

Thermal Degradation of Epoxy Novolac-Phenol Formaldehyde Novolac Resin Systems

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SYNOPSIS

The evolution of organic vapors from encapsulants at elevated temperatures has been implicated as the source of the degradation of the gold-aluminum intermetallic of the wire that connects the bond pad to the leadframe in an integrated circuit. Gas chromatography/infrared spectroscopy/mass spectrometry were used to study the decomposition of three commercial epoxy-novolac thermosetting compounds. Outgassing products have been identified and their origins discussed. Insight into the types of initiators used in encapsulants and their possible influence upon ball bond failure rates has been gained.

INTRODUCTION

Molding compounds used as encapsulants for semiconductor devices are typically silica-filled epoxy cresol novolac (ECN)-phenol formaldehyde novolac (PFN) formulations that are initiated with tertiary amines and/or triphenylphosphine (TPP). These systems can be altered depending on the needs of the user, to include rubber modifiers, flame retardants, coupling agents, dyes, and mold release agents. When exposed to heat, the original oligomeric mixture of resin and hardener forms a three-dimensional network (i.e., gels) and becomes an insoluble solid. An important property of micro-electronic encapsulating materials is their thermal stability. Encapsulants are molded and cured at elevated temperatures and subjected to elevated temperatures several times during standard assembly process flow (i.e., solder dip, burn in, etc.). Standard engineering life testing of molding compounds for qualification involves subjecting these materials to elevated temperatures for extended periods. Long-term storage testing of encapsulated devices at temperatures ranging from 150°C to 220°C has resulted in the degradation of the gold-aluminum intermetallic of the wire bond between the leadframe and the integrated circuit.¹⁻⁵ When the integrity of the bond is compromised, not only is the bond's me-

chanical strength weakened but electrical continuity is also lost. It has also been demonstrated that the encapsulant need not be in direct contact with the ball bond to produce this failure.¹ The evolution of organic vapors from encapsulants is therefore a source of concern. In order to understand the effects of outgassing materials, it is first necessary to identify them. In this paper, the outgassing of several thermosetting epoxies is examined by gas chromatography, infrared spectroscopy, mass spectrometry, and thermogravimetric analysis.

EXPERIMENTAL

Three commercially available molding compounds, referred to throughout this paper as *A*, *B*, and *C*, were analyzed. All three compounds are silica-filled, ECN-PFN-amine/triphenylphosphine formulations. In order to impart stress-reducing properties to these standard formulations, manufacturers sometimes add silicone or hydrocarbon-based rubbers to standard formulation. In this study, compounds *A* and *B* are standard formulations while compound *C* is a rubber-modified compound.

Because these thermosets are based on ECN-PFN resins, the pure resins were also examined in order to aid product identification. Samples of a phenol-formaldehyde resin (Schenectady Chemicals HRJ1166), an epoxy resin (lab sample RE0083,

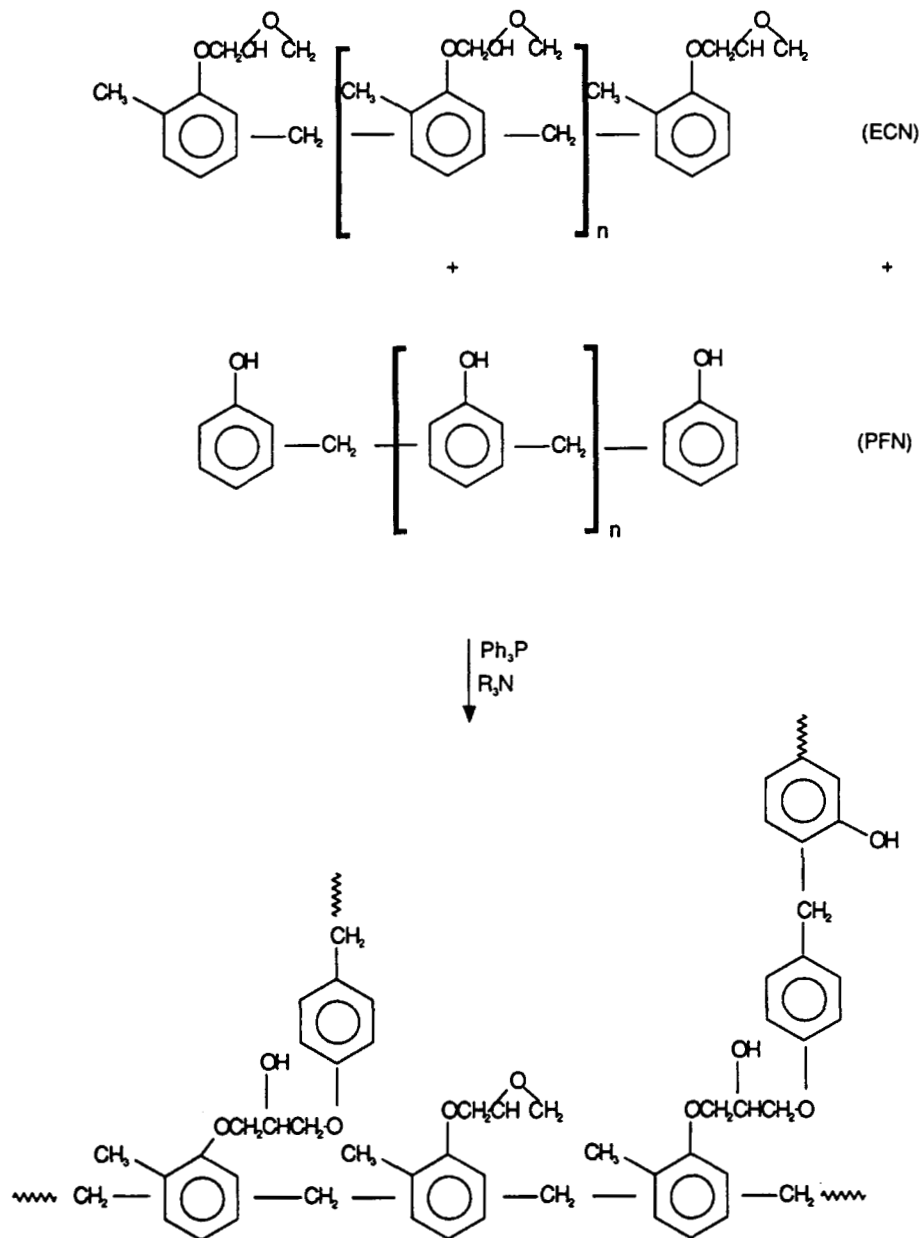


Figure 1 Epoxy-novolac crosslinking reaction.

supplied by Hysol), two samples of brominated resins, a brominated phenol (RM2123 from Hysol), and a brominated diglycidyl ether of bisphenol A (RE0077, Hysol) were analyzed under experimental conditions similar to those used for the molding compounds.

