

SANDIA REPORT

SAND2005-7211

Unlimited Release

Printed December 2005

Component Compatibility of a Removal Process for Removable Encapsulants

James H. Aubert, Sarah K. Leming, and Patricia S. Sawyer

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.



Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865)576-8401
Facsimile: (865)576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: <http://www.osti.gov/bridge>

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800)553-6847
Facsimile: (703)605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: <http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online>



Component Compatibility of a Removal Process for Removable Encapsulants

James H. Aubert¹, Sarah K. Leming², and Patricia S. Sawyer¹,

¹Organic Materials Department, 01821

²Mechanical Design and Analysis Department, 05332

Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87185-0888

ABSTRACT

Removable encapsulants (adhesive, coating, syntactic foam and blown foams) provide system designers with encapsulants that have properties similar to conventional encapsulants but can be removed from an electronic assembly in a fairly benign manner. A gentle removal process is desired so that the electronic assemblies can be reused if desired. Two approaches to encapsulant removal have been proposed and compared with regard to their compatibility with typical components. The most benign removal process is shown to be 50 °C furfuryl alcohol.

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

Introduction.....	7
Diels-Alder Adduct Equilibrium.....	9
Approaches to Encapsulant Removal	11
Project Plan	13
Results.....	14
Results: Dissolution Studies	14
Results: Swelling Studies and Solvent Strength	16
Results: Corrosion Studies.....	20
Results: Test Board Studies	24
Results: Wire/Cable and Connector Studies	30
Results: Component Studies	33
Recommended Baseline Removal Process	35
Plan for Qualification.....	35
Conclusions.....	35
Acknowledgements.....	36
References.....	36
Distribution	38
Appendix I. SS1A4668, Removable Encapsulant Depotting Process	39
Appendix II. SS1A5992, Cover Removal Process	45
Appendix III. Electrical Testing of Board Components Analytical Solutions Inc.	53

Figures

1. Possible ways to remove an encapsulated PWB.	8
2. An electronic assembly that was encapsulated with a conventional encapsulant (top of assembly) and a removable encapsulant (bottom of assembly) after encapsulant removal.....	8
3. Reversible Diels-Alder adduct between a Furan and a Maleimide.	9
4. Epoxy resin, RER 1, containing two epoxide groups and two Diels-Alder adducts.....	9
5. Epoxy resin, RR2 containing two epoxide groups and two Diels-Alder adducts	10
6. Equilibrium between a maleimide and furfuryl alcohol.....	12
7. CDA260 cartridge brass coupons after three weeks of removal solvent exposure. The following removal conditions resulted in a very slight darkening of the coupons: 80 °C 80% 1-butanol / 20% toluene, 90 °C 100% 1-butanol, 90 °C 90% 1-butanol / 10% toluene, and 90 °C 80% 1-butanol / 20% toluene.....	21
8. 7075 aluminum showing strong corrosion in the following four removal schemes: 80 °C 80% 1-butanol / 20% toluene, 90 °C 100% 1-butanol, 90 °C 90% 1-butanol / 10% toluene, and 90 °C 80% 1-butanol / 20% toluene. Corrosion began within 24 hours. No corrosion was observed with 40 °C furfuryl alcohol and 50 °C furfuryl alcohol after three weeks of exposure	22

9.	7075 aluminum showing strong corrosion in the following four removal schemes after three weeks: 80 °C 80% 1-butanol / 20% toluene, 90 °C 100% 1-butanol, 90 °C 90% 1-butanol / 10% toluene, and 90 °C 80% 1-butanol / 20% toluene. Corrosion began within 24 hours. The samples in 80 °C 80% 1-butanol / 20% toluene and 90 °C 80% 1-butanol / 20% toluene were totally corroded with the three week time. No corrosion was observed with 40 °C furfuryl alcohol and 50 °C furfuryl alcohol after three weeks of exposure.....	23
10.	OFE Copper coupons that show slight discoloration in the following removal schemes: 80 °C 80% 1-butanol / 20% toluene, 90 °C 100% 1-butanol, 90 °C 90% 1-butanol / 10% toluene, and 90 °C 80% 1-butanol / 20% toluene. Corrosion began within 24 hours. No corrosion was observed with 40 °C furfuryl alcohol and 50 °C furfuryl alcohol after three weeks of exposure.....	24
11.	Test board for removal studies: a) bare board, b) conformally coated with RCC200, c) sandwiched with a bare board spaced 1/2 inch apart and then foamed with REF308.....	25
12.	Test board (not coated and not foamed) used for exposure to removal solvents	26
13.	Encapsulated coil components shows partial dissolution of the components encapsulation after exposure to any of the four tested removal schemes.....	27
14.	Test boards exposed to 50 °C furfuryl alcohol for 6 days.....	27
15.	Test boards exposed to 90 °C 80 volume % 1-butanol/20 volume % toluene for 7 days.....	28
16.	Photograph of components after 35 days' immersion in their respective solvents; left 50 °C furfuryl alcohol; right 90 °C 80% 1-butanol/20% toluene.....	32

Tables

I.	Estimated equilibrium constants based upon IR measurements on a diol containing two Diels-Alder adducts	11
II.	Results of the dissolution experiments on the six considered removal processes applied to four removable encapsulants and to an underfilled ASIC component. Removal time is in days.....	15
III.	Swelling of polymer coupons in the six proposed removal schemes for three weeks.	16
IV.	Three week exposure of metal coupons to the proposed removal scheme solvent and temperatures	20
V.	Observations on the removal time and damage to sandwiched test boards with four removal schemes. The sandwich test boards are shown in figure 11a and 12.....	29
VI.	Samples exposed to furfuryl alcohol at 50 °C.....	30
VII.	Samples exposed to 80 % 1-butanol/20% toluene at 90 °C	31
VIII.	Components exposed to either 50 °C furfuryl alcohol or to 90 °C 80 volume % 1-butanol/20 volume % toluene for two weeks	33

Component Compatibility of a Removal Process for Removable Encapsulants

Introduction

Polymeric encapsulating materials, i.e. coatings and foams, are used to protect high-value electronic and electro-mechanical components from shock, vibration, and environmental factors and to provide thermal and electrical insulation. All encapsulants for electronics must be electrical insulators and some are also required to provide high voltage standoff. The most common encapsulants are rigid, thermosetting polyurethane or epoxy foams. The typical foaming process is to enclose the electronics in a mold and then pour the pre-mixed reactive components into the mold. The reactants simultaneously foam and cure around the electronics, and the mold is then removed. Conformal coatings can provide a secure envelope around a circuit board and its components and act as a barrier against chemicals, moisture, fungus, dust and other environmental contaminants. Conformal coatings are typically epoxy, silicone, acrylic, polyurethane, or parylene. Encapsulants for high voltage standoff are typically glass filled epoxy.

For some electronic components, it is important to be able to remove the encapsulants at a later time for repairs, upgrades, or to salvage expensive components (figure 1). This requires encapsulants that can be removed without damage to electrical components. However, it is also necessary for removable encapsulants to have mechanical and processing properties that are similar to typical epoxy or polyurethane encapsulants. We have developed new encapsulants for this purpose that have mechanical properties that are similar to conventional encapsulants, but can be removed with a chemical process that is relatively benign. Conventional epoxy or polyurethane encapsulants are difficult to remove due to their crosslinking, solvent resistance, and mechanical toughness. In some instances, these materials have been removed by resorting to harsh means such as chiseling or by using aggressive solvents such as n-methyl pyrrolidinone. These harsher methods of encapsulant removal can often damage electronic components. A comparison between the removal properties of a conventional encapsulant and a removable encapsulant is shown in figure 2.

Our approach to removable encapsulants was to introduce chemically labile linkages within crosslinked polymeric epoxy networks. We explored the [4 + 2] cycloaddition reaction between dienes and dienophiles known as the Diels-Alder reaction [1,2]. Specifically, we investigated the thermally reversible reaction between appropriately functionalized furan and maleimide monomers. With this strategy, we were able to prepare crosslinked encapsulants with good mechanical properties that could be made to lose some crosslinks at elevated temperature for removal. It is well established that Diels-Alder adduct formation between furans and maleimides is favored at mild temperatures - between room temperature and 60 °C [3]. During this process, two isomers, endo and exo, are formed with the latter isomer being thermodynamically more stable. The reverse (retro) Diels-Alder reaction is favored by heating to temperatures of 90 °C or higher as shown in figure 3.

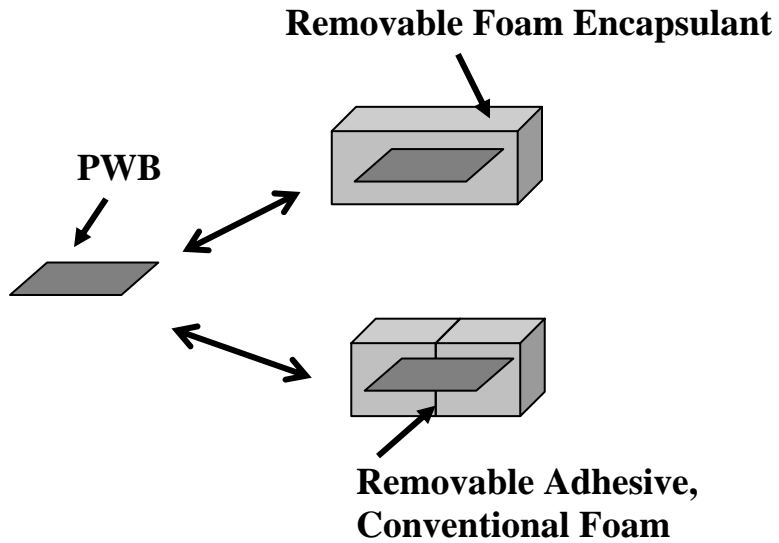


Figure 1. Possible ways to remove an encapsulated PWB.

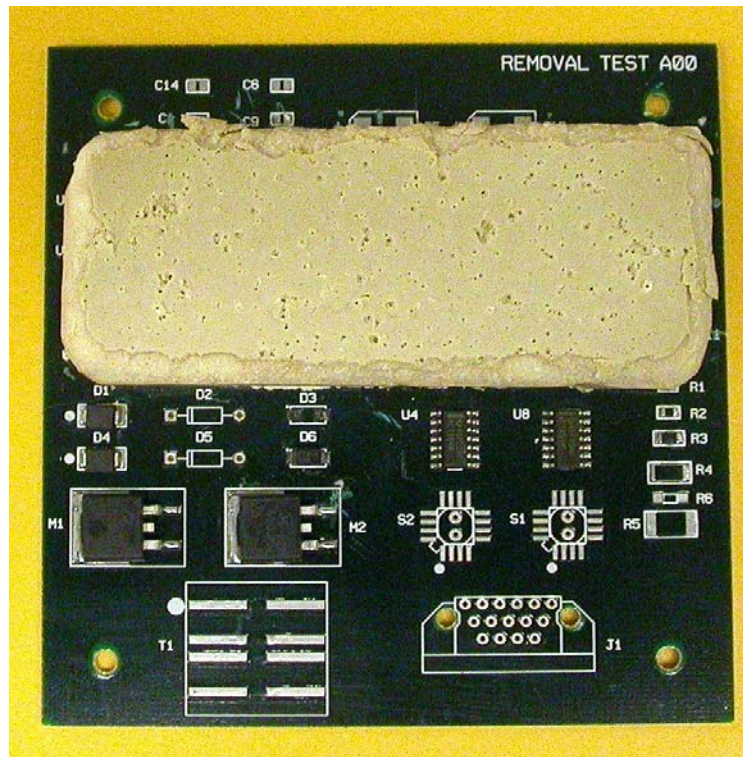


Figure 2. An electronic assembly that was encapsulated with a conventional encapsulant (top of assembly) and a removable encapsulant (bottom of assembly) after encapsulant removal.

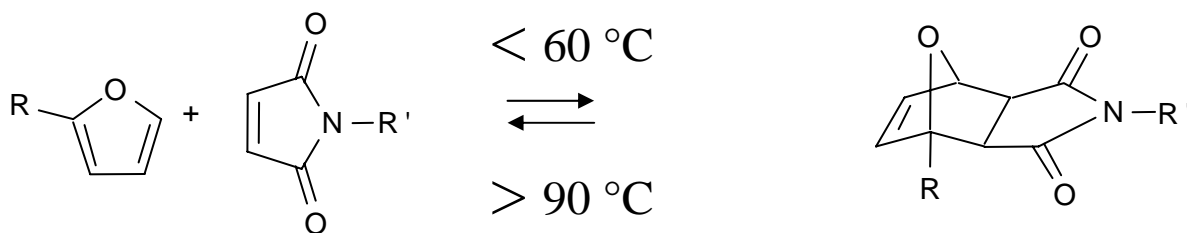
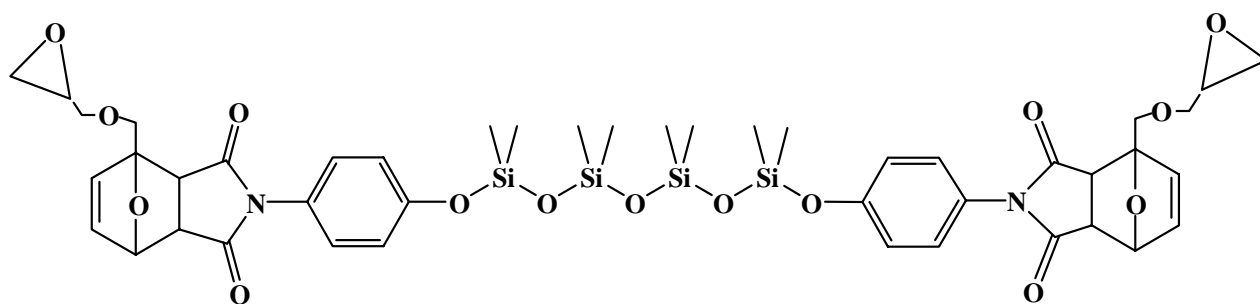


Figure 3. Reversible Diels-Alder adduct between a Furan and a Maleimide.

We incorporated furan-maleimide Diels-Alder adducts into epoxy-based resins, and used them in well-established curing reactions with amines to prepare removable encapsulants. The reaction between oxirane (epoxide) groups and amines leads to a highly crosslinked encapsulant. This epoxy is prepared as a two part liquid system that allows for easy processing that is nearly identical to the processing required for conventional encapsulants. One part consists of epoxy resins while the second part contains amine curing agents. The two components are mixed at room temperature just prior to use. Chemical crosslinking occurs during the epoxy/amine reaction forming an insoluble crosslinked epoxy thermoset. The thermally reversible Diels-Alder adducts within these crosslinked epoxy networks allow for their easy removal. The understanding of the thermally reversible adducts is important to design an optimum encapsulant removal process.

Diels-Alder Adduct Equilibrium

Our approach to removable encapsulants relies upon two epoxy resins that each contain two thermally-reversible Diels-Alder adducts. Figure 4 shows epoxy resin, RER 1, which is synthesized according to procedures described previously [1,2]. The molecular weight of RER 1 is 965.3 g/mole.



