, silicon, sodium Copper, manganese, aluminum	Major Minor Traces Slight traces
Teflon, TFE	Dispersion coating, fused	Copper, magnesium	Slight traces
Teflon, FEP	Dispersion coating, fused	Copper, titanium, magnesium	Slight traces
Teflon, TFE	Molded solid	Titanium	Slight trace
Teflon, FEP	Molded solid	Copper, titanium, magnesium	Slight traces
Kynar	Dispersion coating, fused	Titanium, copper, magnesium	Slight traces

\* Major, 5% or more; Minor, 0.10 to 5%; Trace, 0.01 to 0.10%; Slight trace, 0.0001 to 0.01% (percentages are by weight of ash).  
\*\* Silicon is a structural constituent of silicones and should not be considered an impurity.



The ratio of hardener to resin affects the volume resistivity of the plastic encapsulant. Technical reactants are commercial-grade chemicals; purified reactants are those that have been further purified to remove contaminants.



Volume resistivity of plastic coatings varies with the type of plastic. It decreases with rises in temperature. Molded epoxy gave results similar to the Sylgard 182, and resistivities for a molded phenolic sample ranged from 10<sup>13</sup> to 10<sup>10</sup> ohm-cm.

## Water extract resistivities

Material	Average resistivity (ohm-cm) $\times 10^3$
Epoxy-anhydride-epoxy coating.....	9.0
Epoxy molding compound.....	107
Phenolic molding compound.....	4.7
Alkyd-silicone coating (DC 1400).....	11.5
Alkyd-silicone coating, Vendor A.....	14.7
Alkyd-silicone coating, Vendor B.....	65
Methyl-phenyl silicone coating.....	270
Silicone molding compound (DC 305).	155
Silicone molding compound (DC 304).	290
Silicone (Sylgard 182).....	195
Silicone coating A.....	60
Silicone coating B.....	180
Silicone coating C.....	190
Silicone gel coating, DC-51.....	360
TFE, Teflon, dispersion coating.....	93
TFE, Teflon, molded solid.....	350
FEP, Teflon, dispersion coating.....	177
FEP, Teflon, molded solid.....	198
Kynar, dispersion coating.....	212
Kynar, solid.....	335
Distilled water (control).....	732

ably because ordered ions on the surface are moving to a more random state.

The excellent results with fluorocarbons may be attributed to these plastics' inherently inert, stable, and symmetrical structure. In fact, TFE and FEP Teflons are unique among plastics in their purity, thermal and oxidative stability (up to 500-600 F), chemical inertness, low rate of moisture permeability, and electrical stability.<sup>9</sup> Teflon essentially has a zero temperature coefficient of resistance to temperatures above 200°C, in contrast to the high negative values of most plastics.

### MOS studies

Discrete metal oxide semiconductor devices and MOS integrated circuits containing a number of functional MOS elements have been plastic-coated and tested to evaluate the space-charge mechanism described on page 102. Dual MOS transistors without diode-protected gates or surface passivation were mounted in TO-5 cans without lids and were coated with a variety of silicones. Among the parameters measured were those identified in the table on the opposite page as "failure indicators."

When attempts were made to apply Teflon plastics to MOS devices, the high temperatures—500°F to 700°F—needed to fuse the fluorocarbon particles raised havoc. Interconnection-bond failures were probably caused by purple plague or, more generally speaking, by the formation of brittle gold-aluminum intermetallics due largely to the heat.

## Plastic semiconductors: like glued-together automobiles?

Caution urged by users such as Autonetics is shared by some device manufacturers; others back their confidence in plastic with guarantees to meet military specifications

The trend to nonhermetically sealed device packages seems irreversible—even for highest-reliability military and aerospace applications.

Last month, both the Signetics Corp. and Motorola Inc. announced that they have accumulated sufficient data to guarantee their dual in-line plastic-packaged integrated circuits over the full military temperature range, -55°C to +125°C. In this regard they join Texas Instruments Incorporated, who as long ago as last August was extrapolating the results of 2 million hours of transistor testing to suggest that plastic-covered IC's could meet the military specification.

Today, says TI's manager of IC quality control, James Adams, "we are getting many requests for plastic IC's over the full military temperature range."

**Negative vote.** Tending to agree

with those equipment manufacturers who remain skeptical of the reliability of plastic packages in unlimited applications, Fairchild Semiconductor, a division of the Fairchild Camera & Instrument Corp., files a dissenting opinion among vendors. Says Fairchild's quality control manager, Bryant Rogers, "We only build plastic packages for certain markets—primarily industrial and consumer."