Thermogravimetric analysis was performed on a Perkin-Elmer TGA-7 interfaced to a Perkin-Elmer 7500 Professional computer. The uncured samples (7–10 mg) were heated in air from ambient to 220°C at 10°C/min and held at 220°C for 1 h. Percentage weight loss as a function of time was measured.

Gas chromatography (GC), infrared spectrometry (IR), and mass spectrometry (MS) were all performed on equipment manufactured by Hewlett-Packard. The infrared detector (IRD, Model 5965A) and mass selective detector (MSD, model 5970B) were in series with the GC (model 5890). The ionization energy of the mass spectrometer was 70 eV and the ion source pressure was 8.5×10^{-6} torr.

Time and temperature controlled outgassing of the sample was achieved using a thermal desorption cold trap injector (TCT, Chrompack). Approximately 8 mg of uncured sample was heated in a de-

Table I Thermogravimetric Analysis of Encapsulants

Molding Compound	% Weight Loss 1 h at 220°C
A	0.151
B	0.109
C	0.157

sorption oven. During desorption, the carrier gas transferred the volatile outgassing components to a cold trap held at -70°C to -80°C . Upon completion of desorption, the cold trap was heated rapidly ($10\text{--}15^{\circ}\text{C}/\text{sec}$) to 240°C causing an on-column injection of the trapped components. This technique has been described elsewhere.¹ The injection port was maintained at 220°C . The column used in these experiments was a Hewlett-Packard Ultra 2, 5% phenylmethyl-silicone, with dimensions of $25\text{ m} \times 0.2\text{ mm}$ i.d., and a $0.33\text{-}\mu\text{m}$ film thickness. The oven was programmed to run from 50°C to 240°C at $20^{\circ}\text{C}/\text{min}$ and held at 240°C for 18 min.

The times and temperatures were chosen to duplicate, within experimental constraints, processing conditions and engineering test conditions. Each molding compound was subjected to three different sets of experiments with a fresh sample and desorption tube being used for each run. The time and temperature conditions for the desorption oven were as follows: (1) 3 min desorption at 180°C , (2) 30 min desorption at 180°C , and (3) 30 min desorption at 220°C .

As the sample eluted from the column, it first passed through the infrared detector. An IR spec-

trum was collected for each eluant; the resulting chromatogram is referred to as a total response chromatogram (TRC). The eluant then traveled into the mass selective detector, where a mass spectrum was collected for the eluting fractions. The reconstructed chromatogram is referred to as a total ion chromatogram (TIC).

RESULTS AND DISCUSSION

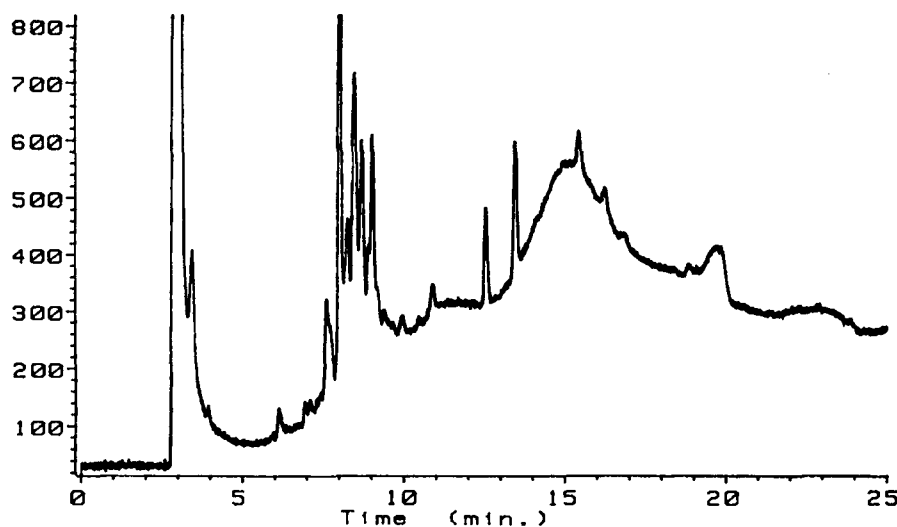
In the curing reaction of the ECN-PFN systems, the epoxy resin reacts with a novolac resin to form a three-dimensional network as shown in Figure 1.⁷ The reaction is an addition reaction, not a condensation reaction. Therefore, the products generated in these outgassing experiments are assumed to be low molecular weight species or degradation products.

TGA

Thermogravimetry showed that these three molding compounds are relatively stable. The total weight loss for each of the samples was less than 0.2% at 220°C . The results are presented in Table I. The appearance of the sample after thermogravimetric analysis showed no evidence of tarry residues or char formation.