RER 1 RESIN

Figure 4. Epoxy resin, RER 1, containing two epoxide groups and two Diels-Alder adducts.

This resin is a bi-functional epoxy resin that cross-links with diamine curatives. In other words, the amine and the epoxy group react to form the network structure. The epoxy resin, RER 1 also contains two thermally-reversible Diels-Alder adducts that can open and reform to an extent dependent on the temperature. Few adducts are open a room temperature, but many more adducts are open at high temperature (90 °C). A second resin, RR2, used in removable encapsulants is shown in figure 5. The molecular weight of RR2 is 576.3 g/mole. Resin RR2 is used in some formulations to increase the glass transition temperature of the resulting encapsulant.

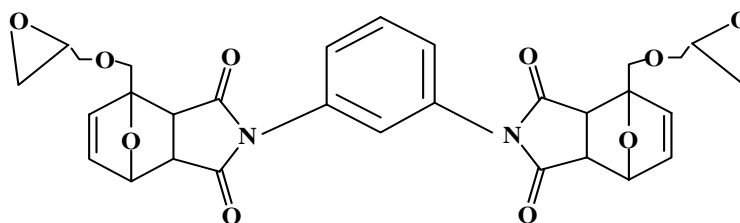


Figure 5. Epoxy resin, RR2, containing two epoxide groups and two Diels-Alder adducts.

The two removable epoxy resins are used in the formulation for a number of removable encapsulants (adhesive, coating, syntactic foam and blown foams). Removable adhesive and removable coating part A, RCC200A (material specification 2140593), and removable syntactic foam part A, RSF200A (material specification 2140595) use only resin RER 1. Removable blown epoxy foam part A (material specification 2140594) for REF308A and REF320A use both epoxy resins, RER 1 and RR2.

The temperatures indicated in figure 3 are only approximate. However, below 60 °C, the equilibrium falls far to the right and above 90 °C, the equilibrium shifts more to the left. In actuality, the formation of adducts and the retro opening of adducts is better described by an equilibrium constant that is a function of temperature according to equation (1).

$$(1) \quad K(T) = \frac{A \left[\begin{array}{c} \text{Diels-Alder Adduct} \\ \text{with R and N-R' groups} \end{array} \right]}{A \left[\begin{array}{c} \text{Diene} \\ \text{with R group} \end{array} \right] A \left[\begin{array}{c} \text{Dienophile} \\ \text{with N-R' group} \end{array} \right]}$$

In equation 1, $K(T)$ refers to the temperature dependent equilibrium constant and A refers to the thermodynamic activity of the species within the brackets. We have recently made measurements of $K(T)$ on a resin similar to RER 1 by FTIR/chemometrics [4]. The resin was a diol rather than a diepoxy. The diol was studied rather than the diepoxy for experimental simplifications [4]. We do not expect that the equilibrium constant of the Diels-Alder adducts will be affected very much by the end groups on the resin. The data was fit to an exponential function shown in equation 2.

$$(2) \quad K(T) = 7.2 \times 10^{-11} \exp\{9787/T\}$$

This exponential function has been used to estimate the equilibrium constant at any temperature. Some estimates at various temperatures are shown in Table I.

The equilibrium constant is very large below 60 °C, which indicates that few adducts are open and which is consistent with the description provided in figure 3. At 90 °C the equilibrium constant is estimated to be 36. This corresponds to approximately 85% of the adducts being closed, $[K = 0.85]/(0.15)^2 = 38$. In this calculation, thermodynamically ideal solutions are assumed. As discussed below, even with only 15% of the adducts open, the removable encapsulants can still be dissolved over time with a mild solvent.

Table I. Estimated equilibrium constants based upon IR measurements on a diol containing two Diels-Alder adducts.

Temperature	Equilibrium Constant
23 °C	16187
60 °C	413
90 °C	36
120 °C	5
150 °C	1

Approaches to Encapsulant Removal

There are two approaches to the removal of removable encapsulants. The first is based upon the description of the reversible Diels-Alder adducts provided in figure 3. In this view, a temperature above 90 °C is necessary for adducts to open. The removable process, based upon this view, requires a temperature of 90 °C or higher and a mild solvent. The solvent is necessary in order to solvate open adducts and limit their ability to reform. In this view, the solvent is also used to dissolve any small fragments of the encapsulant and remove the fragments from the bulk encapsulant. The removal process that was proposed by Russick [5,6], based upon this view of the equilibrium, is the solvent mixture of 80 volume % 1-butanol and 20 volume % toluene at 90 °C. This removal process was demonstrated on removable blown foams and removable syntactic foams. A study of the compatibility of this removal process with numerous COTS (commercial off

the shelf) electronic components was completed by Russick [5,6]. The study showed that most COTS electronic components that were tested survived the removal process without detrimental effects. Some components in the testing suffered some damage when the components were comprised of or contained soft polymeric parts.

The second approach to encapsulant removal is based upon the description of the reversible Diels-Alder adducts provided in equation (1). In this view, an equilibrium exists at all temperatures between adducts and the chemical moieties forming adducts, namely the furans and maleimides. Evidence that this description describes the equilibrium more accurately has been obtained from infrared spectroscopy measurements [4]. In this view, the equilibrium is temperature dependent with adducts preferred at lower temperatures. The removal process that was demonstrated is furfuryl alcohol at 50 °C. The solvent serves two roles. One role is identical to that proposed above. The solvent is necessary in order to solvate open adducts and limit their ability to reform. The solvent is also used to dissolve any small fragments of the encapsulant and remove the fragments from the bulk encapsulant. However, furfuryl alcohol serves another important role. Since it consists partly of a furan ring, it also partakes in the equilibrium as shown in equation (1) and in figure 6. With a large excess of this solvent, the equilibrium is predicted to favor adducts formed between maleimide and the furan ring from furfuryl alcohol. Since furfuryl alcohol is low molecular weight and not attached to the encapsulant network, this should favor faster removal. In fact, the faster removal should allow the process to be conducted at a much lower temperature with similar rates seen with the 1-butanol/toluene scheme conducted at 90 °C. This removal process was demonstrated on removable blown foams, removable syntactic foams and removable conformal coating and adhesive. The removal times of 50 °C furfuryl alcohol were found to be comparable to 90 °C 80 volume % 1-butanol/ 20 volume % toluene.

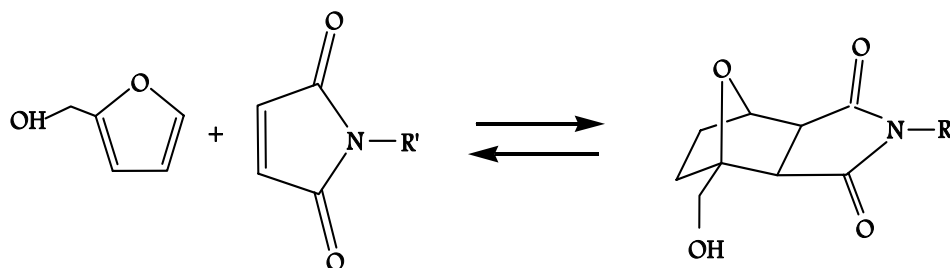


Figure 6. Equilibrium between a maleimide and furfuryl alcohol.

This report compares the performance of these two approaches to the removability of removable encapsulants with regard to removal speed and their compatibility with respect to COTS and other parts.

Project Plan

A project plan was developed to investigate the two removable processes described above along with some slight variations in the temperatures and solvent compositions of each removal process. The plan started with an investigation of the effect of the removal processes on polymer and metal coupons. This allowed us to judge the relative solvent strengths of the removal processes. The goal was to look for the removal process with the lowest solvent strength in relation to damage incurred by both polymer coupons and metal coupons. We then investigated the relative time to remove various removable encapsulants with the different removal processes and compared the relative effectiveness of each.

Test boards, that contained many common system components, were designed and procured. The test boards allowed us to encapsulate a representative board with removable encapsulants and then to remove the encapsulants. We observed the time to obtain complete removal and the relative condition of the test boards. In this way, we could judge the relative effectiveness of each removal process. The components were chosen to be representative of common system components. We also investigated the effects of the removal process on the individual components on the test boards and with some wire and cable.

After each set of tests, we hoped to eliminate the worst removal processes and eventually arrive at the most optimum removal process. This optimum removal process was then to be used on some real assemblies. No real assemblies were made available for this study. Perhaps, this part of the project plan will be done in the future. We plan on observing the time to completely and cleanly remove the encapsulants and then document any damage to the components of real assemblies. We also intend to thermally cycle and age real assemblies that have had their encapsulants removed and document any long term effects found that originated from the encapsulant removal process.

A. Design and Material Acquisition.

1. Selection of removal processes to be studied.
 - i. 90 °C 1-butanol.
 - ii. 90 °C 90 volume % 1-butanol/10 volume % toluene.
 - iii. 90 °C 80 volume % 1-butanol/20 volume % toluene.
 - iv. 80 °C 80 volume % 1-butanol/20 volume % toluene.
 - v. 40 °C furfuryl alcohol.
 - vi. 50 °C furfuryl alcohol.
2. Identify and acquire metal coupons for corrosion testing of each possible removal process.
3. Identify and acquire polymer coupons for testing the solvent strength of each possible removal process.
4. Design and acquire test boards containing many common system components.
5. Design and acquire molds, extraction equipment, and chemicals for testing.
6. Preliminary removal of 3 real assemblies, if available, with three chosen processes (i, iii, vi) - Possible down-selection of processes.

- B. Preliminary Compatibility and Removal Testing.
1. Test metal coupons in removal process for corrosion (visual inspection only) - Possible down-selection of processes.
 2. Test polymer coupons in removal processes for solvent compatibility (wt. gain, dimensional changes, dissolution, degradation) - Possible down-selection of processes.
 3. Define removal time for each process and evaluate removal efficiency (visual) on the test boards with components in a geometry representative of real assemblies (i.e. common board spacing). This will include ASIC underfill removal testing (worst case underfill) on a separate test board) - Possible down-selection of processes.
- C. With the remaining down-selected removal processes, test 2-3 real assemblies (coated, molded, foamed) with each removal process (evaluate electrical functionality of board components before and after coating/foaming/removal). At this point there might only be one or two removal processes still under consideration - Possible down-selection of processes.
- D. Simultaneously with (C), evaluated removal process compatibility with un-mounted components (dimensional changes, wt. changes, electrical functionality). Possible down-selection of processes.
- E. Encapsulant removal of real assemblies with down-selected process. This would complete the conditional qualification of a removal process for real assemblies.
- F. Perform aging and reliability testing on real assemblies. This would complete the final qualification of a removal process for real assemblies.
- margin of safety evaluated by repeated encapsulant removal.
 - long-term aging effects evaluated by evaluation of encapsulated assemblies that had original encapsulant removed.

Results

Results: Dissolution Studies

Dissolution Studies were conducted in which we measured the time for each removal process to completely dissolve various removable encapsulants of a specific size. The removable encapsulants considered were blown removable foam, REF308, with a density of approximately 8 lb/ft³, blown removable foam, REF320, with a density of approximately 20 lb/ft³, removable syntactic foam, RSF200, that contained glass microballoons in an removable epoxy matrix, and removable conformal coating, RCC200, an elastomeric coating. We also compared the removal times for the removal on an ASIC component underfilled with RCC200. The dimensions of the

ASIC were approximately 1.4 inch by 1.4 inch. It was mounted to a glass substrate and the gap between the glass substrate and the ASIC was approximately 0.010 inch. The gap was filled with RCC200. This component was expected to be the most difficult from which to remove the underfill.

The results of the dissolution study are summarized in Table II. RSF200 did not dissolve in 90 °C 1-butanol. This experiment was repeated with the same result. Thus, we can eliminate this removal process from further consideration. REF308 primarily dissolved in this solvent but did leave a small amount of undissolved residue. REF308 was also tested in 90 °C 90 volume % 1-butanol/10 volume % toluene which left residue and probably could not be considered for encapsulant removal either.

Table II. Results of the dissolution experiments on the six considered removal processes applied to four removable encapsulants and to an underfilled ASIC component. Removal time is in days.

Removal Scheme / Removable Material	90 °C 1-butanol	90 °C 90 volume % 1-butanol/10 volume % toluene	90 °C 80 volume % 1-butanol/20 volume% toluene	80 °C 80 volume % 1-butanol/20 volume % toluene	40 °C furfury l alcohol	50 °C furfury l alcohol
REF308(a)	3/residual undissolved	3/small quantity of residual undissolved	1	1	3	3
REF320(b)	3/residual undissolved	3/small quantity of residual undissolved	2	3	6	3
RSF200(c)	insoluble	4	4	4	10	6
RCC200(d)	1	1	1	1	6	2
ASIC underfilled with RCC200(e)	4	2	2	2	16	7

(a) nominal sample weight 2.81 gm, nominal diameter 1.13 inch, nominal height 1.18 inch, nominal 100 ml solvent

(b) nominal sample weight 6.67 gm, nominal diameter 1.13 inch, nominal height 1.18 inch, nominal 100 ml solvent

(c) nominal sample weight 1.81 gm, nominal diameter 0.56 inch, nominal height 0.63 inch, nominal 100 ml solvent

(d) nominal sample weight 1.85 gm, nominal diameter 0.55 inch, nominal height 0.40 inch, nominal 100 ml solvent

(e) ASIC mounted on glass backing with 0.010 inch underfill gap, nominal 1 liter solvent

The slowest encapsulant removal process was the underfill removal from the ASIC component. Based upon the dissolution results corresponding to underfilled ASICs, we made the following ranking. We did not include the results for 90 °C 1-butanol in this ranking (even though it did in fact remove the underfill) since it could not dissolve RSF200 and left residue when dissolving REF308.

Fastest Removal	90 °C 80 volume % 1-butanol/20 volume % toluene (2 days)
	90 °C 90 volume % 1-butanol/10 volume % toluene (2 days)
↑	80 °C 80 volume % 1-butanol/20 volume % toluene (2 days)
	50 °C furfuryl alcohol (7 days)
Slowest Removal	40 °C furfuryl alcohol (16 days)

Results: Swelling Studies and Solvent Strength

Swelling/dissolution studies were conducted with a variety of polymer coupons with all six of the removal processes to gauge the solvent strength of each. The initial dimensions and weight of the coupons were measured and compared to similar measurements after solvent exposure. The solvent exposure was conducted for three weeks, which we estimated was a sufficient length of time to equilibrate the coupons to the solvents. The response of the coupons ranged tremendously based upon the polymer properties and the solvents. The interactions included: no interaction, swelling, discoloration, distortion, and dissolution. The experimental results are recorded in Table III.

Table III. Swelling of polymer coupons in the six proposed removal schemes for three weeks.

