

FAILURE
ANALYSIS OF
ELECTRONIC PARTS:
LABORATORY METHODS



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FAILURE ANALYSIS OF ELECTRONIC PARTS: LABORATORY METHODS

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Edited by

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Prepared by Goddard Space Flight Center



Scientific and Technical Information Office 1975
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

For sale by the National Technical Information Service
Springfield, Virginia 22151
Price — \$4.75

FOREWORD

Scientific and engineering organizations within the National Aeronautics and Space Administration, Department of Defense, and throughout the aerospace industry are mutually concerned with efforts to obtain more reliable electronic parts. Failure analysis of failed parts is a valuable technique which promotes improved reliability by focusing the design and manufacturing efforts on prevention of the underlying failure causes. Failure analysis techniques and data are also frequently used to analyze candidate parts being considered for new designs or new work where proper performance for extended periods in difficult environments, and at minimum overall cost, is required.

Failure analysis of electronic parts requires technical expertise, sophisticated equipment, and much analytical reasoning. Experience plays a large role in the development of such expertise, determination of specific equipment needed, and in the selection of analytic reasoning appropriate to the applications and problems involved.

The Quality Assurance Division of the Goddard Space Flight Center has been performing failure analysis of electronic parts for over 10 years to support the Center's numerous and diversified space science programs. This document has been prepared to help Government, industry, and university communities to benefit from that experience.

This document was prepared by the Quality Assurance Division of the Goddard Space Flight Center with the assistance of the Sperry Support Services Facility, Sperry Rand Corporation, as part of contract NAS5-21444; it was edited by Ethan Goldberg and documents the methods used in the Parts Analysis Laboratory at Goddard.

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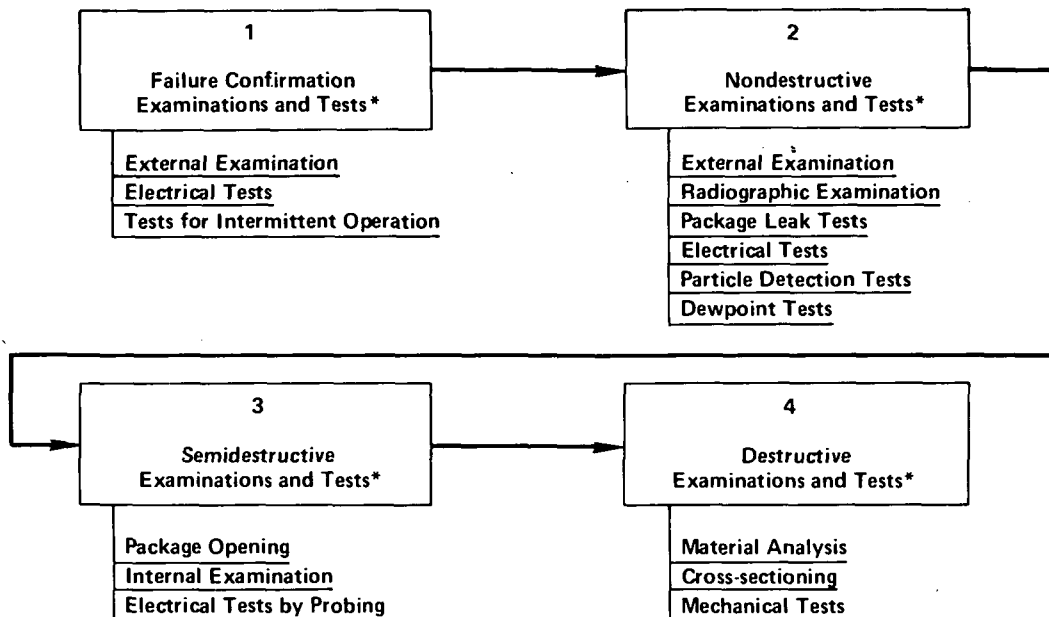
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LABORATORY WORK FLOW

One proper flow of failure analysis (FA) laboratory work is illustrated by figure 1.



*Note: Examinations and tests listed are examples only.

Figure 1. Failure Analysis Laboratory Work Flow

The purpose of failure confirmation examinations and tests is self-evident; it is intended that these be devoted solely to a verification of the reported problem.

Nondestructive examinations and tests are analytical and are intended to provide, to the extent possible without altering the device in any way, additional information that assists in identifying the cause of failure.

Semidestructive and destructive examinations and tests are subsequent analytical procedures intended to exactly identify (when possible) the cause of failure. For purposes of this document, an examination or test is defined as semidestructive if it results in an irreversible change to the device, but, at the same time, would not normally: (a) irreversibly change the active element(s) of the device, or (b) preclude further testing of the functioning of the device.

Destructive, for purposes of this document, pertains to examinations and tests that alter the device beyond the limits set above.

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SPECIFIC EXAMINATIONS AND TESTS BY PART TYPE

Code designations for specific examinations and tests that may apply to each of six common part types during a failure analysis are listed in table 1, followed by brief narrative descriptions of the various examinations and tests. Detailed methods for performing the examinations and tests are presented in the following section.

Table 1
Examination and Test Codes by Part Type

Category of Examinations and Tests*	Integrated Circuit	Transistor	Diode	Resistor	Capacitor	Relay
Failure Confirmation	G1 G2 F1	G1 G2 F1	G1 G3 G2 F1	G1 G2 F1	G1 G2 F1	G1 G2-F2 F1
Non-destructive	G1 N1 N2 G2 N3 N4 G4 G5	G1 N1 N2 G2 N3 N4 G4 G5	G1 G3 N1 N2 G2 G4 N4 G4 G5	G1 N1 N2 G2 G4 G5	G1 G6 N1 N2 G2 G2 N3 N5 G5	G1 N1 N2 G2 N3 N6 N7 G4 G5
Semi-destructive	G2 S1-S3 G3 S2-G2 S4 S5 S6 S7 S8 G5 G4	G2 S1-S3 G3 S2-G2 S4 S5 S6 S7 S8 G5 G4	G2 S1-S3 G3 S2-G2 S4 S5 S6 S7 S8 G5 G4	G2 S1 G3 S2-G2 S4 S7 G5 G4	G2 S1 G3 G6 G7-G2	G2 S1 G3 S9 S10 S2-G2 G4 S11 G8
Destructive	G2-S2 G3 D1 D2 D3 D4 D5 D6 D7 D8	G2-S2 G3 D1 D2 D3 D4 D5 D6 D7 D8	G2-S2 G3 D1 D2 D3 D4 D5 D6 D7 D8	G2-S2 G3 D1 D2 D3 D4 D5 D6 D7	G2-G7-S2 G3 D1 D9 D2 D3 D4 D5 D6 D7	G2-S2 G3 D1 D2 G8 D10 D3 D4 D5 D6 D7

*General examinations and tests are included at appropriate points throughout the list.

The examinations and tests are listed in the order that they would normally be performed; special circumstances, however, often make a different order more sensible. Certainly, very few failure analyses require that every, or even most, of the listed procedures be followed.

The listed examinations and tests fall into five categories. The first category is a general one, including examinations and tests that may be performed throughout all phases of the analysis (for example, microscopic inspection). These are designated by the letter G. The remaining four categories relate to specific examinations and tests performed during failure confirmation (F) and those performed during nondestructive (N), semidestructive (S), and destructive (D) phases of the analysis.

Brief Narrative Descriptions of Examinations and Tests

Failure Confirmation Examinations and Tests

- G1 – Initial external examination and photography as appropriate; data on the package to be recorded at this time
- G2 – Limited electrical tests at room ambient (if applicable)
- G2 – Electrical tests under the exact electrical and/or environmental conditions reported at the time of failure (if necessary)
- G3 – (Glass package only) Limited internal examination (if possible without removal of coating)
- F1 – Tests for intermittent operation (if necessary)
- F2 – Listening test for normal or abnormal mechanical noises

Nondestructive Examinations and Tests

- G1 – Comprehensive external examinations, including examinations with a scanning electron microscope (SEM) (if applicable), and photography as appropriate
- G2 – Extensive electrical tests (to include tests and environmental conditions not used previously). Functional and parametric tests may be performed as appropriate.
- G3 – (Glass package only) Additional internal examination (if possible without removal of coating)
- G4 – Bake and/or vacuum bake (followed by electrical tests)
- G5 – Cleaning of package exterior (followed by electrical tests)
- G6 – pH measurements on any contamination observed on the device exterior (acid electrolyte devices only)
- N1 – Radiographic examination (except possibly metal-oxide-semiconductor (MOS) devices)

- N2 – Package leak tests (hermetically sealed devices only)
- N3 – Particle detection tests
- N4 – Dewpoint tests
- N5 – Temperature profile tests using liquid crystals
- N6 – Moisture content tests
- N7 – Magnetic tests

The following tests are listed for the purpose of analyzing the interior of a device. It should be evident that, if the failure is associated with exterior portions of the device, the following procedures must be adapted to that situation.

Semidestructive Examinations and Tests

- G2 – Electrical tests as applicable after each of the following steps
- G3 – Internal examination with optical microscopes, and photography as appropriate
- G3 – Internal examination with a SEM (if applicable), and photography as appropriate
- G3 – Further microscopic examinations as applicable after each of the following steps and photography as appropriate
- G4 – Bake and/or vacuum-bake
- G5 – Chemical cleaning of device element
- G6 – Tests for electrolyte leakage between the seals (wet electrolyte devices only)
- G7 – Electrical tests by immersion of anode (slug-type devices only) and/or by probing
- G8 – Physical measurement of internal elements (as possible without further disassembly)
- S1, S3 – Package opening or deencapsulation (in conjunction with internal gas ambient analysis where indicated and possible)
- S2 – Electrical tests by probing
- S4 – Voltage contrast analysis of device element
- S5 – Current mode analysis of die with SEM
- S6 – Photoscan of die surface
- S7 – Infrared scan of die surface
- S8 – Profilometer measurements of die surface

- S9 – Ultraviolet light examination for solder flux
- S10 – Observation of internal mechanical operation of device
- S11 – Contact force and over-travel measurements

Destructive Examinations and Tests

- G2, S2– Electrical probing as applicable after each of the following steps
- G3 – Microscopic examinations as applicable after each of the following steps and photography as appropriate
- G7 – Electrical tests by immersion after each of the following steps (as applicable)
- G8 – Additional physical measurements
- D1 – Removal of interconnections and/or isolation of device element from package. Strength tests should be performed at this time (as applicable). Isolation of regions in the device element may be performed at this time.
- D2 – Energy dispersive X-ray and/or electron microprobe analysis
- D3 – Chemical analysis
- D4 – Other material analyses
- D5 – Chemical etching
- D6 – Destructive mechanical tests on package or device elements
- D7 – Cross-sectioning
- D8 – Chemical staining
- D9 – Dielectric pinhole tests (slug-type devices only)
- D10 – Hardness tests

DETAILED METHODS FOR PERFORMING EXAMINATIONS AND TESTS

This section is comprised of detailed laboratory methods for performing the various examinations and tests listed previously. The code system used is identical, with methods presented in the following order:

Category	Code
General	G
Failure Confirmation	F
Nondestructive	N
Semidestructive	S
Destructive	D

Each method is discussed with respect to several items, usually including:

- Applicable part types
- Purpose
- Equipment
- General procedure
- Procedures applicable to individual part types
- Applicable specifications

NOTE: Equipment requirements listed here are only examples. In most instances, there are numerous acceptable substitutes for the particular instruments specified.

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METHOD G1—EXTERNAL EXAMINATION

Applicable Part Type(s)

All

Purpose

Recording of package markings; confirmation of failure concerning package exterior; detection of anomalies or defects, including contamination and extraneous attachments, that are evidence of manufacturing errors, overstress, or mishandling, and that are or may be related to the device failure

Equipment (or Equivalent)

The naked eye; low-magnification microscopes (for example, Nikon Stereo-Zoom); high-magnification microscopes (for example, Leitz Panphot); SEM (for example, Cambridge Stereoscan); and accessory photography equipment as required

General Procedure

Initial Examination

Valuable information may be lost if the device is handled indiscriminately prior to careful external inspection. For instance, devices have been known to fail as a result of an extraneous tiny wire (virtually invisible to the naked eye) attached to the package exterior; such a wire might easily be dislodged and lost in normal handling. Hence, the device exterior should initially be examined (using appropriate instruments) for any condition that might be disrupted by subsequent normal handling.

As part of this procedure, it is imperative that all markings, including manufacturer, part type, date code, pin designations, and so on, be recorded at this time.

The device should then be examined to verify the reported external anomaly or defect, if any. (A more comprehensive external examination will be performed at a later time.)

All significant findings should be recorded photographically, employing standard photographic attachments for the microscopes used.

Comprehensive Examination

It may be useful to first examine the device without the aid of optics. It is usually most productive to then examine the device exterior at low magnifications, such as those available with the Nikon Stereo-Zoom microscopes. Attention should be focused on the integrity and condition of the package; specifically, the device should be examined for:

- Contamination or attached extraneous matter
- Mechanical damage

- Heat or electrical damage
- Seal integrity around the leads as well as around the bottom and top of the unit
- Lead integrity, including plating
- Evidence of mismarking or remarking
- Evidence that pin or lead designations are inaccurate

Suspicious regions should then be examined with equipment which will yield additional information. If higher magnification alone is required, the use of a metallurgical microscope such as the Leitz Panphot is in order (continuing to use optical microscopes offers the advantage of being able to detect color). If greater depth of field would be helpful, then use of the SEM should be considered.

All significant findings should be recorded photographically employing standard photographic attachments for the microscopes used.

Procedures Applicable to Individual Part Types

None

Applicable Specifications

Initial Examination

Since the device is being examined at this time solely for markings, specific reported external defects, and very obvious anomalies, general external inspection criteria do not apply.

Comprehensive Examination

Inspection criteria applicable to integrated circuits may be found in MIL-STD-883. Inspection criteria applicable to transistors and semiconductor diodes may be found in MIL-STD-750. Specifications applicable to resistors, capacitors, and relays are numerous and depend on the exact purpose and style of the individual device. Hence, it is recommended that a current index of military specifications be consulted to locate appropriate specifications.

METHOD G2—ELECTRICAL TESTS

Applicable Part Type(s)

Functional and parametric tests—all; pin-to-pin tests—integrated circuits; junction tests—transistors and diodes

Purpose

To assess the electrical performance of the subject device. Initially, during limited electrical tests, the purpose is limited to confirming the reported failure. Extensive electrical tests,

usually done in conjunction with nondestructive testing, are intended to relate the device failure to its construction. Electrical tests performed after that are usually intended to assess the effect of various other procedures being performed.

At any time, functional, parametric, pin-to-pin, or junction tests may be performed, as applicable. The purpose of functional testing is simply to determine whether the device does its basic job; parametric testing indicates how well the device is doing this job. Pin-to-pin and junction tests, on the other hand, are more analytical tests, which may permit the device failure to be related to its physical makeup.

