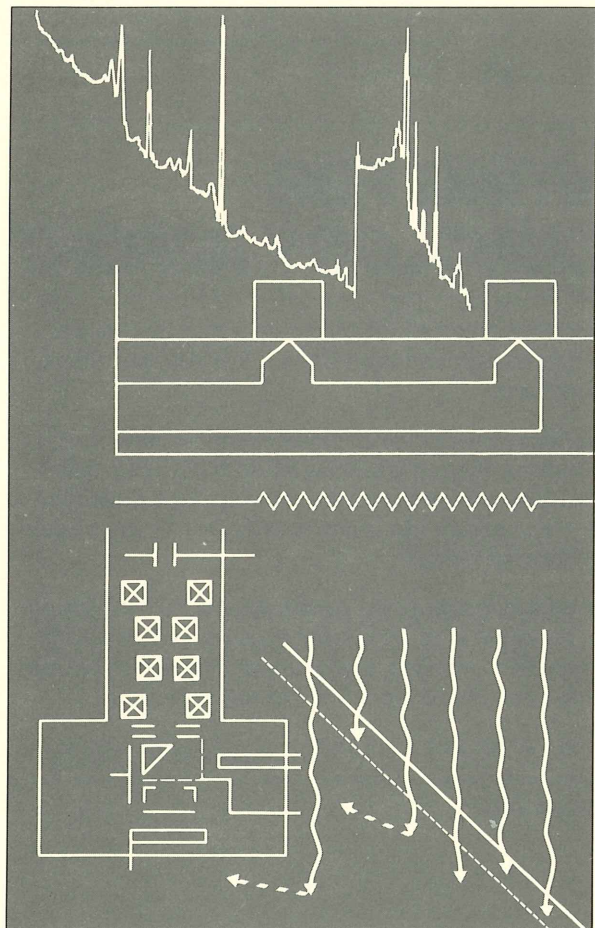


TECHNOLOGY report

COMPANY CONFIDENTIAL



INFRARED
SPECTROSCOPY:
FTIR/GCIR

HIGH TEMPERATURE
DIFFERENTIAL
THERMAL ANALYSIS

VOLTAGE CONTRAST
ANALYSIS IN THE SEM

X-RAY PHOTOELECTRON
SPECTROSCOPY (XPS)

MATERIALS ANALYSIS LABORATORY INCREASES CAPABILITIES

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Why TR?

Technology Report serves two purposes. Long-range, it promotes the flow of technical information among the diverse segments of the Tektronix engineering and scientific community. Short-range, it publicizes current events (new services available and notice of achievements by members of the technical community).

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WRITING FOR TECHNOLOGY REPORT

Technology Report can effectively convey ideas, innovations, services, and background information to the Tektronix technological community.

How long does it take to see an article appear in print? That is a function of many things (the completeness of the input, the review cycle, and the timeliness of the content). But the minimum is six weeks for simple announcements and as much as 14 weeks for major technical articles.

The most important step for the contributor is to put the message on paper so we will have something to work with. Don't worry about organization, spelling, and grammar. The editors will take care of that when we put the article into shape for you.

Do you have an article to contribute or an announcement to make? Contact the editor, Art Andersen, 642-8934 (Merlo Road) or write to d.s. 53-077. □

ENGINEERING ACTIVITIES COUNCIL MEMBERSHIP CHANGES

The semiannual EAC "rotation" took place recently. About every six months the membership of the Engineering Activities Council (EAC) is partially changed (rotated) as old members finish their terms and new members are selected.

The Engineering Activities Council is a group of about 20 engineers and scientists, chartered to stimulate communication between engineering and management, and also among engineers. Members are nominated by their managers, peers, or by themselves, and then selected by Bill Walker, executive vice-president, to represent the different engineering disciplines and organizations within Tektronix. The EAC addresses issues of engineering concern through a diverse set of activities including technical forums, technical seminars, new engineer orientations, and engineering surveys.

EAC Goals

- Promote communications between engineers concerning issues such as professional development, new technologies, and internal developments.
- Promote communications from engineering to management concerning issues such as technology, environment, and marketplace trends and pressures. To this end, the EAC needs to be aware of engineers' views and be capable of advising on issues concerning the engineering community.
- Promote communication from management to engineering concerning company philosophy and business directions. □



The Engineering Activities Council. From left to right: John Sonneborn, Pat Green, Kathy Dagostino, Tom Haven, George Tice, Steve Rintala, Elizabeth Wasson, Rebecca Wirfs-Brock; next row: David Eby, Dan Baker, Mark DeSpain; next row: Preston Seu, Mike Hatch, Robert Jaquiss, Jr.

EAC ROSTER

Ward Cunningham Computer Research Lab	627-6180	50-662	Steve Rintala Instrument Systems Integration	253-5639	C1-904
Jim Prouty Electronic Systems Lab	627-6061	50-370	David Eby Lab Instruments	627-2867	39-222
Nick Fkias CAX Center	685-3033	63-397	Elizabeth Wasson Logic Analyzers	629-1393	92-716
Bill Trent Communications Network Analyzers	627-1447	58-305	Kathy Dagostino Microcomputer Development Products	629-1791	92-515
John Sonneborn Display Devices Engineering	627-4994	50-275	George Tice Microcomputer Development Products	629-1310	92-526
Pat Green Display Devices Engineering	627-5461	50-493	Mike Hatch Portable Instruments	627-2649	39-204
Mike Zuhl Engineering Computing Systems	685-2551	61-215	Robert Jaquiss, Jr. Scientific Computer Center	627-6346	50-454
Richard Greco Graphic Design Applications Systems	685-3176	63-196	Geoff Herrick Solid State Group	627-6374	59-840
Rebecca Wirfs-Brock Graphic Desktop Products	685-3027	63-523	Phil Baker Solid State Group	627-3149	13-035
Mark DeSpain Graphic Peripheral Products	685-3755	63-356	Tom Haven Liquid Crystal Color Shutter Special Project Unit	627-9410	48-300
Preston Seu Graphic Peripheral Products	685-3856	63-356	Dan Baker TV Products	627-1352	58-594

MATERIALS ANALYSIS LABORATORY INCREASES CAPABILITIES

By Kevin Smith, manager, Materials Analysis Laboratory

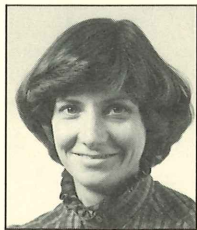
The Materials Analysis Laboratory (MAL) provides analytical services for manufacturing and research projects throughout Tektronix. We have provided these services since 1964 with increasing precision and range.

In the past year, particularly, the Lab has added to the range of its services with new equipment and new techniques. These techniques expand our long-standing facilities in surface analysis, thermal analysis, infrared spectroscopy and scanning electron microscopy. We can tackle your problems with the best procedures in the industry.

To give you an idea of what the Lab can do, this issue of *Technology Report* is publishing four articles, each describing a technique – and some applications. It is impractical to discuss all experimental principles and applications, so readers are urged to contact the appropriate author for details.

A booklet describing the Lab's capabilities is available. Informal tours can be arranged. Please call me, Kevin Smith, at 627-5489, for general information. □

INFRARED SPECTROSCOPY: FTIR/GCIR



Linda Hirschy is an analytical scientist in the Materials Analysis Lab. Linda joined Tektronix early in 1983. After receiving a BA in chemistry from Miami University, she spent several years at the Organic Chemicals Division of the SCM Corporation in Jacksonville, Florida. She then studied for and received a PhD in analytical chemistry from the University of Florida.

Infrared spectroscopy has been used to determine the structure of organic and inorganic molecules since the early 1900s. This technique measures absorption of infrared radiation by molecules undergoing vibrational transitions. The frequencies of these absorptions indicate which functional groups are present and, thus, aid in the structural identification of the molecule.

Conventionally, infrared absorption is done using a dispersive instrument, such as the one depicted in figure 1. This instrument separates the light from a blackbody source into its spectral components using a prism or grating. Since a narrow slit limits the number of spectral components that reach the sample, most of the available light is discarded and only a small portion interrogates the sample. This is a serious limitation of dispersive instruments. When high resolution spectra are required, one must further reduce the light intensity by reducing the slit width.

Fourier transform infrared spectroscopy (FTIR) is a substantial improvement over dispersive IR (see table 1). A typical FTIR instrument is shown in figure 2. This instrument allows all frequencies of light to pass through the sample at one time. The detected signal (ignoring absorptions) can be described by:

$$Y(z) = \int_{-\infty}^{\infty} E(\sigma) \exp(i2\pi\sigma z) d\sigma$$

where z represents the position of the movable mirror, $Y(z)$ is the intensity of light detected at position (z), σ is the frequency of radiation, and $E(\sigma)$ is the electric field strength at frequency σ . The $Y(z)$ data is measured and recorded to form the interferogram. This data may then be transformed by the following equation:

$$E(\sigma) = \int_{-\infty}^{\infty} Y(z) \exp(-i2\pi\sigma z) dz$$

to give the infrared spectrum in the frequency regime σ .

FTIR has two significant advantages over dispersive IR. The *Jacquinot advantage* arises because limiting apertures are used sparingly in FTIR, so light throughput is higher. The *Fellgett* (or multiplex) advantage comes from observing all frequencies of light simultaneously. This improves the signal to noise ratio (S/N) by the square root of the ratio of the spectral width to the resolution. For example, a typical scan runs from 4000 to 400 cm^{-1} at 8 cm^{-1} resolution – a range of 3600 cm^{-1} – so the S/N enhancement from the Fellgett advantage is $\sqrt{(3600/8)} = 21$. These advantages allow high scan speed and excellent resolution.

