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MATERIALS AND PROCESS DEVELOPMENT EFFORTS IN SUPPORT OF THE AIR FORCE MAINTENANCE PROGRAM

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Abstract

The Electronic Failure Analysis Group in the Air Force Wright Aeronautical Laboratories/ Materials Laboratory (AFWAL/ML) was established in 1977 to meet the need for detailed analysis of failed electronic components. The various analytical capabilities and techniques applied to electronic component failures are briefly described. Specific examples of several detailed electronic failure analyses are reviewed. After examining all the failure analyses conducted, eighty-three percent of the failures were attributed to materials or manufacturing related defects. These studies have resulted in solutions and identified technical approaches for improved electronic component reliability and maintenance.

Introduction

The Air Force recognizes that the rapidly expanding electronics technology is vital to its interests. The reliability and maintainability of military electronic systems rests heavily upon an ability to isolate part failures, establish the cause of failure and recommend corrective action to insure improved performance. The Electronic/ Electrical Failure Analysis Group of the Systems Support Division of the Materials Laboratory maintains the necessary technical expertise and laboratory capabilities to conduct electronic failure analyses.

The Systems Support Division receives numerous requests for support with electronic problems. A few years ago, Government Industry Data Exchange Program (GIDEP) and Reliability Analysis Center/ Illinois Institute of Technology Research Institute (RAC/IITRI) were requested to search their data banks for information which related electronic failures to materials and/or process defects. GIDEP surveyed 412 ALERTS involving electronic or electrical failures from 1976 through 1978 and found that 310 failures, or 75%, were due to materials or manufacturing process defects. RAC found that 65% of all the linear and interface microcircuit failure modes were due to material or processing defects. With this strong correlation between electronic failures and material or processing defects, AFWAL/ML formed the Systems Support Electronic Failure Analysis Group to meet the large demand for this type of Systems Support.

The Electronic Failure Analysis Group issued eighteen Evaluation Reports between 26 April 1977 and 5 May 1980. The eighteen reports were classified as to the cause of failure or deficiency of the part submitted for analysis; four of the failures were the result of improper use of materials, two were due to deficient design, six were due to poor quality control of the manufacturing process, five were due to the use of improper manufacturing processes, and one was due to the misuse of the part. These results generally agreed with the GIDEP and IITRI findings as 15 of 18, or 83%, of the failures investigated were materials or manufacturing process related defects. These large numbers of material and process related defects emphasize the important role of AFWAL/ML in electronic/electrical failure analysis.

The AFWAL/ML Electronic Failure Analysis Group has devoted considerable effort to identifying materials and process opportunities to reduce the cost of ownership of Air Force weapons systems. The branch that contains the Electronic Failure Analysis Group was established to interface with the Air Force Logistics Command, to solve day-to-day maintenance problems and to identify long-term technology needs. Many of these longer term technology needs were addressed through rather substantial Manufacturing Technology programs. The activities are divided into three parts consisting of the requirements, the program necessary to meet the requirements and the solutions implementation.

The Electronic Failure Analysis Group has the facilities and expertise to investigate specific component failure on large Air Force wide problems of a very general nature. Some failure analyses will be described and the side benefits of these analyses will be discussed. For example, the high failure rate of fuses after long term storage was associated with the polyvinyl chloride dampening foam positioned between the circuit boards. Several of the analyses have pointed out the need for standardization of potting compounds, the need for accelerated aging data for aluminum electrolytic capacitors and the development of better power supplies. Many of these analyses have pointed-out the need for industry-wide improvements in order to overcome the problems.

Electronic Failure Analysis Group

The Electronic Failure Analysis Group has effectively supported Air Force systems from the Air Logistic Centers, the product divisions, the Aeronautical Systems Division and the Air Force Systems Command. The evaluation reports issued between 26 April 1977 and 5 May 1980 were published in a technical report[1].

Some of the techniques and equipment used in failure analysis are shown in Table I. Figure 1 shows the examination of an integrated circuit with an optical microscope and Figure 2 shows a specimen being placed in the scanning electron microscope. The equipment used in the laboratory consists of oscilloscopes for signal display, power supplies to bias instruments or devices, LCR bridges for electrical parameter measurements, soldering and solder removal tools, particle impact noise detector (PIND) for solid contamination detection in packaged devices, plasma etcher for surface cleaning and glass removal, microprobe station for electrical probing of microminiature circuits, infrared scanners for heat detection, infrared microscope for examination of silicon die attachments, integrated circuit tester, wire bond pull-tester to determine bond strengths, scanning electron microscope, optical microscopes and cameras for report documentation. Other analytical capabilities outside the electronic failure analysis group will be discussed in the next section.