GC/IR/MS

For GC/IR/MS, the samples were heated in a thermal desorption tube as described in the experimental section. The outgassing products were cryofocused

**Figure 2** Total response chromatogram (TRC).

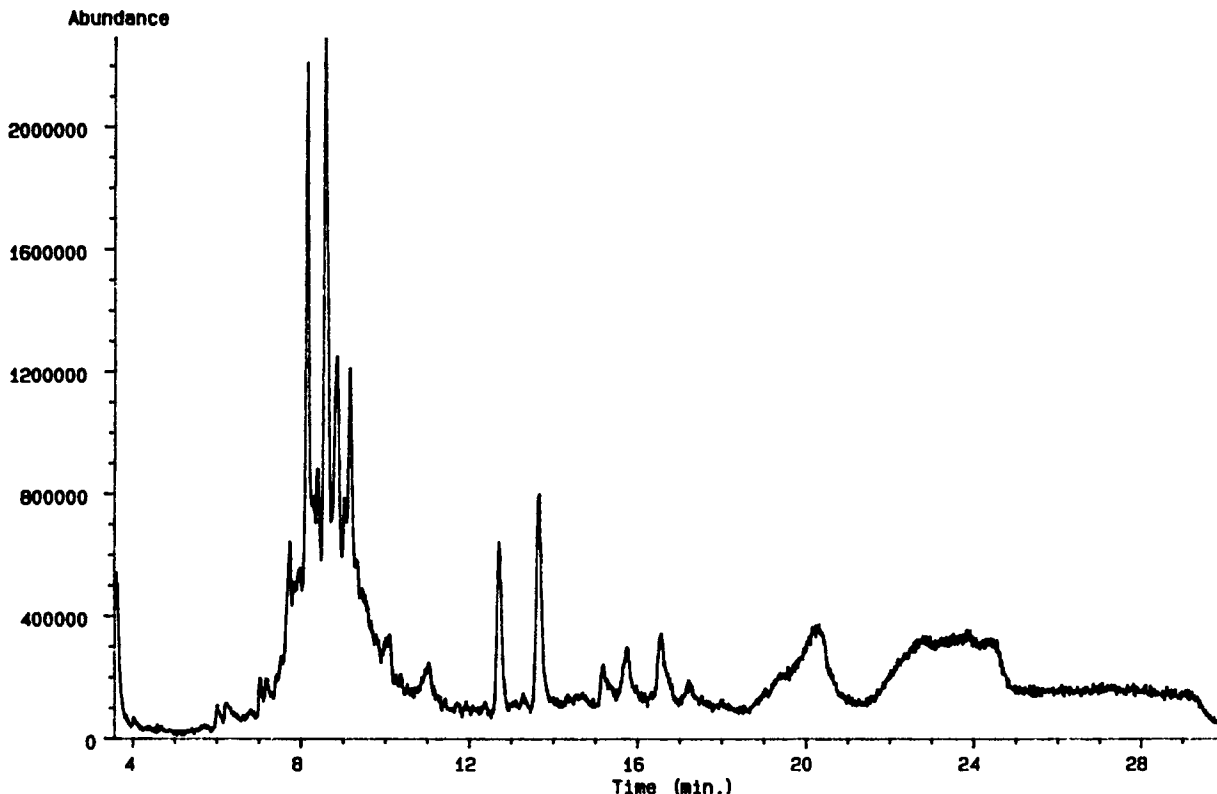


Figure 3 Total ion chromatogram (TIC).

in the cold trap and then injected directly onto the chromatographic column. Typical TRCs and TICs are shown in Figures 2 and 3.

The degradation products for the epoxy resin and the novolac resin are summarized in Tables II and III. Major degradation products of the encapsulants for two temperatures and two soak times are tabulated in Tables IV, V, and VI. Additional organic ucts and organosilicones were present but the structure of these products have only been tentatively identified and will not be discussed here.

In this paper, the outgassing products of commercial ECN-PFN thermosetting resins are examined. In these experiments, the epoxy and the novolac were uncured, at least initially; exposure to heat during desorption will certainly introduce some

degree of cure. L. H. Lee^{8,9} and others¹⁰⁻²⁰ have proposed degradation schemes to account for observed products in the degradation of uncured epoxies and novolacs at elevated temperatures (greater than 350°C). Although the experiments in this laboratory were performed at lower temperatures, the concordance of the degradation products indicates that pathways similar to those previously proposed may operate at these temperatures.

For novolac resins, Lee^{8,9} proposes a homolytic cleavage of the methylene bridges (Fig. 4, dashed lines) by a chain scission path. Following cleavage, the intermediate undergoes a hydrogen abstraction, producing the major phenolic compounds; viz., phe-

Table II Outgassing of Epoxy-Cresol Resin 180°C/30 Min

Phenoxymethyloxirane
[(2-Methylphenoxy)methyl]oxirane
2-2' Methylenebisphenol
Epichlorohydrin
2-[(4-hydroxyphenyl)methyl]phenol

Table III Outgassing of Phenol-Formaldehyde Resin 180°C/30 Min

Phenol
Cresol
2,2' Methylenebisphenol
4-(1-Methyl-1phenylethyl)phenol
2-Hydroxybenzaldehyde
4-Hydroxybenzaldehyde
2-Butoxyethanol

Table IV Outgassing of Encapsulants at 180°C for 3 Min

	A	B	C
Phenol	x	x	x
4 Methylphenol	x	x	
2,2' Methylenebisphenol	x	x	
4,4' Methylenebisphenol	x	x	
2,6 bis(1,1Dimethylethyl)-4-methylphenol		x	
2-(4-Hydroxyphenyl)methylphenol		x	
Phenoxy methyloxirane	x		
Oxiranemethanol		x	
(2,2 bis[<i>p</i> -(2,3 epoxypropoxy)phenyl]propane (D.G.E.B.A.))	x		
Dodecycloxy methyloxirane	x		
2-Phenoxyethanol	x		
2-Dodecycloxyethanol			x
1,2 bis-2-methoxyethoxyethane		x	
2-Tetradecacycloxyethanol		x	
Long chain alcohols	x	x	x
Propanol	x		
Straight ethers, ethers/alcohol	x	x	x
1-methyl-3-(1-methylethyl)benzene		x	
Toluene	x		
Long chain hydrocarbons	x	x	x
Acetic acid	x		
Long chain carboxylic acids	x	x	x
3-Pyridinecarboxylic acid, hydrazide	x		
Phenylmethyl hydrazine	x		
4-Pyridinamine		x	
3-Methylpiperidine	x		
1-Methylpiperidine	x		
1-Methyl-2-pyrrolidinone		x	x
Propanamide		x	
<i>N,N</i> dimethylbenzeneethanamine	x	x	
2,4,6 Trimethylpiperidine		x	
6,6' Dimethyl 2,2'-bipyridine- <i>N</i> -oxide	x		
Triphenylphosphine			x
Triphenylphosphine oxide			x
Butylphosphate			x
Methoxymethyldimethylphosphoric acid			x
Tributylester phosphoric acid			x
1-Chloro-3-phenoxy-2-propanol		x	
1-Chloro-octadecane	x	x	
2,6 Dibromophenol			x
Tetraheptyl ammonium bromide			x

nol, cresol, and methylenebisphenol (Fig. 4 and Table II). These same phenolic compounds were present in the outgassing products of the novolac resin and the molding compounds.