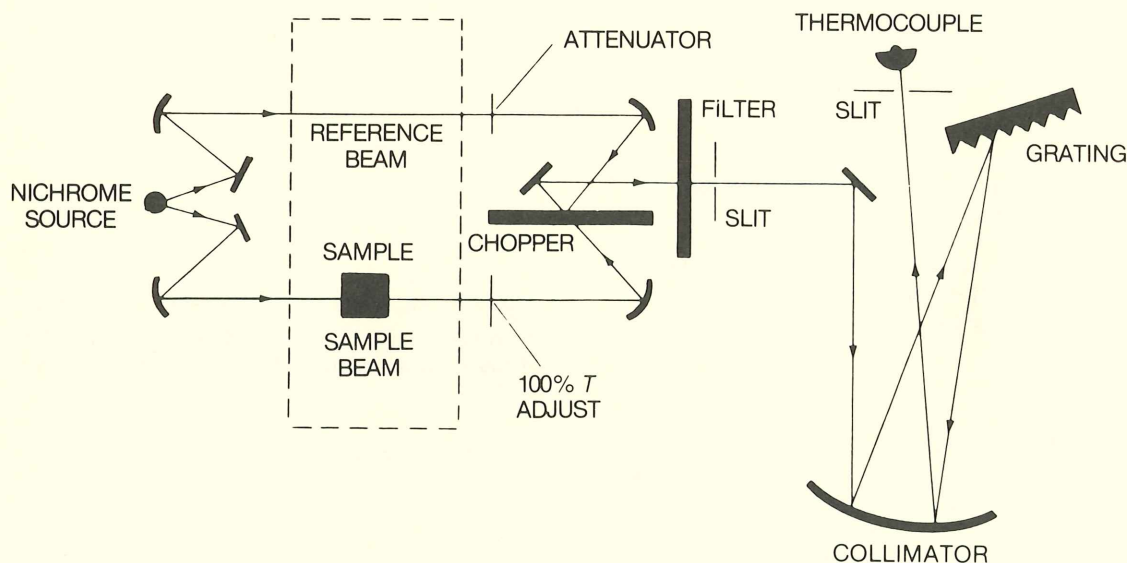


Figure 1. A conventional dispersive infrared instrument.

Table 1
CAPABILITIES COMPARISON

	FTIR	DISPERSIVE
	Nicolet 60SX	Perkin Elmer 467
Dynamic Range	$1/10^4$	$1/10^2$
Frequency Accuracy	$.01 \text{ cm}^{-1}$	3 cm^{-1}
Resolution	$.25 \text{ cm}^{-1}$	1.5 cm^{-1}
Repeatability	$-.01 \text{ cm}^{-1}$	1.5 cm^{-1}
Fastest Scan Speed	down to .05 seconds	6 minutes
Photometric Accuracy	.1%	.1%
Computer Support	YES	NO
On Line Library Search	YES	NO

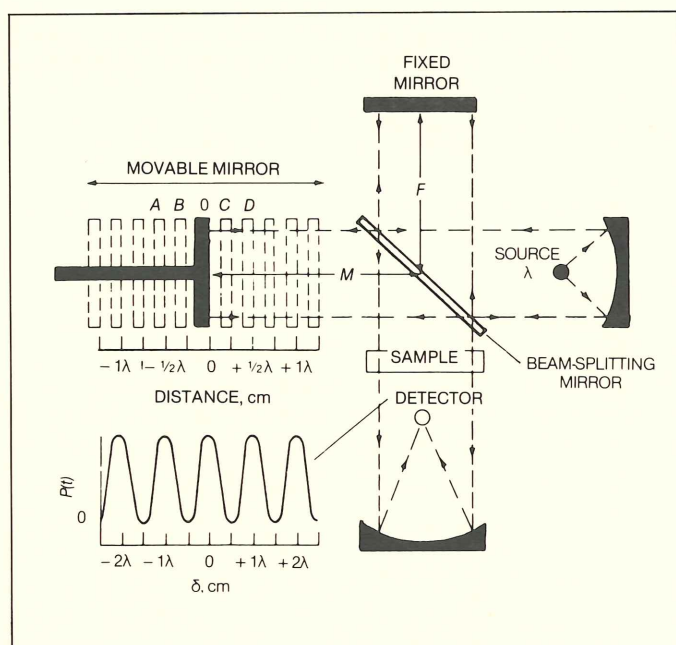


Figure 2. A Michelson interferometer from a Fourier transform infrared instrument (FTIR).

The position of the movable mirror in FTIR is determined by a laser interferometer to better than 1.0 micron. This laser measurement is responsible for the high repeatability and frequency accuracy found in FTIR.

Organic Analysis

Dispersive IR has been used extensively to identify organic molecules. In organic analysis, FTIR has several advantages over dispersive IR: the photometric and frequency accuracies are about ten times better, and all spectra are stored on a computer for comparison and analysis. The high frequency accuracy makes comparing unknown spectra to library files easier.

Tektronix uses the Nicolet/Aldrich library of over 8,000 known spectra to help identify organic unknowns. With this library and a computer, a compound can be identified in minutes instead of

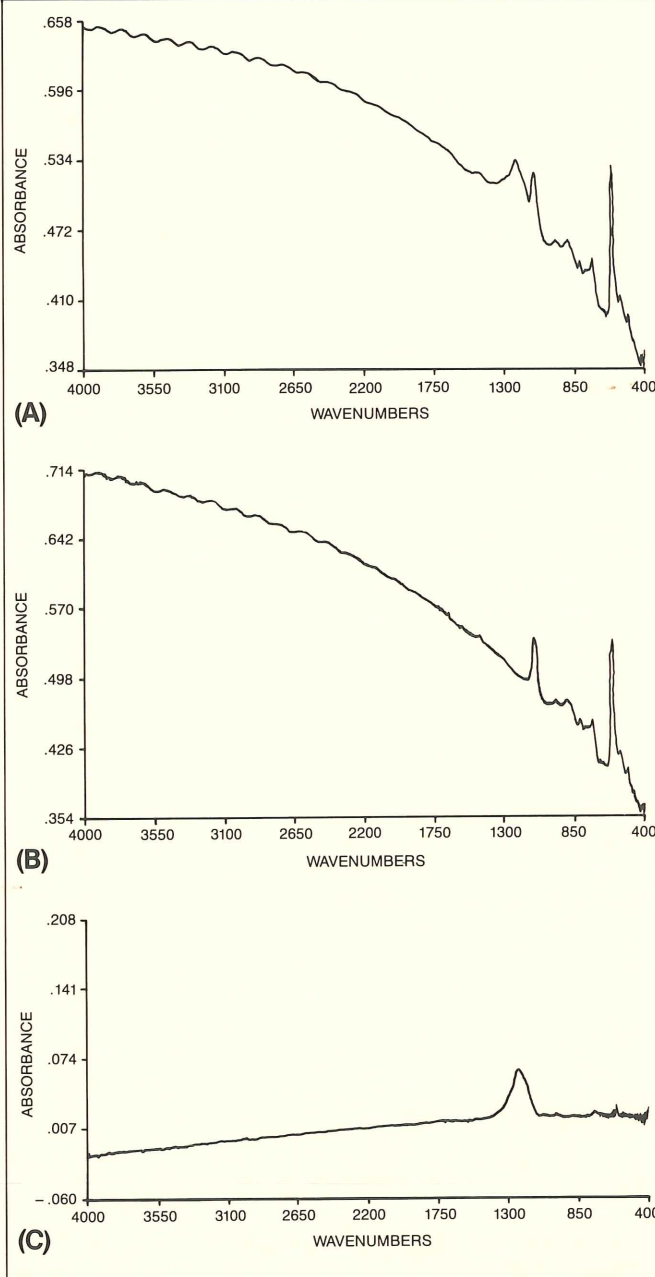


Figure 3. (A) A silicon wafer coated with a fluorocarbon. (B) A reference silicon wafer (uncoated). (C) The spectrum of the fluorocarbon resulting from spectral subtraction (A-B).

the hours required by manual search of previously recorded spectra. The high photometric accuracy of FTIR and the computer capability also make possible spectral subtraction and quantitative analysis of mixtures.

Figure 3 illustrates the use of spectral subtraction in the analysis of a fluorocarbon coating on a silicon wafer. The spectrum of a reference wafer (B) is subtracted from the spectrum of the coated wafer (A) to leave the spectrum of the fluorocarbon coating only (C).

Figure 4 illustrates the use of FTIR to determine the degree of polymerization in polyimide. The first spectrum (A) represents the unprocessed polyamic acid. Structural changes that occur during processing to produce the polyimide (spectrum B) also change the infrared spectrum, providing a useful tool for monitoring the process.

GCIR

A gas chromatograph interfaced with a Fourier transform infrared spectrometer is called a GCIR (figure 4).

A gas chromatograph (GC) is typically used to separate mixtures of volatile organic liquids. However, it is often difficult to identify the components after they have been separated. A GCIR combines the powerful separation ability of the GC with the identification abilities of IR spectroscopy. This combination is made possible by the high data accumulation speed of the FTIR. For typical GCIR runs, the FTIR can take an 8 cm^{-1} resolution spectrum about twice a second. Five or six spectra can be taken in the time required for typical GC peaks to elute.

Our lab was asked to identify the components in a lacquer. The GC showed the lacquer had five. Without GCIR, identification was a week-long task: first separation, consisting of distillation and elution, and then manual searching infrared libraries to identify the components. Major components were identified in less than two hours using GCIR.

Semiconductor Applications

Recently, the role of oxygen in semiconductor processing has received more attention, particularly oxygen as an internal getter in silicon. To predict the gettering efficiency as a silicon wafer is thermally processed one needs to know the concentration of interstitial oxygen. Infrared spectroscopy is the most efficient method for this determination. FTIR can determine O_i concentration in less than one minute. This speed allows the mapping of O_i content across a wafer and also following the O_i content as a function of processing step.

Substitutional carbon has also been thought to play a role in internal gettering. FTIR can detect substitutional carbon down to about one part per million. In addition, cryogenic accessories can detect shallow-level impurities down to levels of $10^{13}/\text{cm}^3$ in silicon. Figure 5 shows typical spectra of float-zone silicon and silicon containing both carbon and oxygen.

Epitaxial layer thickness may also be determined by FTIR spectra. Layers between one and 200 microns may be determined by conventional algorithms. After appropriate standard spectra are obtained, it is possible to determine epitaxial layer thicknesses down to 0.25 micron. Since these precise measurements can be made on wafers with only a small percentage buried layer, FTIR is excellent for controlling the quality of IC manufacturing processes. And since these thickness measurements can be made in minutes, substantial time is saved over conventional techniques.