ELECTRONIC FAILURE ANALYSIS
o SEM & TEM
o SURFACE ANALYSIS
o CHEMICAL ANALYSIS
o CERT
o SAMPLE MOUNTS
o ANGLE LAPPING
o THERMOGRAPHY
o LIQUID CRYSTALS
o IR MICROSCOPE
o PIND
o WIRE BOND PULL TESTER
o PROBE STATION & ELECTRICAL TEST

TABLE I. ELECTRONIC FAILURE ANALYSIS METHODS

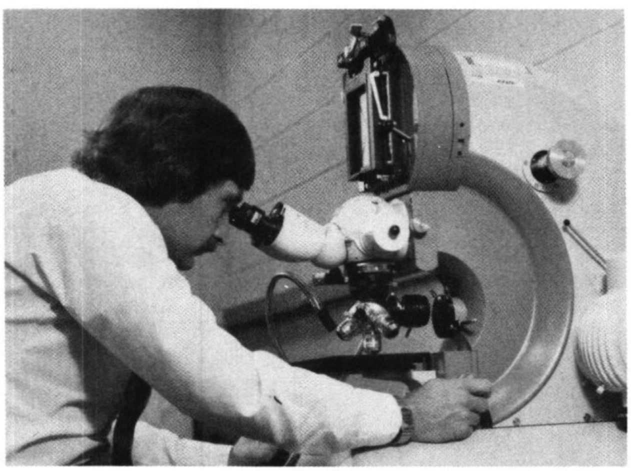

FIGURE 1. Engineer using optical microscope to examine failed integrated circuit.

Computer aided analysis of circuits is accomplished with the SPICE[2] computer program. This capability is very important to the laboratory because data may be collected, or hypothesis examined, in ways that are impractical experimentally. The SPICE program is a general purpose circuit simulation program developed by the University of California.

Each project analyzed by the Electronic Failure Analysis Group culminates in an Evaluation Report which is sent to the customer. The Evaluation Report states the purpose of the analysis with appropriate background information, provides factual data given by any of the analytical techniques applied to the program, records the conclusions reached as a result of the analysis, and makes recommendations for appropriate corrective action. Sometimes the time elapsed between receiving the failed part and issuing the evaluation report is very short, such as a week, and when the problem requires some special treatment it may be as long as a year.

Many difficult problems are solved by a contractual effort. When the resources and facilities required for a problem solution are extremely large, or very specialized, the desired approach is written into a statement of work which is then let as a contract. The contractor then develops an effective problem solution and publishes this in a final report. These contractual efforts may be in the areas of basic research, applied research, development and manufacturing. Several contractual efforts have successfully solved Air Force problems which will be discussed later.

Once a problem has been solved by a contractual effort, care must be taken to insure that the recommended solution is properly incorporated into the Air Force system. This procedure is called technology transfer. It involves moving the technology out of the laboratory and into the Air Force maintenance system by the use of briefings, reports, new specifications and Technical Orders.

The inertia associated with the Air Force maintenance system is tremendous and special techniques are required for affecting it with improvements or any changes at all. This has been accomplished in many cases, however, and some of these will be described.

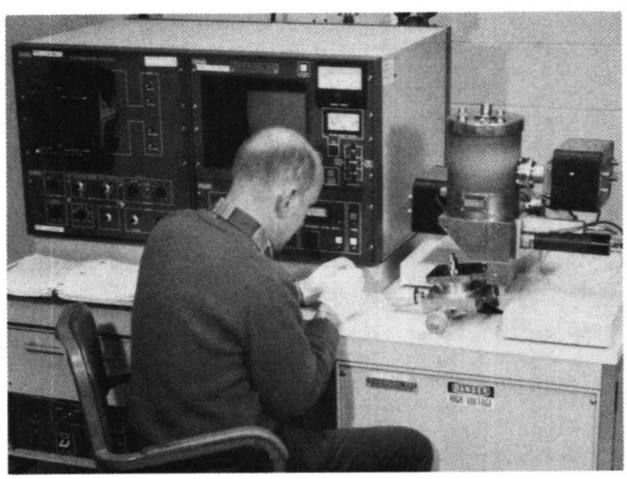

FIGURE 2. Mounting specimen in scanning electron microscope for detailed examination.

Analytical Methods

Techniques required for successful electronic failure analysis are diverse and very specialized, often concerned with microminiature specimens. A few of the many analysis techniques will be discussed below.

Surface Analysis

Surface analysis methods are used for the detection of contamination or any changes associated with a thin atomic surface layer. These methods include Auger Electron Spectroscopy (AES), X-ray Photoelectron Spectroscopy (ESCA), Secondary Ion Mass Spectroscopy (SIMS), and Ion Scattering Spectroscopy (ISS). Tables II and III catagorize these techniques and list some advantages and disadvantages of each. Figure 3 illustrates the interaction of the excitation beam with the surface under examination. Figure 4 is a schematic of an instrument which collects AES and ESCA data and Figure 5 shows the corresponding instrument for the collection of SIMS and ISS data. These surface analysis techniques are powerful analytical tools and are frequently used in electronic failure analysis.