	90 °C 1-butanol	90 °C 90 volume % 1-butanol/10 volume % toluene	90 °C 80 volume % 1-butanol/20 volume % toluene	80 °C 80 volume % 1-butanol/20 volume % toluene	40 °C furfuryl alcohol	50 °C furfuryl alcohol
Polymethyl-Methacrylate (a)	Initial Dimensions and weight: 4.232 gm 0.073"x1.009" x3.022" Dissolved within 24 hours	Initial Dimensions and weight: 4.245 gm 0.073"x1.015" x3.014" Dissolved within 24 hours	Initial Dimensions and weight: 4.279 gm 0.074"x1.021" x3.018" Dissolved within 24 hours	Initial Dimensions and weight: 4.174 gm 0.073"x0.993" x3.015" Dissolved within 24 hours	Initial Dimensions and weight: 4.305 gm 0.073"x1.020" x3.024" Dissolved within 24 hours	Initial Dimensions and weight: 4.265 gm 0.073"x1.008" x3.025" Dissolved within 24 hours

Polystyrene (b)	Initial Dimensions and weight: 2.975 gm 0.058"x0.978" x3.005" Coupon plasticized and flowed to bottom of jar	Initial Dimensions and weight: 3.094 gm 0.058"x1.002" x3.024" Coupon plasticized and flowed to bottom of jar Partial dissolution (1, less than 2)	Initial Dimensions and weight: 3.030 gm 0.058"x0.998" x3.015" Coupon plasticized and flowed to bottom of jar Partial dissolution (3)	Initial Dimensions and weight: 3.034 gm 0.058"x1.000" x3.016" Coupon plasticized and flowed to bottom of jar Partial dissolution (2, less than 3)	Initial Dimensions and weight: 3.022 gm 0.058"x0.992" x3.014" Final Dimensions and weight: 3.396 gm 0.065"x0.999" x3.014"	Initial Dimensions and weight: 2.986 gm 0.058"x0.981" x3.018" Final Dimensions and weight: 3.508 gm 0.075"x1.032" x2.967" curled
Polyimide/ glass circuit board (c)	Initial Dimensions and weight: 5.559 gm 0.062"x1.002" x3.002" Final Dimensions and weight: 5.556 gm 0.063"x1.002" x3.001"	Initial Dimensions and weight: 5.647 gm 0.061"x1.009" x3.002" Final Dimensions and weight: 5.568 gm 0.064"x1.001" x3.002"	Initial Dimensions and weight: 5.480 gm 0.062"x1.002" x3.002" Final Dimensions and weight: 5.482 gm 0.062"x1.002" x3.001"	Initial Dimensions and weight: 5.541 gm 0.062"x1.002" x3.001" Final Dimensions and weight: 5.541 gm 0.062"x1.001" x3.000"	Initial Dimensions and weight: 5.479 gm 0.062"x1.001" x3.001" Final Dimensions and weight: 5.497 gm 0.062"x0.999" x2.999"	Initial Dimensions and weight: 5.469 gm 0.061"x1.002" x3.001" Final Dimensions and weight: 5.487 gm 0.061"x1.001" x3.000"
Sylgard® 184 Coupon (d)	Initial Dimensions and weight: 2.994 gm 0.056"x1.008" x3.014" Final Dimensions and weight: 4.092 gm 0.063"x1.169" x3.434"	Initial Dimensions and weight: 2.829 gm 0.053"x1.009" x3.010" Final Dimensions and weight: 3.990 gm 0.060"x1.190" x3.419"	Initial Dimensions and weight: 2.543 gm 0.054"x0.944" x2.946" Final Dimensions and weight: 3.785 gm 0.060"x1.110" x3.499"	Initial Dimensions and weight: 2.823 gm 0.055"x0.953" x3.058" Final Dimensions and weight: 4.079 gm 0.062"x1.125" x3.550"	Initial Dimensions and weight: 2.803 gm 0.052"x1.002" x2.973" Final Dimensions and weight: 2.850 gm 0.054"x1.024" x3.026"	Initial Dimensions and weight: 2.742 gm 0.053"x0.968" x3.021" Final Dimensions and weight: 2.788 gm 0.054"x0.978" x3.054"
RTV coupon (e)	Initial Dimensions and weight: 5.233 gm 0.092"x1.046" x2.962" Final Dimensions and weight: 7.058 gm 0.097"x1.181" x3.348"	Initial Dimensions and weight: 5.235 gm 0.074"x0.988" x3.010" Final Dimensions and weight: 7.399 gm 0.107"x1.133" x3.485"	Initial Dimensions and weight: 3.063 gm 0.053"x.990" x2.960" Final Dimensions and weight: 4.545 gm 0.068"x1.164" x3.453"	Initial Dimensions and weight: 3.457 gm 0.057"x1.012" x3.002" Final Dimensions and weight: 5.094 gm 0.066"x1.185" x3.463"	Initial Dimensions and weight: 4.353 gm 0.067"x1.041" x3.022" Final Dimensions and weight: 4.351 gm 0.075"x1.025" x3.005"	Initial Dimensions and weight: 4.307 gm 0.071"x1.050" x2.950" Final Dimensions and weight: 4.317 gm 0.075"x1.041" x2.947"

High density polyethylene (f)	Initial Dimensions and weight: 2.832 gm 0.061"x1.004" x3.007" Final Dimensions and weight: 2.094 gm 0.061"x1.010" x3.025"	Initial Dimensions and weight: 2.818 gm 0.060"x1.003" x2.996" Final Dimensions and weight: 2.891 gm 0.061"x1.011" x3.015"	Initial Dimensions and weight: 2.804 gm 0.062"x1.000" x2.995" Final Dimensions and weight: 2.923 gm 0.062"x1.021" x3.033"	Initial Dimensions and weight: 2.820 gm 0.061"x1.004" x2.994" Final Dimensions and weight: 2.941 gm 0.061"x1.017" x3.026"	Initial Dimensions and weight: 2.818 gm 0.061"x1.000" x2.993" Final Dimensions and weight: 2.832 gm 0.061"x0.990" x2.990"	Initial Dimensions and weight: 2.821 gm 0.060"x1.004" x3.005" Final Dimensions and weight: 2.839 gm 0.060"x1.004" x3.009"
Polycarbonate (g)	Initial Dimensions and weight: 3.601 gm 0.063"x0.984" x3.005" Final Dimensions and weight: 3.623 gm 0.066"x0.972" x3.007" very brittle and broken discolored to white	Initial Dimensions and weight: 3.476 gm 0.068"x0.948" x2.994" Final Dimensions and weight: 3.282 gm 0.065"x0.936" x2.972" very brittle and broken discolored to white	Initial Dimensions and weight: 3.582 gm 0.063"x0.971" x3.019" Final Dimensions and weight: Missing piece 0.064"x0.946" missing piece very brittle and broken discolored to white	Initial Dimensions and weight: 3.718 gm 0.064"x1.004" x3.016" Final Dimensions and weight: 3.399 gm 0.068"x0.996" too many pieces very brittle and broken discolored to white	Initial Dimensions and weight: 3.583 gm 0.063"x0.982" x3.029" Final Dimensions and weight: 4.464 gm 0.077"x.972" x3.019" pliable and discolored to white not broken	Initial Dimensions and weight: 3.622 gm 0.065"x0.983" x3.028" Final Dimensions and weight: 4.476 gm 0.077"x0.985" x3.031" pliable and discolored to white not broken
Polyurethane elastomer (h)	Initial Dimensions and weight: 3.805 gm 0.064"x1.020" x3.012" Final Dimensions and weight: Not obtainable, very brittle and could not be handled	Initial Dimensions and weight: 3.643 gm 0.062"x1.022" x3.005" Final Dimensions and weight: Not obtainable, very brittle and could not be handled	Initial Dimensions and weight: 3.815 gm 0.064"x1.029" x3.007" Final Dimensions and weight: Not obtainable, very brittle and could not be handled	Initial Dimensions and weight: 3.754 gm 0.062"x1.028" x3.001" Final Dimensions and weight: Not obtainable, very brittle and could not be handled	Initial Dimensions and weight: 3.592 gm 0.062"x1.017" x3.000" Final Dimensions and weight: 8.226 gm 0.081"x1.340" x3.958" Swollen and rubbery	Initial Dimensions and weight: 3.775 gm 0.063"x1.029" x3.007" Final Dimensions and weight: 9.138 gm 0.085"x1.378" x4.033" Swollen and rubbery

Nylon 6,6 (i)	Initial Dimensions and weight: 3.495 gm 0.062"x1.008" x2.985" Final Dimensions and weight: 3.771 gm 0.0645"x1.039" x3.097" not discolored flexible	Initial Dimensions and weight: 3.500 gm 0.062"x1.009" x3.008" Final Dimensions and weight: 3.779 gm 0.0645"x1.041" x3.108" not discolored flexible	Initial Dimensions and weight: 3.525 gm 0.064"x1.018" x3.007" Final Dimensions and weight: 3.803 gm 0.0645"x1.044" " x3.109" not discolored flexible	Initial Dimensions and weight: 3.527 gm 0.063"x1.020" x3.008" Final Dimensions and weight: 3.803 gm 0.0645"x1.053" x3.108" not discolored flexible	Initial Dimensions and weight: 3.518 gm 0.063"x1.007" x3.007" Final Dimensions and weight: 4.403 gm 0.0675"x1.076" x3.214" orange-yellow color from solvent flexible	Initial Dimensions and weight: 3.545 gm 0.062"x1.015" x3.005" Final Dimensions and weight: 4.469 gm 0.0675"x1.091" x3.222" orange-yellow color from solvent flexible
---------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

- (a) Acrylic LUCITE, Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(b) High-impact Polystyrene, Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(c) The Circuit Shop, 8512 San Joaquin SE, Albq., NM.
(d) Dow Corning Sylgard 184; World Precision Instruments, 175 Sarasota Center Blvd, Sarasota, FL 34240 (941) 371-1003
(e) Dow Corning RTV 3110F; Dow Corning Corporation, Midland, MI 48686-0994
(f) High Density Polyethylene; Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(g) Polycarbonate; Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(h) Polyurethane Elastomer; Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.
(i) Nylon 6,6; Regal Plastics, 3455 Princeton Dr. NE, Albq., NM.

Based upon the interactions of removal solvent with the polymer coupons, we qualitatively ranked the solvent strength of five removal schemes. We did not rank 90 °C 1-butanol since it was proven inadequate as a removal process above (see Table II). In this ranking, the weakest solvent is the best since it will be the least likely to do damage to electrical components.

Strongest Solvent	90 °C 80 volume % 1-butanol/20 volume % toluene
	80 °C 80 volume % 1-butanol/20 volume % toluene
	90 °C 90 volume % 1-butanol/10 volume % toluene
	50 °C furfuryl alcohol
Weakest Solvent	40 °C furfuryl alcohol

Results: Corrosion Studies

Corrosion studies were conducted using coupons of common system metal surfaces. 7075 Aluminum was added because it is known to be sensitive to corrosion and could provide some differentiation between the different removal schemes. OFE copper was added for the same reason. The metal coupons were exposed to the removal conditions for three weeks. Observations were made on the coupons that included: no observable effect, discoloration, and dissolution. The results of the corrosion study are compiled in Table IV.

Table IV. Three week exposure of metal coupons to the proposed removal scheme solvents and temperatures.

	90 °C 1- butanol	90 °C 90 volume % 1-butanol/10 volume % toluene	90 °C 80 volume % 1-butanol/20 volume % toluene	80 °C 80 volume % 1-butanol/20 volume % toluene	40 °C furfuryl alcohol	50 °C furfuryl alcohol
303SS(a)	No visible change	No visible change	No visible change	No visible change	No visible change	No visible change
304LSS(a)	No visible change	No visible change	No visible change	No visible change	No visible change	No visible change
Titanium grade 5(a)	No visible change	No visible change	No visible change	No visible change	No visible change	No visible change
Cover(a)	No visible change	No visible change	No visible change	No visible change	No visible change	No visible change
CDA260 (Cartridge Brass) (a)	Very slight darkening	Very slight darkening	Very slight darkening	Very slight darkening	No visible change	No visible change
Nickel plated Aluminum (a)	No visible change Coupons initially quite discolored	No visible change Coupons initially quite discolored	No visible change Coupons initially quite discolored	No visible change Coupons initially quite discolored	No visible change Coupons initially quite discolored	No visible change Coupons initially quite discolored
Chrome plated Aluminum (a)	No visible change	No visible change	No visible change	No visible change	No visible change	No visible change
Conversion coated Aluminum (a)						
OFE Copper(b)	Very slight darkening	Very slight darkening	Very slight darkening	Very slight darkening	No visible change	No visible change
7075 Aluminum(b)	Severe corrosion within 24 hours including gas bubbling and metal etching	Severe corrosion within 24 hours including gas bubbling and metal etching	Severe corrosion within 24 hours including gas bubbling and metal etching Totally dissolved in 8 days	Severe corrosion within 24 hours including gas bubbling and metal etching	No visible change	No visible change

(a) Metal Samples Co., Munford AL. These coupons are metals that are listed in CD1A2426 except for the chrome plated aluminum.

(b) Metal coupons provided by N. R. Sorensen, Corrosion & Surface Sciences Department, 1832. These coupons are more sensitive to corrosion in order to differentiate between the different removal schemes.

Photographs of CDA260 cartridge brass coupons after three weeks of removal solvent exposure are shown in figure 7. All of the removal schemes that utilized 1-butanol or 1-butanol in combination with toluene resulted in a very slight darkening of the coupons. Neither removal schemes that utilized furfuryl alcohol showed any discoloration of the coupons nor any other visible effects. 7075 aluminum is not commonly utilized in systems, but is a metal that has sensitivity to corrosion. Coupons of this aluminum were exposed to the removal conditions for three weeks in an attempt to differentiate between the removal schemes. Strong corrosion of 7075 aluminum was observed with all of the removal schemes that utilized 1-butanol or 1-butanol in combination with toluene. Corrosion began within 24 hours and was accompanied by gas evolution (perhaps H_2). No corrosion was observed with 40 °C furfuryl alcohol and 50 °C furfuryl alcohol after three weeks of exposure. Photographs of the coupons after solvent exposure are shown in figure 8. Figure 9 shows the coupon remnants after removing them from the removal solvents and rinsing them.