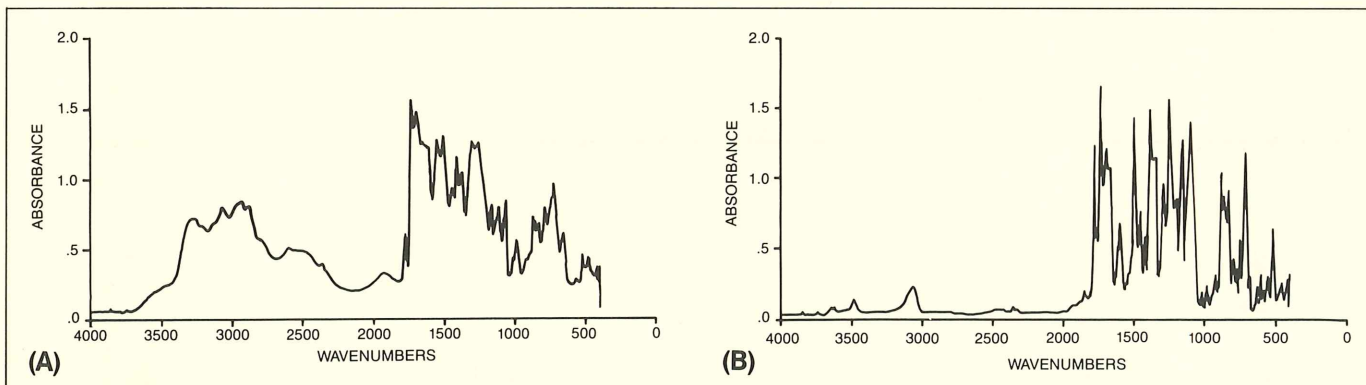


Figure 4. (A) The IR spectrum of polyamic acid. (B) The spectrum of polyimide resulting from heat processing polyamic acid.

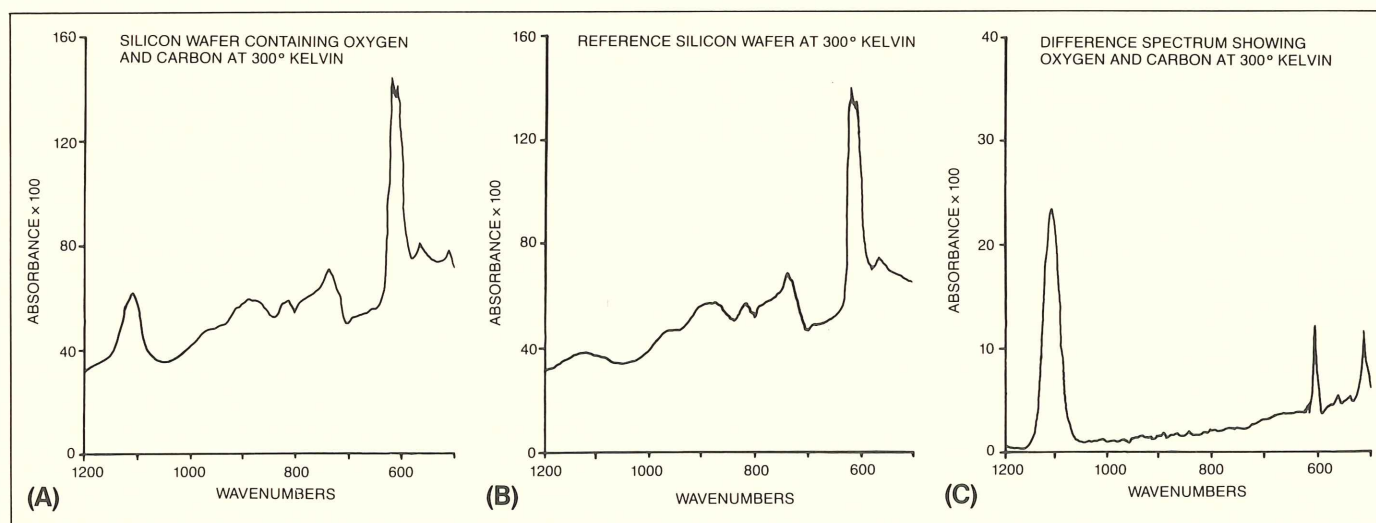


Figure 5. Typical spectra of float-zone silicon and silicon containing both carbon and oxygen.

Summary

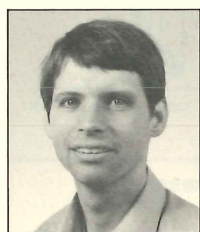
FTIR has upgraded the infrared capabilities of the Materials Analysis Lab by at least an order of magnitude in all important categories. Introduction of library searches and GCIR make analysis of complex mixtures and unknowns routine. Computer capabilities in the Lab allow quantitation and storage of spectra not previously possible. Oxygen and carbon analysis in Si is

also routine with FTIR, as is measurement of epitaxial layers. FTIR can shed new light on previously intractable identification problems.

For More Information

For further information call Linda Hirschy, 627-5482. □

VOLTAGE CONTRAST ANALYSIS IN THE SEM



Dick Tuenge is an analytical scientist in the Materials Analysis Lab. Previously, he worked in electron microscopy at Arizona State University and thin film process development at Tek. Dick joined Tek in 1978. He has a PhD in physical chemistry from Iowa State University.

With ever smaller IC line widths and ever greater packing density, electron beam testing becomes increasingly useful. In these tests, the E-beam can be either a fixed or a scanned high-resolution probe; either can be used without destroying the sample or loading (affecting) the sample's characteristics.

The conventional scanning electron microscope (SEM) operated in the voltage contrast (VC) mode has been used for IC failure analysis for sometime. However, because its sensitivity has been limited to one or two volts, it could test only TTL circuits.

Recently, the voltage-contrast (VC) E-beam technique has received much attention. Developments in electron spectrometers and control circuitry have enabled the VC technique to be applied with better than 10 mV resolution to a wide range of devices, in either static or dynamic operation.

Voltage contrast in the SEM arises from variations in the secondary electron signal caused by changes in the potential on the surface of a device. Because secondary electrons emitted from a positively biased line have to overcome a retarding field, only higher energy electrons reach the detector. This causes a lower signal than that produced when the E-beam is directed to a grounded or negatively biased line.

Qualitatively, IC conductor lines at a positive voltage appear darker on electron micrographs and negatively biased areas appear brighter. This voltage contrast appears superimposed on the normal topographic and material contrast unless the latter are eliminated by using sample-and-hold circuitry or by using phase sensitive detection.

Quantitative Voltage Contrast

A quantitative voltage measurement is based on shifting the entire secondary electron energy distribution by an amount $e\Delta V_p$ to shift the voltage ΔV_p at the measurement point. In addition to the shift in the $N(E)$ spectrum there will be a corresponding displacement of the $\int N(E)dE$ curve (figure 1). In practice, the integral form is usually used for voltage measurement since it requires only an energy filter and a standard SE detector.

Figure 2 shows a cross section of the retarding field electron spectrometer used in our SEM. (This spectrometer was designed by Jon Orloff at the Oregon Graduate Center.) The feedback loop compensates for the change in collected current caused by the variation in the applied specimen voltage by adjusting the operating voltage on the retarding grid of the spectrometer. Setting a grid operating point (V_1) then results in a linear relation between the applied and measured voltages. A plot of the grid voltage versus the voltage applied to the sample will then be a straight line, ideally with a slope of unity.

The voltage resolution that can be obtained using this technique is given by:

$$V_{\min} = C \cdot n \cdot (\Delta f / I_{PE})^{1/2}$$

where C is a constant, n is the signal to noise ratio, Δf is the bandwidth of the system and I_{PE} is the primary beam current.

Accurate absolute voltage measurements with the voltage contrast method require that all other effects that influence the secondary electron signal are controlled or eliminated. For example: (1) The effect of local fields above the IC from closely spaced lines at different potentials can be suppressed by using

strong extraction fields, approximately 1 kV/mm. (2) Unwanted topographic and material contrast can be reduced by contrast-isolation circuitry. This circuitry subtracts the SE signal with no voltage applied from the SE signal containing voltage information. (If all measurements are made on the same material, such as Al or Au, the effects of material contrast can be ignored.) (3) Measurement errors can be caused by contamination in the device's surface. A clean vacuum system with an oil-free pump, such as a turbomolecular pump, will substantially reduce contamination.

Application to Tek ICs

We have applied voltage contrast in analyzing failures of bipolar ICs being developed in Monolithic Circuits Engineering (MCE). Some of these ICs are made with LBT processes that use multi-layer metallization and 2 to 4 μm metal line widths. Many of these devices employ ECL logic, which has voltage swings of 500 mV or less; signals as low as 150 mV are operable on an 8 K string device. Detection of such low voltages requires a secondary electron energy spectrometer, but, presently, absolute voltage measurement isn't needed.

The packaged bipolar devices analyzed so far do not appear sensitive to E-beam damage. Relatively high primary beam energies of about 20 kV can penetrate up to 1 μm of oxide or nitride insulating layer; this minimizes surface charging. Since the drive signal is generally on the first layer metal, in devices with passivation overlaying the second-layer metal low voltage swings are difficult to see.

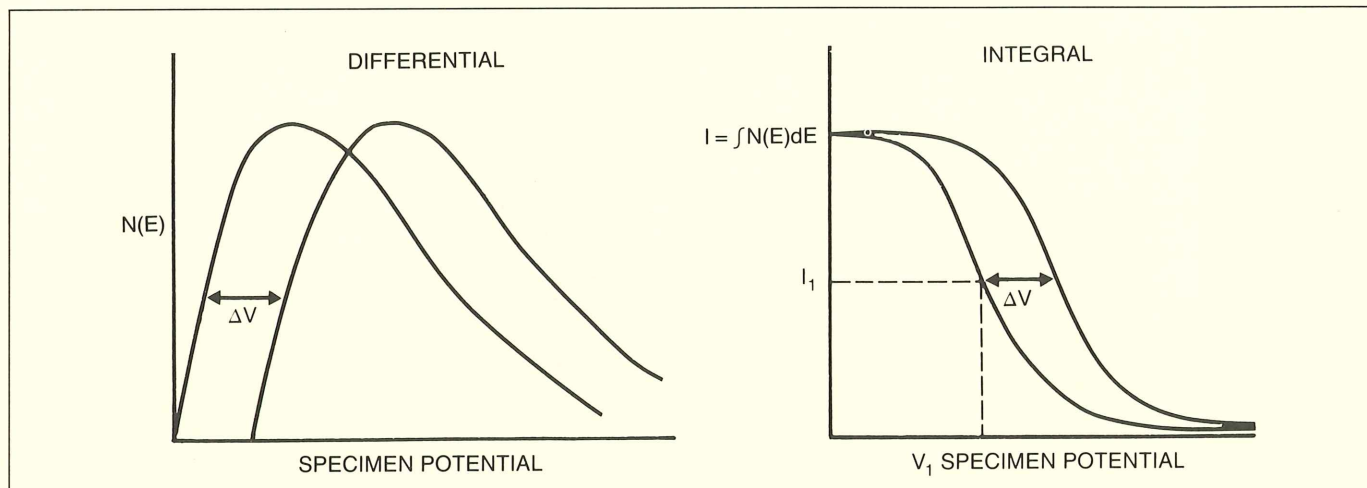


Figure 1. Shifts of the differential and integral scanning electron spectrum resulting from a variation in specimen potential (V_{sp}). If the X axis is the grid voltage V_G of a retarding field analyzer, the measured voltage shift ΔV varies linearly with ΔV_{sp} .