The polymer backbone of the epoxy is similar to the backbone of the novolac, and as expected, follows

a degradation scheme similar to that of the phenolic novolac (Fig. 5). Degradation of the ECN resin yielded both epoxies and phenols. The degradation products of the molding compounds were more diverse. In addition to 1,2 epoxy-3-phenoxypropane, phenols, toluene, anisole, and ethoxypropane were

Table V Outgassing of Encapsulants at 180°C for 30 Min

	A	B	C		A	B	C
Phenol	x			3-Pyridinecarboxylic acid, hydrazide	x		
2,3 Dimethylphenol	x		x	1-Methylcarboxypyridinium		x	
2,6 Dimethylphenol			x	<i>N,N</i> -dimethylbenzenemethanamine	x		
2,2' Methylenebisphenol		x	x	Dinonylamine	x		
4,4' Methylenebisphenol	x	x	x	Hexahydro-2-azepinone	x		
2,6 bis(1,1Dimethylethyl)- 4-methylphenol	x		x	1-Methyl-2-pyrrolidinone		x	x
2-(2-Methylpropyl)phenol	x		x	2-Aminopropane			x
2-(4-Hydroxyphenyl)methylphenol	x		x	Valeramide	x		
1,2 Epoxy-3-phenoxypropane	x	x		6,6Dimethyl-2-2'-bipyridine <i>N</i> -oxide	x		
<i>p</i> -Cresylglycidyl ether	x			1-Methyl-1- <i>H</i> -imidazole- 4-ethanamine	x		
Glycidyl ether		x		2,4,6 Trimethylpyridine	x		
Ethyl oxirane	x			Dimethylbenzenethanamine			x
<i>p</i> -Isopropenylphenyl glycidyl ether		x		1-Methylpiperidine		x	
(2-Methylphenoxy)methyloxirane		x		Hydrazine, phenylmethyl- ethandioate		x	
2- <i>n</i> -Butoxyethylglycidyl ether		x					
[(Dodecyloxy)methyl]oxirane			x	Triphenylphosphine			x
1,3 Benzene dioxane	x			Triphenylphosphine oxide			x
1,3 Benzodioxin	x			Phosphonic acid	x		
2,3 Dihydrobenzofuran	x			Methoxymethylphosphonic acid	x		
2-Methoxyethenylbenzene	x			Ethylphosphate			x
1,2-Diphenoxybenzene		x		Tributylester phosphoric acid			x
Straight chain ethers, ethers/alcohol, long chain alcohols	x	x	x	1-Chloro-3-Phenoxy-2-Propanol		x	
1-Methyl-3-(1-methylethyl)benzene		x	x	3,5 Dichloroanisole		x	
1,2,4 Trimethylbenzene			x	2-Chloro- <i>n</i> -hexylacetamide		x	
1,3 Diethylbenzene		x		Diethylchlorotoluene	x		
Long chain (C5 and C7) hydrocarbons	x	x	x	4-Chlorobutoxybenzene			x
Acetic acid	x			1,2,3,4, tetrabromobutane	x		
Long chain carboxylic acids	x	x	x	4,6 dibromo-2-3 dihydro- 2-methylbenzofuran	x		x
				2,4 Dibromophenol		x	
				1,2 Dimethylpyrazolinbromide	x		
				Pyridiniumbromide	x		x

generated in the degradation scheme of the epoxy molding compound. Additional products such as aldehydes, oxiranemethanol, propanol, and methanol are formed from the 2,3 epoxy propoxy functionality.⁸

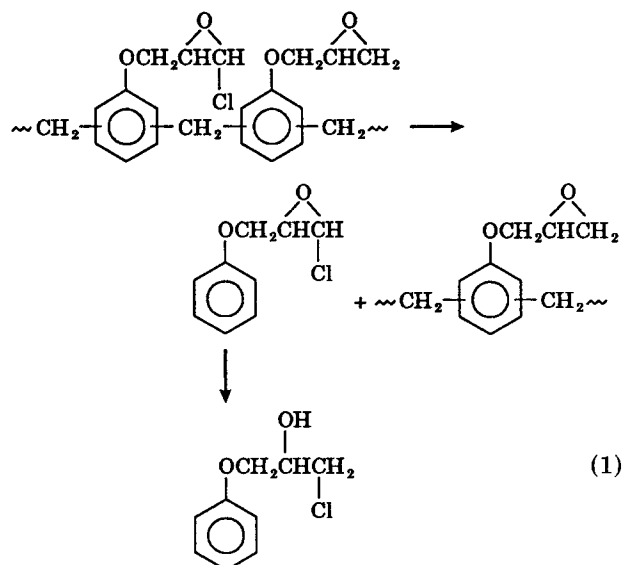
Diglycidyl ether of bisphenol A (2,2 bis[*p*-(2,3 epoxy propoxy)phenyl]-propane) was observed among the outgassing products of A. Brominated DGEBA is sometimes used as a flame retardant in these systems. Not all of the polymer units are brominated, therefore, the appearance of DGEBA can be accounted for by assuming that it is one of the unbrominated monomer units. The degradation scheme given in Figure 6 accounts for some of the

alkylated aromatic compounds found in B,⁷ indicating that DGEBA is also incorporated into this molding compound.

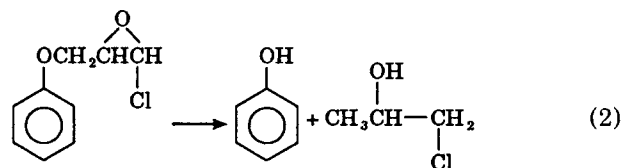
As the system cures, the polymer chains crosslink (Fig. 1). A degradation scheme of the crosslinked network as shown in Figure 7 accounts for the presence of alcohols, anisole, toluene, and methylcyclopentadiene in addition to some of the products accounted for by the previous schemes.