Equipment (or Equivalent)

Functional Tests

Appropriate equipment for functional tests, listed according to part type, is as follows:

- Integrated circuits, digital—Same as for parametric tests
- Integrated circuits, linear—Operational amplifier: 10X amplifier circuit; linear and video amplifiers: Tektronix type 545A oscilloscope, Hewlett-Packard 5100A frequency generator; Tektronix type 577 Curve Tracer
- Transistors—Tektronix type 575, 576, or 577 Curve Tracer
- Resistors—Electro-Scientific Model 291B Impedance Bridge
- Capacitors—General Radio type 1673A Automatic Capacitance Bridge with General Radio type 1672A Digital Control Unit
- Relays—Goddard Space Flight Center (GSFC) Relay Test Station; external power supplies; Hewlett-Packard 3440A Digital Voltmeter with 3444A Plug-in

Parametric Tests

Appropriate equipment for parametric tests, listed according to part type, is as follows:

- Integrated circuits, digital—Precision Standards Corp. Model 801 Integrated Circuit Test Set; Datapulse Model 110A pulse generator; Tektronix type 545A oscilloscope, with type CA or M plug-in
- Integrated circuits, linear—Microdyne Model 735 Automatic Linear Tester; Philbrick Nexus Model 5102 Test Set; Hewlett-Packard type 5100A Frequency Synthesizer; Tektronix type 545A oscilloscope
- Transistors—Birtcher Corp. (now Precision Standards Corp.) Model 70 Semiconductor Test Set; Tektronix type 575, 576, or 577 Curve Tracer
- Resistors—Electro-Scientific Model 291B Impedance Bridge; Angstrohm Precision Model 1012D Bridge, Quan-Tech Laboratories Model 2136 Resistor Noise Analyzer

- Capacitors—General Radio type 1673A Automatic Capacitance Bridge with General Radio type 1672A Digital Control Unit; Hewlett-Packard type 445 Microammeter; Arizona AC-DC Insulation Tester
- Relays—GSFC Relay Test Station; external power supplies (for example, Harrison Laboratories Model 855B); Hewlett-Packard 3440A Digital Voltmeter with 3444A Plug-in; Keithley Instruments Model 502 Milliohmmeter; Tektronix type 7714 Storage Oscilloscope; Arizona AC-DC Insulation tester

Pin-to-pin Tests

Equipment for the pin-to-pin tests includes the following: Tektronix type 576 or 577 curve tracer; a camera for the curve tracer; and an integrated circuit socket, holder, or test fixture to allow electrical testing while minimizing possible mechanical damage to the device.

Junction Tests

Equipment for the junction tests includes the following: Tektronix type 576 or 577 curve tracer and a camera for the curve tracer.

General Procedure

Functional Tests

The exact nature of the functional test performed depends on the part type. (See the section, "Procedures Applicable to Individual Part Types.")

The function of the device should be tested during failure confirmation tests only if the device failure was reported as a functional failure. Functional tests performed during nondestructive tests are for the purpose of better defining the device failure, while those performed during semidestructive and destructive tests are for the purpose of assessing device performance after various analytical steps have been completed.

Parametric Tests

The exact parameters measured depend not only on part type, but also on the nature of the failure and the information sought. In general, the parameters to be considered for measurement during failure analysis work are listed under "Procedures Applicable to Individual Part Types."

All measurements should be made in accordance with the device specifications (following procedures found in the instruction manual for the equipment used) and in accordance with sound electrical measurement practices.

Pin-to-pin Tests

Prior to testing it is advisable to obtain the manufacturer's literature showing the maximum voltage ratings and a schematic of the device. It would be desirable, although not necessary, to have another good device to use for comparison purposes.

If MOS devices are to be tested, grounding straps for personnel and test fixtures or other necessary measures should be used to prevent a static discharge from destroying the device.

In order to minimize the possibility of damaging the device under test, the curve tracer is set to the lowest voltage range and the highest obtainable series resistance. With the POLARITY switch in the NPN position, the collector terminal will be at a positive potential while the emitter terminal of the curve tracer will be at ground potential. The variable collector supply potentiometer should always be returned to zero (counterclockwise) prior to connecting the test leads to any of the device leads. During initial testing the HORIZONTAL and VERTICAL switches should be set so as to limit the maximum voltage and current to about 10 volts and 10 microamperes, respectively.

The emitter lead (which is at ground potential with the POLARITY switch in the NPN position) is connected to pin 1 and the collector lead (which is at a positive voltage potential) is connected to pin 2. The variable collector supply potentiometer is slowly rotated while observing the cathode ray tube (CRT) display. Figure 2 shows typical CRT displays.

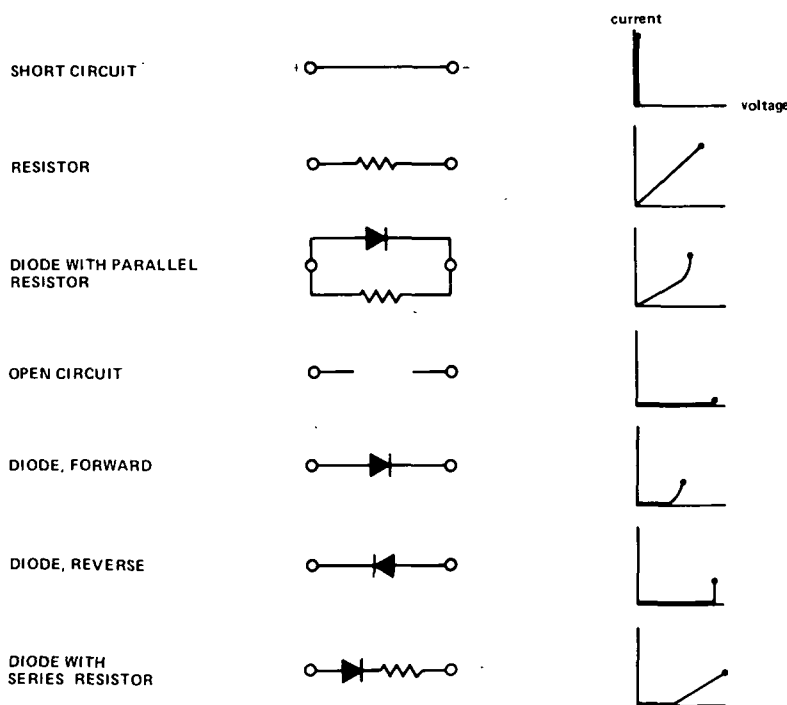


Figure 2. Typical Pin-to-pin Characteristics

The shape of the display is recorded on a matrix-type data sheet noting any pertinent voltages and currents. This same procedure is repeated as the collector lead is in turn connected to all of the other pins and to the case. The emitter lead is then advanced to the next pin and the collector lead once again is applied to all of the other pins and to the case. When the emitter lead has been connected sequentially to all of the pins (including unused pins) and to the case, the test is complete.

An examination of the schematic may dictate whether an indicated open circuit should later be retested with a higher voltage applied. If possible, these higher voltage measurements should first be made with a known good sample device.

Junction Tests

For this procedure, the curve tracer is used as a two-terminal instrument that visually displays the voltage-current characteristics of the device under test. The junctions of bipolar devices that may be tested include:

- The single junction of a diode
- The emitter base junction of a bipolar transistor
- The collector base junction of a bipolar transistor

Any junction may be tested in either the forward or reverse direction.

In order to perform the above tests, the capabilities of the specific curve tracer being used must be known. For example, some models of Tektronix curve tracers permit examination of either junction of a transistor by using a front panel selector switch. With other Tektronix curve tracers, test leads connected to the collector and emitter terminals of the instrument must be used to make contact to the device under test.

Prior to connecting the device under test, appropriate curve tracer settings should be made. In particular: the supply voltage should be set to an appropriate range (and the variable control for this voltage should be placed at its lowest setting); the internal series resistance should be raised to the maximum setting; and appropriate voltage and current sensitivities should be set. (The settings in general will be determined by the manufacturer's specifications for the device under test, which should be studied carefully.)

After the device is connected properly, the variable control for the supply voltage is raised, and the voltage-current characteristics of the junction under test are viewed. Examples of possible junction characteristics are shown in figure 3.

It might be noted that tests may also be made between the collector and emitter terminals of the device, with the base open-circuited. The resultant voltage-current characteristics will depend on the polarity of the connections. In the common collector configuration, for instance, this procedure is usually equivalent to measuring a reverse-biased diode (the emitter base junction) in series with a forward-biased diode (the collector base junction),

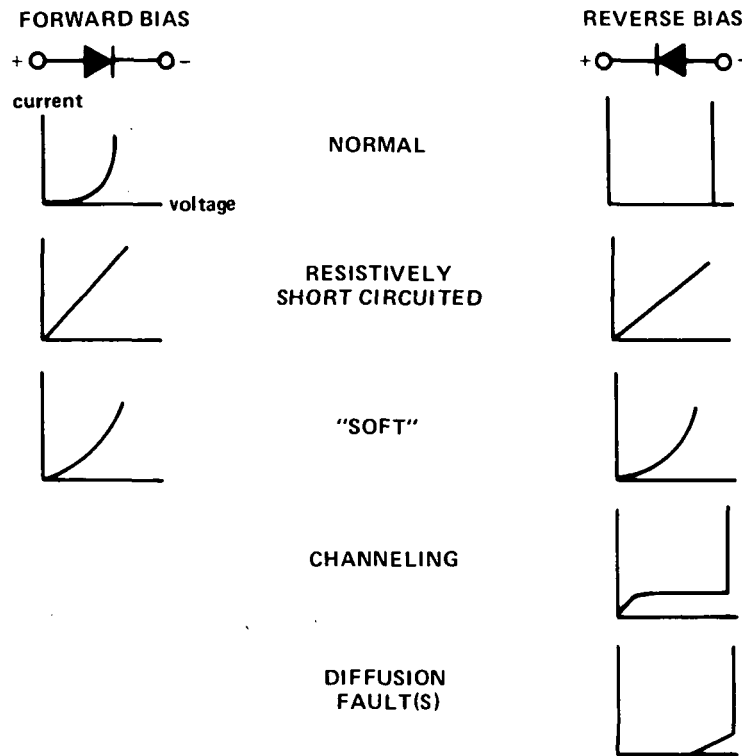


Figure 3. Typical Junction Characteristics (Does Not Apply to Open Base Configurations)

and the expected characteristic is a sharp breakdown about 0.5 volt above the emitter base breakdown voltage (in silicon). In the common emitter configuration, transistor action results in the unique collector-emitter characteristics, including gain-related leakage current, negative resistance regions, and so on.

Voltage-current characteristics that are significant in terms of the device failure should be photographed.

Environmental Conditions

Electrical tests of all kinds may be performed under a variety of environmental conditions.

In practice, it is clear that first testing the device under room ambient conditions is the most productive procedure. If a failure cannot be confirmed at room ambient, then it may be worthwhile to duplicate the environmental conditions at the time of failure, if known. Finally, it may be desirable to expose the device to a variety of environmental conditions, while it is being electrically tested, in an effort to detect intermittent operation (see method F1).

During analytical portions of the investigation, that is, during nondestructive and later testing, it may also be desirable to electrically characterize a device in terms of some environmental parameter. For instance, leakage current or gain might be plotted as a function of temperature. Obviously, this type of characterization must be tailored to the device being investigated and its specific failure.

Procedures Applicable to Individual Part Types

Functional Tests

Appropriate functional tests, listed according to part type, are as follows:

- Integrated circuits, digital—Basic performance of the device in accordance with its truth tables
- Integrated circuits, linear—Operational amplifiers: using a 10X amplifier circuit, measure output for a given input; linear and video integrated circuits: measure gain, as for parametric tests
- Transistors—View voltage-current characteristics with base drive, and estimate gain
- Diodes—View forward- and reverse-bias voltage-current characteristics
- Resistors—Measure resistance
- Capacitors—Measure capacitance and note dissipation factor
- Relays—Check contacts for basic switching when appropriate voltages are applied to the coil(s)

Parametric Tests

Listed according to part type, parameters that should be considered for measurement are as follows:

- Integrated circuits, digital—Gates: quiescent device current, output voltages, drive currents, switching times; flip-flops: quiescent device current, output voltages, switching times; shift registers: quiescent device current, output voltage, threshold voltage, drive current, switching times
- Integrated circuits, linear—Operational amplifiers: gain, input offset current and voltage, bias current, common mode rejection ratio, power supply rejection ratio, maximum output; linear and video amplifiers: gain, input and output impedances, frequency response
- Transistors—Gain, breakdown voltages, leakage currents, saturation voltages, switching times

- Diodes—Forward voltage, breakdown voltage, leakage current, reverse recovery time
- Resistors—Resistance, polarity sensitivity, electrical noise
- Capacitors—Capacitance, dissipation factor, leakage current, dielectric withstanding voltage
- Relays—Pull-in and drop-out voltages, contact resistance, coil resistance, insulation resistance, dielectric withstanding voltage, switching characteristics

Pin-to-pin Tests

The general procedure is specific for integrated circuits.

Junction Tests

The general procedure is specific for transistors and diodes.

Applicable Specifications

Functional and Parametric Tests

For integrated circuits, see MIL-STD-883; for transistors and integrated circuits, see MIL-STD-750 and MIL-S-19500. For resistors, capacitors, and relays, consult a current index of military specifications to find the appropriate document for the specific style of device being examined.

Pin-to-pin and Junction Tests

None

METHOD G3—INTERNAL EXAMINATION

Applicable Part Type(s)

All

Purpose

To ascertain or verify the internal construction of the device; to detect internal anomalies or defects that are evidence of manufacturing errors or misuse and that may be related to the device failure; and to assess the effect of various analytical procedures carried out during the investigation

Equipment (or Equivalent)

The naked eye, low-magnification microscopes (for example, Nikon Stereo-Zoom); a high magnification microscope (for example, Leitz Panphot); an inverted stage microscope (for example, Nikon Model M); and a SEM (for example, Cambridge Stereoscan)

(Internal examination by radiographic techniques is described separately under Method N1.)

General Procedure

Devices with Transparent Packages

There are some devices which may be examined internally prior to package opening. The most common of these is the glass-encased diode without an opaque coating. Such examinations may be conducted during failure confirmation procedures or during nondestructive procedures and are designated "limited internal examination" and "additional internal examination," respectively.

When conducted as a failure confirmation procedure, internal examination of a transparent device should be limited to reported internal defects. For example, a glass diode might be submitted with one of the following comments: "diode appears to have loose particles inside" or "diode works, but contact spring looks cocked." The first internal examination would then address itself to confirming these reports.

When conducted as a nondestructive procedure, internal examination of a transparent device should have the same purposes as nondestructive procedures in general. Specifically, as the first analytical internal examination, it should address itself to identifying a failure mode and mechanism (as opposed to simply verifying a reported failure).

All subsequent internal examinations of transparent devices would be performed in support of semidestructive or destructive procedures and would thus be similar in purpose to internal examinations of parts having opaque packages.

Devices with Opaque Packages

Most devices have opaque packages and thus must be opened prior to internal examination. For these devices, initial internal examination falls into the semidestructive category.

All Devices

In all devices having a hollow package (that is, a package with an internal void), internal examination should address itself to:

- The package interior, including the cap or lid that was removed (if it is still intact)
- The interconnections between the active element(s) of the device (that is, the die, resistance element, coil, and so on) and the package leads
- The active element(s) itself

During all three phases of the internal examination (each of which may benefit from a different type of microscopy), the investigator should be assessing the device in terms of the construction techniques and materials used (the question is: are they as expected?) and general workmanship. At the same time, foreign material or contamination should be noted, as should any obvious flaw, such as cracks or breaks, poorly adhering plating, and poorly dressed wires. Finally, all phases of the internal examination should address themselves to construction features (and faults) peculiar to the device type being investigated. These are discussed under method G3.

All significant findings should be recorded photographically, employing standard photographic attachments for microscopes used.

Procedures Applicable to Individual Part Types

Integrated Circuits

Internal examination should first be concentrated on the package interior, that is, regions surrounding the semiconductor die. In addition to examining the region for general faults listed earlier, the attachment of the die to the package bottom should be examined for voids, excessive material, and so on. The bonds of the interconnection wires to the package leads should also be examined carefully.

The die itself should then be examined. Attention should be paid to the quality of the scribing, and the die should be examined carefully for cracks, including subtle ones. The inspection of the die should be concentrated on the bonds of the wires to the die, the metallization system (looking for obvious overstress damage, scratches and smears, misregistration, microcracking, and proper thickness), the oxide (for imperfections such as damage from overstress, pinholes, and other faulty regions), and the diffusions, as defined by oxide cutouts (for misregistration, flaws in the bulk material, or damage from overstress).

It should be noted that the internal examination may make use of several microscopes, ranging from a low-magnification instrument to a SEM. The order of inspection given above applies to each instrument used; for example, optical inspection of the entire internal structure of the device should be conducted at progressively higher magnifications before progressing to the SEM.