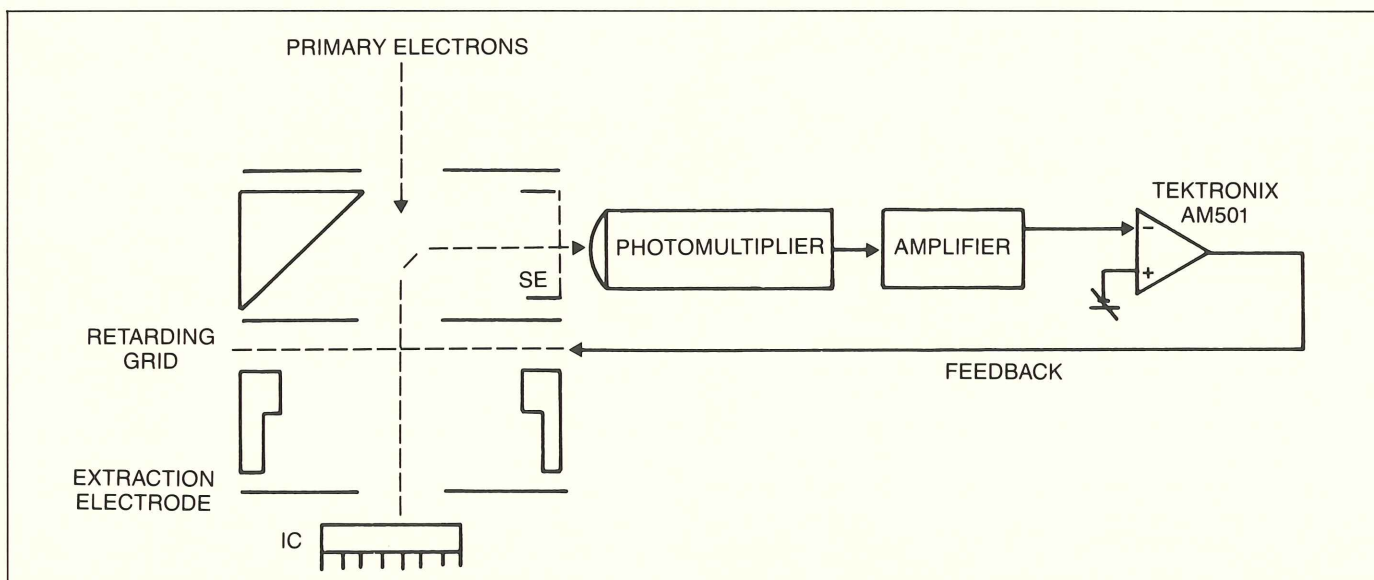


Figure 2. Retarding field voltage spectrometer with signal feedback for linearizing voltage contrast.

In unpassivated devices with one layer of dielectric between metallization levels, quite low voltage contrast signals (20 mV) have been resolved. Figure 3 shows the linearized-spot-mode VC signal obtained from a biased thin film resistor overlayed with 8 kÅ of nitride. A voltage contrast image of the device can be seen on a video monitor with the aid of contrast isolation circuitry such as that in the VC system in figure 4.

VC analysis of MOS circuits is complicated by device susceptibility to electron beam damage. High-energy ionizing radiation can form trapped charges in the oxide and cause interface states that can alter threshold voltages and switching currents. MOS devices can, however, be probed with little or no damage if low primary beam energies (0.7 to 2.5 kV) are used. The Lab's SEM has been modified to include a single crystal LaB₆ cathode and a low voltage anode for more brightness at these low beam potentials; this allows the VC technique to test Tek's 2 μm geometry CMOS devices.

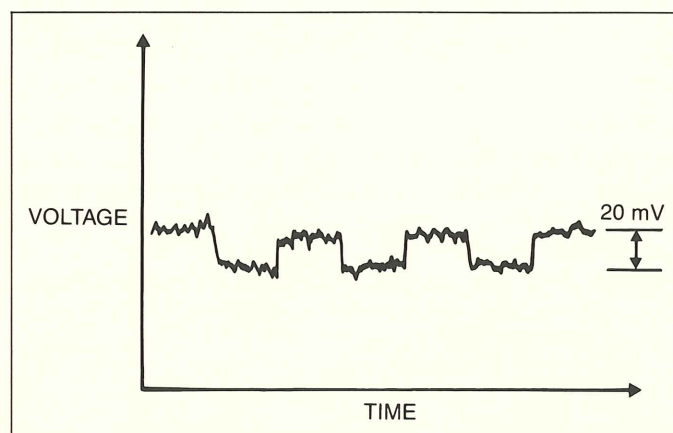


Figure 3. Scanning electron signal resulting from a 20 mV square wave applied to a passivated preohmic NiCr resistor. An SE-spectrometer is required to resolve this low voltage signal.

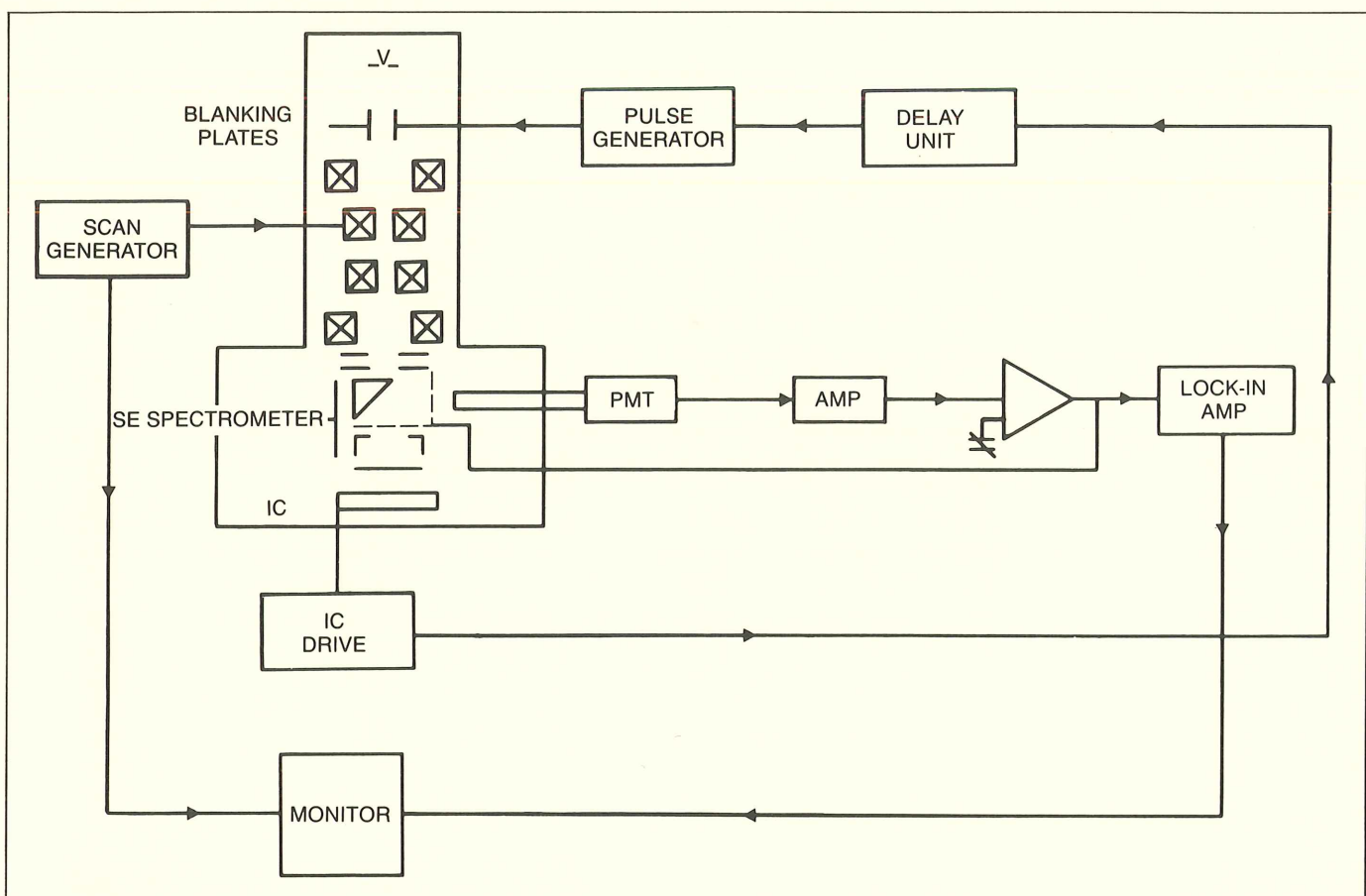


Figure 4. The experimental setup for high resolution dynamic voltage distribution images. The lock-in amplifier eliminates the topographic and material contrast.

Voltage contrast analysis of silicon IC's under actual operating conditions requires extending the VC technique up to frequencies of several hundred MHz. Electrostatic beam blanking plates, such as those in the system in figure 4 have been installed in the Lab's SEM. Primary beam pulses with rise times as short as 0.2 ns can be produced with this system.

The beam is pulsed synchronously with the waveform applied to the device. The entire period of the waveform can be sampled by advancing the phase of the beam pulses in relation to

the phase of the waveform. Using this stroboscopic technique, waveform rise times and propagation delays can be measured by operating in the spot mode; and VC images of the IC at a given phase of the waveform can be seen by operating in the scanning mode.