After outgassing at 180°C for 3 min, all three compounds showed evidence of halogenated products. These epoxy resins are synthesized from the reaction of phenol with epichlorohydrin. Although the manufacturers attempt to remove chlorine from

the finished product, some traces remain. This is obviously the source of 1-chloro-3-phenoxy-2-propanol found in *B* [eq. (1)].



1-chloro-3-phenoxy-2-propanol can degrade further to phenol and epichlorohydrin [eq. (2)]. No epichlorohydrin was found in the molding compounds, but it was found in the pure epoxy resin (Table II):



Thus, the degradation products of 1-chloro-3-phenoxy-2-propanol are the starting materials for the manufacture of the resin.

It is not known whether the chlorinated hydrocarbon (1-chloro-octadecane) is an impurity present in an additive, such as the rubber modifier, or whether the chlorine has been abstracted from 1-chloro-3-phenoxy-2-propanol. The appearance of dibromophenol and dibromoanisole is significant. As noted in the introduction, molding compounds are modified to meet certain flame retardancy requirements. The flame retardant used in these encapsulants is a mixture of Sb_2O_3 and brominated resin. The brominated resin is either a brominated epoxy resin or a brominated bisphenol A. It is believed that the mechanism for flame retardancy in polymer systems containing Sb_2O_3 and a halogen (X) is that the halogen reacts with Sb_2O_3 to form

Table VI Outgassing of Encapsulants at 220°C for 30 Min

	A	B	C
Phenol	x	x	x
2-Methylphenol	x	x	
3-Methylphenol		x	
4-Methylphenol	x	x	
2,3 Dimethylphenol	x	x	
2,6 Dimethylphenol	x	x	x
2,5 Dimethylphenol	x	x	
3,4 Dimethylphenol	x		
2,4 Dimethylphenol		x	x
3,5 Dimethylphenol		x	
2,2' Methylene bisphenol	x		x
4,4' Methylene bisphenol	x		
2-(4-Hydroxyphenylmethylphenol)	x		x
1,1'-Oxybis[2-methoxyethane]		x	
Ethylbenzene	x	x	
1,3 Dimethylbenzene	x	x	
1,2 Dimethylbenzene		x	
1,4 Dimethylbenzene		x	
Cyclopentadiene		x	
Long chain alkanes	x	x	x
Nonanamide		x	
6-Aminohexanoic acid		x	
1-Aziridine ethanol		x	
2-Methyl pyrimidine	x		
2,3 Dimethylpyridine	x		
Pyridine	x		
1-Hexadecylpyridinium monochloride		x	
Piperazine	x		
2-Ethyl-3,5-dimethyl 1-H-pyrrole	x		
4,5-Dihydro-3-phenyl-1H-pyrazole		x	
1-Nitropiperazine	x		
4-Ethyl 1-oxide pyridine	x		
(1-Methylpropyl)-hydrazine	x		
Triphenylphosphine	x		x
Triphenylphosphine oxide	x		x
1-Chloro-octadecane			x
1-Bromo-2-propanone	x		
2,4 Dibromoanisole			x
1,12 Dibromodecane	x		

SbOX , with subsequent thermal decomposition of this intermediate to evolve SbX_3 which is the actual flame retardant.²¹⁻²⁴

A sample of tetrabromobisphenol A was allowed to outgas at 180°C for 30 min under the same conditions as the molding compounds. The outgassing

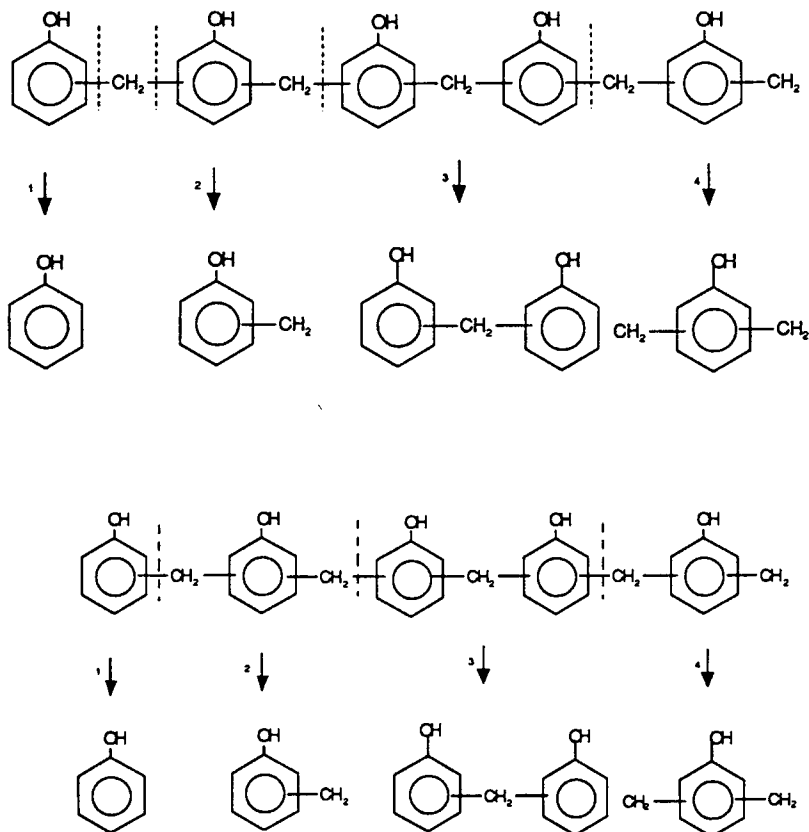
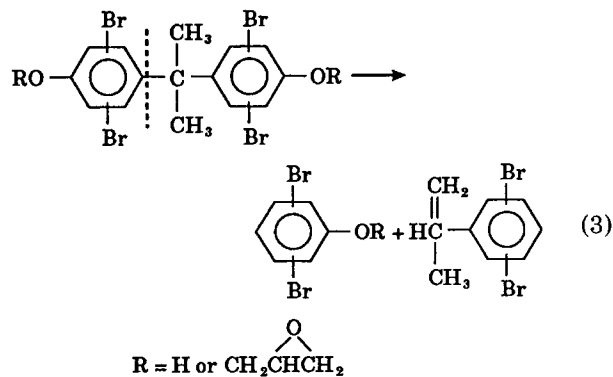