Transistors

Internal inspection of transistors is, in all respects, similar to internal inspection of integrated circuits, described above.

Diodes

For limited internal and additional internal examinations, which are performed on glass-encased diodes without an opaque coating prior to package opening, the following procedure applies.

The device is placed under a low-magnification microscope. For limited internal examinations, the investigator simply looks for the reported problem; as soon as its existence is verified, that particular examination is complete.

For additional internal examinations, the device is examined for any significant anomalies, including those related to positioning of the die, condition of the contact spring, and condition of the anode contact to the die. In addition, the device is inspected for the presence of foreign particles or other material and for physical defects associated with the package or leads.

During additional internal examinations, innovation with the examining equipment may be fruitful. For instance, it is sometimes useful to use two light sources, one above and one beneath the device. Microscopes capable of greater magnification or capable of providing hybrid lighting may also prove useful (once the device has been examined at lower magnifications). It should be clear that the SEM is of no use at this time, because the device package is still in place. Additional internal examinations might include viewing the device interior as the diode is energized, in an effort to detect possible loss of contact due to motion of connecting ribbons, arcing, or other anomalous behavior. Additionally, a permanent magnet could be used at this time to determine whether any internal particles are magnetic and/or loose.

For comprehensive internal examinations, the device is examined as described above, but as or after it is opened. In general, exclusive of interconnection wires and bonds, construction features requiring inspection are the same as those described above for integrated circuits.

Resistors

In devices of all constructions, the resistance element should be examined for evidence of electrical overstress or other abuse. Where possible, the internal lead attachments to the resistance element should be inspected for poor bonding or defective soldering or welding. If a conductive paste is used in the construction of the device, for example, between the resistance film and the end caps, then it should be examined for microcracks or lack of continuity.

The resistance element itself should be inspected carefully for defects. In film-type resistors, the film itself should be examined for inadequate thickness, voids, necked-down regions, and so on. In wirewound resistors, the resistance wire and its insulation should be examined. In some wirewound resistors, it may be practical to unwind the wire for further investigation.

The core of the resistor, especially when made of glass or ceramic, should be examined for breakage or subtle cracks. Hollow-core resistors, or resistors of other construction which have internal voids, should be examined carefully for evidence of arcing.

Capacitors

Of primary interest inside capacitors is the integrity of the dielectric material and connections to both the anode and cathode; in addition, the interior of the device should be inspected for faults (other than dielectric faults) that might cause leakage currents between anode and cathode. In capacitors having a slug-type anode, evaluation of the dielectric integrity may best be accomplished by special tests for pinholes (see method D9). It should be noted that cross-sectioning is necessary to expose construction features of some capacitors, particularly ceramic block type devices. Cross-sectioning techniques are discussed under method D7.

Relays

Several procedures related to internal examination of relays are described elsewhere in this document. For instance, observation of internal mechanical operation is described under method S10; contact force and over-travel measurements, method S11; and physical measurements of internal elements, method G8.

Beyond these procedures, internal examination should concentrate on: the condition of the coils, their insulation, and their connections to the package leads; the condition of mechanical portions of the device, including the coil frame, the armature and its pivot, and the magnet (if any) and its attachment; the condition of the contacts, including the contact arms and the mating surfaces; and the condition of the header, including insulating spacers, glass seals around the package leads, connections of the contacts to the package leads, and so on. Throughout this procedure, it is mandatory that all contamination, in any form, be carefully noted and be considered in terms of its possible role in the reported failure. In addition, any evidence of electrical overstress should also be carefully noted.

Applicable Specifications

Inspection criteria applicable to integrated circuits may be found in MIL-STD-883; those applicable to transistors and semiconductor diodes may be found in MIL-STD-750. Specifications applicable to resistors, capacitors, and relays are numerous and depend on the exact purpose and style of the individual device. Therefore it is recommended that a current index of military specifications be consulted to locate appropriate specifications.

METHOD G4—BAKE

Applicable Part Type(s)

Integrated circuits, transistors, diodes, resistors, and relays

Purpose

To determine whether there exists a condition in a device which responds to an extended exposure to high temperature

Equipment (or Equivalent)

Environmental chamber (Delta Model MK2800); a temperature measuring device; a power supply (Harrison Model 865B); and instruments (such as voltmeters) necessary for setting the test conditions

General Procedure

This procedure, which is first performed prior to package opening, must be preceded and followed by electrical tests. The procedure is usually done on devices which are reported to have high or unstable leakage currents, low or unstable resistance, low gains (integrated circuits and transistors only), or high contact resistance (relays only).

One of the more common causes of these defects is contamination on the surface of the active element of the device. In integrated circuits, transistors, and diodes, the contamination may be on the die or in the oxide passivation, as well as elsewhere in the device package; in resistors, contamination which is significant is usually on the surface of the resistance element; and, in relays, contamination on the contacts is most significant (although contamination elsewhere in the package can cause failures).

After electrical tests have been made, the device is placed in the environmental chamber and baked overnight (about 12 hours) at its specified maximum storage temperature without any bias. At the end of that period, the device is allowed to stabilize at room conditions and is then retested electrically. If the post-bake electrical tests indicate that the characteristics of the device are now normal, or within specification, or simply have changed significantly, it may be possible to conclude that there was contamination in the device.

For integrated circuits, transistors, and diodes, additional tests may disclose which of the two defects (contamination in or above the oxide) was present. Toward this end, another bake is done. This time a bias voltage is applied to the device. The bake is done at the maximum permissible temperature (with bias) for time periods ranging up to approximately 48 hours. At the end of this period, the temperature is lowered and then the voltage is turned off. This exact sequence is necessary. The device is again electrically retested. If a high leakage current or low gain reappears, then it may be possible to conclude that the defect in the device is caused by contamination in the oxide passivation. If it does not reappear, then the defect was probably caused by surface contamination on the die or contamination elsewhere in the package.

The choice of bias depends entirely on the individual part being tested. A choice of biasing that results in a junction(s) being reverse-biased at approximately 75 percent of its rated breakdown voltage is often best to show up problems associated with contaminated oxides.

A bake (with or without bias) may also be performed after the device has been opened. The procedure to be followed is that described above; however, precautions should be taken to prevent external contaminants from reaching critical interior portions of the

device. Contamination is particularly likely in an environmental chamber that has been used for a variety of chores without periodic cleaning.

A vacuum-bake, achieved through the use of a thermal-vacuum chamber, may encourage stubborn contaminants to volatilize. In particular, contaminants that permeate portions of a device (especially the interior of a device) may not bake out with high temperature alone, although they will if a vacuum is used.

Procedures Applicable to Individual Part Types

Procedures relating to biasing and parametric measurements of the various part types may be found under method G2, electrical tests.

Applicable Specifications

For general information, see MIL-STD-202; for integrated circuits, see MIL-STD-883; and for transistors and diodes, see MIL-S-19500.

METHOD G5—CHEMICAL CLEANING

Applicable Part Type(s)

All

Purpose

To remove any invisible contamination on the exterior or interior surfaces of the subject device which could be related to its faulty electrical performance

Equipment (or Equivalent)

Ultrasonic cleaner (Bendix sonic energy products Model SEC-48 AB-2), dry nitrogen, deionized water, various chemical cleaning solutions, and various containers and tweezers normally found in the chemical laboratory

General Procedure

This procedure is intended to be used only on devices which exhibit an electrical problem that could conceivably be related to invisible contamination on or in the package (such as high leakage current). After it has been ascertained that there are no package leaks, external cleaning may be considered a nondestructive procedure. Internal cleaning must be performed after package opening and is therefore, at the very least, in the semidestructive category of procedures.

If visible contamination is observed on or in the device, a specimen should be collected for further analysis beyond the scope of this procedure. There are two circumstances under which cleaning should not be carried out: (a) when there is a previously detected package

fault that bears further analysis; and (b) when there is no way an invisible contaminant might cause the detected electrical failure (for example, an external contaminant might cause an excessive leakage current between package leads, but could not directly cause an internal open circuit).

Prior to external cleaning, any tape, spaghetti tubing, or other obvious extraneous material on the device should be removed and saved, and the faulty electrical parameter remeasured. If the electrical problem still exists, then a series of cleaning operations can be started, with an electrical measurement following each operation.

For each operation, the part is usually held with tweezers and submerged in a small beaker containing the desired chemical cleaner. The part is moved around within the solution and is then withdrawn and immediately dried with a gentle stream of dry nitrogen. More efficient cleaning can be accomplished with an ultrasonic cleaner, but a judgment will have to be made concerning the device fragility versus the energy imparted to the device in the ultrasonic cleaner. For example, the possibility should be considered that small interconnection wires and their bonds might be damaged.

The order in which the various chemical cleaners are used is important so that some information concerning the nature of the contamination can be determined. An example might be an oil-type film on or within a part. If water were to be the first cleaning agent used, it probably would not remove the oil, but it might form a gummy residue. This new residue might not be removable with the organic cleaner that would normally have removed the oil.

In general, chemical cleaning is usually carried out in steps designed to remove, in order: organic contaminants, nonorganic/non-water-soluble contaminants, and water soluble contaminants. The chemical selected from among the various groups is chosen so that the materials making up the device exterior or interior will not be damaged. Particular care should be taken with devices utilizing plastics.

Organic cleaners are tried first. Trichlorethylene is good for removing oils and grimes. Oils, inert, nonionic, and pure organic particles may be removed with cleaners such as freon, toluene, xylene, or hexane. The next group of chemicals is effective against oils, salts, and part-ionic, part-polar substances. These chemicals include acetone, propanol, and ethyl alcohol. After one or more of these is used, deionized water and then deionized water plus detergents may be tried. These are useful against salts and ionic and nonorganic substances.

After this stage in the cleaning, each cleaning step is followed by a rinse before making the electrical measurement. The rinse should consist of deionized water followed by propanol (or equivalent) to remove the water; the part should then be dried with a gentle stream of dry nitrogen.

If no electrical change has been detected, acids may next be used to clean the device. The acids must be carefully selected so as not to damage the part. One particular caution is to avoid acids when they may leach out conductive materials in the package sealing glass.

Another caution is that a normally safe acid may combine with a contaminant on or in the device with results that are catastrophic to the device. Bases may be tried next, if possible without damage to or undue contamination of normal constituents of the device.

If the electrical problem still exists after all of these cleaning operations, it can be assumed that contamination on an external (or internal, as applicable) surface of the device did not cause the problem. (It is still possible, of course, that an included or embedded contaminant is responsible for the failure.) If at some point in the cleaning operation the electrical problem clears up, then the last chemical used may give an indication of the nature of the contamination.

Procedures Applicable to Individual Part Types

None

Applicable Specifications

None

METHOD G6—pH MEASUREMENTS

Applicable Part Type(s)

Capacitors (acid electrolyte devices only)

Purpose

To determine whether there is an acid contaminant on the exterior surfaces of the capacitor package or leads or between the seals of a capacitor having a double-seal arrangement. This condition is usually a result of electrolyte leakage past the seal(s).

Electrolyte leakage is a potential cause of failure for a number of reasons. First, complete loss of electrolyte obviously leaves the device inoperative with an open circuit; second, electrolyte reaching portions of the anode not insulated with dielectric material, or reaching the uninsulated anode lead, may simply cause the device to become short circuited or to have a high leakage current; and third, corrosive effects of the leaking electrolyte may cause damage that results in a failure.

Equipment (or Equivalent)

Litmus paper or a set of Fisher short-range Alkacid test papers

General Procedure

This procedure is usually first carried out on the unopened package (prior to significant handling and of course prior to package cleaning, if any). The procedure may later be carried out during various stages of device disassembly and especially after the space between inner and outer seals is accessible.

Since the quantity of acid on the surface to be tested is likely to be small, the tip of the strip of litmus paper is moistened with a drop of water. This portion of the litmus paper is then brought into contact with the surfaces of interest. If acid is present, the litmus paper will turn red. (A base would cause the litmus paper to turn blue.)

The Fisher set of Alkacid test papers consists of seven different paper types that permit actual pH values throughout the complete range from 0.0 to 14.0 to be determined, if desired. Acids have values less than pH 7, with hydrogen ion (H⁺) concentration increasing toward pH 0. Alkalies have values greater than pH 7, with hydroxyl ion (OH⁻) concentration increasing toward pH 14. Neutral solutions have a pH value of 7.

Procedures Applicable to Individual Part Types

The general procedure is specific for capacitors with an acid electrolyte.

Applicable Specifications

None

METHOD G7—ELECTRICAL TESTS BY IMMERSION

Applicable Part Type(s)

Capacitors having a slug-type anode

Purpose

To permit electrical testing of a capacitor after the anode slug has been removed from the device package. This procedure is analogous to electrical probing of other device types.

Equipment (or Equivalent)

Sulfuric acid, tweezers, clamps and stands, various beakers or dishes normally found in a chemical laboratory, and electrical testing equipment as required for the particular parameter(s) being measured (see method G2, electrical tests)

General Procedure

Sulfuric acid is poured into a shallow beaker. The anode slug is positioned such that it is immersed in the sulfuric acid, but the lead wire and seal area are above the acid level. The capacitor case (removed earlier) is also immersed in the acid for use as the cathode electrode. (If the case is not available, then another suitable electrode must be substituted for it.) The slug and the case (or other electrode) are supported in such a manner as to allow affixing of electrical test leads without introducing a short circuit between them and without damage to the test leads by the acid. The electrical testing is then performed with the sulfuric acid acting as the capacitor cathode.

Procedure Applicable to Individual Part Types

The general procedure is specific for capacitors with a slug-type anode.

Applicable Specifications

None

METHOD G8—PHYSICAL MEASUREMENTS OF INTERNAL ELEMENTS

Applicable Part Type(s)

Relays

Purpose

To check the dimensions of internal elements of the relay, which, if improper, could result in binding or "slop" and be responsible for a variety of permanent and intermittent failures

Equipment (or Equivalent)

Nikon Shadowgraph Model 3A

General Procedure

The deencapsulated relay is placed on the specimen stage of the shadowgraph. The proper shadowgraph objective is chosen for the measurement to be made. The relay and/or the specimen stage is moved about until one edge of the piece to be measured is positioned along a line on the shadowgraph display and the piece is also oriented along one axis of movement of the specimen stage. The micrometer reading on the chosen axis is recorded, and then the specimen stage is moved, using the micrometer adjustment, until the other edge of the piece being measured occupies the initial starting spot on the shadowgraph display. The new micrometer reading is recorded and the difference in the two readings, that is, the desired dimension, is calculated. For critical measurements, several repetitions of the same measurement are in order. Particular care should be taken to prevent backlash in the micrometer movements from influencing the measurements.

Procedures Applicable to Individual Part Types

The general procedure is specific for relays.

Applicable Specifications

None

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METHOD F1—TESTS FOR INTERMITTENT OPERATION

Applicable Part Type(s)

All

Purpose

To reproduce reported intermittent failures or to detect failures which do not manifest themselves under ambient conditions. Intermittent operation may result from many conditions; for example, movement of a loose conductive particle during vibration might intermittently short-circuit internal elements, separation of materials having different coefficients of thermal expansion might cause intermittent open circuiting of internal elements, and so on.

Equipment (or Equivalent)

- Temperature method—Environmental chamber (for example, Delta Model MK2800); temperature potentiometer; and suitable instruments for monitoring the device (see method G2, electrical tests)
- Vibration method—Vibrator unit (for example, M.B. Electronic Automatic Vibrator Unit); suitable instruments for monitoring the device
- Shock method—Shock machine (for example, AVCO Model SM005-2); suitable instruments for monitoring the device

General Procedure

Of the three basic methods available, involving temperature cycling, vibration, and shock as means to induce a failure, a choice must be made. If it is reported that the device exhibited its failure during temperature cycling, vibration, or during conditions of shock, the choice is obvious. If conditions are not specified, it is most usual to follow the sequence given below.

Temperature Method

The first measurements or observations are made at room temperature or the ambient temperature at which the device normally operates. These measurements should be recorded. If an oscilloscope is used, photographs of the initial displays may be in order.