For More Information

For further information about voltage contrast, contact Dick Tuenge at 627-5474. □

X-RAY PHOTOELECTRON SPECTROSCOPY (XPS)



Larry Church is an analytical scientist in the Materials Analysis Lab. He joined Tektronix in 1980. He received his PhD in physical chemistry from Carnegie Institute of Technology. He taught chemistry at the State University of New York at Buffalo and at Reed College. At Reed he was also the director of the college's nuclear reactor.

XPS is a technique that determines the kinetic energy of core electrons that have been photoelectrically removed from the surface of a sample by X-rays. This surface analysis technique is diagramed in figure 1. Typically Mg or Al K_{α} X-rays are the excitation source. Although 1200-to 1500-eV X-rays can penetrate a solid to at least 2 microns (20,000 Å), the short mean-free-path of the photoelectrons in the solid assures that only electrons generated in the outer 50 Å will be detected by the electron analyzer. This is shown schematically in figure 2.

The XPS method is also called ESCA (for electron spectroscopy for chemical analysis).

The spectrometer analyzes the photoelectron kinetic energy. This equals the X-ray photon energy less a constant work function energy and the binding energy required to remove the electron from its atomic (or molecular) orbital. The amount of the binding energy primarily depends on the element and the atomic orbit from which the electron is removed. The binding energy also depends on the oxidation state of the atom; small oxidation state "shifts" permit you to determine the chemical bonding properties on an element's surface.

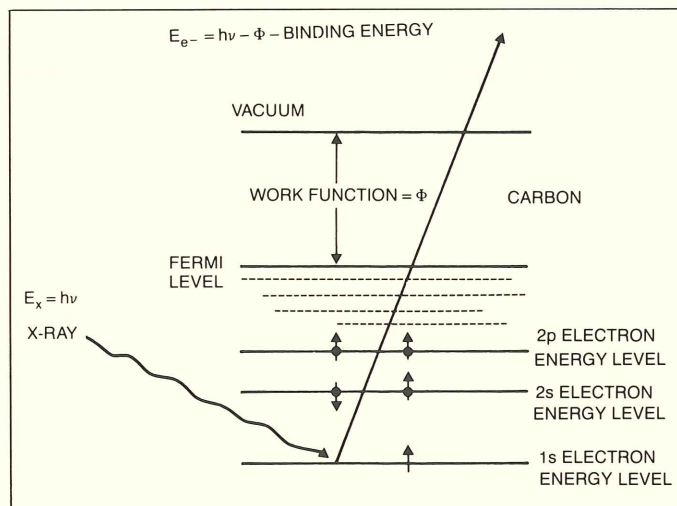


Figure 1. X-ray photo electron spectroscopy (XPS).

As figure 2 indicates, an ion-sputter gun can remove surface layers from a sample. Removal is done to either clean the sample prior to analysis or to look at the outer surface layers of the sample in profile to determine how elemental concentrations and/or oxidation states change with depth. All of the hardware in figure 2 is in an ultra-high vacuum chamber; pressures are typically in the 10^{-10} Torr range. This ultra-high vacuum reduces perturbations of the electron energy between the sample and analyzer.

Comparing XPS to Other Surface Analysis Techniques

The most popular surface analysis technique is the *scanning electron microprobe* (SEM). Most SEM instruments can detect the X-rays emitted from atoms as the result of removing inner-shell electrons. However, the long mean-free-path of X-rays (as compared to photoelectrons) allow a SEM to analyze elements to a depth of 2 microns, while XPS is more a surface-sensitive instrument, having a 50 Å depth limit.

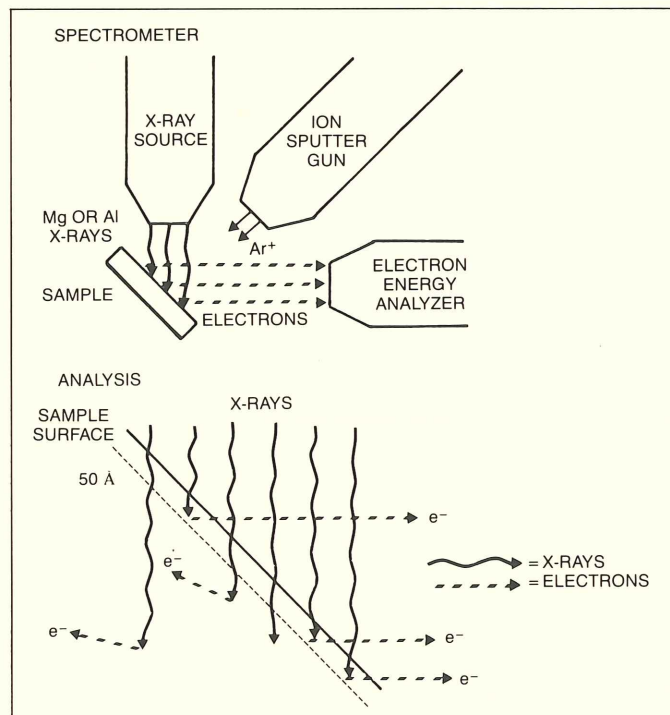


Figure 2. In XPS, the short mean-free-path of the photoelectrons assures that only the outer 50 Å of a sample surface will be analyzed.

Auger electron spectroscopy (AES) closely resembles XPS. Auger electrons have about the same energy as photoelectrons, therefore, both techniques have good depth resolution. Because Auger electron spectroscopy excites with an electron beam, its spatial resolution is far superior to XPS. Commercial Auger instruments have spatial resolutions of at least 1,000 Å. Compare this to XPS's much broader spatial resolution of about 5 mm.

However, since Auger electron spectroscopy bombards the sample with electrons, a dielectric sample can become charged, making analysis impossible. The same dielectric sample will not become charged nearly as much under X-ray excitation and thus XPS is more suitable for analyzing materials having dielectric properties.

Also, very little chemical oxidation state information is usually available from the spectra of an Auger electron transition.

Some Recent Problems Investigated with XPS

The oxides and oxide thickness on reclaimed Co powder used in direct-view storage CRTs

The fine Co particles used to form dots on the face plates of direct-view storage tubes (DVST) have an outer layer of oxide. The chemistry and thickness of this layer depends on the particles' baking and milling history. In this layer, three oxidation states are important: CoO, Co₃O₄ and Co. As can be seen in figure 3, each state has a unique XPS spectra; this allows the difference in the oxidation state between one sample to the next to be determined as a function of depth within the oxide layer. This study was made to determine how these oxidation states affect the adherence of Co dots to the indium-tin oxide conductive layer on the face plates.

Figure 4 shows a cobalt spectrum from one sample. This spectrum closely resembles (both in binding energies and peak shapes) the spectrum for Co₃O₄ (figure 3(B)). However, the location of an electron peak near the binding energy of -786 eV suggests some CoO is also present (see figure 3(C)). After the removal of 80 Å of surface material, some Co metal is observed and figure 4(C) shows that with removal to 160 Å only Co metal is present.

These data and similar data from other samples showed that when Co₃O₄ is the dominant oxide, the oxide layer was thinner. It was also discovered that Co dots made from material where oxide layer is CoO adhere less strongly than dots where the oxide layer is Co₃O₄. This analysis showed that the surface of Co powder should be fully oxidized to Co₃O₄ for better dot adhesion.

Finding shorts through hybrid thick-film substrate material

Shorts through the alumina material used in hybrid thick-film circuits had occurred in about 10% of some devices. Under a microscope, a long trail following the short could be seen in the failed substrates. The dielectric nature of the substrate material made it necessary to use XPS as the analysis technique.

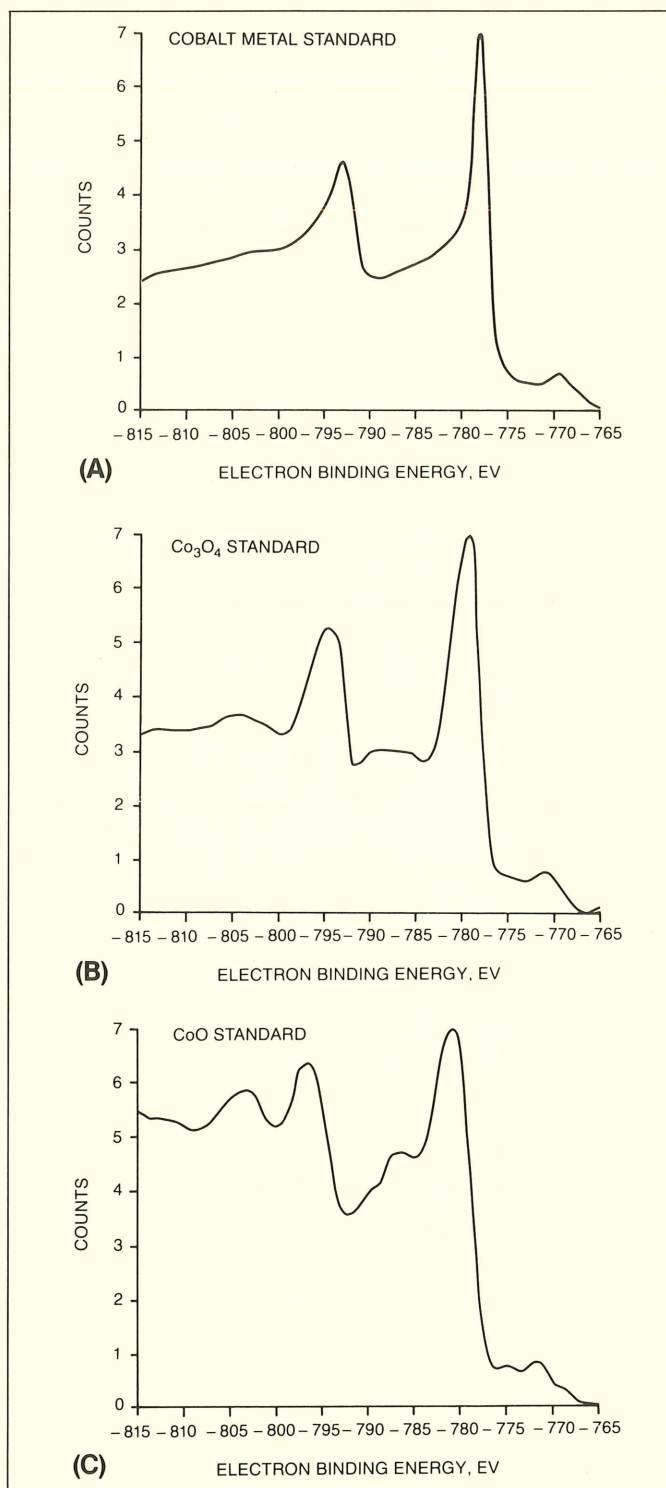


Figure 3. Three oxidation states of Co in DVST dots were studied with XPS to achieve better dot adhesion.