SURFACE ANALYTICAL TECHNIQUES

	QUAL. ANAL	QUANT ANAL	CHEM BONDS
AUGER ELECTRON SPECTROSCOPY	A	B	C
X-RAY PHOTOELECTRON SPECTROSCOPY	A	B	A
SECONDARY ION MASS SPECTROSCOPY	A	C	B
ION SCATTERING SPECTROSCOPY	B	A	C

A - Very Good
B - Useful
C - Fair to Poor

TABLE II. SURFACE ANALYTICAL TECHNIQUES

Chemical Analysis

The methods of chemical analysis used in electronic failure analysis are listed in Table IV. The infrared absorption may be obtained on a Fourier Transform Spectrometer schematically illustrated in Figure 6. This instrument obtains the interferogram, shown in Figure 7, and computes the Fourier transform from the interferogram. This allows the collection of useful data from very weak signals and results in quick and accurate data reduction.

Scanning Electron Microscopy

The scanning electron microscope (SEM) provides imaging in the backscattered electron or secondary electron modes. The characteristic x-ray

SURFACE ANALYSIS TECHNIQUES

ADVANTAGES	DISADVANTAGES
ISS	
GOOD SENSITIVITY	PEAK OVERLAP
MAPPING	COMSUMES SAMPLE
SEMI-QUANTITATIVE	ROUGHNESS SENSITIVE
TOP LAYER SENSITIVE	MATRIX EFFECTS
	NO CHEMICAL INFO
SIMS	
ALL ELEMENTS	STRONG MATRIX EFFECTS
HIGH SENSITIVITY	CONSUMES SAMPLE
CHEMICAL INFO	PEAK OVERLAP
SEPARATES ISOTOPES	ORIENTATION ROUGHNESS SENSITIVE
MAPPING	
ESCA	
MOST ELEMENTS	SLOW
CHEMICAL EFFECTS	NO ISOTOPE SEP
SEMI-QUANTITATIVE	H He EXCLUDED
MINIMAL SAMPLE DAMAGE	NO MAPPING LARGE AREA
AES	
FAST	E-BEAM
MAPPING	SENSITIVITY > 01%
MOST ELEMENTS	NO ISOTOPE SEPARATION
CHEMICAL EFFECTS	H He EXCLUDED
SEMI-QUANTITATIVE	PEAK OVERLAP
METALS INSUL. SC	
NOT CONSUMING	

TABLE III. A COMPARISON OF FOUR SURFACE ANALYSIS TECHNIQUES

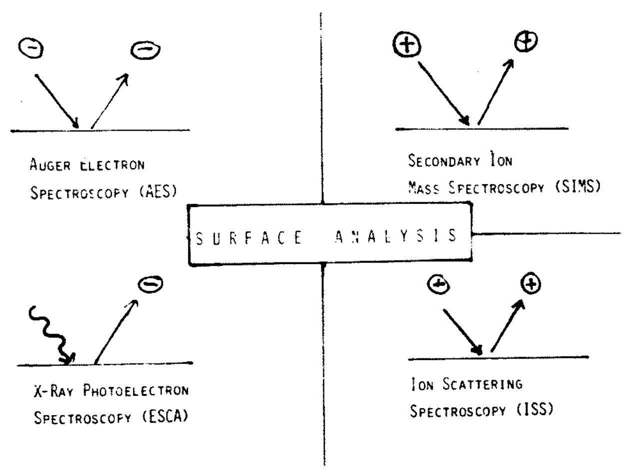

FIGURE 3. Schematic representation of four surface analysis techniques.

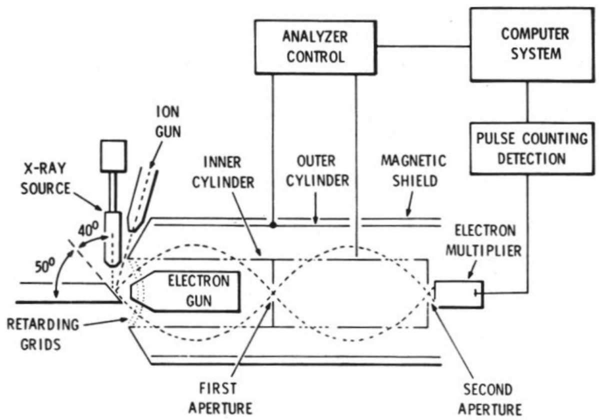

FIGURE 4. Schematic representation of instrument used for both AES and ESCA.