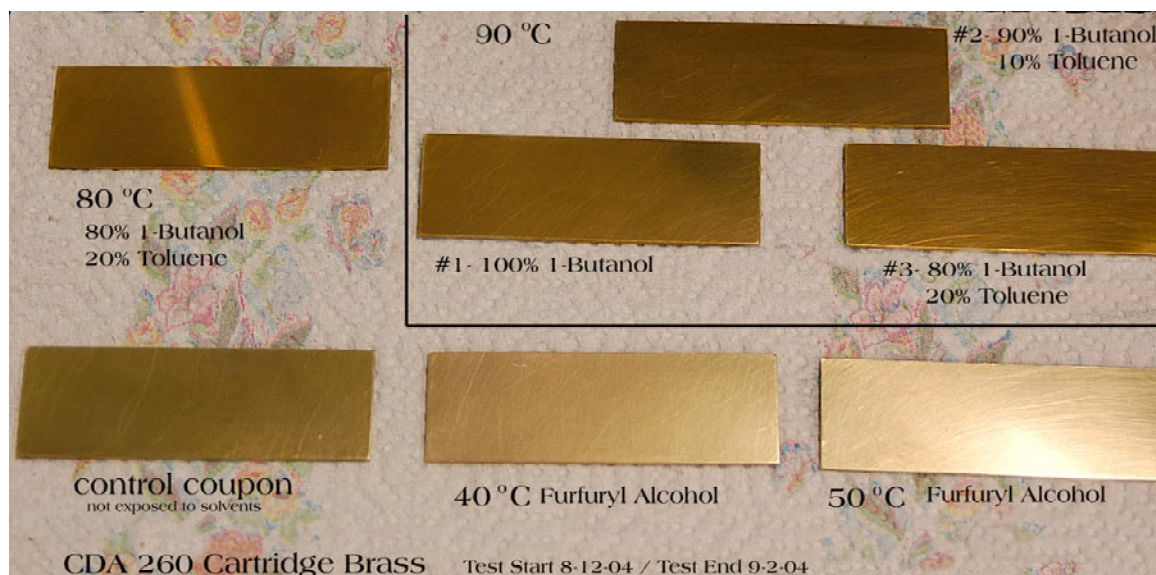


Figure 7. CDA260 cartridge brass coupons after three weeks of removal solvent exposure. The following removal conditions resulted in a very slight darkening of the coupons: 80 °C 80 volume % 1-butanol / 20 volume % toluene, 90 °C 100% 1-butanol, 90 °C 90 volume % 1-butanol / 10 volume % toluene, and 90 °C 80 volume % 1-butanol / 20 volume % toluene.

To differentiate between the effect of solvent and temperature on the corrosion of 7075 aluminum, we also exposed the metal to furfuryl alcohol at 90 °C for three weeks and to toluene at 90 °C for three weeks. There was no observable corrosion of 7075 aluminum under these two conditions. We conclude that 1-butanol is especially corrosive to 7075 aluminum compared to either toluene or furfuryl alcohol.

OFE Copper coupons showed slight discoloration in the removal schemes that contained 1-butanol or 1-butanol in combination with toluene. Corrosion began within 24 hours. No corrosion was observed with 40 °C furfuryl alcohol and 50 °C furfuryl alcohol after three weeks of exposure. Photographs of these coupons after solvent exposure are shown in figure 10.



Figure 8. 7075 aluminum showing strong corrosion in the following four removal schemes: 80 °C 80 volume % 1-butanol / 20 volume % toluene, 90 °C 100% 1-butanol, 90 °C 90 volume % 1-butanol / 10 volume % toluene, and 90 °C 80 volume % 1-butanol / 20 volume % toluene. Corrosion began within 24 hours. No corrosion was observed with 40 °C furfuryl alcohol and 50 °C furfuryl alcohol after three weeks of exposure.

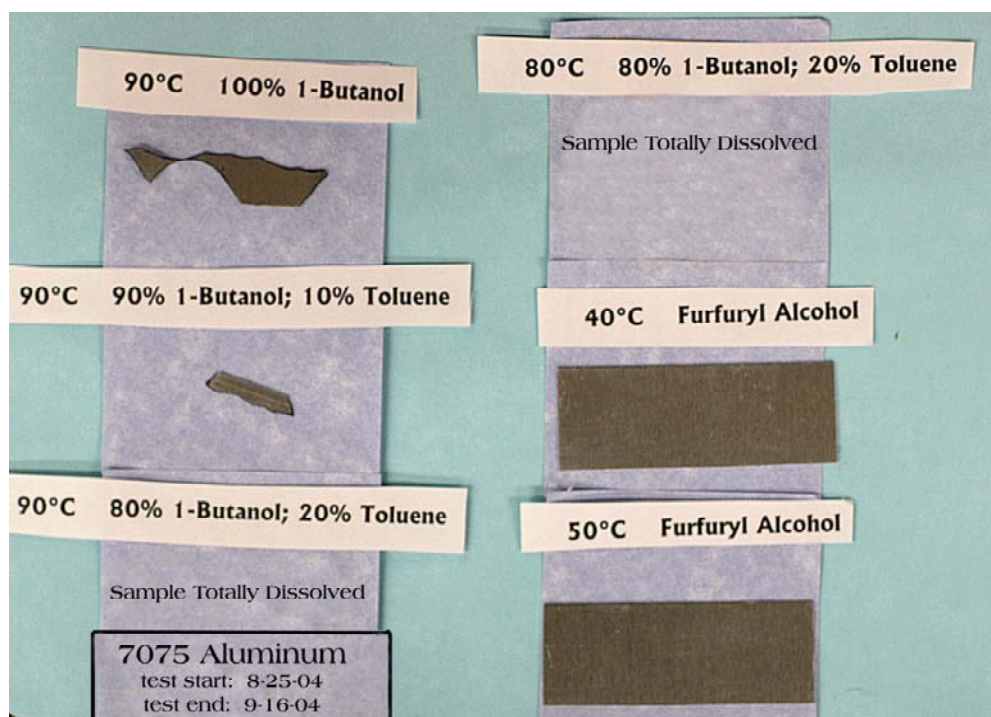


Figure 9. 7075 aluminum showing strong corrosion in the following four removal schemes after three weeks: 80 °C 80 volume % 1-butanol / 20 volume % toluene, 90 °C 100% 1-butanol, 90 °C 90 volume % 1-butanol / 10 volume % toluene, and 90 °C 80 volume % 1-butanol / 20 volume % toluene. Corrosion began within 24 hours. The samples in 80 °C 80 volume % 1-butanol / 20 volume % toluene and 90 °C 80 volume % 1-butanol / 20 volume % toluene were totally corroded with the three week time. No corrosion was observed with 40 °C furfuryl alcohol and 50 °C furfuryl alcohol after three weeks of exposure.

Based upon the corrosive interactions of solvent with a large number of metal coupons, we can rank the corrosive sensitivity of five removal schemes. Again we did not rank 90 °C 1-butanol since it was inadequate as discussed above (see Table II).

Most Corrosion	90 °C 80 volume % 1-butanol/20 volume % toluene
↑	80 °C 80 volume % 1-butanol/20 volume % toluene
	90 °C 90 volume % 1-butanol/10 volume % toluene
	50 °C furfuryl alcohol
Least Corrosion	40 °C furfuryl alcohol

Note that, excluding the cartridge brass, most common system metals showed no signs of corrosion with any of the six proposed removal schemes. Corrosion observed with the cartridge brass was very minor. Copper is a metal that is present in most systems and it did show corrosion with all of the removal schemes that used 1-butanol and 1-butanol in combination with toluene.

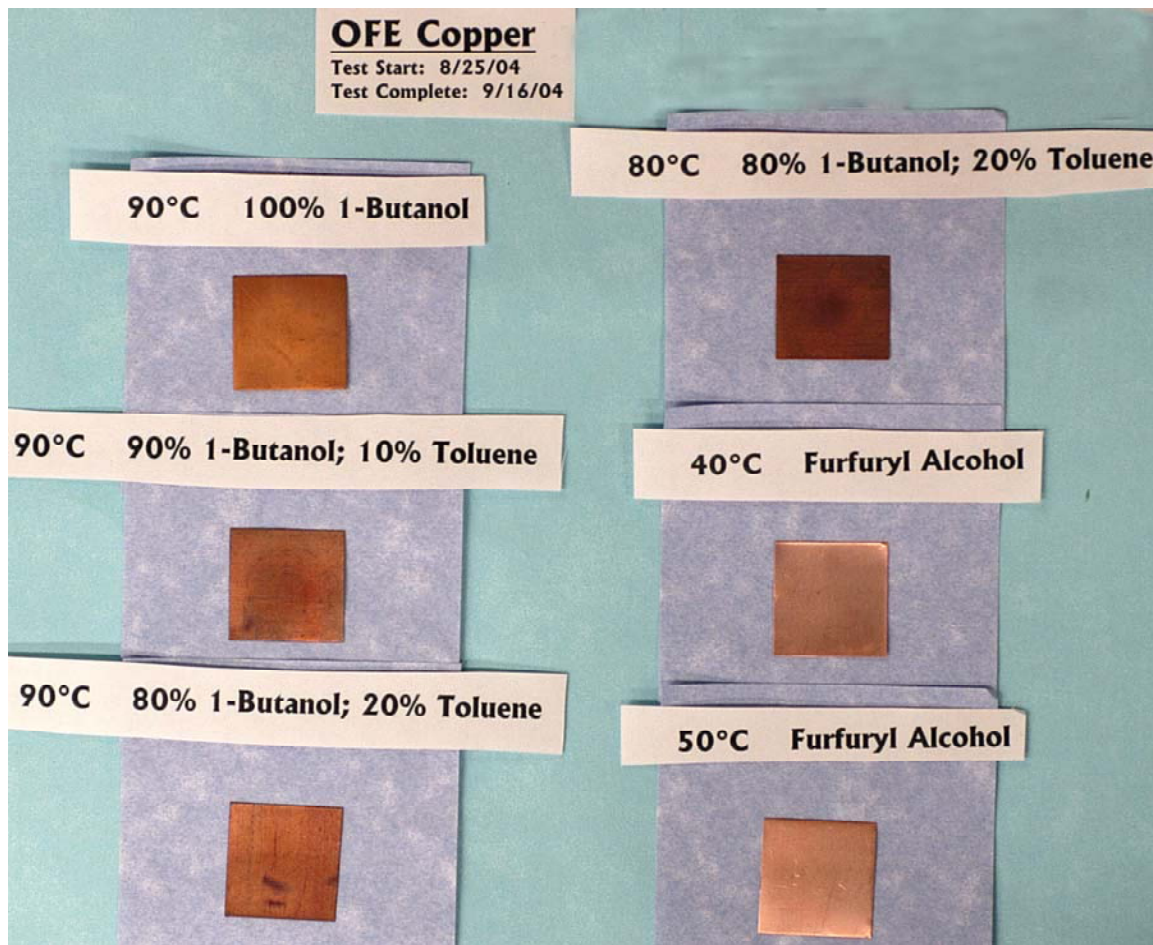


Figure 10. OFE Copper coupons that show slight discoloration in the following removal schemes: 80 °C 80 volume% 1-butanol / 20 volume % toluene, 90 °C 100% 1-butanol, 90 °C 90 volume % 1-butanol / 10 volume % toluene, and 90 °C 80 volume % 1-butanol / 20 volume % toluene. Corrosion began within 24 hours. No corrosion was observed with 40 °C furfuryl alcohol and 50 °C furfuryl alcohol after three weeks of exposure.

Results: Test Board Studies

Test boards were polyimide/glass and were populated with electronic components common to many electronic assemblies. A photo of the test board is shown in figure 11a. The components were selected based on their package types and prevalence in selected electronic assemblies. The components included different sizes of dual-in-line packages (SO14, 28-Lead SOIC, SO8, SC70, SOT23), which required underfill, D2Pack components which had high leads that were underfilled, and various surface mount components (DO214AC, 403A-03, CC0805, C0805, SOD123, RM0705, RM1206, RM2010, RM0603, T491D). After underfilling with RCC200, the entire board was covercoated with RCC200. Both the underfill and the overcoat were done according to the procedure described in SS1A5063.

The conformal coating, RCC200, is an elastomeric coating that is applied via syringe to first underfill board components and then to overcoat the entire board [7]. The coating was applied at a thickness of between 254 μm and 762 μm (0.010 in and 0.030 in). A picture of a coated test board is shown in figure 11b. The linear CTE was determined by using the DMA-7E Pyris Thermo-mechanical analyzer (TMA) which measured the vertical displacement of a probe as it moves due to thermal expansion of the sample. The CTE of RCC200 was measured between $-80\text{ }^{\circ}\text{C}$ and $51\text{ }^{\circ}\text{C}$ ($-112\text{ }^{\circ}\text{F}$ and $124\text{ }^{\circ}\text{F}$). At low temperatures, RCC200 is a glass. We report the linear CTE of RCC200 in the glassy state as $51.2 \times 10^{-6}/^{\circ}\text{C}$. At the highest temperatures, RCC200 is a rubber. We report the linear CTE in the rubbery state as $330 \times 10^{-6}/^{\circ}\text{C}$. Both the glassy and the rubbery linear CTE are typical for a polymer in those states. In the temperature range from $-56\text{ }^{\circ}\text{C}$ to $15\text{ }^{\circ}\text{C}$ ($-69\text{ }^{\circ}\text{F}$ and $59\text{ }^{\circ}\text{F}$), the material is transitioning from a glassy material to a rubbery material and the linear CTE varies accordingly.

After coating the test boards, they were assembled into a sandwich configuration with 1/2 inch stand-offs. The sandwich was then foamed with removable epoxy foam, REF308 according to SS1A0564. REF308 has a density of approximately $8\text{ lb}/\text{ft}^3$ ($0.13\text{ g}/\text{cm}^3$). A picture of a foamed sandwich is shown in figure 11c.

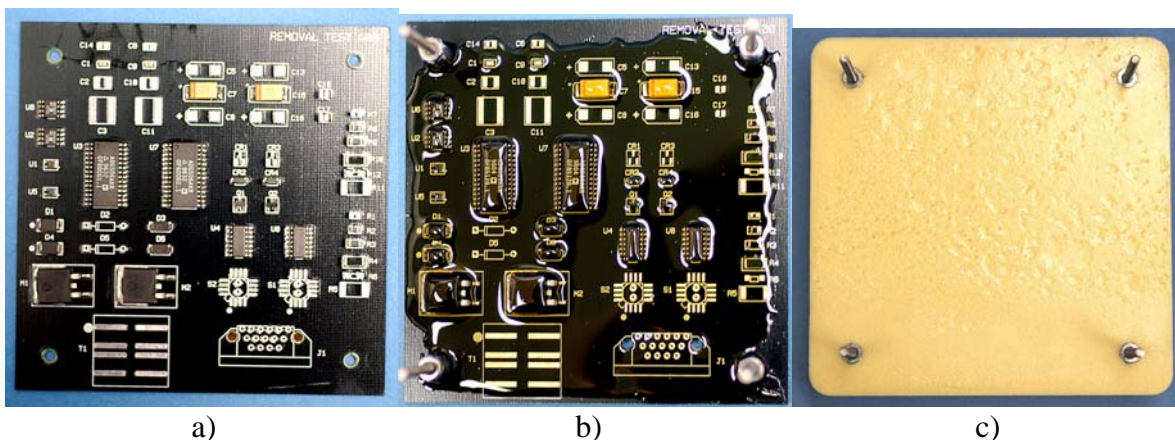


Figure 11. Test board for removal studies: a) bare board, b) conformally coated with RCC200, c) sandwiched with a bare board spaced 1/2 inch apart and then foamed with REF308.