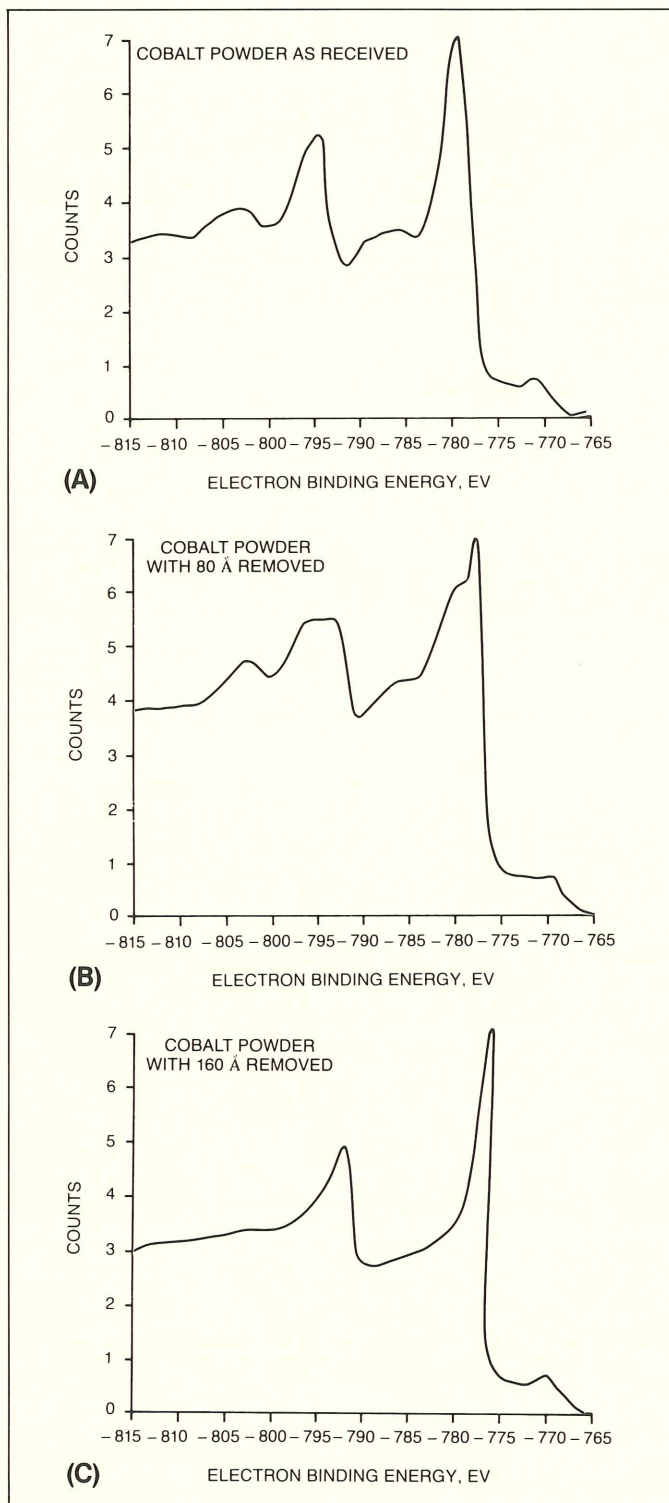


Figure 4. XPS spectra of Co sample at the surface (A), at 80 Å (B), and at 160 Å (C).

Figure 5(A) is a survey spectra of shorted substrate material; compare it to figure 5(B) which has not failed. Each sample has had about 1000 Å removed by sputtering with Ar ions prior to taking these spectra; note the presence of Ar at -240 eV. Copper is conspicuous in the shorted-out substrate with its $2p_{3/2}$ and $2p_{1/2}$ electrons at about -940 eV binding energy. This substrate also had a larger concentration of F (with photoelectrons

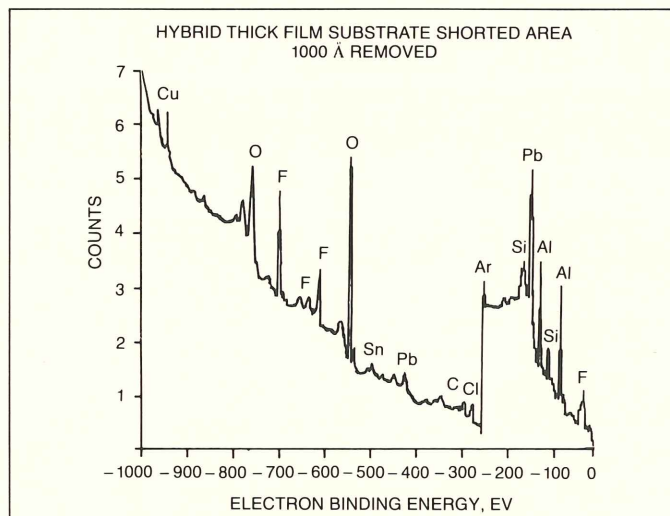


Figure 5A. XPS spectra of thick film substrate that had shorted through the substrate.

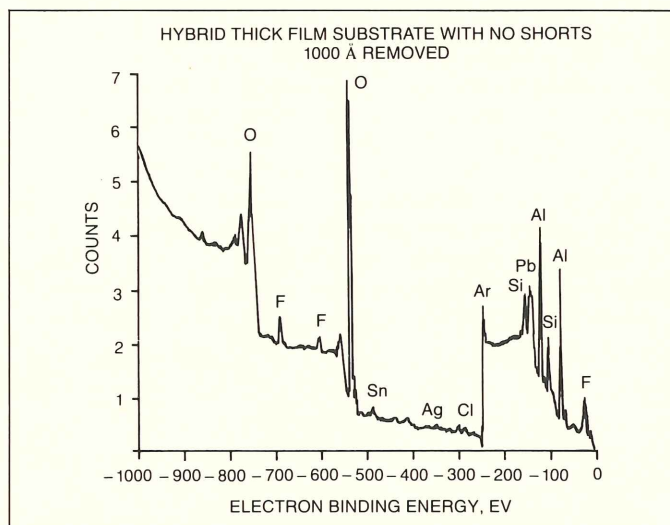


Figure 5B. XPS of alumina thick film substrate that did not have a shorting problem.

at -680 and -605 eV) and Cl (at -270 eV). Upon high-resolution examination, as was done in figure 4, the copper had an oxidation state similar to that found in CuCl. The Cl was present as the chloride (Cl^-), whereas the F was present as an organic fluorochemical, similar to freon.

We determined that CuCl in the substrate material could have caused the shorts in the hybrids.

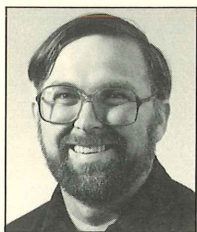
Summary

XPS is usually used to either determine the chemical oxidation state of surface materials or to investigate the elements on a dielectric surface, which cannot be analyzed with a charged particle beam. When used with an ion-sputter gun, the elemental concentration and oxidation state is determined as a function of depth below the surface.

For More Information

Questions regarding the use of XPS should be directed to Larry Church at 627-5490. □

HIGH TEMPERATURE DIFFERENTIAL THERMAL ANALYSIS



Hal Frame is an analytical scientist in the Materials Analysis Lab. Hal joined Tektronix in 1968. He has a BS in chemistry from Portland State University.

Because many materials used in Tektronix equipment are thermally processed, it is often useful to determine their thermal properties under process conditions. The Materials Analysis Lab can do this using differential thermal analysis (DTA).

Whenever a material changes its physical state, heat is either absorbed or liberated. Melting, crystalline restructuring, and chemical reactions involve heat and can usually be initiated by simply raising or lowering the temperature of the material.

DTA instruments measure the enthalpies of physical and chemical changes of state by measuring the differences between the temperatures (ΔT) of a sample and a reference material (see figure 1) as heat is applied equally to both. The applied temperatures are usually scanned (changed) at a linear rate. This plots ΔT vs. time (see figure 2).

Since 1978, the Materials Analysis Laboratory has analysed materials at low to medium temperatures (-50°C to 627°C) using the Perkin-Elmer DSC (differential scanning calorimeter). Now, with the recent addition of a Perkin-Elmer DTA 1700 system, our laboratory can characterize the thermal behavior of

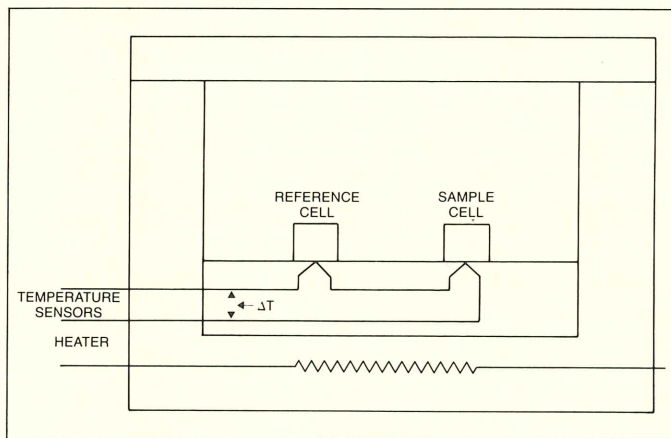


Figure 1. Block diagram of a typical Boersma DTA cell.