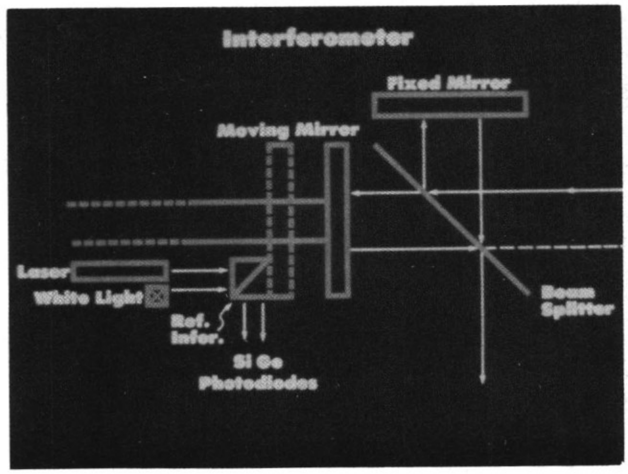

FIGURE 6. Schematic of interferometer used in Fourier transform spectroscopy.

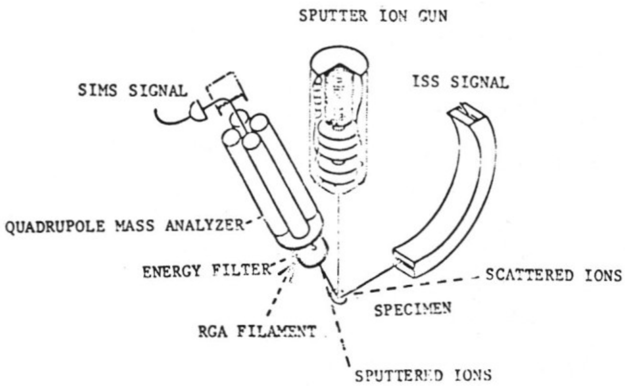

FIGURE 5. Schematic representation of instrument used for both ISS and SIMS.

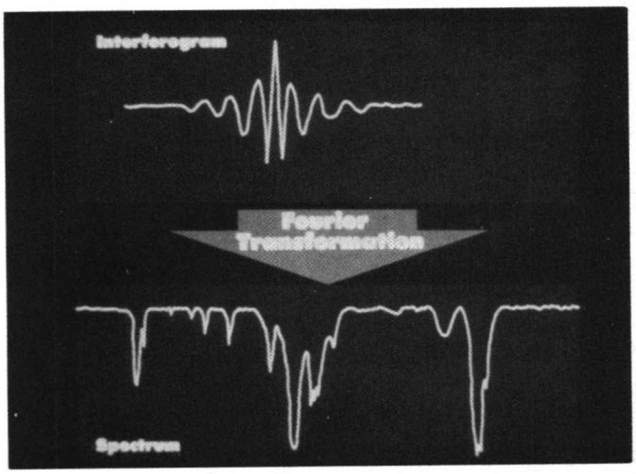

FIGURE 7. Fourier transform spectrum obtained from interferogram.

CHEMICAL ANALYSIS METHODS

- INFRARED, VISIBLE & ULTRAVIOLET ABSORPTION
- RAMAN SPECTROSCOPY
- X-RAY DIFFRACTION
- ATOMIC ABSORPTION
- GAS & LIQUID CHROMATOGRAPHY
- MASS SPECTROMETRY
- WET CHEMICAL & MICROELEMENTAL ANALYSES

TABLE IV. CHEMICAL ANALYSIS TECHNIQUES

spectrometer yields elemental material analysis. A useful technique of analysis for integrated circuits employs electron beam induced current (EBIC). Figure 8 illustrates the sample and equipment used to make the measurement. The semiconductor sample is placed in the SEM and the sample current is measured by the logarithmic amplifier before display on the x-y plotter. The microscope electron beam is represented by the arrow. This type of analysis provides information on the minority carrier diffusion length.

Liquid Crystal Circuit Mapping

The use of nematic liquid crystals to identify active circuit elements is shown in cross-section in Figure 9. The circuit is viewed through the cover glass with polarized light. The liquid crystals above a biased conductor are oriented differently than the liquid crystals above an unbiased material. This difference in crystal orientation is visible with polarized light, so that the function of the circuit may be examined.

Angle Lapping

The application of this technique to a sample is illustrated in Figure 10. The sample is polished at a small angle to enlarge and to expose regions of interest below the substrate surface. Once an integrated circuit has been polished to the desired depth the semiconductor may be stained to establish the different p-type and n-type regions. This technique permits the measurement of diffusion depths or ion implantation depths.