Figure 4 Degradation of novolac resin to produce (1) phenol, (2) cresol, (3) methylenebisphenol, and (4) dimethylphenol.

products included phenol, bromophenol, 2,4 dibromophenol, 2,4,6 tribromophenol, and 2,2'-methylenebisphenol. A sample of a brominated epoxy resin was subjected to the same conditions and, in addition to the aforementioned phenols, produced dibromophenylglycidylether. A plausible reaction that accounts for these products is:



The tribrominated species might be present in the original oligomer or might be the result of a rear-

angement during degradation. There was evidence of the alkylated bromobenzene in the resin degradation but both brominated phenols and alkylated bromobenzenes were found in the degradation products of the molding compounds. These brominated species arise from the degradation of the flame retardant. These products can degrade further to produce bromine radicals, which react with antimony as described above. Nara et al.^{25,26} studied the degradation of brominated resins with similar results. The presence of tetraheptylammonium bromide among the degradation products of C is probably related to the degradation products of the amine initiator reacting with bromine radicals.

Similar species of outgassing products were found regardless of temperature. At 220°C, no epoxies were in evidence but a greater variety of substituted phenols were found. As shown in Figures 5 and 7, both uncured epoxy resin and the crosslinked network polymer degrade to produce phenols. At 220°C, the epoxy has either completely reacted and is fully incorporated into the crosslinked network with sub-

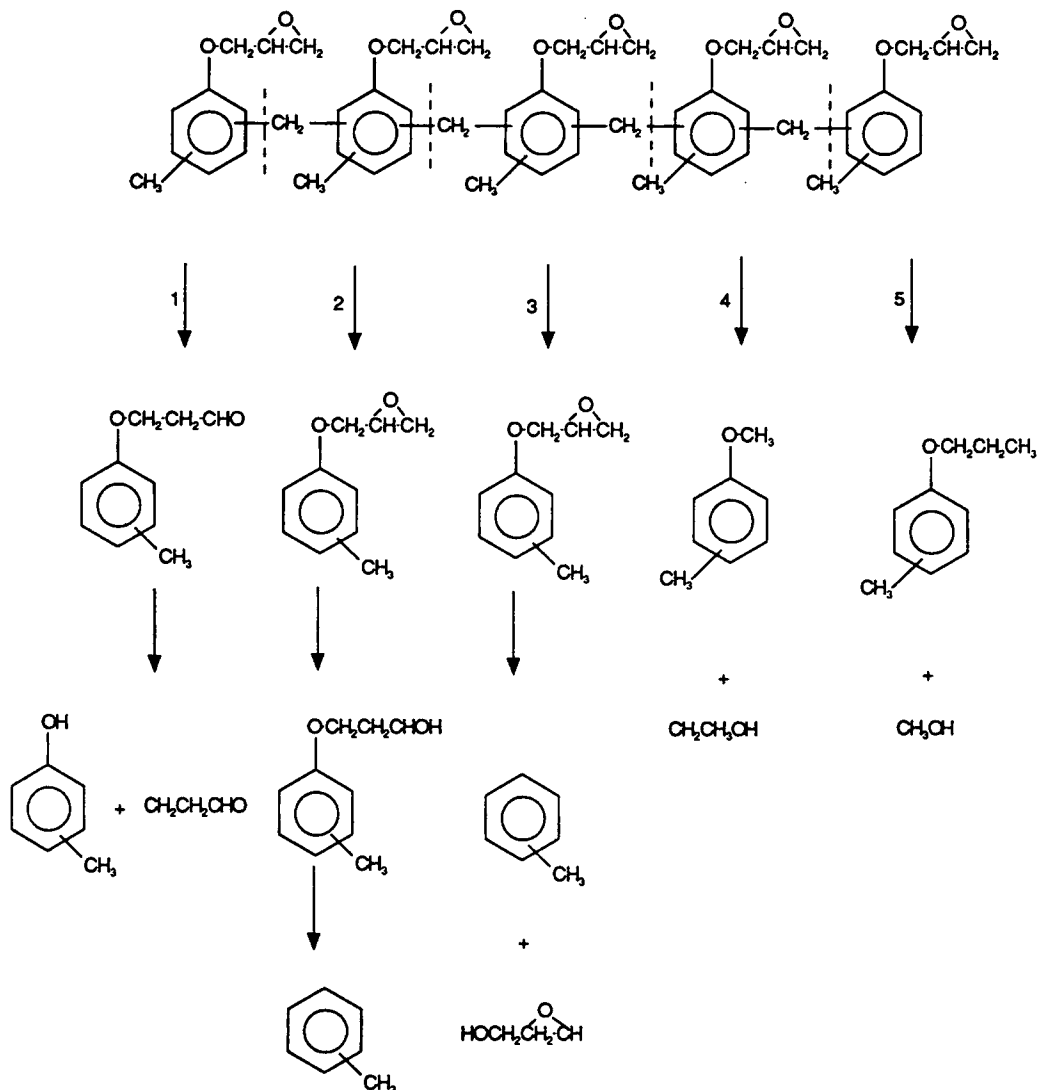


Figure 5 Degradation of epoxy cresol novolac resin to produce (1) cresol and aldehydes, (2) 1,2 epoxy-3-phenoxypropane, toluene, (3) oxiranemethanol, (4) propanol and anisole, and (5) propoxytoluene. (Methylene linkages have been omitted but can produce such methylated species as dimethylbenzene, trimethylbenzene, etc., in the final product.)

sequent degradation of the network (via path 4 or 5 in Fig. 7) or unreacted epoxide has degraded via path 1 in Figure 5. Following either path, no epoxides are predicted to appear among the outgassing products.