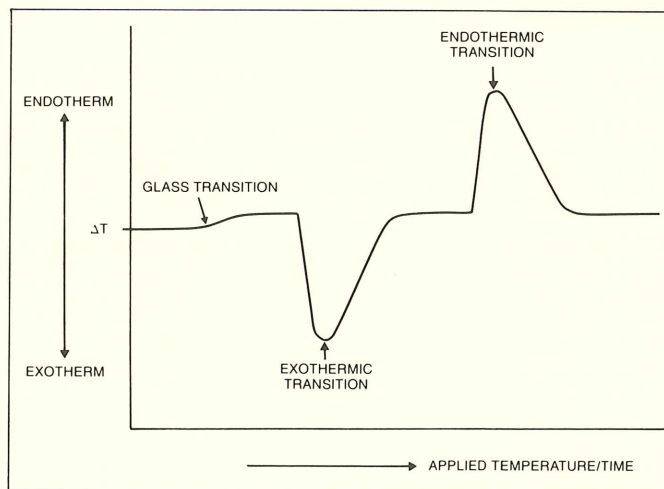


Figure 2. An idealized thermogram showing the possible thermal transitions.

materials to 1500°C . This more than doubles our temperature range. The DTA 1700 also provides a choice of atmosphere conditions within the sample chamber, including reactive or nonreactive gasses in static or controlled flow situations and vacuums of 1×10^{-3} Torr.

The ability to characterize materials at relatively high temperatures and to control the atmosphere around the sample makes the DTA 1700 system excellent for process control and development as well as materials characterization. Let's look at three DTA applications.

CV-98 Solder Glass

CV-98 solder glass is used to seal ceramic covers over hybrid circuits, ceramic CRT funnels, and other devices. A thermogram of this material shows the information that the DTA 1700 can obtain (see figure 3).

From left to right, the first event on the thermogram is the glass transition temperature (T_g). At T_g , the glass changes from a hard glassy material to a viscous plastic material. This change is accompanied by a change in the specific heat of the material, which shows as a shift in the baseline level. The next event is the glass softening temperature (T_s). At T_s , the material becomes fluid and begins to flow. On the thermogram, T_s is the temperature at which the new baseline can be determined. T_s is the lowest temperature at which glazing (sealing) can be done.

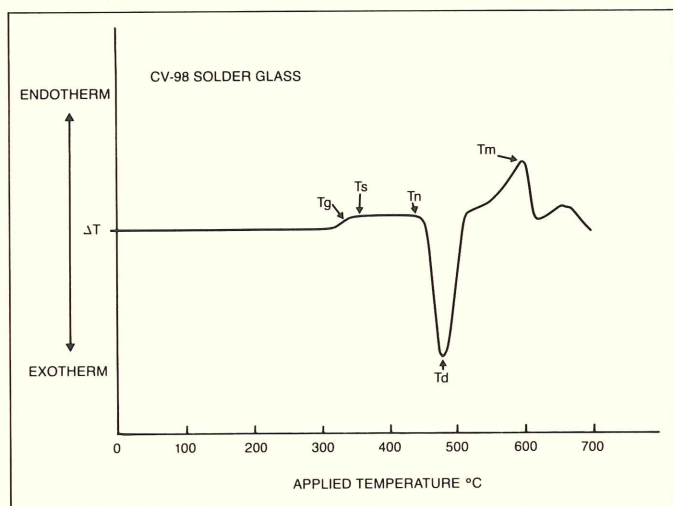


Figure 3. This thermogram shows typical transitions and types of information available from DTA scans. In this case, CV-98 solder glass is thermally characterized.

T_n, the next event, is the nucleation temperature; at this point devitrification begins. T_n is the lowest temperature for final firing of the frit. At T_d, the devitrification temperature, the fastest devitrification takes place. At T_m, glass melts to an isotropic liquid; T_m is frequently used to identify unknown glasses. All these temperatures are useful in determining curing cycles for hybrid and ceramic sealants.

Polyvinyl Alcohol

Polyvinyl alcohol (PVA) is used in many processes to bind inorganic materials. It allows the material to hold its physical shape until thermal processing stiffens the base material; then the PVA burns off.

Because PVA comes in a variety of molecular weights and molecular weight distributions, PVAs can require grossly different bake-out temperatures. How can the optimum material and the bake-out temperature be found? Differential thermal analysis using a controlled flow of air provides the answer without process juggling.

Rare Earth Phosphors

Some Tektronix products require custom-made phosphors. Process temperatures and bake times must be known for good quality and yield. The temperature for proper crystal formation is also needed. You can get these temperatures by trial and error, or you can get them by using a DTA to characterize phosphors under simulated process conditions.

Thermal Analysis Capabilities

In addition to DTA 1700, the Materials Analysis Laboratory has three other instruments for thermal characterization:

Differential Scanning Calorimetry (DSC) is like differential thermal analysis (DTA) except DSC measures the difference in power required to hold sample and reference materials at equal temperatures. (DTA measures the differential temperature while maintaining equal power to the sample and reference materials.) Our DSC equipment has a high-temperature limit of 627 °C and requires subjecting the sample to an inert gas purge.

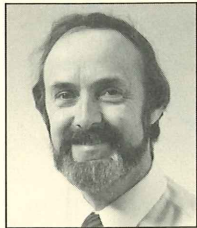
Thermomechanical analysis (TMA) uses a linear displacement-voltage transformer to measure very small movements of a quartz probe. Typically, this instrument is used to determine coefficients of linear expansion. The Lab's TMA has a sensitivity of 5×10^{-5} inches/inch on a 10 mV recorder.

Thermogravimetric analysis (TGA) is also available upon request. This method measures weight loss as a function of temperature and can be used with either a static-air or a nitrogen purge atmosphere.

For More Information

Call Hal Frame, 627-5482, for more information about thermal analysis. □

RELIABILITY GOALS, PREDICTION, AND DEMONSTRATION FOR HYBRID CIRCUITS



Mal Gilbert is the manager of the Hybrid Design Base Extension program in the Hybrid Microelectronics department. Mal joined Tektronix in 1978. He has been involved in hybrid circuits since 1968, serving in various design and management roles. Mal holds a BSEE from the Hatfield College of Technology in England.

This article was adapted from material contained in Volume 1 of the Hybrid Circuits Design Manual. This three-volume manual is designed to familiarize designers with all aspects of hybrid-circuit design. Design Manuals are available upon request from Mal Gilbert, 627-4021.

One task of the designer is to assign a realistic reliability goal to the hybrid that is compatible with the overall reliability requirements of the system. In some instances, the system designer will propose a reliability goal based on a simple budgeting exercise. For example, the hybrid shall not contribute more than X percent to the total system failure rate. In this case, reliability can be predicted to determine whether this goal is reasonable.

If the details of the hybrid design are not yet known, a reliability goal must be estimated based upon the anticipated complexity of the part, the worst-case operating conditions expected in the system, and historical data on similar hybrids. If a discrepancy exists between the system requirements and the reliability goal assigned to the hybrid, the designer must determine whether the reliability demanded by the system is indeed achievable, and, if so, at what cost.

To accurately assess the reliability of a hybrid, a designer should be familiar with failure mechanisms and reliability improvement techniques, in addition to the fundamentals of reliability engineering. These topics are discussed in greater detail in Chapter 11 of the Hybrid Design Manual.

Hybrid circuitry typically increases system reliability by reducing the number of intermetallic interfaces (see figure 1). Not only are interfaces within the hybrid reduced in number, but etched-circuit boards and their connectors can often be simplified or even eliminated. Other benefits from hybrids are increased resistance to environmental stresses (lower mass, hermetic or quasi-hermetic sealing of critical subparts, excellent thermal characteristics) and greater consistency in manufacturing processes.

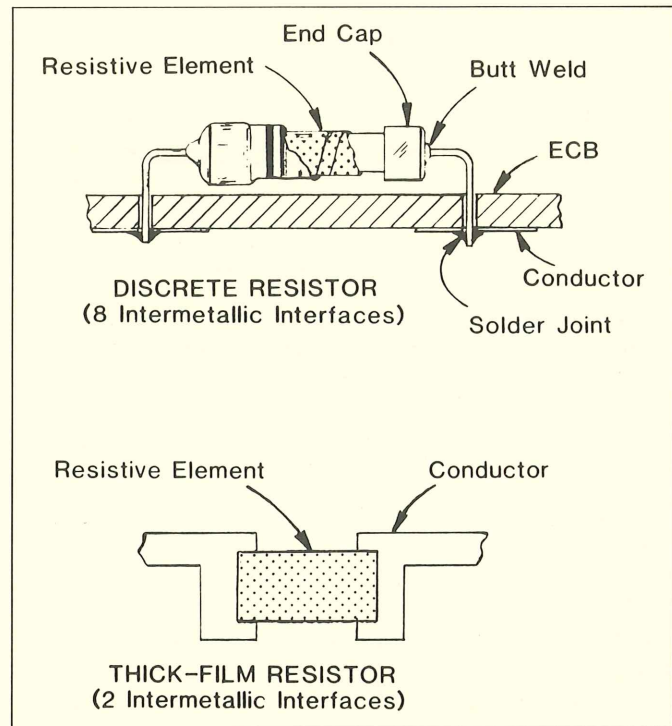


Figure 1. Hybrids increase system reliability because they have fewer intermetallic surfaces than discrete components.

Hybrid reliability is a function of many factors, including design, materials, process control, in-process screening, and end-use application. Although it is beyond the scope of this article to provide a detailed statistical analysis of reliability engineering, some comments are pertinent.

The Designer's Role

The designer has considerable control over two factors that influence the reliability of a hybrid: design and materials. End-use can also be taken into account, although the designer may have little control over the product's final application. It is the designer's role to see that cost-versus-reliability decisions are made to match the system requirements. The hybrid must have not only the lowest initial cost commensurate with performance, it must also be the lowest-cost device over the life of the system.