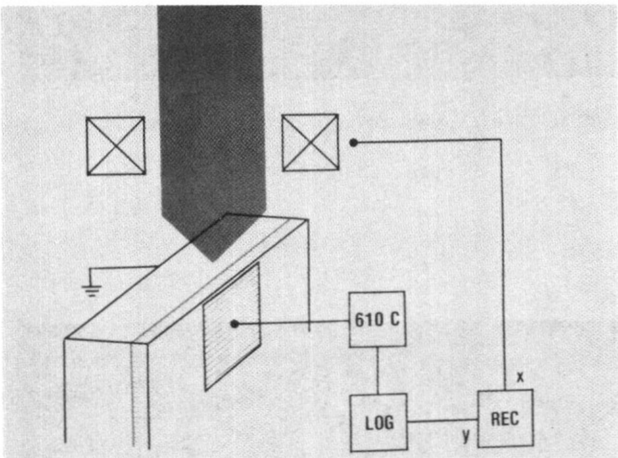

FIGURE 8. Scanning electron microscope used to measure electron beam induced current in semiconductor device. Dark arrow represents electron beam.

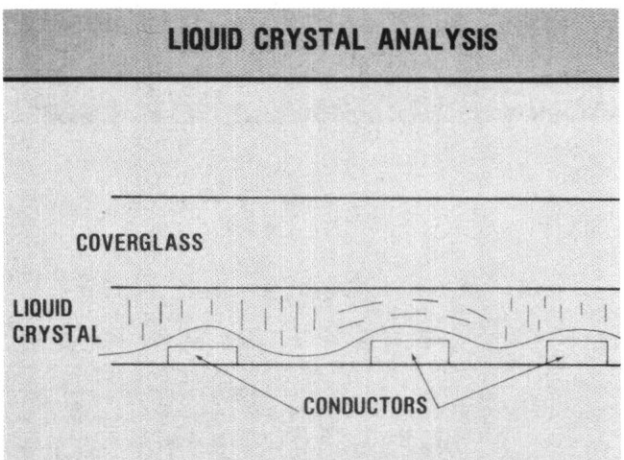

FIGURE 9. Liquid crystal represented by hashed lines between coverglass and lecithin covered conductors and substrate.

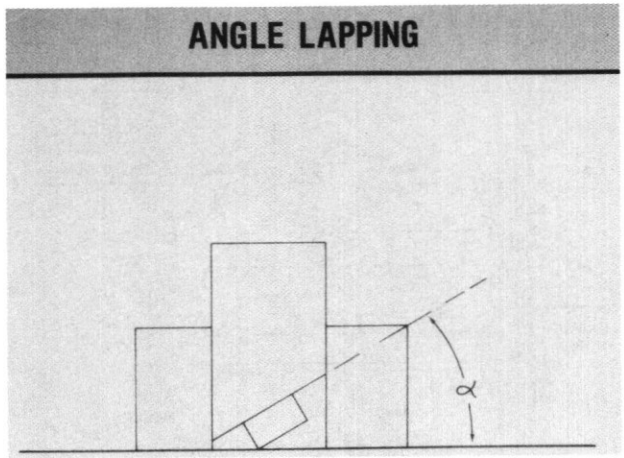

FIGURE 10. Angle lapping of failed device which is mounted at the angle α.

Failure Analysis Projects

Eight different failure analysis projects or system support activities will be discussed in terms of the original requirements, the coordinated activities necessary to meet the requirements, and the solutions. The results of these projects are directed toward improved maintenance of Air Force electronic equipment.

Polyvinyl Chloride (PVC) Foam

The printed circuit boards in a munition were separated by a PVC dampening foam. Mechanically the dampening foam, Figure 11, worked well but chemically the foam released chlorides which collected on the printed circuit boards in the device. The transistor failures were traced to chlorine contamination and small amounts of moisture caused severe corrosion of the chloride contaminated printed circuit boards. It was determined that a different foam material was needed to replace the PVC foam. Motorola, Inc., Government Electronic Division qualified a new polyacrylic elastomer foam material to be used in all new munitions. The substitution of the new foam satisfied the dampening requirements and eliminated the corrosion associated with the chloride.

Aluminum Electrolytic Capacitors

An aluminum electrolytic capacitor (Figure 12) is required to function properly after being stored for up to 10 years at ambient conditions. This requirement necessitated the development of an accelerated aging technique for aluminum electrolytic capacitors. Under an Air Force contract, Hughes Aircraft Co. developed an accelerated aging technique for these capacitors. During this testing it was found that the capacitors did not have the necessary 10 year shelf life. An improved capacitor package was developed which reduced the amount of electrolyte evaporation. With the improved capacitor, the shelf life exceeded the 10 year requirement. The improved capacitors are to be used in Air Force equipment which requires a long shelf life.