While monitoring the electrical performance of the device, the temperature of the chamber containing the device is increased in steps of 5°, 10°, 15°, or 20° until the maximum temperature specified by the manufacturer is reached. Five to 10 minutes is allowed for the temperature in the chamber to stabilize after each step. The same procedure is followed during the cold cycle until the minimum temperature specified by the manufacturer is reached. The procedure is repeated as many times as is practicable, or until a failure is detected.

Sometimes a specific temperature at which the device was observed to have failed is reported. If this is the case, the analyst usually proceeds to first observe the device at this temperature. If the failure is not induced at this temperature, then a complete temperature cycling procedure is followed.

Another method involves the use of a hot air gun and spray coolant to effect temperature changes. This method is generally acceptable as long as the temperature of the part is carefully monitored; hot air guns, in particular, can quickly raise the temperature of some devices beyond their maximum ratings. There is also other equipment that may be used to effect temperature changes. An example is the EG&G ThermoSpot, a temperature probe system that facilitates simple temperature control of some device types.

Vibration Method

Initial measurements and records of the device's electrical performance should be made. The frequency range (for example, 10 to 2000 Hz) and the acceleration (for example, 98 m/s^2 , 147 m/s^2 , 196 m/s^2) at which the device is to be vibrated are selected according to the manufacturer's specification for the part type.

There are two standard cycles that can be used: the 10-minute cycle and the 20-minute cycle. If the 10-minute cycle is selected, then the device is vibrated from 10 Hz to 2000 Hz and back to 10 Hz in a maximum of 20 minutes. This procedure is done in each of three mutually perpendicular planes. The device performance is monitored throughout the test. The 20-minute cycle is simply twice as long (that is, 40 minutes).

Shock Method

The device should be mounted rigidly on the shock testing apparatus. Its initial electrical performance is then measured and recorded. For each shock blow, the shock machine carriage shall be raised to the height necessary for obtaining the required peak acceleration and then allowed to fall. Means shall be provided to prevent the carriage from striking the anvil a second time. Testing should be conducted at low shock levels, progressing up to the maximum acceptable level for the device, or until a failure occurs. Another method used frequently is to gently tap the device while it is being tested functionally.

Monitoring

The type of electrical monitoring performed is a function of (a) the part type being investigated, (b) available knowledge regarding the internal structure of the device, and (c) available knowledge regarding the failure of the device. Once the decision has been reached regarding the type of monitoring to perform, then there are questions to be answered regarding the sensitivity of available monitoring equipment, in terms of detecting both amplitude changes and changes that occur over very short time durations.

As an example, an integrated circuit is reported to fail at ambient conditions with an open circuit at pin 2 and is submitted for investigation. However, during early confirmation tests, the failure cannot be reproduced, and it is decided to perform one or a number of tests for intermittent operation. Because of the reported open circuit at pin 2, it makes sense to monitor some electrical parameter associated with pin 2. The only remaining question regards the monitoring equipment: What equipment will ensure that open circuits of extremely short durations will be detected? (The investigator must answer this for himself.)

Suppose the reported (but unreproducible) failure with the integrated circuit had been a periodic drop in output voltage of 2 mV. It would make sense to monitor the errant output voltage. The only remaining question is: What monitoring equipment will detect so small an instability, particularly if it occurs over only a very short time duration? (Again, this is a question for the investigator.)

Procedures Applicable to Individual Part Types

The procedures most definitely related to individual part types are those relating to electrical monitoring. Method G2 deals with functional, parametric, junction, and pin-to-pin testing on a part-type-by-part-type basis; method G2 may contain information useful for making a decision with regard to monitoring.

Applicable Specifications

Some information pertaining to each of these tests may be found in MIL-STD-202D.

METHOD F2—LISTENING TESTS

Applicable Part Type(s)

Relay

Purpose

To determine whether the device emits normal mechanical sounds when operated

Equipment (or Equivalent)

The ear; a stethoscope; a tape recorder

General Procedure

A listening test should not be performed at this time unless a decision has been made to attempt to operate the relay. (There may be compelling reasons to not operate the relay at this time.) If a decision has been made to attempt operation of the relay, then the listening test can be an adjunct to this.

As voltages are applied to or removed from the device in an attempt to cause the relay to switch, the device is listened to. There are three possible basic results:

- The device emits no detectable sound.
- The device emits normal sound.
- The device emits abnormal sound.

Since different relay types emit characteristically different sounds and sounds of different intensities, it may be useful or necessary to have an operating relay of the same type available for comparison.

Procedures Applicable to Individual Part Types

The general procedure is specific for relays.

Applicable Specifications

None

METHOD N1—RADIOGRAPHIC EXAMINATIONS

Applicable Part Type(s)

All

Purpose

To detect defects within enclosed packages

Equipment (or Equivalent)

The apparatus and materials for this test shall include:

- Radiographic equipment (for example, Picker Dynamic System or other)
- Radiographic film—Very fine grain film, with 0.025-mm (0.001-in.) resolution (Kodak M2 Industralex film)
- Radiographic viewer—Capable of 0.025-mm resolution in major dimension (for example, Nikon Model 3A shadowgraph)
- Holding fixtures—Capable of holding devices in the required positions without interfering with the accuracy or ease of image interpretation

General Procedure

The device should be mounted in the holding fixture in such a manner that the device is not damaged or contaminated. The X-ray equipment should be adjusted for proper voltage, focal spot, and film distance. If a dynamic X-ray system (for example, Picker unit) is used, the device can be seen on the Vidicon screen. Before any radiographs are made, the device can be examined thoroughly while being rotated or moved along the X, Y, or Z axis. Many physical defects (including loose particles) have been observed in this manner.

After a thorough and satisfactory examination with dynamic equipment has been made, the device is “shot” for the predetermined time interval required to reproduce acceptable radiographs. Radiographs should be made for each view required or for each view necessary to show up defects, if any. At times it is important to record on the film the following:

- Device manufacturer’s name or code identification number
- Device type or part number
- Production lot number or date code
- Date

After the films have been processed, they should be examined on an illuminator or shadowgraph (for example, Nikon Model 3A) at a magnification between 6X and 8X. Any radiographs not clearly illustrating defects should be retaken.

Procedures Applicable to Individual Part Types

- Integrated circuits and transistors—Prior to performing radiographic examination, consideration should be given to possible damage to MOS devices caused by the X-rays.
- Relays—If dynamic X-ray equipment is used, a relay may be energized during the examination to assess the internal operation of the device.

Applicable Specifications

For integrated circuits, see MIL-STD-883; for resistors, capacitors, and relays, see MIL-STD-202; and for transistors and diodes, see MIL-STD-750.

METHOD N2 - PACKAGE LEAK TESTS

Applicable Part Type(s)

All

Purpose

To determine the integrity of the hermetic seals used in the device package (only for devices intended to be hermetically sealed) and to determine the extent of package leaks, if they exist. A leak may result in the escape of normal gases from within the device, or, more importantly, the introduction of undesirable gases, liquids, and other contaminants into the device. Such contaminants can be responsible for a large number of difficulties, ranging from corrosion to low insulation resistance.

Equipment (or Equivalent)

Radiflo leak detection system (for example, Consolidated Electrodynamics Corporation (CEC) Model 24-510), a vacuum-pressure chamber, vacuum pump, hot plate, various vessels or containers, and various chemicals (for example, fluorochemical FC-78 and FC-43, krypton-85, silicone oil, fluorescein dye, dry nitrogen, and helium gas), all depending on the test being made.

General Procedure

Fine leak detection may be performed in accordance with the operation manual supplied with the CEC Model 24-510 Radiflo leak detector. Gross leak detection is performed, after fine leak detection, in accordance with NASA TP961-001, *Gross Leak Detection Using a Fluorocarbon Method*. The order in which fine and gross leak tests are done is purposeful. If gross leak tests were to be performed first, there is the real possibility that a fine leak will be plugged up by the agents used; hence, the leak might not be detected during subsequent fine leak tests.

Prior to leak-testing a device, any tape, contamination, shrink tubing, wax, and so on, which could give false indications of package leaks, should be removed from the package exterior.

When there is a high probability of a device being leaky (for example, when a crack or hole is discovered in the package during external examination), then the Radiflo test could leave some devices, such as a relay with Teflon tape inside, or a capacitor with an internal Teflon seal, in a radioactive condition. This could delay further testing for an unreasonable length of time, and in these instances a helium fine leak test might be a better choice.

Similarly, when a device is almost certain to be a leaker, there may be good reason to avoid a gross leak test altogether. The agent used may obliterate important evidence within the device package. In all instances, an independent decision must be made that takes account of all known factors and findings. (It should be noted that some individuals advocate not using gross leak tests during failure analysis; this extreme position, although it removes the need to make a decision, may result in a repeated loss of useful information and should not be encouraged.)

It should be noted that, just as the helium method is a possible substitute for Radiflo leak detection, there are possible substitutes for the fluorocarbon gross leak detection method. One of these, a bubble test using silicone oil, is considered less sensitive than the fluorocarbon method and offers no known advantages. The use of a penetrating dye, on the other hand, may offer advantages in some instances. For one thing, the penetrating dye is thought by some individuals to be more sensitive a leak detector than any bubble method; but, more significantly, the dye leaves a permanent indication that can be used to trace the exact path of the leak to the package interior. Thus, the dye may be more useful in instances where a detailed study of the cause of the leak is desired.

Procedure Applicable to Individual Part Types

Information applicable to individual part types may be found in the referenced specifications (see below).

With particular regard to integrated circuits, or any device having relatively large package surface areas, special attention should be paid to the maximum pressures used during both fine and gross leak tests. Packages having large surfaces without central support have been damaged by pressures used successfully to leak test smaller packages.

Maximum absolute pressures presently being used at GSFC are as follows:

TO-5, TO-18, TO-46, TO-100 to -111, TO-66 (curved top only), metal stud-mounted TO-60 and TO-61, DO-7	620,000 N/m ² (90 psia)
TO-3 (curved top), TO-114, glass diodes with internal cavities, DO-7	517,000 N/m ² (75 psia)
TO-3 (flat top), TO-66 (flat top)	413,000 N/m ² (60 psia)

Flat pack (0.95 by 0.95 cm (3/8 by 3/8 in.) or smaller), dual in-line package (DIP), relay crystal can or 1/2-crystal can, capacitors (round can)

310,000 N/m²
(45 psia)

Flat pack (larger than 0.95 by 0.95 cm (3/8 by 3/8 in.)), relays larger than crystal can size, capacitors (rectangular cans)

207,000 N/m²
(30 psia)

Applicable Specifications

For integrated circuits, see MIL-STD-883, Method 1014; for transistors and diodes, see MIL-STD-750A, Method 1071; and for capacitors, relays, and resistors, see MIL-STD-202D, Method 112A.

METHOD N3—PARTICLE DETECTION TEST

Applicable Part Type(s)

Transistors, diodes, capacitors, relays, and integrated circuits

Purpose

To detect loose extraneous matter within the subject device. Such matter, if conductive, may cause short circuits or intermittent short circuits. Any such matter, conductive or not, may be indicative of dirty processing by the manufacturer, of a disintegrating device interior, or, in some rare instances, of electrical overstress.

Equipment (or Equivalent)

Radiographic equipment (for example, Picker Dynamic System or other); vibration unit (M.B. Electronics system)

General Procedure

- Monitored vibration method—See method F1, tests for intermittent operation.
- X-ray/vibrate/X-ray method—This method has frequently been used in the laboratory. The device should be radiographed first and a careful study made of the radiograph. The methods used in making the radiograph should be the same as those employed in method N1, radiographic examinations. The device should be vibrated and radiographed again. The second radiograph is then compared closely with the original to see if any objects or particles have moved. In some instances, these objects can be identified from the radiograph.
- Acoustical noise method—No established procedure

- Accelerometer method—No established procedure
- Particle impact noise detection (PIND) test method—No established procedure
- Tape trap method—No established procedure

Procedure Applicable to Individual Part Types

Procedures applicable to individual part types are discussed in the two referenced procedures, that is, methods F1 and N1.

Applicable Specifications

Applicable specifications are listed in the two referenced procedures.

METHOD N4—DEWPOINT TESTS

Applicable Part Type(s)

Integrated circuits, diodes, and transistors

Purpose

To detect (or measure the amount of) moisture within the package cavity of a hermetically sealed device. Moisture, in a device intended to have a dry internal atmosphere, can cause several types of anomalous behavior as a result of its mere presence and can also produce permanent catastrophic failure, for example, by corrosion. There are many situations in which dewpoint tests are superfluous, however, and the need to perform the test should be considered carefully.

Equipment (or Equivalent)

Environmental chamber capable of varying the temperature from the specified high temperature to the specified low temperature while the device parameters are being monitored (for example, Delta Design MK2800); Birtcher Corporation (now Precision Standards Corp.) Model 70 Semiconductor Test Set or other test equipment suitable for measuring the device leakage current

General Procedure

To minimize a false indication of moisture due to moisture on the package exterior, it is desirable to place the device under test (complete with its leads) inside a test tube or other suitable container filled with silicone oil; alternately, the moisture in the test chamber may be reduced to very low levels by various methods.

A device parameter (usually leakage current) is monitored while the environmental chamber is brought up to the specified high temperature (at least 10 K above ambient temperature if no high temperature is specified). The temperature is next decreased, at a rate not to

exceed 10 K per minute, to the specified minimum temperature; the temperature is then raised, at a similar rate, back to the high temperature. The dewpoint temperature is indicated by a sharp discontinuity in the parameter being monitored with respect to temperature (for example, a sharp discontinuity in leakage current).

If no discontinuity in leakage current is observed, it might be assumed that the dewpoint is at a temperature lower than the minimum temperature reached and that the device being tested is acceptable. However, it may only mean that internal moisture did not condense on surfaces critical to leakage current, and a repetition of the test might therefore be considered.

Since the dewpoint is most likely to show up at low temperatures, it may be desirable to decrease the temperature at a slower rate than 10 K per minute once low temperatures are encountered.

Procedures Applicable to Individual Part Types

Electrical characteristics monitored during dewpoint tests should be ones expected to change in the presence of moisture. Considerations for different part types are discussed below.

Integrated Circuits

In general, it would be desirable to measure leakage current between adjacent metallization stripes on the die. This requires two adjacent stripes that can be biased with respect to one another without incurring any current drain other than leakage. This in turn requires a knowledge of the device construction which may not be available. If this information is not available, monitoring of one or more transistor junctions accessible from the outside pins would be an acceptable substitute procedure. (See "Transistors," below.)

Transistors

Three possibilities exist: (a) monitoring of emitter-base leakage current (disadvantageous since only a relatively low voltage can be used); (b) monitoring of collector-base leakage current (possibly of little meaning if there is no collector metallization on top of the die); and (c) monitoring of both junctions connected in parallel (providing none of the advantages of (b) and all of the disadvantages of (a)). In any case, the highest acceptable measurement voltage should be applied, without driving the device into breakdown.

Diodes

With a diode, measurements are limited to one junction. Reverse leakage current, measured at as high a voltage possible without inducing breakdown, and without exceeding the specified maximum voltage of the device, is generally the most useful parameter for detecting dewpoints.

Applicable Specifications

For integrated circuits, see MIL-STD-883, Method 1013, and for transistors and diodes, see MIL-STD-750A, Method 1066.1.

METHOD N5—TEMPERATURE PROFILE TESTS

Applicable Part Type(s)

Capacitors

Purpose

To detect significant anomalies in the temperature profile of the device (for example, "hot-spots"), as detectable from the exterior of the device. Such anomalies could be indicative of a fault region, and thus could be useful in localizing a failure.

Equipment (or Equivalent)

Not established at this time

General Procedure

Not established at this time

Procedures Applicable to Individual Part Types

The general procedure is specific for capacitors.