The sandwich configuration was tested in only four removal schemes: $40\text{ }^{\circ}\text{C}$ furfuryl alcohol, $50\text{ }^{\circ}\text{C}$ furfuryl alcohol, $80\text{ }^{\circ}\text{C}$ 80 volume % 1-butanol/20 volume % toluene, and $90\text{ }^{\circ}\text{C}$ 80 volume % 1-butanol/20 volume % toluene. We did not test either $90\text{ }^{\circ}\text{C}$ 1-butanol nor $90\text{ }^{\circ}\text{C}$ 90 volume % 1-butanol/10 volume % toluene since they both left residue in the dissolution study (see Table II). The removal conditions were identical in each test with the exception of the solvent and temperature. The extraction bath was a rectangular glass vessel of size $16\text{cm} \times 6\text{cm} \times 17\text{cm}$ and contained a 1 inch Teflon coated stir bar that was rotated at 150 RPM. The glass vessel was covered with a glass plate to preserve solvent. Evaporated solvent was replaced as needed. Heat was provided by placing the glass vessel into a large silicon oil bath positioned on top of a heating plate. The removal conditions were not optimized to minimize the removal times, rather they were chosen to provide a comparative time between the different removal schemes. Hence, the removal

times recorded are larger than those that would actually be used in an optimized removal scheme. In each test we recorded the time to fully dissolve the foam and the coating. We then removed the sandwich, rinsed it in isopropanol, and then dried it. Boards were inspected for any visual damage or foam remnants under a microscope at a magnification of 10 and photographed.

A second test board, figure 12, was designed and procured with a different selection of components. This test board was neither coated nor foamed, but was exposed to each of the four removal conditions simultaneously with one of the coated and foamed sandwiches.

Table V lists the observations made after exposing the one coated and foamed test board and the other uncoated and unfoamed test board (figure 11a and figure 12) to four of the removal conditions. 50 °C furfuryl alcohol removed encapsulants faster than 40 °C furfuryl alcohol as expected. Both removed encapsulants very cleanly (total dissolution) with no encapsulant remnants. The encapsulant on the encapsulated coil components shown in figure 12 was partly dissolved with furfuryl alcohol at both temperatures as shown in figure 13. Pictures of two boards after exposure to 50 °C furfuryl alcohol are shown in figure 14. The removal processes that utilized 1-butanol and toluene were more problematic because at the higher temperatures a lot of solvent evaporation occurred. The solvent was replaced as needed, but addition of fresh solvent would temporarily lower the bath temperatures. It is also possible that the solvent ratios varied if one solvent was more volatile than the other. In general, the removal schemes that utilized 1-butanol and toluene did not remove the encapsulants as cleanly. A lot of remnants remained on the board, components, and leads. Also some leads appeared to have been corroded slightly. The same encapsulated coils shown in figure 13 were also partly dissolved by the removal schemes utilizing 1-butanol and toluene. Pictures of the two boards after exposure to 90 °C 80 volume % 1-butanol/20 volume % toluene are shown in figure 15.

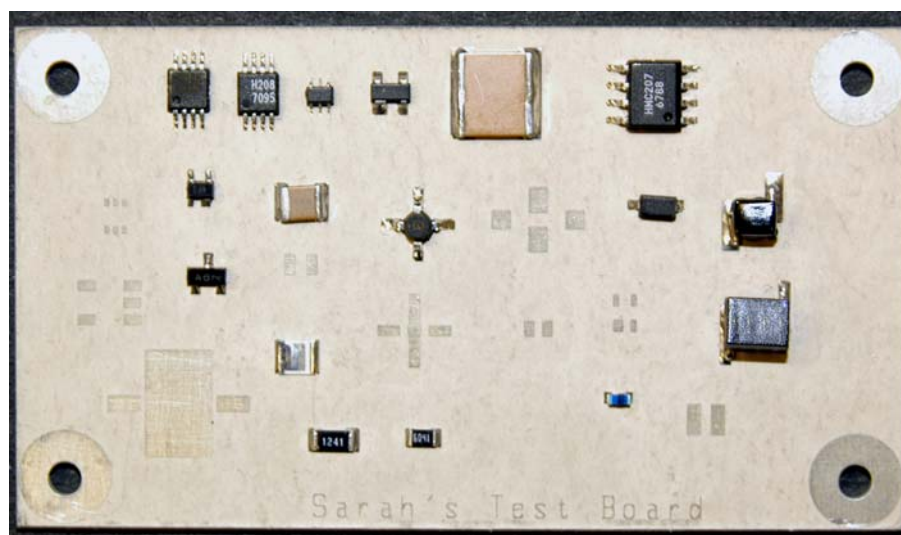


Figure 12. Test board (not coated and not foamed) used for exposure to removal solvents.



Figure 13. Encapsulated coil components shows partial dissolution of the components encapsulation after exposure to any of the four tested removal schemes.

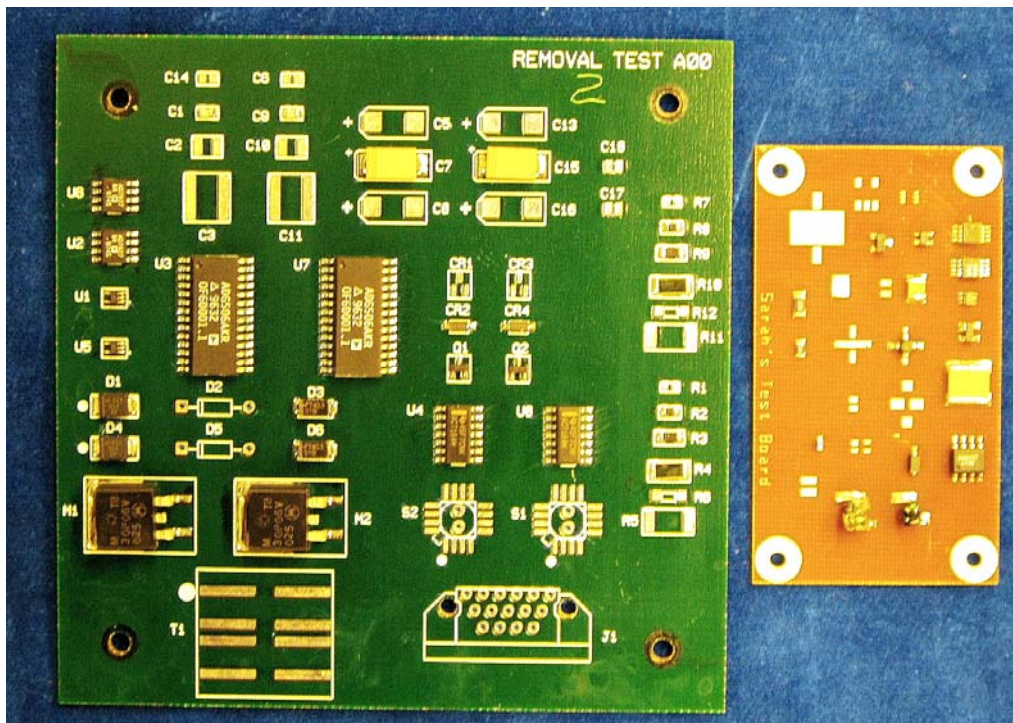


Figure 14. Test boards exposed to 50 °C furfuryl alcohol for 6 days.

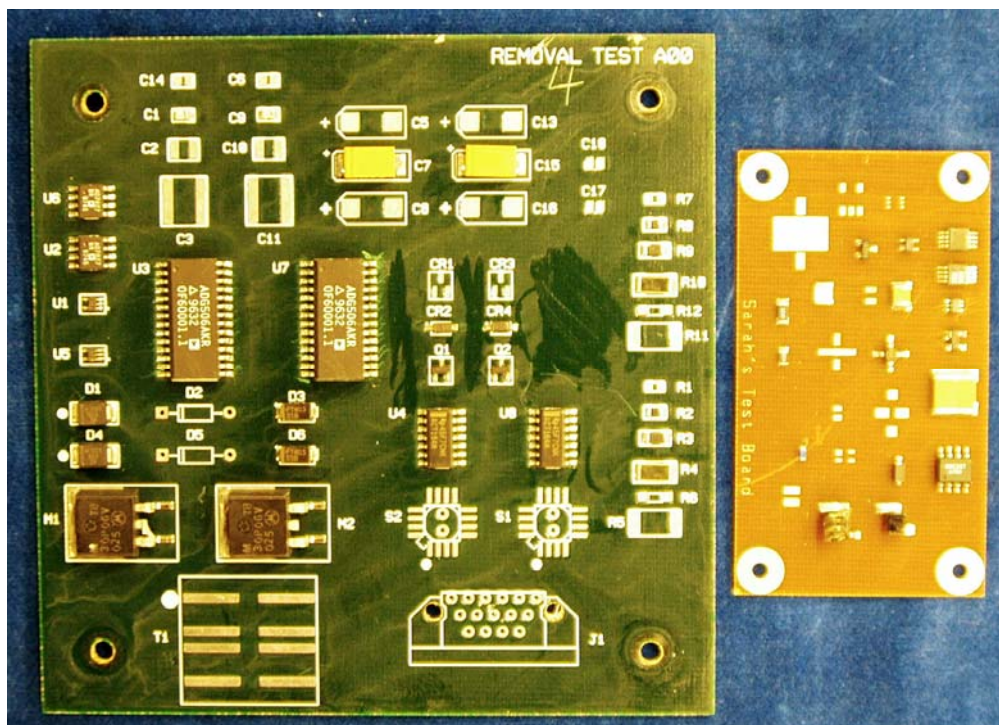


Figure 15. Test boards exposed to 90 °C 80 volume % 1-butanol/20 volume % toluene for 7 days.

Table V. Observations on the removal time and damage to sandwiched test boards with four removal schemes. The sandwich test boards are shown in figure 11a and 12.

REMOVAL SCHEME	REMOVAL TIME	OBSERVED DAMAGE	OBSERVED REMANANTS
40 °C furfuryl alcohol	11 days	Two coils encapsulants on uncoated test board (figure 12 and 13) are partly dissolved	No remanants. Boards are very clean.
50 °C furfuryl alcohol	6 days	Two coils components on brown board (figure 12 and 13) are partly dissolved	No remanants. Boards are very clean.
80 °C 80 volume % 1-butanol/20 volume % toluene	11 days, Many pieces of foam in removal solvent did not dissolve.	Two coils components on brown board (figure 12 and 13) are partly dissolved. Possibly some board damage.	Significant amount of foam residue on both boards.
80 °C 80 volume % 1-butanol/20 volume % toluene	4 days, Many pieces of foam in removal solvent did not dissolve.	Two coils components on brown board (figure 12 and 13) are partly dissolved. Possibly some board damage.	Significant amount of foam residue on both boards.
90 °C 80% 1-butanol/20% toluene	7 days.	Two coils components on brown board (figure 12 and 13) are partly dissolved.	Some foam residue on both boards. Possibly some board damage.

90 °C 80 volume % 1-butanol/20 volume % toluene	5 days, Many pieces of foam in removal solvent did not dissolve.	Two coils components on brown board (figure 12 and 13) are partly dissolved. Possible corrosion on leads. Aluminum standoffs very corroded.	Significant amount of foam residue on both boards. Possibly some board damage.
-------------------------------------------------	------------------------------------------------------------------	---------------------------------------------------------------------------------------------------------------------------------------------	--------------------------------------------------------------------------------

Results: Wire/Cable and Connector Studies

We performed a compatibility test on some wire, cable, and connector samples with the two primary encapsulant removal schemes. The samples were divided into two groups; one group was immersed in furfuryl alcohol at 50 °C and the other group was immersed in a mixture of 80 volume % 1-butanol/20 volume % toluene at 90 °C. The samples included a blue plastic coated wire, an RTV spacer, a Kapton ribbon cable segment, and a wire with a connector. Table VI. and Table VII. list the measurements taken on each sample as a function of time for the two removal conditions.

After 35 days of exposure to the two removal schemes, the samples were removed from the solvents, rinsed well with isopropanol and placed in a 50 °C oven to dry and to remove absorbed solvents. The purpose of this was to determine if the materials would return to their initial sizes and weights.

Table VI. Samples exposed to furfuryl alcohol at 50 °C.

Sample	Initial	7 days	14 days	28 days	35 days	1 day after removal from solvent	7 days after removal from solvent
Blue plastic coated wire							
diameter (inch)	.036	.0365	.0355	.036	.036	.036	.036
length (inch)	2.42	2.401	2.402	2.37	2.42	2.44	2.44
weight (gram)	.123	.126	.124	.125	.125	.122	.122
RTV spacer							
dimensions (inch)	.106x .144x .163	.106x .141x .165	.114x .144x .170	.114x .151x .163	.111x .142x .163	.112x .143x .164	.112x .143x .164
weight (gram)	.034	.035	.035	.038	.035	.035	.034

Kapton Ribbon Cable Segment							
Length (inch)	2.261	2.258	2.252	2.20	2.251	2.254	2.253
Width (inch)	.790	.803	.809	.802	.803	.800	.793
Thickness (inch)	.0125	.016	.016	.017	.0175	.012	.012
Weight (gram)	.734"	.901	.907	.912	.908	.768	.750
Wire with connector							
Diameter (inch)	.1035	.1043	.106	.106	.106	.103	.1045
Length (inch)	1.468	1.468	1.475	1.497	1.471	1.473	1.472
Weight (gram)	Initial weight not taken	After only 2 days: 3.123 grams	3.140	3.135	3.129	3.090	3.085

Table VII. Samples exposed to 80 volume % 1-butanol/20 volume% toluene at 90 °C.

<u>Sample ID</u>	<u>Initial Values</u> <u>4/28/04</u>	<u>Week 1</u> <u>5/6/04</u>	<u>Week 2</u> <u>5/14/04</u>	<u>Week 4</u> <u>5/27/04</u>	<u>Week 5</u> <u>6/02/04</u>	<u>1 day removed from solvents</u> <u>6/03/04</u>	<u>1 week removed from solvents</u> <u>6/09/04</u>
<u>Blue plastic coated wire</u>							
diameter	.0365"	.0355	.036"	.037"	.0345"	.036"	.0365"
length	2.48"	2.48"	2.48"	2.48"	2.48"	2.48"	2.48"
Weight	.125 grams	.126 grams	.127 grams	.126 grams	.127 grams	.127 grams	.126 grams
<u>RTV spacer</u>							
Dimensions (approx.)	.107"x.146"x .161"	.111"x.180"x .165"	.129"x.168"x .124"	.167"x.174"x .124"	.123"x.161"x .174"	.161"x.156"x .114"	.161"x.114"x .156"
weight	.037 grams	.045 grams	.049 grams	.047 grams	.044 grams	.035 grams	.035 grams
<u>Kapton Ribbon Cable Segment</u>							
Length	2.257"	2.253"	2.244"	2.246"	2.253"	2.252"	2.252"
Width	.916"	.928"	.936"	.937"	.935"	.937"	.9325"
Thickness	.012"	.014"	.014"	.016"	.015"	.015"	.0145"
Weight	.915 grams	.993 grams	1.002 grams	1.011 grams	.991 grams	.955 grams	.923 grams

Wire with connector							
Wire diameter	.103"	.1043"	.104"	.104"	.104"	.1025"	.104"
Total length	1.418"	1.418"	1.420"	1.406"	1.411"	1.409"	1.413"
weight	Initial weight not taken	After only 2 days: 3.101 grams	3.096 grams	3.092 grams	3.095 grams	3.045 grams	3.040 grams

The blue plastic coated wire had no significant weight change and no significant dimensional changes with either removal scheme; 50 °C furfuryl alcohol or 90 °C 80 volume % 1-butanol/20 volume % toluene. The RTV spacer had no weight change and no dimensional change in 50 °C furfuryl alcohol. It did have a reversible weight gain and associated dimensional increase in 90 °C 80 volume % 1-butanol/20 volume % toluene. The RTV spacer also discolored somewhat in 90 °C 80 volume % 1-butanol/20 volume% toluene. The wire with connector had a small reversible weight gain and associated dimensional increase in 50 °C furfuryl alcohol. In 90 °C 80 volume % 1-butanol/20 volume % toluene the wire with connector showed a very small, reversible weight gain.