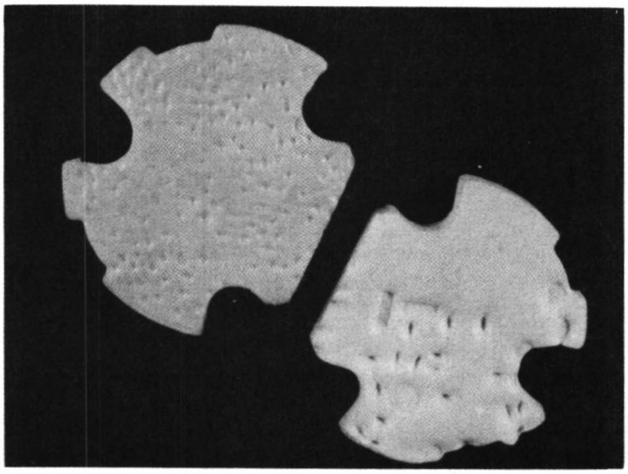

FIGURE 11. Polyvinyl chloride (PVC) vibration dampening foam pad. Pad is placed between printed circuit boards.

FIGURE 12. Aluminum electrolytic capacitor.

Potting Compounds

Potting compounds are used in numerous electrical and electronic applications in the Air Force. These potting compounds provide structural support, damp vibrations, and protect these various components from the service environment. The electrical, processing and physical property requirements for the various potting materials are quite strenuous and diverse. In addition in order to maintenance the electronic components, the potting material must be removable.

Potted power supplies have been an Air Force problem for years. Problems occur in both the low voltage and high voltage supplies. Figure 13 shows a failed power supply which had potted modules soldered onto the mother board. The poor potting procedures caused solder cracks in the modules. In a redesign of the power supply the modules are to be conformally coated instead of potted.

Potting problems have been cited in other studies (3, 4, 5) as well. Some of these problems can be addressed by requiring the use of a standard potting material on electronic modules. The Electronic Failure Analysis Group has received numerous requests for system support in the area of potting compound standardization for electronic modules. Too many different types of materials are currently being used and a large portion of these materials[6] cannot be de-potted. At the request of the Air Logistic Centers a survey[7] was conducted within the Air Force to determine if anything could be done to reduce the number of different potting materials and to encourage the use of potting compounds which are repairable. Many electronic modules are too expensive to throw away but they are potted in a material which makes any repair work extremely difficult.

One example of a nonrepairable item submitted by an Air Logistic Center consisted of an 8" x 10" printed wiring board embedded in an epoxy. The board cost $22,000. and was totally unrepairable. If the potting material could be removed from the board a repair would cost less than a few hundred dollars. A repairable board design has been proposed, Figure 14, which would provide the necessary environmental protection with the outer coating and the repairability with the inner coating. The gross waste of materials, money and time could be eliminated with effective planning and design required by an embedment material standardization specification. Such a standardization specification has been advocated by the Electronic Failure Analysis Group to the appropriate Air Force agency.

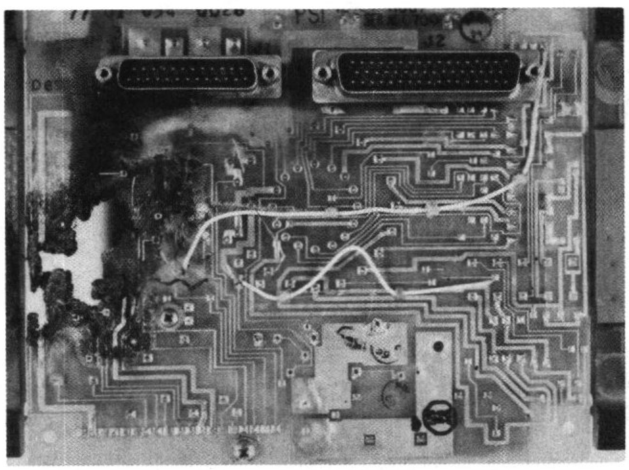

FIGURE 13. Failed motherboard from power supply. Foam pads on each end normally cover conductor traces and could possibly trap moisture around conductors.

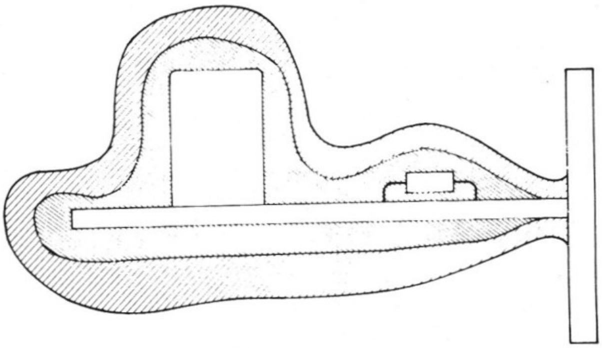

FIGURE 14. Printed wiring board embedded in two component potting materials. Outer potting material provides environmental protection.