Applicable Specifications

Not established at this time

METHOD N6—MOISTURE CONTENT TESTS

Applicable Part Type(s)

Relays

Purpose

To detect the presence of (and possibly measure the amount of) moisture in the packages of hermetically sealed devices. Moisture in relays may cause high leakage currents, corrosion, or anomalous contact performance.

Equipment (or Equivalent)

Environmental chamber (for example, Delta Model MK2800) and milliohm meter (for example, Keithley Model 502)

General Procedure

First, the contact resistance of a given set of contacts in the subject relay should be measured at room temperature and recorded. That set of contacts should then be opened electrically

and the temperature in the environmental chamber lowered to the freezing point of water.. (If there is internal moisture, ice may form on the contacts.) The contacts are then closed electrically and the contact resistance remeasured. If no ice was formed, the resistance should be normal. If ice was formed, the resistance may be excessively high. Since internal moisture may condense on interior portions of the device other than the contacts, it may be worthwhile to repeat the procedure a number of times if no moisture is detected initially.

Procedures Applicable to Individual Part Types

The general procedure is specific for relays.

Applicable Specifications

None

METHOD N7—MAGNETIC TESTS

Applicable Part Type(s)

Relays

Purpose

The purpose of this test is to determine the strength of the magnetic field associated with a permanent magnet-type relay. Some relay failures have resulted from a loss of permanent magnetism.

Equipment (or Equivalent)

RFL Industries Model 750 Gauss Meter

General Procedure

The relay can be tested properly only in an area remote from significant external magnetic fields. Using a gauss meter, the sensing element (a Hall-effect device in the referenced equipment) is moved about the relay until a maximum reading is obtained. Unfortunately, manufacturers' specifications for permanent magnet-type relays do not normally address themselves to the magnetic field strength of the device; hence, a similar device known to be operating properly must be used as a reference standard.

Frequently it may be necessary or desirable to remove the device case to obtain information regarding field strength. These measurements would by definition then fall into a semidestructive category and should be avoided until all nondestructive tests have been completed. Opening of the device prior to magnetic measurements will be necessary if the case serves as a magnetic shield, and removing the case is a prerequisite for making magnetic measurements in (or as close to as possible) the magnetic circuit of the relay.

Procedures Applicable to Individual Part Types

The general procedure is specific for relays with permanent magnets.

Applicable Specifications

None

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METHOD S1—PACKAGE OPENING OR DEENCAPSULATION

Applicable Part Type(s)

All

Purpose

To allow direct internal examination of the device and to permit internal tests as necessary.

Equipment (or Equivalent)

Buehler Ltd. grinding wheels, Buehler handimet grinder, Buehler cutter, Motorola transistor can opener, GSFC FA collet-type can opener, GSFC FA flat pack opener, cutting pliers, jeweler's saw, hypodermic needles, knife edges, vise, various chemicals, low magnification microscope (for example, Nikon Stereo-Zoom)

General Procedure

The package lid should be cut or ground open or portions of the package exterior removed to gain access to the internal elements of the package. (Methods and tools applicable to individual part types are described later.) In the event that opening or deencapsulation must be done either wholly or partly by chemical means, the manufacturer of the device should be contacted to determine appropriate reagents and techniques. There are so many different potting and packaging materials in use that it is usually impractical to guess or even determine by trial-and-error what deencapsulation chemicals will be effective for a particular device.

With regard to X-ray examinations and grinding procedures used in the process of package opening, methods N1 and D7, radiographic examinations and cross-sectioning, respectively, may be consulted.

On some occasions, there may be interest in potting the device interior prior to extensive opening. Applicable only to devices normally having an internal void, this procedure is intended to "freeze" internal features and defects (loose particles, poor wire dress, and so on). The exact manner in which prepotting is done must be worked out for the individual device. As an example, the following procedure has been used successfully on flat pack integrated circuits having metal lids. First, the lid thickness is considerably reduced by grinding (described in more detail later). Then holes are made in opposite corners of the lid, using either a microminiature drill or a sharp tool that serves to puncture the lid. Finally, a clear, thermosetting epoxy (for example, Acme epoxy resin 655 from Acme Chemicals) is allowed to enter one hole (the opposite hole acts as a vent). After the epoxy has been cured, the remainder of the lid is removed in a conventional manner. This method precludes much further testing of the device; however, energy dispersive X-ray analysis (EDXA) or electron microprobe analysis of contaminating particles is facilitated, requiring only that the device be ground down until the particle of interest has been reached.

Procedures Applicable to Individual Part Types

Integrated Circuits

Most cylindrical metal packages can be opened with the Motorola transistor can opener.

Flat packages having a metal lid are usually opened by grinding. The device is positioned on a puck with the lid facing outward and is attached by taping the external leads to the puck. The puck is held in the hand and the device lid is held against and drawn across an abrasive. No water or oil is used on the abrasive since this could contaminate the package interior. As the grinding progresses, a finer abrasive is used. An outline of the package frame can be observed through the lid after the lid has been ground very thin. The device is observed frequently under a low power microscope during the final stages of grinding.

When the lid is very thin, a sharp hypodermic needle point may be inserted carefully under the lid, and the lid pried off by slowly working the hypodermic needle or knife edge around the circumference of the lid while trying to lift it off. Care must be taken so as not to allow the needle point to protrude deeply into the package or to allow the lid to fall into the package.

Another technique sometimes used with devices having a solder-sealed lid is to use a hot plate to melt the solder so the lid may be removed. This method is not used often because of possible internal contamination from solder splash or flux residues.

Ceramic flat packages may be opened by grinding as described above, with a few minor variations. When a small hole first appears in the lid, the grinding is stopped and a hypodermic needle point is inserted into the hole. Slight outward pressure is used to chip or knock out small portions of the lid. The edge of the lid is gradually broken away until the whole top falls off. The device is usually inverted during this operation but nevertheless contamination in the form of fine particles or dust always deposits itself on the die and in the package. Before indiscriminately blowing the contamination away, the device interior should be observed microscopically to determine if additional contamination which is not related to the package lid material or the abrasive material is also present within the package interior. If there is no additional contamination, then a gentle, controlled stream of dry nitrogen can be used to remove the contamination introduced during opening, while observing the device interior through the microscope.

Ceramic flat packages can also be opened by shearing off the lid. A tool is available in the GSFC FA Lab for this operation; shearing off the lid may also be accomplished with diagonal cutters, using a developed technique of simultaneously cutting and popping the lid.

There are both advantages and disadvantages to these methods. Five to ten packages might be opened by a skilled operator using the shear method in the time required to grind open one device. There is little or no contamination introduced by the shear technique. However, there is a greater probability of destroying the device with the shear technique. For instance, the case can shatter, dislodging the external leads, causing the die to crack or become loose, and/or breaking the interconnection wires. If only one or two devices are submitted for a failure analysis, then use of the grinding method is recommended. If

several devices are submitted, then the shear technique might be used, especially on devices being opened for purposes of comparison or evaluation.

Plastic-encapsulated packages should be X-rayed to determine the location of internal elements. Grinding techniques are then used to grind the lid until it is very thin (so that it becomes almost transparent) or until another type of plastic surrounding the die is encountered. At this point a chemical deencapsulant is used. The manufacturer should be contacted in order to determine a satisfactory solvent or chemical. The grinding is done first to reduce the lid thickness. As desired, the thin lid will then dissolve before the body mainframe (which holds the leads intact).

Transistors

Most cylindrical metal transistor packages can be opened with the Motorola can opener. When using this can opener, clean the instrument, including the cutting wheel and roller guides, before starting. Use the limit adjustment for controlling depth of cut. The opening procedure may be observed using a low power microscope. Accumulated particles should be blown away as the work progresses. A clean environment should prevail in the work area and the opened device should be kept in a closed container except when observations or tests are being performed on it.

Some power transistors cannot be opened with the Motorola can opener due to their large size. The FA Lab collet can opener will open some large cylindrical transistor packages using the same basic technique as the Motorola can opener.

Grinding techniques similar to those mentioned previously for integrated circuits are often used with large power transistors. If the cap is made of a relatively thick metal, it may be best to grind around the top edge on an angle so that the top can be lifted or peeled off without having to grind through all of the metal on the lid. It should be noted that some power transistor cases use a crimped tubular lead construction (these are devices in which the leads emerge from the package top). Removal of the package in these devices must be preceded by removal of the leads (or at least removal of the crimped portions of the leads).

Plastic-encapsulated transistors are opened in the same manner as plastic-encapsulated integrated circuits.

Diodes

Unless a specific problem is being evaluated which dictates a particular method of package opening or cross-sectioning at an odd angle, the following procedure is normally used to open a diode.

A thin film of epoxy is placed on an aluminum puck and the diode is positioned on its side upon this epoxy film. The ends of the diode leads are gently pressed down upon the puck and are secured to the puck with a drop of epoxy. After the epoxy has cured, the diode is hand-held against an abrasive and drawn along it. To prevent breaking the epoxy bond, the

direction of cut is always lengthwise along the diode. Grinding is continued until the case material is very thin, as if a window were being ground in the side of the diode. If the diode case is glass, a hypodermic needle is then used to puncture the glass and chip away the remaining glass in the "window" area just ground. If the diode has a metal case, the hypodermic needle or a knife edge is inserted into the edge of this window and carefully worked around the edge of the window until the window is pried out.

Internal microscopic examination is done at this time. If particles entered the device during opening, they may be carefully picked out or blown away with a gentle stream of dry nitrogen. However, if the failure could be related to particle contamination, no attempt should be made to clean the package at this time. It may be desirable at this time to fill the interior cavity with a clear epoxy so that the particle will be retained. This step also helps to hold the device intact during any subsequent operations that may be performed.

Resistors

Carbon resistors are not usually opened or deencapsulated; sometimes they are cross-sectioned.

The outer cases of metal film resistors can be removed using a combination of grinding and chemical solvents. The process may be hastened if the resistor case is ground carefully on four sides, not quite deep enough to cut into the end caps or the metal film. If this appears too difficult without possible damage, then no grinding need be done. The device is then soaked in the appropriate chemical solution (determined through discussions with the manufacturer) and may be periodically brushed to remove material that is dissolving (an acid brush is useful for this). In some instances, the case becomes softened to the extent that the edge of a hypodermic needle can be used to break away large chunks of the case material, thereby exposing the core and metal film. If this technique is not used, the device can be soaked and brushed until the entire case is dissolved.

Wirewound resistors can be opened by grinding and then carefully cutting away the outer case material. Chemicals are not used because of the risk of destroying the insulation coating on the resistance wire and the resistance wire itself. The cutting is usually performed using a hypodermic needle or a knife edge while observing the device with a low power microscope. If a Mylar or similar insulating tape has been used to cover the resistor core, it may be best to attempt to unwind this tape whenever possible.

Capacitors

An X-ray radiograph showing the slug and seal location is useful in selecting the location to be used when cutting apart a slug-type capacitor. In particular, this permits the case to be opened (with certainty) below the seal area, which obviates the need for venting. (If for any reason a slug-type capacitor case must be opened in the seal region, gas pressure in the electrolyte region may force electrolyte past the inner seal, creating a false impression that

the seal was defective. In order to avoid this, the case should first be vented in the electrolyte region.)

A slug-type capacitor may be opened using the FA Lab collet-type can opener or by sawing around the body of the capacitor. The cut is made uniformly deep around the package so that the case may be severed without damaging the slug or internal wire and seal. The one end containing the slug and seal can then be pulled out of the package.

Foil-type capacitors can be opened by unwinding the foil and cutting along the edge of the end caps as required. For some designs, it may be necessary to grind away portions of the end caps or body before the foil can be unwound.

The covering of some disc capacitors can be dissolved in a chemical specified by the manufacturer, thereby exposing the outer electrodes and dielectric.

There are too many different capacitor styles to discuss each here. The construction of any given type of capacitor must be studied and a decision made, on an individual basis, as to the best way of opening it, generally keeping within the guidelines already presented in this procedure. If at all possible, one or two additional capacitors, identical to the failed device, should be obtained and opening techniques practiced on these first.

Relays

Solder-sealed relays may be decapped by melting the solder and lifting the cap off. First, the center bracket support seal, usually located on the top or top-back portion of the lid, must be located. This seal must then be desoldered by using a soldering iron or gun. Next the relay may be mounted in a vise and a soldering gun used to heat the solder seal around the cap while the relay leads are gently pulled with pliers. When the solder melts, the relay innards can be pulled out.

Another method would be to place the relay, lid down, on a hot plate; when the solder melts, pliers would be used to pull the relay innards and the cap apart.

Relays sealed with a welded flange can be opened by making successive cuts into the lid weld with diagonal cutters. The procedure is to cut around the entire outer edge of the welded flange, using a motion that throws the resultant particles away from the package; the lid can then be lifted off.

Another method used to open relays is to grind along the top and side edges until the edge metal is thin but not cut through (as this may collapse the device). When all of the edges are ground thin, then the top edges or edges along a side are ground further or cut until the top can be removed or until the side can be peeled away. At this time, diagonal cutters and pliers can be used to peel back the other sides as if peeling a banana.

Applicable Specifications

None

METHOD S2—ELECTRICAL TESTS BY PROBING

Applicable Part Type(s)

All

Purpose

To permit electrical tests in addition to those possible with the external package leads; specifically, electrical tests of devices with severed interconnection wires, or tests of portions of internal circuitry which is electrically inaccessible from the external package leads

EQUIPMENT (or Equivalent)

Micromanipulator Company Model 1624 or Comaltest Mark VIII probe station; suitable electrical test equipment (see method G2, electrical tests)

General Procedure

If necessary, the package may be opened (see method S1, package opening). The condition of the probe points should be checked under the microscope and the points resharpener if necessary. Two methods of sharpening commonly used are electrochemical etching and mechanical grinding.

One electrochemical procedure involves repeated dipping of the probe point (at a rate on the order of twice a second) in an unsaturated solution of sodium or potassium hydroxide, with 5 to 20 volts ac (from a Variac) applied to the probe point and to a copper ring submerged in the solution. The repeated dipping is carried out until the desired probe point is formed.

The mechanical grinding method is an artful procedure and can be done using either a stationary piece of abrasive material (for example, No. 600 wet or dry paper) or rotating grinding equipment such as that used in cross-sectioning and polishing.

The nature of the electrical tests to be performed should be determined (reference method G2), and the appropriate test equipment connected to the probe station. The equipment is then adjusted to the proper settings for the desired measurement. When the probes are suitably sharp, the device is mounted on the probe station and the microscope adjusted until the general region to be worked on is in the field of view and can be focused upon.

Using a schematic if necessary, the region in the device where the probe is to be placed is selected. The probe is moved approximately over the position desired. As the probe is carefully lowered, the microscope focus may be adjusted to ascertain the relative positions of the probe and its desired destination. The probe is gently lowered onto the chosen locations using the appropriate probe controls, while the operation is observed through the microscope. The same method is used to position one or more additional probes as

desired. It may be helpful to initially position the second probe at an adjacent region on the same conductor as the first probe and then test for a short circuit between them. This will ascertain that the first probe does indeed make contact as desired. The second probe (and additional probes, if necessary) is then moved to the desired position in the device; the test instruments can then be used to electrically test the chosen circuitry.

If isolation of certain internal elements is necessary in order to make useful measurements, refer to method D1, isolation of internal elements.

Procedures Applicable to Individual Part Types

Electrical tests applicable to individual part types are discussed under method G2. Isolation procedures applicable to individual part types are discussed under method D1.

Applicable Specifications

None

METHOD S3—GAS AMBIENT ANALYSIS

Applicable Part Type(s)

Integrated circuits, transistors, and diodes

Purpose

The purpose of this procedure is to determine what types of gases were in fact present within the device package before it was opened. The knowledge of the internal gas ambient of the device may be instrumental in both the identification of the failure mechanism and the failure cause.

For example, transistors are normally sealed in dry nitrogen. Gas ambient analysis may reveal the presence of water vapor as well. If package leak tests have shown that the hermetic seal of the device is intact, then it can be concluded that the water vapor was introduced during manufacturing of the device. Thus, analysis of the gas ambient has revealed a foreign agent (water vapor) (a) which is capable of causing several types of failure and (b) the source of which might be tracked down by a cooperative manufacturer intent on really finding and eliminating the basic, original cause of failure.