Rogers acknowledges that competitors have published some impressive test results on the performance of plastic-packaged IC's. "The trouble lies," he says, "in correlating those figures with conventional tests. Hermeticity gives a figure of merit for the predictable life of IC's, but you can't test for hermeticity where there is no void. Tests of the plastic package have a different criterion, which you can't yet correlate with the old."

The new tests performed by plastic-device manufacturers may be valid, concedes Rogers, but they are different. "Suppose someone marketed an automobile that was put together with Elmer's glue, and published data to show that it was as good as a welded car. You might believe the data—but would you buy the car?"

For Fairchild, the question of plastics is in some respects moot, since it is banking on a flip-chip dual in-line package [Electronics, Mar. 6, p. 153] to reduce costs. Plastics cost just as much as ceramic, Fairchild insists. "The flip-chip ushers in a new era of reliability," says Rogers, "which will exploit automatic assembly techniques to cut costs."

**Inner sanctum.** New methods of passivating the semiconductor chip, such as the silicon-nitride approach pursued by Bell Telephone Laboratories and others, may be forerunners of techniques that will get to the heart of the device and make the purity of additional protective coatings not at all critical.

What vendors claim for today's devices depends partially on the

### Test results for silicone-coated MOS transistors\*

Coating	Sample size	Number of failures		Failure indicator	
		After 77 hours	Additional after 1000 hours	After 77 hours	After 1000 hours
Controls (uncoated canned)	10	none	none	—	—
Coated, Silicone A	7	2	1	$V_{(th)GS}$ 2 failures $BV_{DSS}$ 2 failures $I_{DSS}$ 2 failures	$V_{(th)GS}$ 1 failure $BV_{DSS}$ 1 failure $I_{DSS}$ 1 failure
Coated, Silicone B	13	none	2	—	$V_{(th)GS}$ 1 failure $BV_{DSS}$ 2 failures $I_{DSS}$ 2 failures
Coated, Silicone C	7	2	1	$V_{(th)GS}$ 1 failure $BV_{DSS}$ 2 failures $I_{DSS}$ 1 failure	$V_{(th)GS}$ 1 failure $BV_{DSS}$ 1 failure $I_{DSS}$ 1 failure
Coated,** Silicone dielectric gel	10	none	none	—	—

\* Static tested 125°C, 150 milliwatts.

\*\* Gel-coated devices were subjected to an additional 1,000 hours of temperature-power stresses to complete a total of 2,000 hours without in-test failures. Three in-test failures occurred among the controls toward the end of this second 1,000-hour period.

This wasn't a problem in the other tests where fluorocarbons were applied to diodes, because more thermally stable gold-silicon bonds were employed.

While test results indicated little initial reaction to the encapsulant, many silicone-coated devices operating in a static life test at 125°C with power applied failed at about 70 hours.

Notable exceptions were devices coated with a silicone dielectric gel (DC-51); in these cases, 20,000 socket hours were achieved without any in-test failures. Although some failures cropped up in the control units, none occurred with the units coated with DC-51. This can be attributed to the coating's high degree of purity, evidenced by low

kind of plastic used. The Signetics Corp.'s mil spec package is all silicone, but it is made in two layers. The company first tried an epoxy outer layer, but switched to the silicone because it provided better resistance to moisture and made a better thermal match with the initial silicone layer.

Ti uses a single-material epoxy system that, like the Signetics package, is transfer molded. Motorola has a two-layer system but won't disclose the materials used.

RCA, after expressing some doubt about the need for plastic IC packages [Electronics, Sept. 5, 1966, p. 38], last month announced plans for IC's in silicone packages.

**Bandwagon.** Companies such as Sylvania Electric Products Inc., a subsidiary of the General Telephone & Electronics Corp., and the Transitron Electronic Corp., who have experience with discrete semiconductor components in plastic, plan to market plastic IC's.

Transitron envisions a May or June introduction of a line of epoxy-encapsulated IC's. Edward Shaut, the firm's IC product sales manager, says: "We aren't promoting them

for military use, but if they turn out the way we expect them to, they will be reliable enough for military equipment."

Sylvania, too, plans to put integrated circuits in epoxy packages. Roger Swanson, marketing manager for the company's semiconductor division, says: "Except for the extreme reliability required for missiles and some other aerospace uses, epoxy packages appear to be adequate for most semiconductor applications, and in fact are being designed into computer, industrial, and consumer gear."