Magnetic Tape Recorder Replacement Heads

In response to an Air Logistic Center request to the Electronic Failure Analysis Group to develop a qualification specification for replacement of magnetic tape recorder heads, a PRAM program was initiated to develop a military specification that could be used by all government agencies to procure Wide Band Group II Instrumentation Tape Heads, Figure 15.

The Air Logistic Center requested assistance because Air Force procurement documents do not adequately define replacement tape heads and problems were occurring in the quality control of heads being procured. This resulted in the purchase of tape recorder heads which did not operate properly.

The specification, developed under Air Force contract to IITRI, provided qualification and performance specifications so that quick and accurate checks on tape heads could be made to insure their suitability and acceptability at the time they are procured. This military specification is currently in the final stages of coordination and is scheduled for publication soon. It is expected to result in over one half million dollars annual savings for the Air Force.

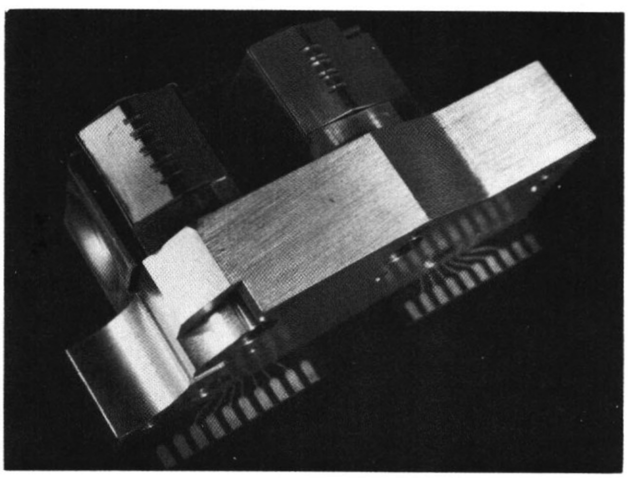

FIGURE 15. Magnetic tape recorder replacement heads.

Electrical Wire Insulation

Electrical wire, supposedly qualified to MIL-W-5086, was examined to determine if the insulation was flame retardant. This wire was found to have a transparent outer layer of polyamide and an inner layer of polyvinyl chloride. The wire was clamped at a 60° angle and ignited with a flame. The insulation continued to burn once the ignition source was removed, Figure 16. This analysis revealed that the insulation was not fire retardant but flammable and unsuitable for aircraft. A GIDEP ALERT LC-A-80-01, 11 April 1980, was issued as a result of this work.

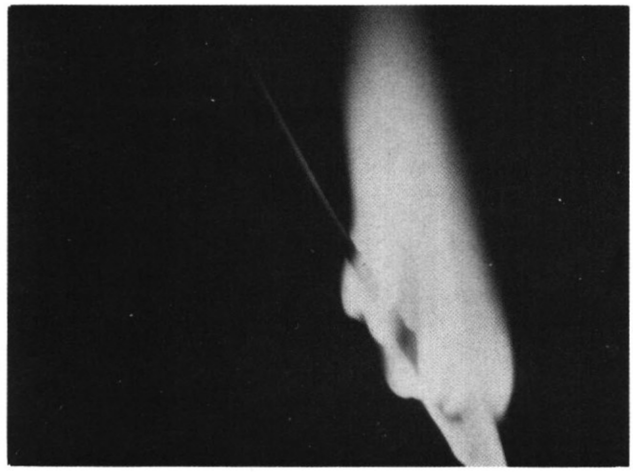

FIGURE 16. Flammability test of wire at 60° angle. The insulation continues to burn after ignition is removed.

Combined Environment Reliability Test (CERT) Chamber

The Electronic Failure Analysis Group has supported the CERT of several different systems.[8,9] This facility includes a chamber, Figure 17, which is equipped to monitor components while powered and to provide the combined stresses of random vibration, temperature change, relative humidity and pressure. The simultaneous application of these stresses frequently gives different results than the independent application of the stresses. This facility was used by the Electronic Failure Analysis Group to test a gyroscope. After 120 simulated flights, the gyroscope failed. The subsequent analysis showed that this non-hermetically sealed gyroscope failed due to water entrapment and corrosion. This facility is a valuable tool for the early identification of deficiencies and for the evaluation of new electronic equipment before it is placed in operational service.

Conformal Coatings for Printed Wiring Boards

Several different System Program Offices and Air Logistic Centers have received system support from the Electronic Failure Analysis Group in the area of conformal coatings. There have been several Manufacturing Technology Programs[10,11] in this area and results of these programs are being incorporated into the Air Force Technical Order "General Shop Practice Requirements for the Repair, Maintenance, and Test of Electronic Equipment", T.O. 00-25-234. This transition of the information from the laboratory into the Air Force Logistic Centers is termed technology transfer and it is designed to benefit the Centers by improving repair procedures and techniques.