Initiator chemistry is of the utmost importance in epoxy molding compound formulation.^{27,28} In the development of epoxy resin based encapsulants, manufacturers tailor the initiator to the formulation so that when molded, the polymer crosslinks to build a three dimensional network with the desired properties. For this reason, the initiators used in these systems have historically been proprietary and de-

scribed only in generic terms by the manufacturer. Therefore, the general consumer of molding compounds knows little about the exact nature of the initiator for a given molding compound.

All of the experiments showed a number of nitrogen-containing species among the degradation products. These are believed to be initiator related. Working backwards from the degradation products to piece together the original compound, the amine initiator of *A* is most likely 3-pyridinecarboxylic acid, hydrazide or 3-pyridinecarboxylic acid phenyl hydrazine and a methylimidazole. The amine based initiator of *B* is also pyridine based but, in this case,

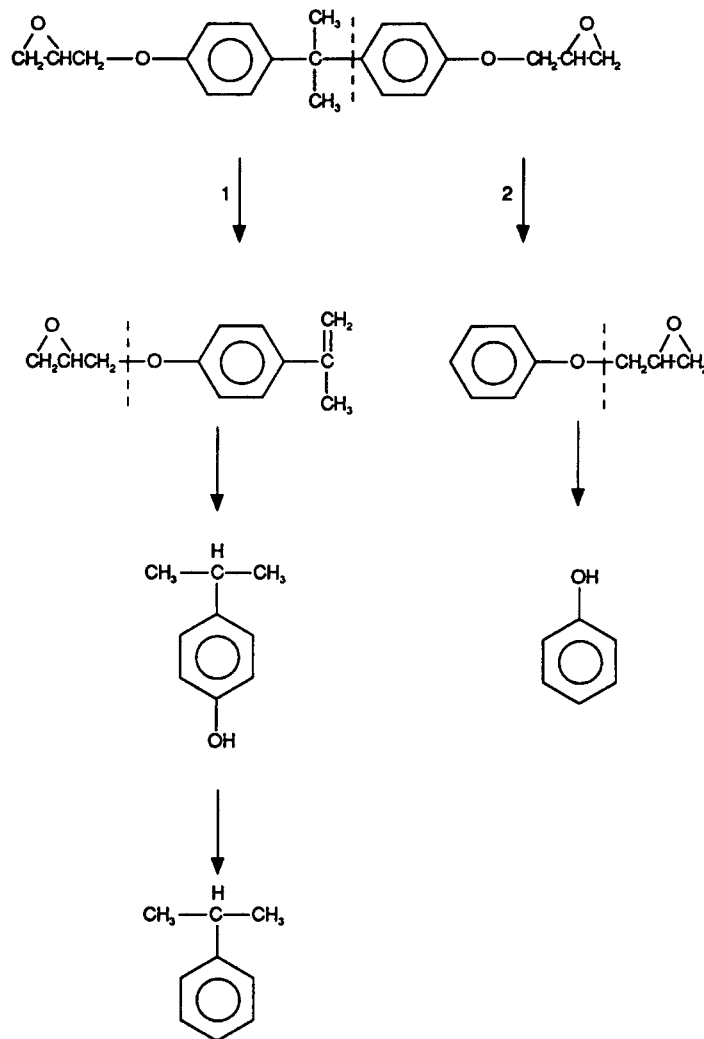


Figure 6 Degradation of Bisphenol A to produce (1) isopropylphenylglycidyl ether, isopropylphenol, and isopropylbenzene and (2) phenyl glycidyl ether and phenol.

a 1-methylcarboxypyridinium hydrazide pyrazole. The 1-methyl-2-pyrrolidinone detected among the degradation products of *B* probably results from the oxidation of the initiator. The hydrogenation of pyridine would account for the presence of piperidine.

1-Methyl-2-pyrrolidinone also appeared among the outgassing products of *C*. As with *B*, this derives from the oxidation of the initiator, possibly a substituted pyrrole. Pyridinium was in evidence as a bromine-substituted moiety. *C* showed no evidence of hydrazine. The nitrogen containing outgassing species, 2-propanamine and dimethylbenzene amine, indicate that the amine-based initiator is a hydrocarbon-based amine.

Triphenyl phosphine (TPP) is known to be an initiator for epoxy molding compounds used in mi-

croelectronic encapsulation^{27,29} and its presence among the outgassing products of *A* and *C*, confirmed its use. During polymerization, TPP is incorporated into the polymer matrix. As the polymer degrades, organophosphate esters could conceivably be formed, accounting for the presence of methoxymethyldiphosphoric acid.

Degradation

It has been demonstrated that the outgassing products of pure brominated resins alone cause ball bond degradation.¹ Others^{1,33} have proposed mechanisms for the degradation of the gold-aluminum intermetallic by bromide released from resin. Since all three of these molding compounds contain brominated resin, yet produce bond failures at the gold-