Equipment (or Equivalent)

Not established at this time

General Procedure

Not established at this time

Procedures Applicable to Individual Part Types

Not established at this time

Applicable Specifications

None

METHOD S4—SEM VOLTAGE CONTRAST ANALYSIS

Applicable Part Type(s)

Integrated circuits, transistors, diodes, and resistors

Purpose

The purpose of this procedure is to use a special capability of the SEM to detect electrical open or short (or resistive short) circuits in regions too minute to probe effectively with mechanical instruments. Briefly, when operated for this purpose, the SEM exhibits conductive regions that are positively and negatively biased as dark and light, respectively. This clearly makes possible the detection of a break in the conductivity of an element, and thus isolation of an open circuit perhaps too small to be otherwise detected. In a similar fashion, an anomalous connection between conductive regions (that is, a short circuit) will cause both regions to be distinctly light or dark when only one is biased.

Equipment (or Equivalent)

SEM, such as the Cambridge Stereoscan; various batteries, power supplies, pulse generators, voltmeters, and so on, as needed to appropriately bias the device under investigation.

General Procedure

SEM voltage contrast analysis can be approached in two different ways. First, if there is no specific defect suspected in a failed device, it may be useful to obtain potential (that is, voltage contrast) maps under a variety of bias conditions. These maps, when compared with corresponding maps of a good device, may yield information regarding the failure site.

Second, if a specific defect is suspected, for example, an open or short circuit, it may be possible to design a specific voltage contrast test to verify that defect. In this case, the challenge is to apply bias to the device in a manner that results in a voltage appearing at the defect region. Unfortunately, this is not always possible, even with the application of pulsed voltages to the device.

It should be emphasized that the usefulness of voltage contrast analysis is highly dependent on engineering decisions and interpretations relating to the specific device being investigated. There is no effective voltage contrast analysis procedure that can be followed by rote.

With respect to actual operation of the SEM during voltage contrast analysis, trained operators find equal value in using various techniques. In general, however, it has been found useful to operate the first and second condenser coils at minimum current and to view the device at angles not exceeding 40° to 45°. Accelerating potentials must be chosen to suit the part type being investigated.

There are several recently published papers on voltage contrast analysis which may be of interest.*

Procedures Applicable to Individual Part Types

Useful information related to biasing and test equipment for individual part types may be found under method G2, electrical tests.

Applicable Specifications

None

METHOD S5—SEM CURRENT MODE ANALYSIS

Applicable Part Type(s)

Integrated circuits, transistors, and diodes

Purpose

To determine the exact position and shape of junctions at the surfaces of semiconductor devices, and/or to determine the current paths through the device. The results of this procedure are often highly interpretive. Basically, the procedure relies on another special capability of the SEM, that of activating P-N junction regions with its electron beam. In essence, a bias is applied to a region of the device under study, and the current resulting from that bias is used to modulate intensity on a CRT. The CRT is then scanned synchronously with scanning of the device by the SEM beam. Whenever the SEM beam crosses a junction, the resulting activation may cause an increased current flow that manifests itself as an increased intensity on the CRT. In this manner, a map of P-N junctions may be formed, and information regarding the position and shape of the junction unobtainable by optical or normal SEM techniques may be obtained. Such information may be invaluable in locating an exact region of failure, and thus may lead to a better understanding of the exact cause of failure.

*See R. P. Beaulieu, C. D. Cox, and T. M. Black, "A SEM Surface Voltage Measurement Technique," *10th Annual Reliability Physics Proceedings* (IEEE, N.Y., N.Y.), p. 32; and S. K. Behera and D. P. Speer, "A Procedure for the Evaluation and Failure Analysis of M.O.S. Memory Circuits using the Scanning Electron Microscope in Potential Contrast Mode," *10th Annual Reliability Physics Proceedings* (IEEE, N.Y., N.Y.), p. 5.

Equipment (or Equivalent)

SEM, such as the Cambridge Stereoscan; various batteries, power supplies, measuring instruments, and so on, as needed to appropriately bias the device under investigation

General Procedure

There are two basic approaches to SEM current mode analysis. Both approaches involve scanning the device with an electron beam while observing the device current through intensity modulation of a synchronously scanned CRT display.

First, if there is no specific defect suspected in a failed device, it may be useful to obtain current maps under a variety of conditions. These maps, when compared with corresponding maps of a good device, may yield information regarding the failure site. Second, if a specific defect is suspected, for example, an open or short circuit, it may be possible to design a specific current mode test to verify that failure. In either instance, the basic procedure is to apply voltages to the device in a manner that places reverse bias on junctions of interest. When the electron beam traverses and activates a junction, excess current flows through the device, and a clear representation of the junction should be seen.

There is no established and fixed procedure for operating the SEM during current mode analysis. It should be noted that this procedure is almost wholly experimental, and results are subject to interpretation. The exact manner in which the SEM is operated (for example, the accelerating potential used) may greatly influence the results and should be in accordance with engineering decisions based on the particular part and failure mechanism being studied.

Procedure Applicable to Individual Part Types

Useful information related to biasing and test equipment for individual part types may be found under method G2, electrical tests.

Applicable Specifications

None

METHOD S6—PHOTOSCAN ANALYSIS

Applicable Part Type(s)

Integrated circuits, transistors, and diodes

Purpose

This technique is essentially similar to SEM current mode analysis, except that a light (perhaps laser) source is used as the activating energy. With proper equipment and technique, the procedure can produce a map of a device, showing regions subject to activation under fixed conditions of bias. Comparison of the map from a known good device with

that of the failed device can be useful in localizing the failure site. This type of technique is potentially most useful for devices too complex for analysis by more conventional methods.

Equipment (or Equivalent)

Not established at this time

General Procedure

Not established at this time

Procedure Applicable to Individual Part Types

Not established at this time

Applicable Specifications

None

METHOD S7—INFRARED SCAN ANALYSIS

Applicable Part Type(s)

Integrated circuits, transistors, diodes, and resistors

Purpose

To produce a thermal map of the device being investigated, for the purpose of detecting regions of excessively low or high temperature or regions having abnormal temperature gradients

Equipment (or Equivalent)

Sierra Model 750B infrared plotter; various batteries, power supplies, and measuring instruments, as needed to power the device being investigated

General Procedure

Not established at this time

Procedures Applicable to Individual Part Types

Not established at this time

Applicable Specifications

Not established at this time

METHOD S8—PROFILOMETER TESTS

Applicable Part Type(s)

Integrated circuits, transistors, and diodes

Purpose

To measure the profile of a surface. Information from these tests which can be very useful concerns metallization thickness, oxide-step height, and surface characteristics in anomalous regions.

Equipment (or Equivalent)

Not established at this time

General Procedure

Not established at this time

Procedure Applicable to Individual Part Types

Not established at this time

Applicable Specifications

None

METHOD S9—ULTRAVIOLET EXAMINATION

Applicable Part Type(s)

Relays

Purpose

To detect the presence of solder flux within solder-sealed relays

Equipment (or Equivalent)

Bausch and Lomb Fluorescence Illuminator

General Procedure

CAUTION: Direct exposure of the unprotected eye to invisible ultraviolet light can result in blindness. At the time of exposure there is no discomfort to the eye and the effects of the injury are not apparent until some time after it has occurred. Always use barrier filters which are opaque to ultraviolet to protect the eyes. Use the ultraviolet light source only in a manner that pre-

cludes danger to other individuals. The ultraviolet light source is a high pressure mercury arc and, since mercury vapor is toxic, the area should be evacuated if a violent lamp failure occurs.

Read the instruction manual for the light source and follow the necessary precautions implicitly. Then place the relay in the light beam and observe it visually. A microscope, fixed with filters, may be used. If solder flux is present in the relay, it will fluoresce.

Procedures Applicable to Individual Part Types

The general procedure is specific for relays.

Applicable Specifications

None

METHOD S10—OBSERVATION OF INTERNAL MECHANICAL OPERATION

Applicable Part Type(s)

Relays

Purpose

To observe the actual mechanical operation of internal portions of the relay in an effort to determine: (a) whether mechanical misbehavior is responsible for the failure, and (b) where the mechanical misbehavior (if any) is occurring

Equipment (or Equivalent)

Equipment for electrical testing (see method G2, electrical tests) and suitable optical microscopes (see method G3, internal examination)

General Procedure

Electrical connections are to be made as required to operate the particular relay under test. Care should have been taken during deencapsulation not to deform the relay innards nor to remove any coils or other components. The relay is to be placed (while maintaining the electrical hookup) under the microscope and the relay operated while observing it through the microscope. The armature and the movable contacts should be checked for full travel. A search should be made for open gaps between the armature and pole pieces, and it should be determined if any parts are deformed and causing binding, or if particles are inhibiting the full travel of the armature or movable contacts.

This procedure is limited to observation of the relay operation. Anomalous conditions not directly related to operation, such as contamination, should have been observed during the initial internal examination described under method G3. Observation of the contact faces

for pitting is generally done at a later time, since the movable contact arm must usually be bent to expose the contact areas.

Procedures Applicable to Individual Part Types

The general procedure is specific for relays.

Applicable Specifications

None

METHOD S11—CONTACT FORCE AND OVER-TRAVEL MEASUREMENTS

Applicable Part Type(s)

Relays

Purpose

To determine the contact force which, if inadequate, may cause high contact resistance and to measure the amount of over-travel, which could affect switching characteristics

Equipment (or Equivalent)

Mech-el Industries, Inc. wire pull tester or Ametek Model CTM-tester, various mechanical force gage, and the Keithley Model 502 milliohmmeter

General Procedure

In order to measure contact force, the deencapsulated relay can be mounted on the Mech-el Industries, Inc. wire pull tester with the pull test hook positioned under the movable contact arm and near the area of the contact points. An ohmmeter is connected across the movable and fixed contacts by means of the external relay leads. These contacts must be closed, so that the relay contact resistance is indicated on the ohmmeter. The mechanical force gage is set to zero and is then used to exert a force to pull the movable contact away from the fixed contact. The contact force is that force required to separate these contacts. The contacts are considered separated when the ohmmeter indicates an open circuit (a high resistance of about 1000 ohms if the Keithley Model 502 milliohmmeter is used).

The difference in position of the fixed contact as measured with the contact set in closed and open conditions is the over-travel.* Over-travel is a seldom made measurement but may be measured either optically (using a shadowgraph or photographs) or mechanically, depending upon the configuration of the particular relay being investigated. Over-travel

*This definition applies only to relays with compliant fixed contacts; excess armature movement comprises over-travel in devices with noncompliant fixed contacts.

deficiencies will usually be indicated by abnormal switching characteristics such as operate or bounce times, although defects not related to over-travel can cause these same abnormal characteristics. Since manufacturers do not include over-travel among their specifications, comparisons will have to be made with an identical relay that operates satisfactorily.

Procedures Applicable to Individual Part Types

The general procedure is specific for relays.

Applicable Specifications

None

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METHOD D1—ISOLATION OF INTERNAL ELEMENTS

Applicable Part Type(s)

All

Purpose

To electrically isolate internal elements of the device in order to facilitate testing of individual elements without other circuitry influencing the measurement. If applicable, strength measurements may be made at this time.

Equipment (or Equivalent)

Micromanipulator Company Model 1624 or Comaltest Mark VIII probe station, Mech-el Industries Model BT-200 Bond Tester, Unitek Model 6-092-03 Micro-pull Tester, Ametek Model TTH Spring Gage, Ametek Model CTM Spring Gage, cutting pliers, saws, needles, knife edges, and so on

General Procedure

If necessary, the package may be opened (see method S1, package opening). Any wires, metallization stripes, or other conductors to or from the internal elements to be isolated are to be removed or cut as required. Strength measurements are to be performed as required. (It should be noted, however, that strength tests are often, and sometimes unexpectedly, destructive. A decision in favor of strength tests, then, must follow consideration of the damage they may do and their relative importance to the analysis.) Most often, strength measurements involve pull tests on wires (and wire bonds) found within devices, and pull tests on package leads. One common exception are shear tests on semiconductor dice, which are used to evaluate the bonding of the die to the device package.

In addition, there are a multitude of mechanical tests that may be performed on devices, but which are not often performed during failure analysis work. Included are twist and bend tests on leads and break-strength tests on resistor substrates. Usually, these must be tailored to the particular part being investigated, taking into account its construction and mechanism of failure.

With respect to the more common strength measurements, pull tests fall into two general categories, namely those on very small wires and those on heavier wires (such as package leads). Very small wires, having expected breaking strengths up to 15 centinewtons (grams force), are tested using equipment equivalent to the Mech-el Model BT-200. The device containing the wire(s) of interest is placed on the holding pedestal and, following the operating instructions for the equipment, the wire is pulled either to a predetermined force level or destruction. Heavier wires, such as package leads, may be tested for strength using the Unitek Model 6-092-03, the Ametek Model TTH, or the Ametek Model CTM, depending on

expected breaking strength (up to about 205 newtons (45 pounds force)). The specific, written operating instructions should be followed in all cases.

Shear tests on semiconductor dice may also be performed with the Ametek Model CTM. Shear testing of devices having a recessed die usually requires removal of at least one package wall, to permit access of the mandrel on the Model CTM to the die. Furthermore, it may be necessary to mount the test device to a puck to permit the device to be securely held during the test. (Information regarding these auxiliary procedures may be found under method D7, cross-sectioning.)

Procedures Applicable to Individual Part Types

Integrated Circuits or Transistors

In devices of conventional construction, removal of the interconnection wires will electrically isolate the die from the package. If isolation of a given element on the die is desired, then the metallization stripes surrounding the element will have to be severed. If a glass overlay is present on the die, it will have to be removed chemically (see method D5, chemical etching).

The following procedure is used when the die metallization is aluminum: The device is mounted in the probe station and the test probe of a micromanipulator is repeatedly scratched across the selected metallization stripe until it is severed. The test probes can then be used with a curve tracer or ohmmeter to verify the desired discontinuity. This method is repeated until the desired element is isolated. In some instances, an incomplete discontinuity can be opened up by using a brief aluminum etch to remove residual traces of aluminum from the scratched areas, without seriously affecting the overall integrity of the die metallization (see method D5).

It is more difficult to isolate an element on the die of a device with gold-molybdenum metallization, since scratching with a test probe is unlikely to cut through the molybdenum. Some success is possible when test probes are touched to both sides of a metallization stripe and an external, charged capacitor is allowed to discharge through the metallization stripe. This controlled "zap" will often open-circuit the metallization stripe. However, a narrow portion of metallization, located as far as possible from the element of interest, should be chosen, and the technique should not be carried out until practiced on a device of similar construction.

Diodes

Removal of the S-spring or other contact in a glass diode will isolate the die from the package. (This is normally the full extent of isolation possible in axial-lead diodes.) Since removal of the S-spring is usually a concomitant of package opening, different methods of achieving the latter should be carefully considered before proceeding. An X-ray radiograph, by revealing information concerning the internal construction, may aid in choosing the best method to open the device (see method N1, radiographic examinations).

In the final analysis, an engineering decision (based on the device construction) must be made regarding an opening technique and an effective isolation method for any particular diode.

Resistors

The resistor body or core can usually be isolated from the resistor leads in metal film or wirewound resistors, respectively, by removing end caps or by cutting the resistance wire where it is wrapped around and soldered (or welded) to the external leads. The integrity of the lead attachment should also be examined at this time. The leads of carbon composition resistors are usually embedded within the resistor body, in which case removal of the leads without damage to the resistor body is not possible. In this instance, the integrity of lead attachment can be evaluated by cross-sectioning (see method D7) or pull tests (described earlier in this method), but isolation is not practical.

Capacitors

In slug-type units, the package opening technique can be simplified by use of an X-ray radiograph showing the anode slug location (see method N1). After the slug is removed from the package, the anode lead (complete with the package seal) can be cut away from the slug, thereby isolating the slug from the package.