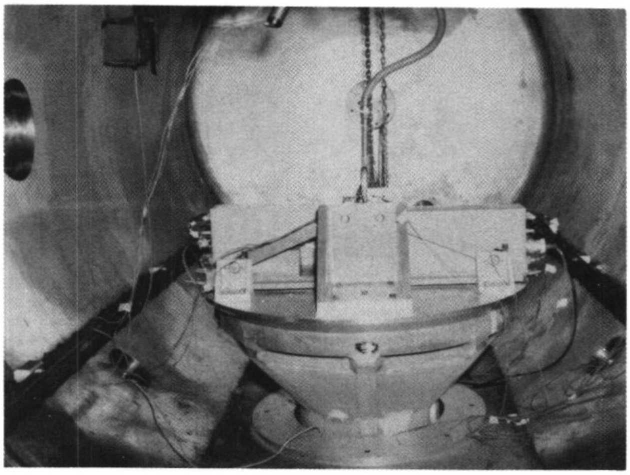

Figure 17. Vibration platform in combined environments reliability testing chamber.

Electronic Repair Center

The Sacramento Air Logistic Center is responsible for repair and maintenance of about five hundred ground base electronic systems. The requirement exists to reduce repair and maintenance costs by improving maintenance productivity. Automated equipment to identify, locate and describe defects in printed wiring boards would significantly improve the repair operations. The Manufacturing Technology Division has initiated two separate programs to meet these requirements. One program is to identify the high cost repair/manufacturing areas and to define the initial approaches to improve the Centers maintenance capabilities. It is expected that the use of Integrated Computer Aided Manufacturing (ICAM) analytical tools will greatly facilitate the analysis and provide the appropriate basis for integrating the analytical results into the center. The other program will attempt to develop automated or semiautomated equipment for rapid screening of printed circuit boards.

In the Electronic Failure Analysis Group, the use of infrared thermography has been very effective in rapid fault isolation. Figure 18 shows an unbiased circuit board on the left and the same board biased. Figure 19 shows a computer subtraction of the two images shown in Figure 18. The dark area, in Figure 19, shows the components that are running at high temperatures.

Summary

The failure analysis activities presented represent a sampling of the activities conducted by the Electronic Failure Analysis Group over the past several years. These activities show how the problems were identified, solved and transitioned. The examples presented show that rather complex electronic and electrical system failures are tractable to careful laboratory analysis. In addition to providing the solution to a specific problem, these failure analysis activities identify the need for improved specification and new technology development programs. The careful analysis of various electronic and electrical failures offers the potential of improved system reliability, increased productivity and reduced maintenance costs.

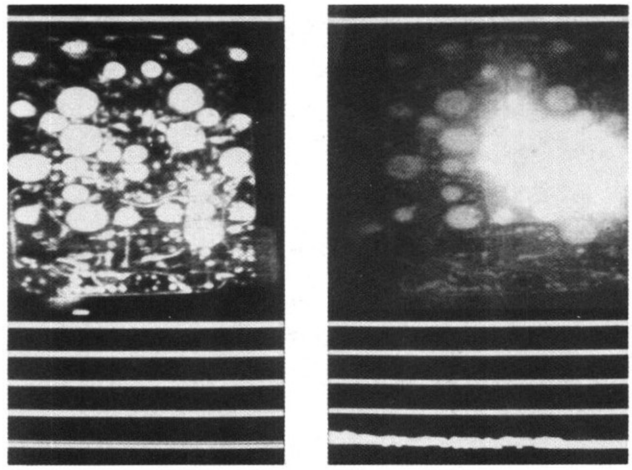

FIGURE 18. Thermograph of printed circuit board without bias (left) and with bias (right).

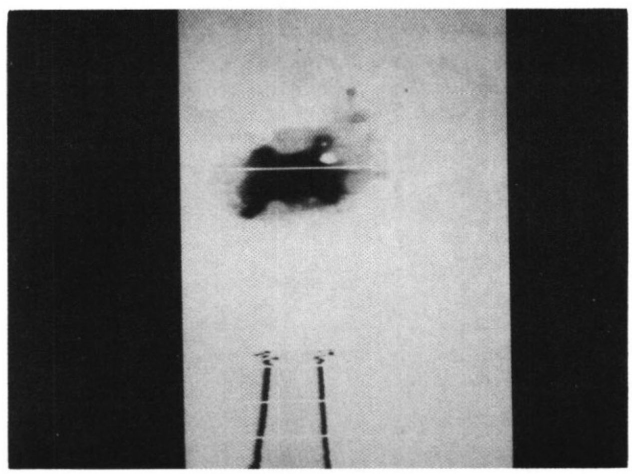

FIGURE 19. Resultant image of computer subtraction of two images shown in Figure 18. Dark area shows hot spot.

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