In 50 °C furfuryl alcohol, the Kapton ribbon cable segment had a small amount of weight gain after the first week. This was accompanied by a slight dimensional increase primarily in the thickness. The weight gain was mostly reversible upon drying. Noticeable changes began to appear in the 90 °C 80 volume % 1-butanol/20 volume % toluene Kapton ribbon cable segment after the second week. This Kapton ribbon cable segment became increasingly darker and the wires inside appeared to deteriorate a bit. Both weight and the dimensions of the cable in the 90 °C 80 volume % 1-butanol/20 volume % toluene mixture increased. The weight increase was reversible. The dimensional changes were not reversible. Visually, the cable was severely and irreversibly damaged by this removal scheme. The visible differences between samples from both removal schemes are illustrated in Figure 16.

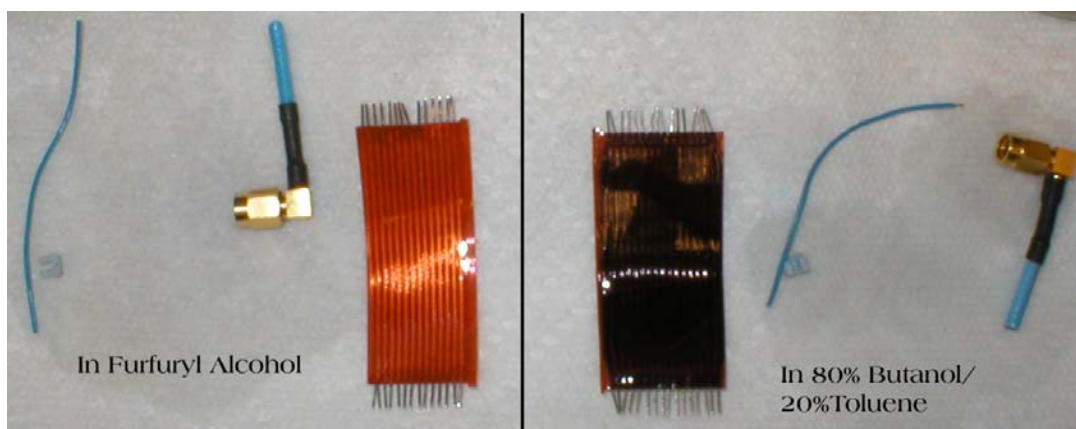


Figure 16: Photograph of components after 35 days' immersion in their respective solvents; left 50 °C furfuryl alcohol; right 90 °C 80 volume % 1-butanol/20 volume % toluene.

The above exercises demonstrated that 50 °C furfuryl alcohol was less detrimental to circuitry cabling and materials compared to 90 °C 80 volume % 1-butanol/20 volume % toluene mixture.

Results: Component Studies

A select number of components were exposed to the two primary removal strategies: 1) 50 °C furfuryl alcohol and 2) 90 °C 80 volume % 1-butanol/ 20 volume % toluene. The components tested are listed in Table VIII. They included resistors (RM2010 M55342K08B49D9R), capacitors (T491DT491D227MO10AS), diode (SOD123MMSZ5228BT1), diode (SOT23 BAS16LT1), SMA connectors (MMSSM5250B SMA CONN), and inductor (L0603 LQW1608A47NGoo). Photographs of the components are included in the report in Appendix III. Some components had only one sample available for testing. In these circumstances only 50 °C furfuryl alcohol was tested.

Table VIII. Components exposed to either 50 °C furfuryl alcohol or to 90 °C 80 volume % 1-butanol/20 volume % for two weeks.

Component	50 °C furfuryl alcohol initial	50 °C furfuryl alcohol (2 weeks)	90 °C 80 volume %1-Butanol/ 20 volume % Toluene-initial	90 °C 1-butanol (2 weeks)
MSSM 5250B	Wt. 0.553 gm Dim. L 0.370", thread Φ 0.186", top Φ 0.234"	Wt. 0.553 gm Dim. L 0.371", thread Φ 0.186", top Φ 0.235"	Wt. 0.549 gm Dim. L 0.371", thread Φ 0.187", top Φ 0.232"	Wt. 0.549 gm Dim. L 0.370", thread Φ 0.186", top Φ 0.233"
MSOP8	Wt. 0.026 gm Dim. 0.122"x0.113"x 0.035"	Wt. 0.026 gm Dim. 0.122"x0.115"x 0.035"	Wt. 0.026 gm Dim. 0.124"x0.115"x 0.035"	Wt. 0.026 gm Dim. 0.125"x0.116"x 0.036"
WW107	Wt. 0.016 gm Dim. 0.0605"Hx Φ 0.074"	Wt. 0.016 gm Dim. 0.0605"Hx Φ 0.074"	--	--
SOIC8	Wt. 0.0828gm Dim. 0.191"x0.150"x 0.059"	Wt. 0.082gm Dim. 0.191"x0.151"x 0.060"	--	--
C2225	Wt. 0.198 gm Dim. 0.229"x0.244"x 0.038"	Wt. 0.198 gm Dim. 0.229"x0.244"x 0.038"	--	--
T491D	Wt. 0.326 gm Dim. 0.295"x0.174"x 0.116"	Wt. 0.326 gm Dim. 0.295"x0.175"x 0.116"	Wt. 0.325 gm Dim. 0.294"x0.173"x 0.114"	Wt. 0.327 gm Dim. 0.295"x0.169"x 0.117"

RM2010	Wt. 0.020 gm Dim. 0.203"x0.099"x 0.018"	Wt. 0.021 gm Dim. 0.204"x0.099"x 0.018"	Wt. 0.021 gm Dim. 0.204"x0.100"x 0.0175"	Wt. 0.020 gm Dim. 0.203"x0.099"x 0.017"
SOT343*	Wt. 0.0058 gm Dim. 0.045"x0.079"x 0.036"	Wt. 0.0058 gm Dim. 0.0455"x0.080"x 0.035"	--	--
SOT2302*	Wt. 0.0082 gm Dim. 0.115"x0.051"x 0.039"	Wt. 0.0082 gm Dim. 0.117"x0.051"x 0.038"	Wt. 0.0083 gm Dim. 0.115"x0.051"x 0.038"	Wt. 0.0083 gm Dim. 0.114"x0.051"x 0.038"
SOD123*	Wt. 0.0110 gm Dim. 0.106"x0.064"x 0.050"	Wt. 0.0110 gm Dim. 0.106"x0.064"x 0.049"	Wt. 0.0112 gm Dim. 0.105"x0.065"x 0.045"	Wt. 0.0112 gm Dim. 0.105"x0.066"x 0.045"
LO603*	Wt. 0.0028 gm Dim. 0.067"x0.036"x 0.034"	Wt. 0.0028 gm Dim. 0.067"x0.036"x 0.034"	Wt. 0.0028 gm Dim. 0.064"x0.035"x 0.033"	Wt. 0.0028 gm Dim. 0.065"x0.035"x 0.034"

* indicated components that were measured with a more accurate balance (.0000 place)

Only one component, T491D, that was exposed to 90 °C 80 volume % 1-butanol/20 volume % toluene for two weeks possibly showed a small weight gain and associated small dimensional changes. None of the other components tested showed any measurable weight changes nor any measurable dimensional changes within the accuracy of the measurements.

A total of 6 lots of components (3 parts each) were test for electrical functionality. The components were exposed to the following conditions: 1) two weeks of 50 °C furfuryl alcohol, 2) two weeks of 90 °C 80 volume % 1-butanol/20 volume % toluene, and 3) ambient. The components were identified as follows:

- RM2010 M55342K08B49D9R (resistors),
- T491D T491D227MO10AS (capacitors)
- SOD123 MMSZ5228BT1 (diodes)
- MMSSM5250B SMA CONN (SMA connectors)
- SOT23 BAS16LT1 (diode)
- L0603 LQW1608A47NGoo (inductor)

All devices passed the electrical verification tests. The report from Analytical Solutions, Inc. is included in Appendix III.

Recommended Baseline Removal Process

The recommended removal process for electronic boards and assemblies is 50 °C furfuryl alcohol. This removal process was the most benign process with respect to polymer coupons, metal coupons, test boards, and electronic components. The removal time for 50 °C furfuryl alcohol is larger than that for 90 °C 80 volume % 1-butanol / 20 volume % toluene. However, it is our recommendation that the longer removal time is less important compared to less damage expected with the use of 50 °C furfuryl alcohol. This recommendation is included in the process specification for removable encapsulant removal, SS1A4668, included in Appendix I.

For removal of encapsulated metal or ceramic parts, that are not susceptible to corrosion, we recommend 90 °C 80 volume % 1-butanol / 20 volume % toluene since this removal process will be faster. This recommendation is included in the process specification for cover removal, SS1A5992, with the title of “Removal of Cover Bonded to Container with RCC200,” included in Appendix II.

Plan for Qualification

To qualify a removal process in order to reuse electronic assemblies in system applications requires demonstrating two things. Firstly, damaged components, parts, or materials would need to be specifically identified so that those parts could be removed and replaced in a reuse scenario. Secondly, the components that show no damage would need to be characterized for their long-term survivability. In other words, we would need to prove that there is no damage that occurred in these components that would manifest itself long-term. Evidence for this could be obtained by taking components exposed to the encapsulant removal process and aging, thermal cycling, and testing those components.

Conclusions

Removable encapsulants (adhesive, coating, syntactic foam and blown foams) provide system designers with encapsulants that have properties similar to conventional encapsulants but can be removed from an electronic assembly or mechanical assembly in a fairly benign manner. A gentle removal process is desired so that the assemblies can be reused if desired. The removal process relies upon thermally-reversible Diels-Alder adducts that are synthesized into epoxy resins utilized in removable encapsulant formulations. The original removal process has been 90 °C 80 volume % 1-butanol and 20 volume % toluene [5,6]. The thermal equilibrium of the Diels-Alder adducts is of paramount importance to understand and optimize the removal properties. We have recently made measurements of the Diels-Alder equilibrium constant, $K(T)$, by FTIR/chemometrics [4]. We found that the equilibrium was a continuous function of temperature between room temperature and 90 °C. This knowledge allowed us to propose and demonstrate a new second removal process, 50 °C furfuryl alcohol, that is more benign.

Six approaches to encapsulant removal have been proposed and compared with regard to their compatibility with common system materials. The two primary approaches investigated were 50 °C furfuryl alcohol and 90 °C 80 volume % 1-butanol/20 volume % toluene. We also investigated slight variations around these primary removal approaches. These variations included 90 °C 1-butanol, 90 °C 90 volume % 1-butanol/ 10 volume % toluene, 80 °C 80 volume % 1-butanol/20 volume % toluene, and 40 °C furfuryl alcohol. Two of these approaches, 90 °C 1-butanol and 90 °C 90 volume % 1-butanol/ 10 volume % toluene, were eliminated as contenders early on because they did not fully dissolve all of the removable encapsulants (Table II). One removal process, 80 °C 80 volume % 1-butanol/20 volume % toluene, was not considered to be different enough from the primary process of 90 °C 80 volume % 1-butanol/20 volume % toluene and was eliminated from consideration. The most benign removal process for electronic components was shown to be 50 °C furfuryl alcohol. We recommend 50 °C furfuryl alcohol as the removal process for encapsulated electronic assemblies. The removal process of 40 °C furfuryl alcohol was not differentiated from 50 °C furfuryl alcohol except in the time for removal and so it was eliminated from consideration.

The process to remove encapsulants from electronic assemblies is defined in the specification included in Appendix I, SS1A4668, with the title of “Removable Encapsulant Depotting Process.” For removal of encapsulated metal or ceramic parts, that are not susceptible to corrosion, we recommend 90 °C 80 volume % 1-butanol / 20 volume % toluene since this removal process will be faster. This recommendation is included in the process specification for cover removal, SS1A5992, with the title of “Removal of Cover Bonded to Container with RCC200,” included in Appendix II.

Acknowledgements

Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

References

1. J. H. Aubert, J. R. McElhanon, R. S. Saunders, P. S. Sawyer, D. R. Wheeler, E. M. Russick, P. B. Rand, and D. A. Loy, SANDIA REPORT, SAND2001-0295, 2001.
2. McElhanon, J. R., Russick, E. M., Wheeler, D. R., Loy, D. A., and Aubert, J. H., *J. Appl. Polym. Sci.*, **85**, 1496-1502 (2002).
3. M. P. Stevens, “Polymer Chemistry, An Introduction,” 3rd edition, Oxford University Press, 1999.
4. J. H. Aubert, D. R. Tallant, P. S. Sawyer, and M. J. Garcia, “Development of a Removable Conformal Coating Through the Synthetic Incorporation of Diels-Alder Thermally

Reversible Adducts into an Epoxy Resin, “ preprints of the American Chemical Society 2005 Smart Coatings Conference, 2/16-18/2005, Grosvenor Resort, Orlando, FL.

5. E. M. Russick, R. W. Wavrik, D. R. Tallant, M. J. Garcia, T. T. Borek, E. P. Lopez, N. R. Sorensen, S. J. Lucero, F. J. Hosking, “Compatibility of Removable Epoxy Foam and the Foam Removal Process with Electronic Components for the W76-1 AF&F,” Sandia Report, Sandia National Laboratories, SAND2003-0155 (January 2003).
6. E. M. Russick, T. A. Huber, D. R. Tallant, M. J. Garcia, T. T. Borek, III, “Compatibility of W80-3 Electronic Components with Removable Epoxy Foam and the Foam Removal Process,” Sandia Report, Sandia National Laboratories, SAND2004-3194 (July 2004).
7. J. H. Aubert, P. S. Sawyer, and M. E. Stavig, “Development and Characterization of a Removable Conformal Coating for Printed Wiring Board Applications,” SAND2004-1975, 2004.