Interdigitated plates found in some capacitor types can be isolated by grinding away the end contacts, using methods similar to those used in cross-sectioning (see method D7). The location and direction of grinding must be determined on an individual basis, depending on the construction of the capacitor being investigated.

The end caps of foil-type capacitors may be cut away and then the foil layers unwound. The unwrapped foil can then be cut into sections to isolate a defective region as examinations or measurements dictate.

Relays

Once opened, connecting wires to the coils (and to other elements, if they exist) may be cut. The coils may also be removed to isolate or facilitate inspection of other internal components. Contact arms may be bent to allow inspection of contact wear; these are not usually cut out, however, as it may be of interest to study the location of their mating surfaces at a later time.

Applicable Specifications

None

METHOD D2—ENERGY DISPERSIVE X-RAY ANALYSIS AND/OR ELECTRON MICROPROBE ANALYSIS

Applicable Part Type(s)

All

Purpose

This is the first procedure directed toward an exact identification of specific materials. (Previous internal cleaning, it should be noted, was directed at identifying classes of materials.) Briefly, both procedures involve exciting an X-ray response from the material in question by directing an electron beam on that material. The X-ray response, which is characteristic of the elemental makeup of the material, is then analyzed to obtain the required information. EDXA involves a SEM; electron microprobe analysis involves an instrument by that name, that is, an electron microprobe.

Identification of materials in a device being failure analyzed may serve the following purposes:

- Verification of materials thought to be used in the construction of the device
- Identification of unknown materials used in the construction of the device
- Detection of normal construction materials in abnormal places within the device
- Identification of foreign materials within the device

The knowledge gained in turn serves to (a) provide information regarding the normal makeup of the device, (b) reveal materials that may have been misplaced as a result of either manufacturing errors or misuse of the device, and (c) provide the type of information necessary to identify the source of foreign material in the device, by identifying the foreign material itself. To the extent that any of the above disclosures can be related to the failure of the subject device, the basic cause of failure may be better understood.

Equipment (or Equivalent)

- EDXA—Cambridge Stereoscan SEM with Princeton Gamma-Tech Series LS EDXA unit
- Electron microprobe analysis—Materials Analysis Corporation Model 400S electron microprobe

General Procedure

EDXA

Energy dispersive X-ray analysis may be performed at the same time that a SEM examination is being carried out. This constitutes the major advantage of this procedure over electron

microprobe analysis. Actual operation of the EDXA unit and the SEM must be in accordance with instruction manuals for these instruments and must be carried out by a trained operator. However, it should be useful for the investigator and/or the individual preparing the specimen to be aware of the following information:

- There must be no obstruction between the material of interest and the EDXA detector in the SEM. Achieving this may necessitate modification of the specimen, or at least careful consideration of its positioning in the SEM.
- It is generally unadvisable to coat the specimen. A specimen which provides poor secondary-electron pictures due to charging may nevertheless yield good EDXA results. If coating is necessary, it is mandatory that the coating material be as far removed as possible in X-ray response from the material being analyzed. This is obviously problematic if nothing is known about the material being analyzed.
- Whenever possible, materials surrounding the material in question should be removed, to prevent spurious readings and masking effects.

When observing EDXA readouts, it is advisable to carefully record and check all data as it is generated, double-checking questionable results as the analysis progresses.

Electron Microprobe Analysis

The electron microprobe offers the advantages of increased precision and the ability to perform quantitative analyses. However, carefully prepared samples and considerable patience are prerequisites for obtaining good results. Again, it is essential that operation be in accordance with instruction manuals for the instrument and be carried out by a trained operator.

Beyond that, the investigator or person preparing the specimen should be aware that focusing on the specimen presents considerably more difficulty in the electron microprobe than in the EDXA system. Having a flat specimen surface is thus highly desirable, perhaps even essential for serious work. For this reason, a specimen that is (for other reasons) being cross-sectioned is an ideal candidate for electron microprobe analysis.

If the device to be analyzed is not being cross-sectioned, it may be worthwhile to attempt analysis with preparation similar to that for the SEM. However, if results are questionable or confusing, the most straightforward next step is producing a flat surface (however small) on the material being analyzed. This may best be accomplished by cross-sectioning techniques. In addition, all the preparation requirements for EDXA also apply to electron microprobe analysis.

Procedures Applicable to Individual Part Types

None

Applicable Specifications

None

METHOD D3—CHEMICAL ANALYSIS

Applicable Part Type(s)

All

Purpose

To identify materials in the device being investigated, in place of, in conjunction with, or following EDXA or electron microprobe analysis

Equipment (or Equivalent)

Various equipment and apparatus normally found in a chemistry lab, including an exhaust hood, goggles, rubber gloves, and so on; a hotplate and a timer; and a variety of reagents, in particular those given in the Chemical List found below

General Procedure

All work shall be carried out with the strictest regard for accepted safety practices in the chemistry laboratory. If doubt exists regarding safety practices, or if these practices are not known, there are guides that should be consulted.*

If the device is contaminated with a material present in quantities too small to collect, refer to method G5, chemical cleaning. That method is analytical to the extent that it may at least permit the class of material to be identified. If a collectable sample is present, it may be suitable for chemical analysis. However, the trial-and-error nature of chemical analysis makes a fairly substantial sample a necessity.

Judgment is the most important factor in making best use of a limited sample. An initial judgment is required to choose a first analytical test, based solely on the appearance of the material being analyzed. In short, to perform successful chemical analyses, it is necessary not only to know a lot, but to have a great deal of experience as well. It is thus most sensible to perform any analytical work under the guidance of a person trained in chemistry.

A document that may be of service is *Handbook of Analytical Chemistry*, edited by Louis Meites and published in New York by McGraw-Hill (1963).

*See Manufacturing Chemists' Association, Central Safety Committee, *Guide for Safety in the Chemical Laboratory*, Von Nostrand, New York, 1954.

Procedures Applicable to Individual Part Type(s)

None

Applicable Specifications

None

Chemical List

Material	Uses
Acetic acid	Etchant
Acetone	Solvent for plastics; hygroscopic
Ammonium chloride	Buffer
Ammonium hydroxide	Base and others
Ammonium persulfate	Etchant for copper; oxidizing agent
Ammonium sulfide	Source of sulfide
Barium chloride	X-ray tracer
Benzene	Nonpolar solvent
Benzyl alcohol	Plastic solvent
Bromine	Metal etch, stain
Boric acid	Buffer
Buffer pH 4.00	Buffer
Buffer pH 7.00	Buffer
Buffer pH 10.00	Buffer
Calcium carbonate	Buffer
Chloroform	Solvent
Chromic acid	Etchant, stain
Copper sulfate	Stain
Cyclohexane	Solvent, nonpolar
Dimethyl formamide	Solvent for plastics
Ethylene glycol	Antifreeze, bubble test
Ethylether	Organic solvent
Ferric chloride	Copper etchant
Formic acid	Solvent
Hexanes	Mild, nonpolar solvent and cleaner
Hydrobromic acid	Metal etch, stain
Hydrochloric acid	Metal etch
Hydrofluoric acid	Dissolves silicon with oxidizer (H_2O_2) and SiO_2 ; very toxic fumes! Keep off skin!
Hydrogen peroxide	Etchant, stain, oxidizer
Hydro-quinone	Photography stain

Isopropyl alcohol	Polar solvent
Methyl alcohol	Electrolyte, solvent
Methyl ethyl ketone	Solvent for plastics
Methylene chloride	Dissolves plastics, epoxies
Nickel sulfate	Stain
Nitric acid	Acid
Oxalic acid	Stain, etch
Petroleum ether	Solvent
Phosphoric acid	Etchant, polish
Potassium chloride	Buffer, electrolyte
Potassium cyanide	Etchant, stripper; very toxic
Potassium dichromate	Stain, etchant
Potassium hydroxide	Alkaline etchant
Sodium acetate	Buffer, etchant
Sodium bicarbonate	Buffer, electrolyte
Sodium chloride	Buffer, salt
Sodium citrate	Buffer
Sodium cyanide	Alkaline, etchant; very toxic
Sodium hydroxide	Alkaline, aluminum etchant, dye
Sodium hypophosphite	Reducing agent
Sodium potassium tartrate	Buffer, useful for crystal studies
Sodium silicate	Etchant, coater
Sodium sulfide	Stain
Stannous chloride	Catalyst
Sucrose	Reducing agent
Sulfuric acid	Strong acid, etchant, oxidizer
Toluene	Solvent
Xylene	Solvent
Zinc oxide	Stain

METHOD D4—OTHER MATERIAL ANALYSES

Applicable Part Type(s)

All

Purpose

To identify materials in the device being investigated, in place of, in conjunction with, or following EDXA, electron microprobe analysis, or chemical analysis.

Infrared spectrophotometry, for example, may be used to identify an organic contaminant (a class of material not susceptible to analysis by EDXA or electron microprobe analysis).

X-ray diffraction may be used to study certain materials, particularly inorganic materials which exist in insufficient quantity for EDXA or electron microprobe analysis, and which do not lend themselves to analysis by other methods. Generally, these procedures are not among the more routine used in failure analysis.

In addition, there are state-of-the-art analysis and inspection techniques, often requiring truly exotic (and sometimes prohibitively expensive) equipment that is available only at special sites. In the analysis field, for example, activation analysis is said to be a sensitive means of detecting materials that exist in truly minute quantities. In the inspection field, techniques requiring exotic equipment might include ion-beam microscopy and neutron radiography.

Equipment (or Equivalent)

Various (see list, Special Analytical Equipment, found below)

General Procedure

Use of all listed equipment requires specialized training and is not considered a routine operation.

Procedures Applicable to Individual Part Types

None

Applicable Specifications

None

Special Analytical Equipment

- Infrared spectrophotometer—Measures infrared spectrum of organic materials.
- Mass spectrometers
 - a. Surface ionization—Measures relative isotopic abundances of rare earth elements (age dating) in ppm concentration range
 - b. Ion microprobe—Measures isotopic abundance of most elements to mass 200; sensitivity approximately 1 ppm
 - c. Nuclide gas—Measures isotopic abundance of noble gases at 0.5 mass unit resolution
- X-ray diffraction
 - a. X-ray diffraction unit—Measures chemical composition, oxidation state; most effective for inorganic composition of known elements; sensitivity 10 to 1000 ppm

- b. X-ray diffraction unit—Determines crystal structure of materials and composition of materials in either powder or solid form
- Infrared spectrometer—Measures surface (one wavelength depth) composition of materials; most effective for organic compositions; minimum sample size 1 mg
 - Gas chromatograph—Measures chemical composition of materials; sensitivity 1 ppb (hydrocarbons), 1 ppm (hydrogen), 10 ppm (argon), 5000 ppm (water)
 - Emission (light) spectrograph—Detection and/or determination of minor elements. Sample is consumed. Data is semiquantitative or quantitative depending on element analyzed.
 - Atomic absorption analyzer (light)—Determination of minor elements. Sensitivity depends on element analyzed.
 - Electron microprobe—Determination of composition of chemical elements (boron or greater mass). Sensitivity 1 monolayer 100 ppm in bulk, 1000 ppm for lightest elements. Resolution 0.5 to 1.0 μm . Detection and/or determination of elements $Z = 5$ and above on the microscale (10 μm and below).
 - X-ray fluorescence unit—Detection of elements, $Z = \text{Si}$ and above. Quantitative measurement of composition in materials when standards are available. Samples should be 1 mm to 25.4 mm in size, and in powder or solid form.

METHOD D5—CHEMICAL ETCHING

Applicable Part Type(s)

All

Purpose

This procedure has purposes distinctly different from chemical analysis. Included are: removal of materials in the device (metallization, oxides, gold plating, and so on) for the purpose of examining portions of the device obscured by these materials; and delineation of faults or characteristics in solid materials, such as stacking faults, grain boundaries, and the like. The information obtained may assist in identifying a site of failure, or in understanding the basic cause of a failure whose site has already been identified.

Equipment (or Equivalent)

Various equipment and apparatus normally found in a chemistry lab, including an exhaust hood, goggles, rubber gloves, and so on; chemicals of the varieties listed under Etch Solutions and Rates, found below; a hotplate; and a timer

General Procedure

All work shall be carried out with the strictest regard for accepted safety practices in the chemistry laboratory. If doubt exists regarding safety practices, or if these practices are not known, there are guides that should be consulted.*

In general, chemical etching is performed toward the end of an investigation. If done to permit inspection of an obscure region of the device, it should be carried out only after careful consideration has been given to the removal of a particular material and to the side effects of removing that material. Chemical etching to delineate faults and characteristics of a material (stacking faults, grain boundaries, and such) should be tailored to the particular situation, taking into account the material being investigated and the material fault or characteristic most likely to be present or of interest.

Different types of etching that might be considered during an analysis are listed for individual part types below. Actual etch solutions, typical etch rates, and other pertinent information are listed under Etch Solutions and Rates, found below.

Procedures Applicable to Individual Part Type(s)

Integrated Circuits, Transistors, and Diodes

Materials commonly removed in these device types are pyrolytic or other overlay glass, aluminum metallization, gold-molybdenum metallization, silicon dioxide, and silicon.

The semiconductor material faults most commonly studied by etching are stacking faults (which occur during manufacture) and miscellaneous material damage (most often caused by electrical overstress). Beyond this, other etching that may be appropriate would relate to the package or leads and might involve such steps as removing plating from the package leads or from metal portions of the package itself.

Other Part Types

The variety of materials used in other part types is so great that no hard and fast guidelines are possible. For these devices, etching procedures can be considered and chosen only after the device construction is fully understood. In general, however, etching procedures for resistors, capacitors, and relays fall into the same categories as for semiconductor devices. That is, tests may be done on the essential element of the device (for example, the resistance element) or on the package or its leads; and tests may involve removal of material (for example, the thin-film resistance material from a resistor substrate) or may involve delineation of material characteristics (for example, grain boundaries in a relay magnet).

*See Manufacturing Chemists' Association, Central Safety Committee, *Guide for Safety in the Chemical Laboratory*, Von Nostrand, New York, 1954.

Applicable Specifications

None

Etch Solutions and Rates*

Etches for Removing Materials

- Gold wires and metallization—Use 10 g of Technic-Au powder in 100 cm³ water at 333 K (+60° C). Etch time will normally be 10 seconds to several minutes (etch rate is about 1 μm per 10 seconds).
- Aluminum wires and metallization
 - a. 1:1::HCl:H₂O (by volume); approximate etch time is 1 minute.
 - b. 20:1:5::H₃PO₄:HNO₃:H₂O (by volume); etch time is several minutes at room temperature.
 - c. 1:5::NaOH:H₂O (by volume); etch time is about 1 minute. Caution: Sodium ion contamination of the device may result from use of this etch.
- Molybdenum (thin films)—Concentrated H₂O₂ at 303 K (+30° C) for 10 seconds to 1 minute
- Silicon oxides—Note: A dip in 10 percent hydrofluoric acid solution for 1 second will clean debris from silicon dioxide surfaces (and will attack the passivation slightly).
 - a. Pyrolytic glass overlay—HF:H₂O:NH₄F::2:15:8 (by weight) solution. (This is a buffered hydrofluoric acid solution.) Etch rates are as follows in m/s:

pyrolytic glass	256 × 10 ⁻¹⁰
silicon dioxide (grown)	9.5 × 10 ⁻¹⁰
aluminum metallization	0.4 × 10 ⁻¹⁰
sputtered silicon oxide (quartz)	33 × 10 ⁻¹⁰
 - b. Sputtered (quartz) overlay—HF:H₂O:NH₄F::3:8:9 (by weight) solution. Etch rate is 60 × 10⁻¹⁰ m/s.
 - c. Grown silicon dioxide (basic passivation)—1:1::HF:H₂O or 1:1::HF:C₂H₄O₂ (by volume). Total etch time may be up to 1 minute or more.
- Silver—5:1:10::HNO₃:H₂SO₄:H₂O (by volume)

*Etch rates, if specified, are in some instances expressed in the time range necessary for completion of common FA laboratory applications. Shorter times should be used to remove limited amounts of material.