**Mufti or military?** At least one vendor is surprised that aerospace equipment manufacturers would consider plastic. "If you're going to buy junk, you're going to get junk," he declares. "For military-grade equipment, you just don't use it."

But, TI's Adams feels such comments reflect the "emotion that was prevalent in 1961." There was some trouble with plastic packaging in the early 1960's, he says, "but great strides have been taken since then in both materials and methods."

Engineers at Autonetics plan to conduct physics-of-failure studies of plastic-packaged devices to explain anomalies observed in earlier tests, rather than to intensively study the purity and properties of the plastics. The plastics will, however, be categorized with respect to known or probable impurities and their concentrations.

Such information could be obtained from chemical analysis, manufacturing-process data, or estimates of rates of likely deterioration modes. Also useful, Autonetics notes, is information from degradation studies being carried out for space applications, such as data on plastics in an oxygen space-capsule atmosphere<sup>1</sup> and on radiation effects.<sup>2</sup> But Autonetics cautions that potentially harmful levels of impurities may not be detectable with present instruments.

#### References

1. W.D. English, "Man-Materials Interactions in Space Flight Systems," SAMPE Journal, June 1966.
2. R. Bolt and J. Carroll, "Radiation Effects on Organic Materials," Academic Press, 1963.

water-extract conductivity and the absence of metallic impurities in spectrographic analysis. Since the material is also very soft, it imparts little stress to devices in the curing process. Because of its softness, though, it requires the use of an auxiliary rigidizing plastic to complete the package.

Because such characteristics as dipoles in the molecule or the plastic's adhesion to the devices may contribute to the deterioration of electrical parameters, no one property in the other silicone

coatings can be confidently designated as the principal cause of failure. However, it's noteworthy that none of the other three silicone coatings tested exhibited the high purity and resistance to mechanical stress of the DC-51.

### Recommendations

Preliminary tests of the interaction of epoxy, phenolic, silicone, and fluorocarbon plastics with semiconductor devices under various environments have indicated that contaminants inherent in or generated by the plastics can affect device performance. Therefore plastics must be classified with respect to contaminants in resins, hardeners, and formulation ingredients, and in terms of their probable effects on semiconductors.

To assess the effects of molecular polymer structure and polarity on semiconductor parameters, ultrapure polymer types will have to be prepared. The task requires new or refined ultramicroanalytical methods.

For the packaging of high-reliability, long-life military and space devices, a more fundamental understanding of plastics' characteristics and their effect on electrical parameters is necessary.

Epoxyes or silicones may well be satisfactory for the outer rigidizing coating, which also provides an additional barrier to ambient moisture and contaminants. In this case, the inner barrier should probably be a high-purity flexible coating. However, until long-term exposure data is acquired on the transmission of impurities to the semiconductor through the flexible inner coating, caution should be employed in using such packages for high-reliability, long-life applications. The ideal, of course, would be an ultrapure material for both the surface coating and encapsulant.

However, the purity of the initial plastic layer may become less important as improvements are made in the integrity of the passivation layer and as more reliable passivation materials and techniques are developed.

**How humidity affects reverse current of plastic coated diodes**

Coating systems	Condition	Initial $I_r$ (na) @ 50V	$I_r$ (na) @ 50v after 96 hr @ 160°F & 95% RH, 75v rev. bias
Epoxy-anhydride*	Stoichiometric purified	8	11
		8	7
		8	9
		6	5
		8	8
		11	12
Epoxy-anhydride	Nonstoichiometric, purified	10	10
		8	7
		13	8
		11	69,000
Epoxy-anhydride	Stoichiometric, technical	10	9
		8	9
		9	Open failure
		13	650
Epoxy-anhydride	Nonstoichiometric, technical	9	9
		11	9
		10	193
		16	Open failure
		12	199
		14	11
Fluorocarbon, FEP Teflon**	Dispersion coating	11	8
		12	12
		8	8
		32	13
		9	9
		17	19
Fluorocarbon, Kynar	Dispersion coating	8	8
		10	10
		52	45
		17	13
		15	16
		15	15
Silicone, elastomeric room temperature curing	Dispersion coating	14	15
		20	17
		14	15
		13	9
		19	18
		9	8
		1.16x10 <sup>3</sup>	Open failure
Uncoated	Not applicable	9	Open failure
		6	Open failure

\* All epoxy-anhydride systems were cured 16 hours at 248°F followed by 1 hour at 356°F.  
\*\* Three thin coats were used with fusion at 575°F for 5 minutes after each coat.

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