Appendix I.
Removable Encapsulant Depotting Process
SS1A4668

REMOVABLE ENCAPSULANT DEPOTTING PROCESS(U)

CHANGE HISTORY

<u>CONTROL NUMBER</u>	<u>ISSUE</u>	<u>RELEASE/CHANGE NO.</u>	<u>DATE</u>
SS1A4668-000	A		6/05

1. GENERAL

1.1. Scope.

This specification covers processes for the removal of encapsulants from assemblies encapsulated with removable epoxy foams REF308, REF320, and RSF200, and removable conformal coating RCC200. The process for encapsulating assemblies with REF308 and REF320 foams is specified in SS1A0564. The process for potting assemblies with RSF200 is specified in SS1A4620. The process for underfilling and coating with RCC200 is specified in SS1A5063.

2. DOCUMENTS

The following documents form a part of this specification to the extent herein.

4601040-01	1-Butyl alcohol
4612020 thru 4612021-01	Toluene
4601004	Furfuryl alcohol
4601031	ISOPROPYL ALCOHOL

3. REQUIREMENTS

3.1. Removal Vessel

The removal vessel shall be made of glass to allow viewing of the removal process. The vessel shall be large enough to hold a container with a cover and with sufficient height to provide the ability to circulate the solvents. The vessel shall have a closure mechanism that contains the solvents without spillage or leakage. The vessel shall have an opening for a temperature-measuring device such as a thermocouple in the solvents to monitor and control the temperature. Another opening in the vessel lid shall have a reflux condenser or other similar device to minimize solvent loss from the solvent bath without allowing the bath to pressurize with solvent vapor.

3.2. Heater for Vessel

The heater for the vessel and the solvents (such as an oil bath, hot plate, or similar heating device) shall have the capability to control and maintain a vessel temperature of $121\text{ }^{\circ}\text{F} \pm 10\text{ }^{\circ}\text{F}$ ($50\text{ }^{\circ}\text{C} \pm 6\text{ }^{\circ}\text{C}$) when furfuryl alcohol is used or $194 \pm 10\text{ }^{\circ}\text{F}$ ($90 \pm 6\text{ }^{\circ}\text{C}$) when a solvent mixture of 1-butanol and toluene is utilized. A thermocouple or similar temperature-measuring device shall measure the temperature of the solvents and control the heating source accordingly. An insulating jacket or blanket made of fiberglass or other similar non-flammable insulating fabric is recommended (but not required) for use around the outside of the vessel to decrease heat-up time and improve temperature uniformity. The heater shall have over-temperature protection to avoid inadvertent temperature overrun.

3.3. Circulation

There shall be the capability to circulate the solvents in the vessel. A magnetic stirrer, mechanical stirrer, gas sparge assembly, or liquid jet nozzles can be used to circulate the solvents in the depotting vessel.

3.4. Removal Solvents

The solvents used in encapsulant removal are either furfuryl alcohol or the mixture of 1-butyl alcohol (i.e., 1-butanol) and toluene. A solvent mixture of 80% by volume 1-butanol and 20% by volume toluene may be used in applications where faster encapsulant removal is desired and the use of toluene is permitted. Any toluene concentration between 0% by volume and 20% by volume may be used, however, the maximum toluene concentration shall not

exceed 20% by volume. Furfuryl alcohol is recommended for electronic assemblies. The design agency component engineer in conjunction with the production agency process engineer shall make the determination as to the removal solvent to be used.

CAUTION: THE SOLVENTS USED IN THE DEPOTTING PROCESS AND THE DISSOLVED ENCAPSULATION MATERIALS MAY BE TOXIC. THEREFORE, ADEQUATE VENTILATION SHOULD BE PROVIDED IN THE HANDLING OF THESE COMPONENTS TO PREVENT UNDUE EXPOSURE TO VAPORS. INGESTION OR SKIN CONTACT WITH THESE MATERIALS SHALL BE AVOIDED. SHOULD ACCIDENTAL SKIN CONTACT OCCUR THE EXPOSED AREAS SHOULD BE WASHED IMMEDIATELY WITH SOAP AND WATER.

3.5. Encapsulant Removal Procedure

The following procedure shall be used to remove encapsulants:

- a. Place the assembly in the vessel. If possible, the orientation of the unit should maximize the ease of removal with respect to gravity and solvent circulation. This may be such that PWBs are orientated in the direction of gravity.
- b. Add the solvents (specified in 3.4) to the vessel such that the cover/container is fully covered with the solvents and that the level of solvents is sufficiently high to allow for the circulation of the solvents.
- c. Seal the vessel lid to the vessel body. Attach the reflux condenser and thermocouple to the vessel through the appropriate openings in the vessel lid.
- d. Circulate the solvents.
- e. Turn on the heating source and adjust the temperature setting such that it will achieve and maintain a solvent temperature (specified in 3.4). The vessel may be insulated in order to help maintain this temperature.
- f. Maintain solvent circulation and heating of bath until encapsulation is sufficiently removed based on visual observation. The circulation may be stopped momentarily to view the progress of encapsulant removal.

- g. When unit has been sufficiently depotted, shut off the heating source and solvent circulation.
- h. When solvent bath temperature has cooled to 122°F (50°C) or less, remove unit from solvent bath. Manually remove any solvent-laden remnants of encapsulant taking care not to damage the assembly. Rinse the unit with clean solvent (the same as specified in 3.4). Allow excess rinse solvent to drain from the assembly. Rinse the unit with isopropyl alcohol. Waste solvent shall be disposed of in an approved container.
- i. Place the rinsed unit in a forced convection oven at 194±10°F (90°C) for drying. Drying time in the oven shall be 24 hours minimum.

4. QUALITY ASSURANCE PROVISIONS

No acceptance testing required.

5. PACKAGING, HANDLING AND STORAGE.

All production parts produced to this specification shall be packaged, handled, and stored according to the procedures specified by the design agency component engineer.

6. NOTES.

Not applicable.

Appendix II.
Removal of Cover Bonded to Container with RCC200
SS1A5992

CAGE CODE 14213

SS1A5992

PAGE 1 OF 6

M. PENYOCK Q12KC
J. AUBERT 1811SA
M. BENKOVICH 834KC
KCP-EDS (SS1A5992_A.DOC)
TIE SA/KC DRC 2

**REMOVAL OF COVER BONDED TO CONTAINER WITH RCC200
(U)**

CHANGE HISTORY

<u>CONTROL NUMBER</u>	<u>ISSUE</u>	<u>RELEASE/CHANGE NO.</u>	<u>DATE</u>
SS1A5992-000	A	DTER 20051791SA	06/05

TABLE OF CONTENTS

1. GENERAL.....3
1.1. Scope.....3
1.2. ES&H.....3
2. DOCUMENTS.....3
3. REQUIREMENTS.....3
3.1. Removal Vessel.....3
3.2. Vessel Heater.....4
3.3. Circulation.....4
3.4. Removal Solvents.....4
3.5. Cover Removal Procedure.....5
4. QUALITY ASSURANCE PROVISIONS.....6
5. /M/ PACKAGING, HANDLING AND STORAGE.....6
6. NOTES.....6

1. GENERAL

1.1. Scope

This specification covers a process for removal of the cover from the container bonded with RCC200. The process for bonding the cover with RCC200 is specified in SS1A5065.

1.2. ES&H

Some of these materials are hazardous. Consult the MSDS's for personnel protection and waste disposal guidance.

2. DOCUMENTS

The following documents form a part of this specification to the extent indicated in the text. The latest issue shall be used.

4601040	1-Butyl Alcohol
4612020 thru 4612021	Toluene
4601031	Isopropyl Alcohol

3. REQUIREMENTS

3.1. Removal Vessel

The removal vessel shall be made of glass to allow viewing of the removal process. The vessel shall be large enough to hold a container with a cover and with sufficient height to provide the ability to circulate the solvents. The vessel shall have a closure mechanism that contains the solvents without spillage or leakage. The vessel shall have an opening for a temperature-measuring device such as a thermocouple in the solvents to monitor and control the temperature.

3.2. Vessel Heater

The heater for the vessel and the solvents (such as an oil bath, hot plate, or similar heating device) shall have the capability to control and maintain a vessel temperature of 194 ± 10 °F (90 ± 6 °C) when a solvent mixture of 1-butanol and toluene is utilized. A thermocouple or similar temperature-measuring device shall measure the temperature of the solvents and control the heating source accordingly. An insulating jacket or blanket made of fiberglass or other similar non-flammable insulating fabric is recommended (but not required) for use around the outside of the vessel to decrease heat-up time and improve temperature uniformity. The heater shall have over-temperature protection to avoid inadvertent temperature overrun.

3.3. Circulation

There shall be the capability to circulate the solvents in the vessel. A magnetic stirrer, mechanical stirrer, gas sparge assembly, liquid jet nozzles, or equivalent can be used to circulate the solvents in the depotting vessel.

3.4. Removal Solvents

The solvents used for cover removal are a mixture of 80% by volume (+/- 5%) of 1-butyl alcohol (1-butanol) and 20% by volume (+/- 5%) of toluene.

NOTE: CAUTION: THE SOLVENTS USED IN THE REMOVAL PROCESS AND THE DISSOLVED ADHESIVE MATERIALS ARE HAZARDOUS. THEREFORE, ADEQUATE VENTILATION SHOULD BE PROVIDED IN THE HANDLING OF THESE COMPONENTS TO PREVENT UNDUE EXPOSURE TO VAPORS. INGESTION OR SKIN CONTACT WITH THESE MATERIALS SHALL BE AVOIDED. SHOULD ACCIDENTAL SKIN CONTACT OCCUR THE EXPOSED AREAS SHOULD BE WASHED IMMEDIATELY WITH SOAP AND WATER.

3.5. Cover Removal Procedure

The following procedure shall be used to remove the cover when bonded to the container with RCC200:

3.5.1. Preparation

Place the container/cover in the vessel. The container/cover should be placed inverted such that the cover will be pulled off of the container by gravity when the RCC200 is removed. The bottom of the vessel or support stand must be protected with a soft material, such as Teflon, so that no damage is incurred on the cover when it becomes loose and slides to the vessel bottom or onto the support stand.

3.5.2. Solvent Addition

Add the solvents (specified in 3.4) to the vessel such that the cover/container is fully covered with the solvents and that the level of solvents is sufficiently high to allow for the circulation of the solvents.

3.5.3. Vessel Closure

Place the lid on the vessel body. Attach the thermocouple to the vessel through an opening in the vessel lid.

3.5.4. Circulation

Circulate the solvents.

3.5.5. Heating

Turn on the heating source and adjust the temperature setting such that it will achieve and maintain the solvents temperature (specified in 3.2). The vessel may be insulated in order to help maintain this temperature.

3.5.6. Cover Removal

Maintain stirring and heating of bath until cover is removed and slides to the bottom of the vessel or support stand. The stirring may be stopped intermittently to view the progress of cover removal.

3.5.7. Completion

When the cover and all visible RCC200 are removed, shut off the heating and circulation sources.

3.5.8. Cooling

When solvent bath temperature has cooled to 122 °F (50 °C) or less, remove unit from solvents. Rinse the unit with clean solvent (the same as specified in 3.4). Allow excess rinse solvent to drain. Rinse the unit with isopropyl alcohol. Waste solvent shall be disposed of in an approved container.

3.5.9. Drying

Place the rinsed cover and container in a forced convection oven at 194 ± 10 °F (90 ± 6 °C) for drying. Drying time in the oven shall be 15 minutes minimum.

4. QUALITY ASSURANCE PROVISIONS

No acceptance testing required.

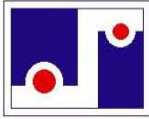
5. /M/ PACKAGING, HANDLING AND STORAGE

The cover must be handled carefully so that no damage occurs that would make the cover unable to be reused. The cover must not be dented or deformed such that it is out of round.

6. NOTES

Not applicable.

Appendix III.
Electrical Testing of Board Components
Analytical Solutions Inc.



ANALYTICAL SOLUTIONS INC.

PARTS AND MATERIALS ANALYSIS

Analysis:	0503-0739-T	P.O. Number:	30286-SAWYER Line #SNL0739
Objective:	ELECTICAL TESTING (SOLVENT SUSCEPTIBILITY)	Date Received:	03-07-2005
Customer:	SANDIA NATIONAL LABORATORIES	Report Date:	05-17-2005 Rev -
Contact:	PATTI SAWYER		
Report:	C. ALDRIDGE	Approved:	C. ALDRIDGE

Device:	A00 TEST BOARD COMPONENTS	Function:	UNKNOWN
Quantity:	18	Package:	VARIOUS
Vendor:	UNKNOWN	Date Code:	
Markings:	See Photos		

ANALYSIS SUMMARY:

A total of 6 lots of devices (3 parts each) were received for electrical functional checks.

The lots were identified as follows;
-RM2010 M55342K08B49D9R (Resistors)
-T491D T491D227M010AS (Capacitors)
-SOD123 MMSZ5228BT1 (Diodes)
-MMSSM5250B SMA CONN (SMA Connectors)
-SOT23 BAS16LT1 (Diode)
-L0603 LQW1608A47NG00 (Inductor)

CONCLUSIONS:

All devices passed the electrical verification tests.

DISCLAIMER

ANALYTICAL SOLUTIONS , INC. performs analysis work as a technical service to its customers and extends every effort to report reliable data and an accurate interpretation thereof. However, ANALYTICAL SOLUTIONS , INC. agrees only to apply its best professional effort to any work performed. NO WARRANTY IS EXPRESSED OR IMPLIED REGARDING RESULTS OBTAINED.

10401 RESEARCH S.E. ALBUQUERQUE, NM 87123 (505) 299-1967 FAX (505) 292-0225



Analysis #: 0503-0739-T

PART NUMBER: M55342K08B49D9R **SPECIFICATION:** MIL-PRF-55342

DEVICE	Resistance 49.401Ω to 50.399Ω
1	49.915Ω
2	49.939Ω
3	49.909Ω

PART NUMBER: 414216-01 **SPECIFICATION:** N/A

DEVICE	Insulation Resistance @ 500VDC
1	30TΩ
2	50TΩ
3	30TΩ

PART NUMBER: LQW1608A47NG00 **SPECIFICATION:** Murata

DEVICE	Continuity
1	PASS
2	PASS
3	PASS

Note: Inductance could not be measured due to the limitations of test equipment (1MHz max. test frequency).

PART NUMBER: T49D227M010AS **SPECIFICATION:** Kemet

DEVICE	Capacitance 120Hz @ 1Vrms 176uF to 264uF	Dissipation Factor 120Hz @ 1Vrms 8% max.
1	209.158uF	3.11%
2	208.732uF	5.93%
3	207.188uF	3.80%

PART NUMBER: MMSZ5228BT1 **SPECIFICATION:** On Semiconductors

DEVICE	IR VR = 1V 10uA max.	VF IF = 10mA 0.9V max.	VZ IZ = 20mA 3.71V min. 4.1V max.
1	0.245uA	0.81V	4.08V
2	0.429uA	0.80V	3.89V
3	0.306uA	0.80V	3.95V

PART NUMBER: BAS16LT1 **SPECIFICATION:** On Semiconductors

DEVICE	IR VR = 75V 1uA max.	VF IF = 1mA 715mV max.	VF IF = 10mA 855mV max.	VF IF = 50mA 1000mV max.
1	0.010uA	565.5 mV	744 mV	877.6 mV
2	0.011uA	592.5 mV	691.9 mV	873.8 mV
3	0.010uA	586.4 mV	711.1 mV	852.6 mV



Figure 1
S/N RM2010
M55342K08B49D9R

Caption:
Group photo of the packaging of
the devices as received for
analysis.