Etches for Material Characteristics

- Silicon etches (all by volume)
 - a. Polish—3.2:9.6:8.6::HF:C₂H₄O₂:HNO₃
 - b. 111/100 planes—1:1:4::H₂O₂:HF:H₂O
 - c. Dislocations—2:5:3:HF:C₂H₄O₂:HNO₃
- Copper alloys (for grain boundaries)—1:1::HNO₃:H₂O (by volume), with one drop of HCl for every 4 cm³ of solution
- Iron-nickel alloys (for grain boundaries)
 - a. 1:1::HCl:H₂O (by volume)
 - b. 1:1:1::NH₄OH:H₂O₂:H₂O (by volume)
- Tantalum (for grain boundaries)—3:1:3::HF:NH₄F:H₂O (by volume)

METHOD D6—DESTRUCTIVE MECHANICAL TESTS

Applicable Part Type(s)

All

Purpose

To test the limits of strength and/or durability of a device under conditions that: (a) represent experiences the device is likely to have; (b) offer a fair test of the integrity of a mechanical part of the device; or (c) accelerate normal wear-out mechanisms in a manner that permits those mechanisms to be studied

Equipment (or Equivalent)

Various; see procedures and references below.

General Procedure

Destructive mechanical procedures related to wires inside devices, package leads, and die attachment (in semiconductors) are discussed under method D1, isolation of internal elements. Other destructive mechanical tests must be chosen and performed on an individual basis. The most common mechanical tests which may be carried out destructively are vibration, shock, and thermal cycling (the last, although not strictly a mechanical test, is generally a test of the mechanical integrity of the device).

Equipment requirements and general guidelines for vibration, shock, and thermal cycling may be found under method F1, tests for intermittent operation. Acceleration levels for vibration and shock, temperature extremes for thermal cycling, and other test parameters

(maximum displacement during vibration, rates of temperature change, and so on) must be determined on the basis of the individual part being tested and the intended purpose of the test. It should be emphasized that destructive mechanical testing is usually somewhat experimental in nature, and therefore no fixed instructions apply.

Procedures Applicable to Individual Part Types

None

Applicable Specifications

None

METHOD D7—CROSS-SECTIONING

Applicable Part Type(s)

All

Purpose

To expose, for further examinations and tests, the interior of a solid material or the interior of an object having a solid enclosure

Equipment (or Equivalent)

Buehler Ltd. grinding wheels, Buehler handimet grinder, and Buehler cutter; an assortment of waterproof silicon carbide and emery abrasive papers (adhesive-backed in both strips and disks); potting compounds, grinding preparations, oil, polishing cloths, and other supplies listed under *Materials for Sectioning*; suitable microscopes, such as the Nikon Stereo-Zoom, and the Nikon Model M inverted stage microscope; and an oven for curing potting compounds, such as the Fisher Isotemp.

General Procedure

Cross-sectioning generally involves four discrete steps: opening or partial disassembly of the device, as applicable; potting of the device into a puck; grinding or cutting of the puck (and the part); and polishing of the exposed surface of the part. (See the listing, *Materials for Sectioning*, for suggested cross-sectioning materials and supplies.)

It is emphasized that virtually all aspects of cross-sectioning, in particular rough and fine polishing, require a great deal of experience to obtain repeatable and meaningful results. Furthermore, it has been found that cross-sectioning is not limited to a single valid technique; rather, individual technicians are found to adopt very different techniques, to use materials and supplies differently, with equivalent results. This procedure is very much an art.

Opening

This step usually precedes cross-sectioning for devices having an internal void; detailed procedures for opening are described under method S1. For any of various reasons, a device may instead be partially opened or disassembled prior to cross-sectioning. The need for further preparation prior to cross-sectioning must be determined on an individual basis.

Potting

The purposes of this step are to: (a) hold the device and its internal elements together during the sectioning process; (b) provide a handle to facilitate holding the part during grinding and polishing operations; (c) provide a support around the part that permits easy positioning of the device on microscope stages; and (d) provide a surface around the part that minimizes relieving during grinding and polishing operations. The potting compound found to be consistently most suitable for failure analysis work is Acme 655. (See the listing, Materials for Sectioning, for further details and for alternate potting compounds.)

The device under investigation should be placed in a suitable mold of potting compound, paying particular attention to positioning it in the most useful orientation for subsequent work. If it is intended to electrically monitor the device during cross-sectioning (and if this is in fact possible), then suitable test leads should be connected to the device leads prior to potting. Positioning of the test leads in the potting compound is important, to ensure that subsequent cross-sectioning can be carried out without damage to the leads.

It should be noted that if Acme 655 is used as the potting compound, a cure temperature of about 339 K (+66° C) is required. It should be evident that the device being investigated must be capable of withstanding this temperature without damage.

Grinding (or Cutting)

The purpose of this step is to quickly reach the region of interest; this permits reaching the exact item of interest by subsequent, slower polishing techniques, in a reasonable time period. For example, a transistor is potted in preparation for cross-sectioning. In this example, the region of interest is a ball bond on the silicon die. In order to reach that bond in a reasonable amount of time, the package header and a portion of the silicon die must be ground or cut away. This must be done without damaging remaining portions of the device.

As performed at GSFC, grinding entails the use of silicon carbide paper up to No. 600 (the finest), using water as a lubricant. The grinding may be done either on straight strips of abrasive paper, using a device for holding the paper such as the Buehler handimet, or on disks of abrasive paper, mounted on rotating, horizontal grinding wheels.

In some instances, cutting through the potted specimen may be a more efficient manner of reaching the area of interest. There are several possible ways of cutting through a specimen. A large item may be rough-cut by hand. More controlled cutting may be accomplished

with machines, such as the Buehler Model 10-1030 cutter (for large specimens) or the Buehler Model 11-1180 Isomet low-speed saw (for small specimens). The effect of cutting on the specimen, that is, possible damage to the specimen, must be considered prior to taking this approach, however.

Polishing

This procedure falls into two categories—rough and fine polishing. During all polishing, attention should be paid to cleanliness and the possibility of contamination. In particular, if the specimen is being prepared for EDXA or electron microprobe analysis, polishing compounds containing elements similar to those that may be present in the specimen, for example, alumina, should be avoided.

Rough polishing, as generally defined in the GSFC FA Laboratory, begins where grinding leaves off. Therefore, 4/0 emery paper, lubricated with oil, is often the starting point for rough polishing. (Although 4/0 emery paper is similar in roughness to No. 600 silicon carbide paper, its effect on the specimen is normally somewhat different, the emery paper having less of a tendency to fracture brittle portions of the device. Subsequent rough polishing is usually done with oil mixed with diamond pastes having progressively smaller maximum particle size, starting with 9 μ m and working down to 3 μ m paste. These polishing compounds are applied to a disk-shaped polishing cloth, which is in turn mounted on a horizontal grinding wheel. Several useful polishing cloth types are given in the listing, Materials for Sectioning.

It should be noted that highly polished specimens are often impossible to photograph. It has been found, however, that specimens that have been rough polished usually photograph satisfactorily—therefore, if photography is required, it should be done while polishing is in the 9- to 3- μ m particle size range.

Fine polishing, useful primarily in preparing the specimen for subsequent analytical procedures (such as electron microprobe analysis), is done with compounds having smaller particle size. Where aluminum contamination is not a problem, 0.3- and .05- μ m alumina, in water, may be suitable. Where aluminum is a problem, small particle sized diamond pastes are available.

Procedures Applicable to Individual Part Types

None

Applicable Specifications

None

Materials for Sectioning

Material	Remarks
Acme Epoxy Resin 655 Acme Epoxy Hardener 555 Acme Chemicals, New Haven, Conn.	Water-clear bubble-free epoxy for mounting specimens to be sectioned. Mix 7 parts hardener to 100 parts resin. Cure 16 hours at 339 K (150° F).
Quick Mount Powder Resin Quick Mount Liquid Hardener Fulton Metalurgical Prod. Corp.	Semiclear plastic for mounting specimens. Mix 1.5 parts by volume of powder into 1 part liquid. Cure 1 hour at room temperature.
Epoxide Liquid Resin 208130 Epoxide Liquid Hardener 208132 Buehler, Ltd., Evanston, Ill.	Clear, straw yellow epoxy for mounting specimens to be sectioned. Mix 30 parts by weight resin to 6 parts hardener. Cure 8 hours at room temperature.
Epocast - Resin Liquid No. 202 Epocast - Hardener Liquid No. 9615 Furane Plastics, Inc., Hempstead, N.Y.	Clear, straw yellow, extra hard for sectioning semiconductors. Mix per instructions on container.
Metaduct - Silver Epoxy Resin - Base Metaduct - Liquid Hardener Activator	Silver conductive epoxy for attaching wire connectors. Mix 1 g silver paste with 2 drops Activator. Cure 15 minutes at 339 K (150° F).
Mereco Epoxy Resin Adhesive Mereco Epoxy Activator Metachem Resins Corp., Cranton, N.J.	Quicksetting epoxy for preattaching small parts preliminary to potting. Mix 2 parts resin to 1 part activator. Cure 1 to 2 minutes.
Fluorocarbon Spray M.S. 122 Miller Stephenson Chemical Company	Mold releases for coating inside of molds prior to pouring epoxy. Releases puck when cured.
Alumina Liquid Alfa 0.3 μ m Alumina Liquid Gamma 0.05 μ m Buehler, Ltd.	Fine polish (0.3 μ m); extra fine polish (0.05 μ m); dilute with distilled water, 1 part to 10 parts water.
Zirconium Oxide Tizon Chem. Co., Flemington, N.J.	1200 silicon and germanium polish. Excellent for silicon dice. Has electrochemical action. Will sometimes help delineate junctions
Lapping Oil - 60-3250 Buehler, Ltd.	Coolant lubricant for use with diamond pastes when rough polishing.
RTV-102 General Electric	Used as a sealant in preparation of molds used in making epoxy specimen pucks.

Ethyl Alcohol Octagon Process Co.	Degreaser for specimen pucks.
Pelletized Alumina Coors Porcelain Co., Golden, Calif.	Three grades: hard, medium, soft; 180 mesh. Special use in cross-sectioning to prevent relieving at interface.
Diamond Paste Elgin Watch Company	For last steps in final polishing. 9 μm - Rough polish 3 μm - Medium polish 0.25 μm - Fine polish 0.10 μm - Extra fine polish
Linde B. Metallographic Polishing Compound 0.05 μm	Super fine final polish on silicon dice may be slightly diluted with distilled water as desired.
Buehler 40-7058 Nylon polishing cloth Buehler, Ltd.	Used primarily with diamond pastes.
Buehler 40-7218 Microcloth polishing cloth Buehler, Ltd.	Used primarily with alumina polishing preparations.
Geoscience Microlon polishing cloth Geoscience Instruments Corp. Mt. Vernon, N.Y.	Used primarily with alumina polishing preparations.

METHOD D8—CHEMICAL STAINING

Applicable Part Type(s)

Integrated circuits, transistors, and diodes

Purpose

To identify the nature and location of dopants in semiconductor material; and, thus, to determine the positioning of (and possible faults in) junctions, epitaxial layers, and so on

Equipment (or Equivalent)

Various equipment and apparatus normally found in a chemistry lab, including an exhaust hood, goggles, rubber gloves, and such; a timer, a light source, and a variety of reagents, particularly those listed under Staining Solutions

General Procedure

All work shall be carried out with the strictest regard for accepted safety practices in the chemistry laboratory. If doubt exists regarding safety practices, or if these practices are not known, there are guides that should be consulted.*

Identification of dopant locations and type is usually only performed on cross-sectioned specimens. (See method D7 for specimen preparation.) It may be helpful (or even necessary) to cross-section the device at an angle, to provide mechanical magnification of the region of interest. Of course, if physical measurements (such as junction depth) are being made, the angle of cross-sectioning must be known precisely.

The first step is to choose an appropriate etching, staining, or plating solution from the following list, and, after meticulously cleaning the specimen, apply the solution to the region of interest. The results should then be observed under a microscope. If this procedure is critical to the investigation, it is worth repeating one or more times. Results of staining procedures are often difficult to interpret; therefore, if results with the first solution are questionable, it may be useful to try additional, different solutions. Grinding the specimen very slightly, to produce a new surface, may also help.

Procedures Applicable to Individual Part Type(s)

The general procedure is specific to semiconductor devices.

Applicable Specifications

None

Staining Solutions

Junction Delineation

- Sirtl etch: 5.0 g chromic acid
7.5 cm³ hydrofluoric acid
10.0 cm³ water
- CP-8 etch: 50 cm³ nitric acid
24 cm³ hydrofluoric acid
- Copper plating: 5 g copper sulfate
95 cm³ water
(use illumination to activate process)

*See Manufacturing Chemists' Association, Central Safety Committee, *Guide for Safety in the Chemical Laboratory*, Von Nostrand, New York, 1954.

N-region Solutions

- Etch: 20 cm³ hydrofluoric acid
10 cm³ acetic anhydride
1 drop nitric acid
1 drop nickel sulfate
- Copper plating: 20 g copper sulfate
1 cm³ hydrofluoric acid
100 cm³ water
(use illumination to activate process)
- P-region Etch Solution: 6 cm³ phosphoric acid
1 cm³ hydrofluoric acid

METHOD D9—DIELECTRIC PINHOLE TESTS

Applicable Part Type(s)

Capacitors having a slug-type anode

Purpose

To reveal the exact location of dielectric defects that are responsible for short circuits or leakage paths

Equipment (or Equivalent)

Hydrochloric acid, salt water, tweezers, clamps and stands, various beakers or dishes normally found in a chemical laboratory; power supply (dc) capable of supplying the maximum working voltage of the capacitor

General Procedure*

Salt water is poured into a beaker. The anode slug is positioned such that it is immersed in the salt water but the lead wire and seal area are above the water level. The capacitor case (removed earlier) is also immersed in the salt water for use as the cathode electrode. (If the case is not available, then another suitable electrode must be substituted for it.) The slug and the case (or other electrode) are supported in such a manner as to allow affixing of electrical test leads without introducing a short circuit between them and without damage to the test leads by the liquid solution. The maximum working voltage of the capacitor is now applied. Any bubbles formed pinpoint areas responsible for leakage current.

*Another procedure, previously used, is no longer recommended. This involved the use of benzidine dehydrochloride, a substance determined to be carcinogenic.

Procedures Applicable to Individual Part Types

The general procedure is specific for capacitors having a slug-type anode.

Applicable Specifications

None

METHOD D10--HARDNESS TESTS

Applicable Part Type(s)

Relays

Purpose

To determine the hardness of the various metals used in critical portions of the relay, such as at pivots, at contact faces, and in spring material

Equipment (or Equivalent)

Not available

General Procedure

Not established

Procedure Applicable to Individual Part Types

The general procedure is specific for relays.

Applicable Specifications

None

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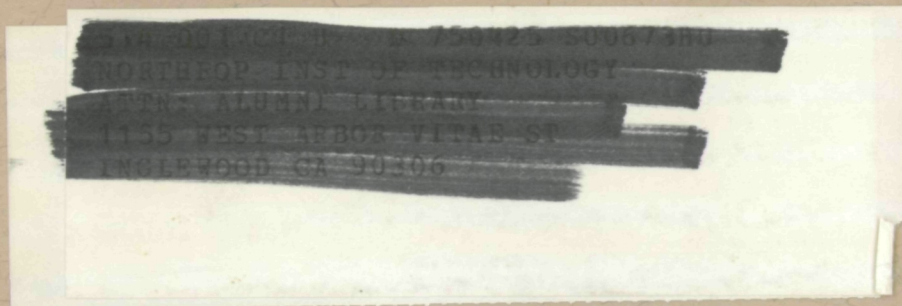
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