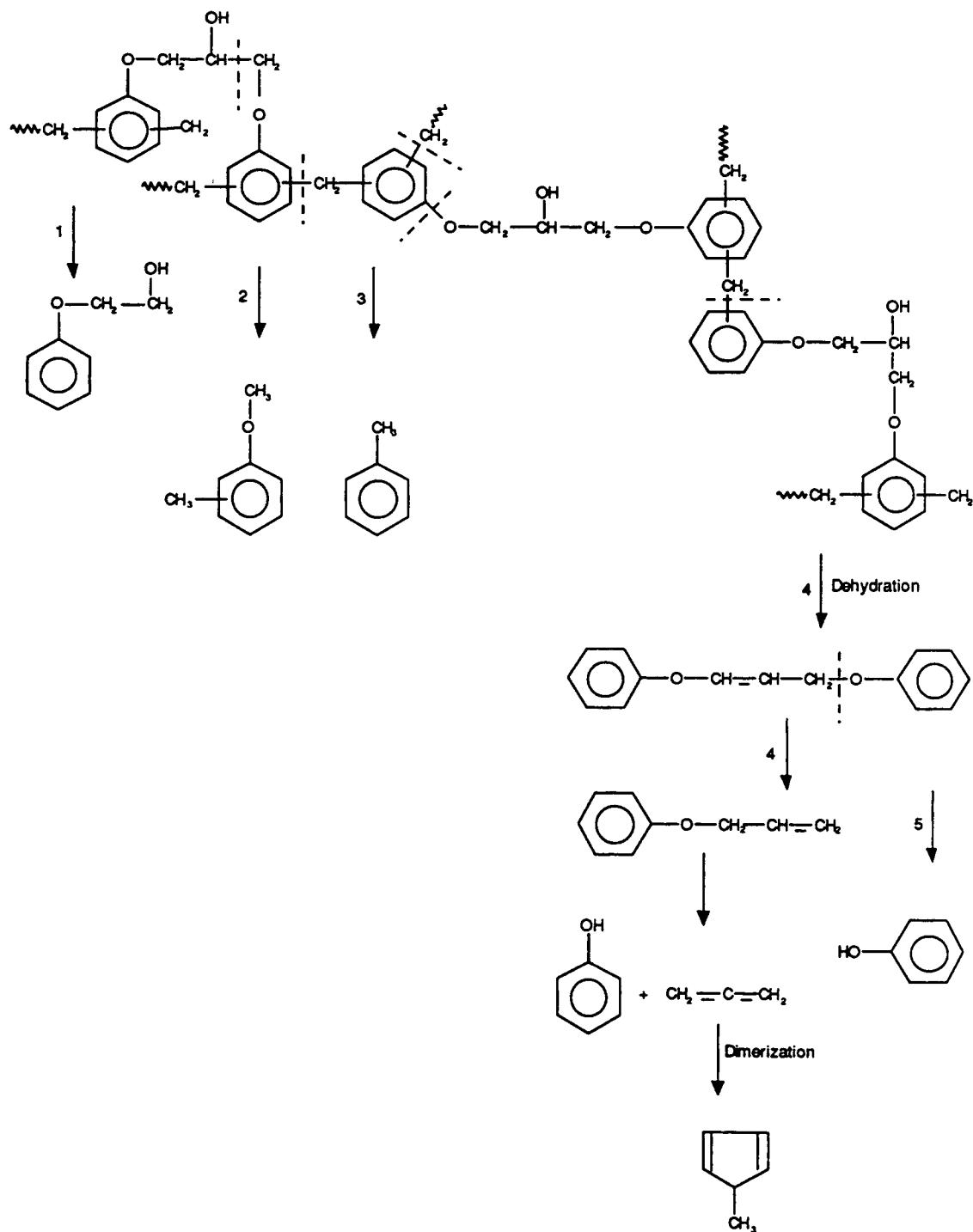
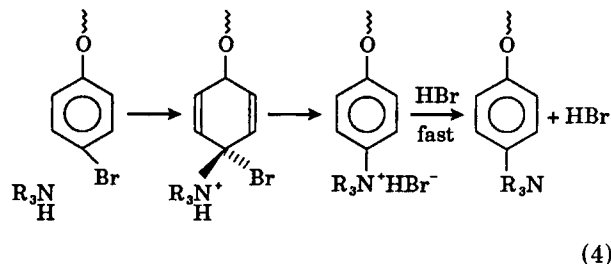


Figure 7 Degradation of crosslinked resin to produce (1) 2-phenoxyethanol, (2) methylanisole, (3) toluene, (4) phenol and methylcyclopentadiene, and (5) phenol. (Methylene linkages have been omitted for convenience.)

aluminum intermetallic at different rates, there must be some accelerating influence(s). One possibility that might account for the accelerated degradation

of intermetallics is nitrogen bromination of the amine initiator and rapid elimination of HBr as proposed by Nako et al.³⁰



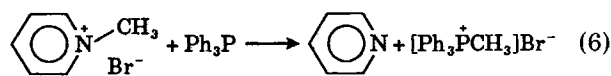
The presence of brominated pyridinium and brominated pyrazoline among the degradation products of *A* and *C* indicates a reaction of the amine initiator with bromine. The production of tetraheptylammonium bromide confirms that a nucleophilic reaction of amine with bromine has occurred and this may have an accelerating effect on the degradation of intermetallics.

In thermal aging tests, *C* and *A* both produce ball bond failures earlier than *B*. It is further noted that *C* and *A* both contain a phosphorous-based initiator in addition to an amine initiator.

It is known³¹ that triaryl phosphines react with aryl and alkyl halides, in this case an aryl bromide, by extracting the halogen from the aromatic ring and forming quaternary phosphonium salts:



Extraction of Br from the brominated resin with subsequent decomposition of the quaternary salt could be a source of ionic bromine which accelerates the degradation of the intermetallic. The outgassing products included a number of alkylated heterocycles, i.e., 1-methylpiperidine, 1-methylcarboxypyridinium, 1-methyl-1H-imidazole-4-ethanamine, etc. The reaction between the quaternary salts of nitrogen heterocycles with TPP dealkylates the heterocycle while forming the quaternary phosphonium salt. For example, the reaction between methylpyridinium bromide and TPP produces pyridine and a bromophosphonium salt.³²



It has been shown that an increase in ionic bromide accelerates wire bond degradation.³³ An interaction between the amine and phosphorous initiator might account for the increased acceleration of ball bond degradation. *B* uses only an amine initiator and is far less susceptible to this failure mechanism. When a combination of amine and phosphorous initiators is used, as is the case of *A* and *C*, the mechanism is

accelerated. An interaction between the two types of initiators causing an increase in ionic bromide, provides one explanation of the increased failure rates for *A* and *C*. It is recognized that this is one possible explanation and this mechanism probably accounts only partially for the acceleration of the ball bond failure. A number of other factors such as the presence of rubber modifiers and other additives may contribute.

CONCLUSIONS

GC/IR/MS has been used to identify a number of the major outgassing products of three commercial molding compounds, referred to as *A*, *B*, and *C*. Degradation schemes to account for these products have been shown. Some insight into the types of amine and phosphorous initiators used in these systems has also been obtained. Specifically, *A* and *C* use a combination of amine and phosphine-type initiator while *B* is amine initiated. Compounds *A* and *C* both show accelerated degradation of Au-Al intermetallics. A mechanism taking into account the interaction between the initiators and the brominated resin has been proposed to explain accelerated ball bond degradation when an amine initiator is used in combination with triphenylphosphine.

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