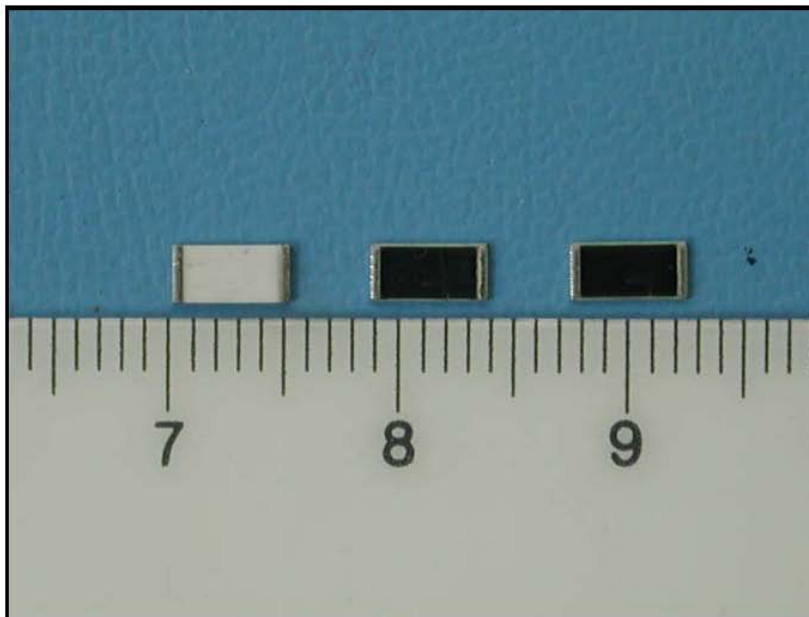


Figure 2
S/N RM2010
M55342K08B49D9R

Caption:
Group photo of the devices as
they were received for analysis.

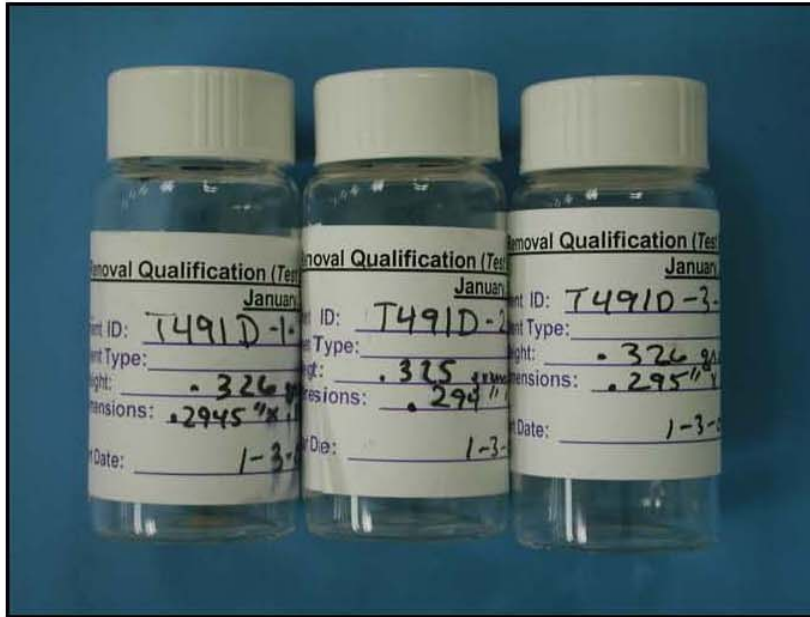


Figure 3
S/N T491D T491D227M010AS

Caption:
Group photo of the packaging of
the devices as received for
analysis.

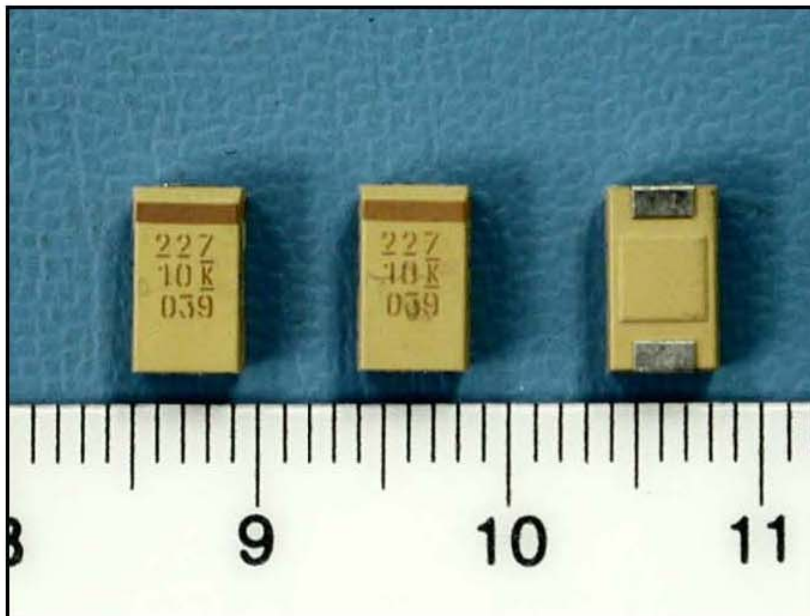


Figure 4
S/N T491D T491D227M010AS

Caption:
Group photo of the devices as
they were received for analysis.



Figure 5
S/N SOD123 MMSZ5228BT1

Caption:
Group photo of the packaging of
the devices as received for
analysis.

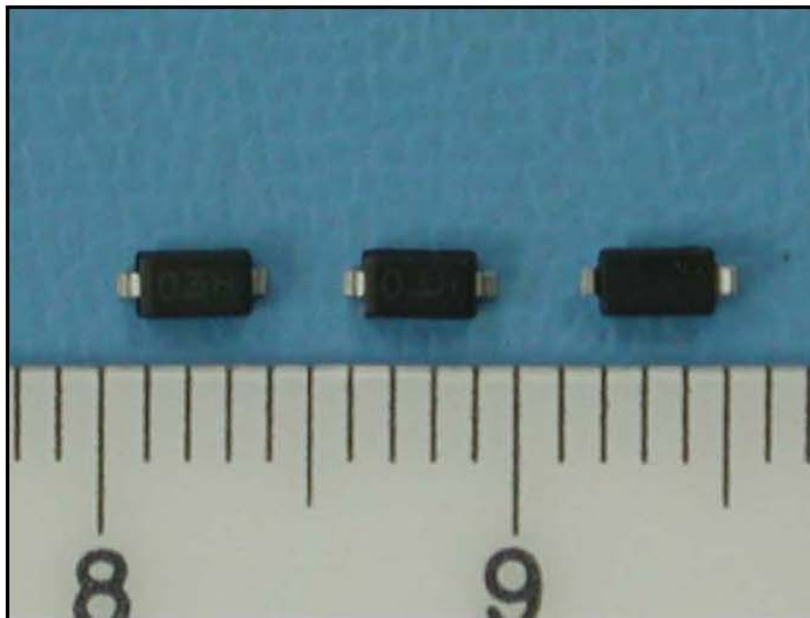


Figure 6
S/N SOD123 MMSZ5228BT1

Caption:
Group photo of the devices as
they were received for analysis.



Figure 7
S/N MMSSM5250B SMA
CONN

Caption:
Group photo of the packaging of
the devices as received for
analysis.



Figure 8
S/N MMSSM5250B SMA
CONN

Caption:
Group photo of the devices as
they were received for analysis.

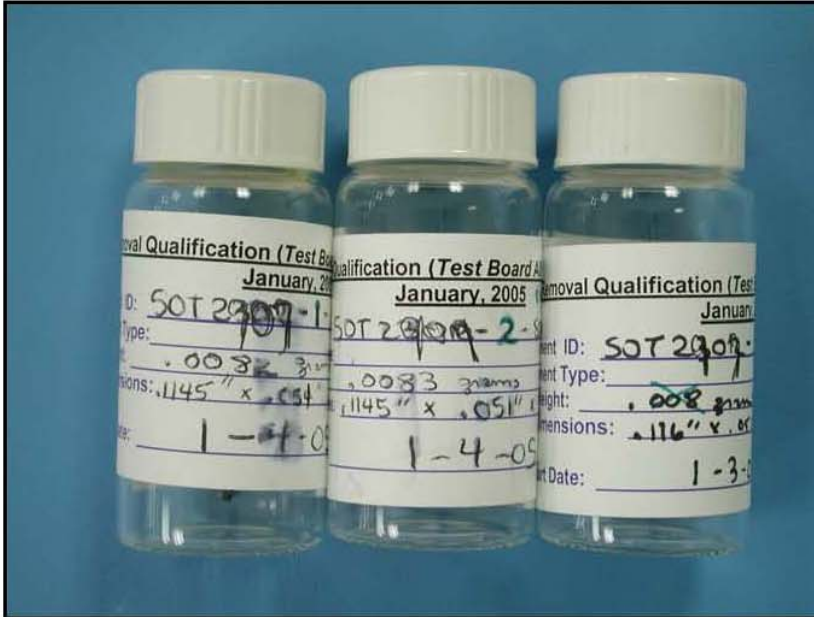


Figure 9
S/N SOT23 BAS16LT1

Caption:
Group photo of the packaging of
the devices as received for
analysis.

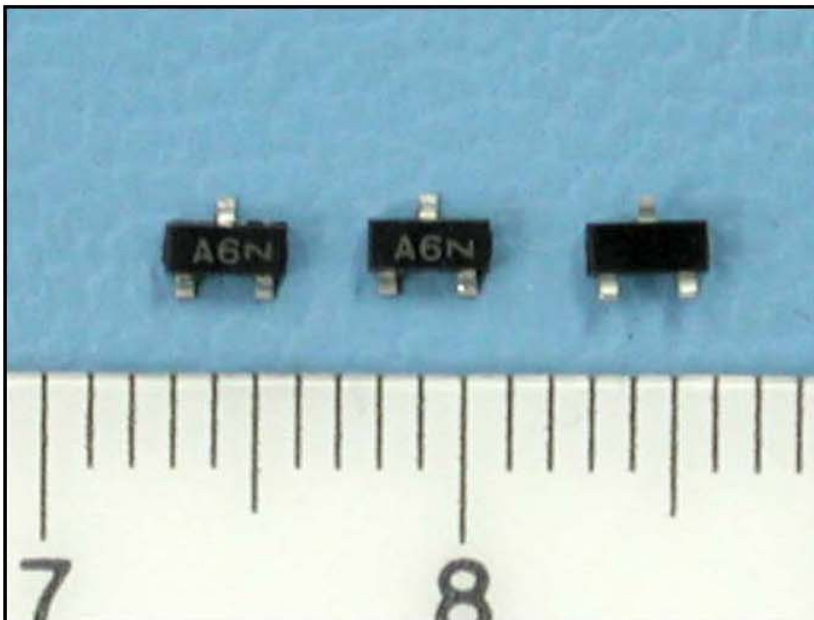


Figure 10
S/N SOT23 BAS16LT1

Caption:
Group photo of the devices as
they were received for analysis.



Figure 11
S/N L0603
LQW1608A47NG00

Caption:
Group photo of the packaging of
the devices as received for
analysis.

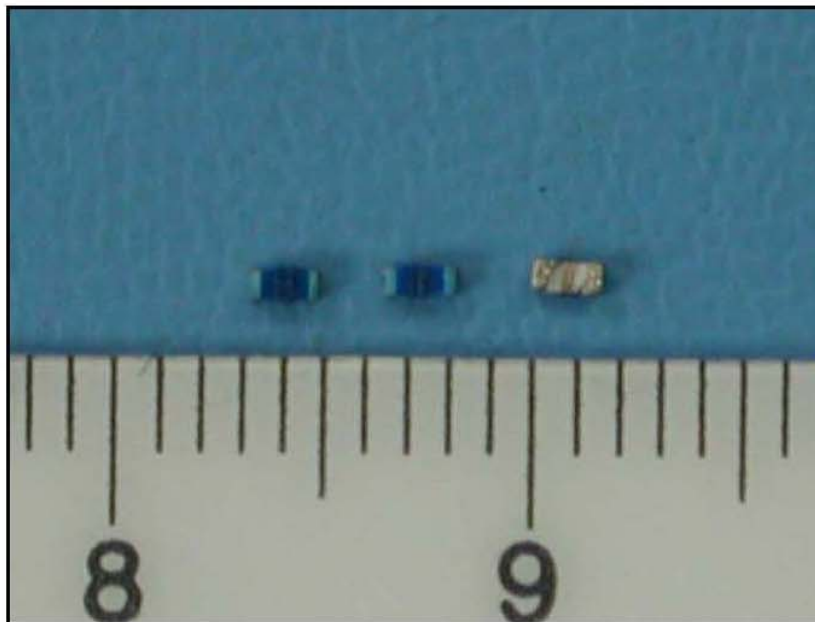


Figure 12
S/N L0603
LQW1608A47NG00

Caption:
Group photo of the devices as
they were received for analysis.

Distribution

MS-0311 G. Benavides, 2616
MS-0311 G. Randall, 2616
MS-0311 J. Schare, 2616
MS-0481 S. Barnhart, 2132
MS-0481 R. Harrison, 2132
MS-0481 J. Montoya, 2132
MS-0481 D. Thomas, 2132
MS-0481 E. Wyckoff, 2132
MS-0501 M. Craig, 5332
MS-0537 G. Luguna, 5353
MS-0537 T. Rohwer, 5353
MS-0537 D. Weiss, 5353
MS-0537 R. Woodrum, 5353
MS-0638 S. Kalemba, 12341
MS-0885 R. Salzbrenner, 1820
MS-0888 R. Clough, 1821
MS-0888 P. Rand, 1821
MS-0888 E. Russick, 1821
MS-0888 P. Sawyer, 1821
MS-0889 J. Braithwaite, 1825
MS-0889 S. Monroe, 1825
MS-0899 Technical Library, 4536 (2)
MS-9018 Central Technical Files, 8945-1 (2)
MS-9403 J. McElhanon, 8762

Honeywell FM&T, KCP

MS-2C43 M. Benkovich
MS-2C43 D. Bowen
MS-2C43 E. Grotheer
MS-2C43 E. Nail
MS-2D39 M. Gerding
MS-2D39 S. Mistele
MS-2D39 D. Tran
MS-MG39 D. Brandenburg
MS-MG39 D. Jarrell
MS-SC4 T. Wilson
MS-XD44 D. Brown