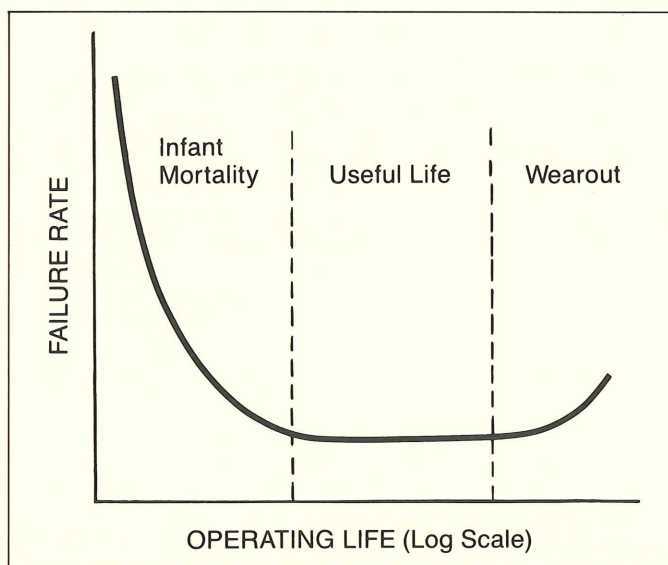


Figure 2. Failure rate curve. The pattern of failure rate plotted as a function of time, usually characterized by the 'bathtub' curve. Note: Semiconductor devices are unlikely to reach the wearout period because the equipment containing the devices usually becomes obsolete long before the wearout failure mechanisms become effective.

Reliability considerations start early in the design cycle with the choice of materials. Subparts for a hybrid should be preferred parts, selected from qualified vendors. If a quality history is not available for a subpart, or if a new vendor is to be used, qualification testing should be conducted on the subparts prior to incorporation in the hybrid. It is also important to write comprehensive specifications for each subpart, detailing performance and the *Quality Assurance Provisions* required.

The hybrid should be fabricated using preferred processes. Uncharacterized processes, new processes with little history, or processes recently transferred to a new production line often lead to lower reliability.

Electrical design is equally important. If a hybrid is over-specified so that yield is low that hybrid will be a lifelong source of trouble. If, on the other hand, worst-case analysis indicates the existence of adequate performance margins, supplemented with 'guard-banded' test limits during manufacture, electrical problems are unlikely (unless, of course, the hybrid is used where environmental or electrical stresses exceed the design).

Another aspect of electrical design is the stress to which every subpart is subjected. *MIL-HDBK-217C Reliability Prediction*¹ describes the relationship between electrical stress and failure rate of subparts. Part stress analysis is the preferred method of estimating failure rate when the detail design is complete and part stresses can be defined.

Some examples of stress effects are shown in figures 3, 4, and 5.

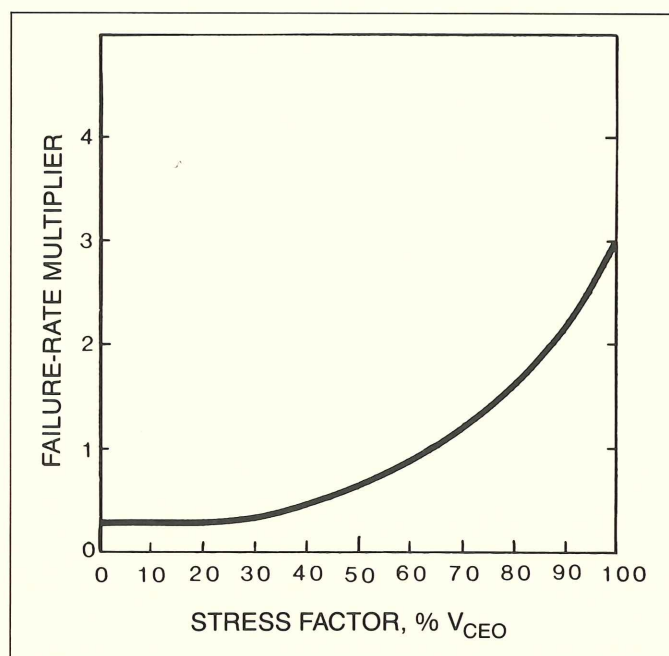


Figure 3. Junction transistors – electrical stress impact on failure rates. The failure-rate multiplier is constant for collector-to-emitter voltages equal to 25 percent or less of the V_{CE0} rating; from 25 to 100 percent of the rating, the multiplier increases exponentially, so that the 100-percent stress factor is 10 times the 25-percent factor.

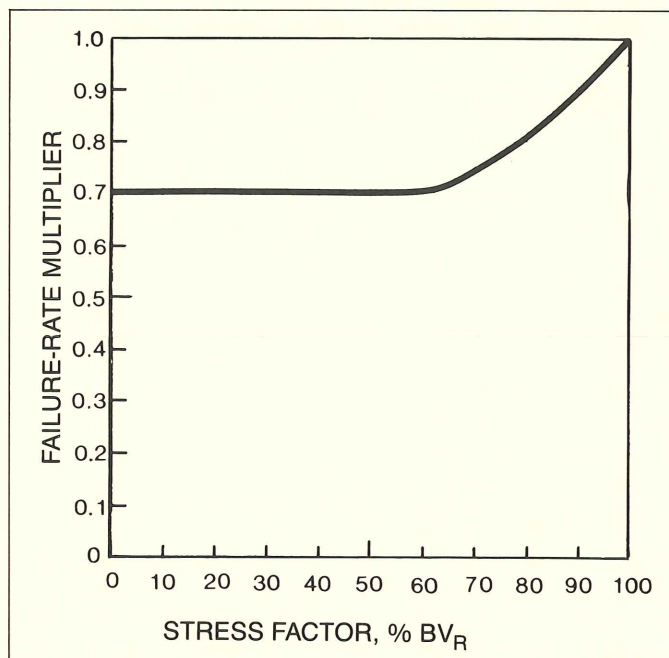


Figure 4. General-purpose diodes – electrical stress impact on failure rates. The electrical stress factor for diodes is the applied voltage divided by the rated reverse breakdown voltage.

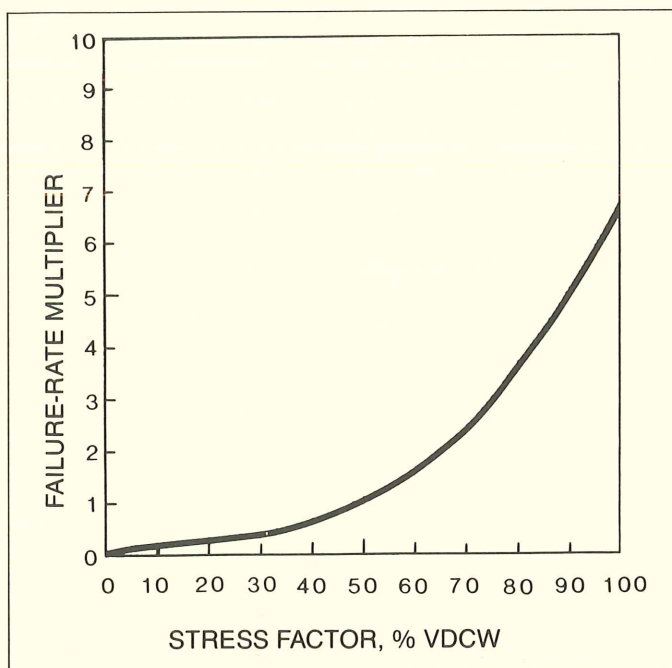


Figure 5. Ceramic capacitors – electrical stress. The stress factor for capacitors is the ratio of the sum of the applied DC and the peak AC voltages to the rated voltage. The effect on failure rate for the types of ceramics capacitors commonly used in hybrids is shown here. As a matter of good engineering practice, no capacitor should be subjected to a voltage stress exceeding 50 percent of its rating.

The Manufacturer's Role

From a manufacturing viewpoint, part reliability depends on (1) the continuity of production processes and (2) simple hybrid construction that fits a standard production flow.

Since virtually every step in a typical hybrid production flow depends on yield as the mark of successful operation, this leads to constant monitoring of yield and striving for its increase through process improvement. Clearly, process control is the key that enables high yields to be maintained, and thus assures the reliability of hybrids made on those lines.

The chief objective of process control is to maintain satisfactory and uniform hybrid quality, reliability, and repeatability. The three keystones of process control are:

1. Specifications for the material, equipment, and operating procedure used in the process.
2. Inspection of product to determine acceptance or rejection.
3. Relating the causes for rejection to the process, and correcting the process.

Hybrid manufacturing processes are controlled by:

- *In-process lot acceptance* – A sampling test used in high-volume product operations.
- *Process monitoring* – Comparing process variables to specification limits.
- *Process audit* – Regular audits of both the process and the product to assure adherence to manufacturing specifications. Deviations are reported, and corrective action instituted.
- *Operator certification* – Regular grading and classification of production operators and inspectors. Based upon the grade of the operator, process monitoring may be varied from minimal sampling to 100 percent inspection.

These process control techniques produce many data points. For an effective closed-loop system, this data must be collated and made visible to management.

The Role of Reliability and Quality Assurance

The Reliability and Quality Assurance group integrates the many quality programs into an overall quality plan, and then implements that plan throughout the manufacturing process. This overall plan includes quality assurance and quality control, process and equipment audits, quality and reliability policies and guidelines, closed-loop corrective systems, material control and traceability, documentation control, quality data programs, customer satisfaction, and vendor qualification.

Reliability Prediction

Since several fundamental limitations affect the accuracy of reliability predictions, why bother if the resulting prediction is going to be meaningless?

If the results would be truly meaningless, then the response should be: "don't bother."

However, in most cases, even the "inaccurate" reliability prediction can be very useful. For one thing, although the accuracy may be poor, basing predictions on consistent assumptions allows realistic comparisons between hybrids, or enables reliability trade-offs between various design approaches. Also, over time, actual failure rates can be compared to predictions, and assumptions can be modified to improve future predictions.

Assuming that a reliability goal has been established for a particular hybrid, there are three choices the designer can make:

1. Take no action. Rely on intuition and experience. (This approach is valid if the materials, processes, and application are similar to hybrids with known failure rates.)
2. Complete the design, assemble the parts, and then attempt to demonstrate that the parts can meet the reliability goal.
3. Attempt to predict reliability, and then compare the prediction to the goal. This approach can be augmented by a reliability demonstration. (If there is sufficient confidence in the prediction, a demonstration would be an unnecessary expense).

A common belief is that since any form of prediction is known to be inaccurate, action 2 – design, build, and demonstrate – is the logical choice. Unfortunately, there are a number of fallacies in this belief:

First, the parts subjected to a reliability demonstration must use material and processes that fully represent production parts. This means the parts must be those built late in the design cycle.

This end-of-the-cycle requirement leads to a second problem: If changes are required to meet the reliability goal, those changes typically occur just as the part is released to manufacturing.

A third problem rests with the method of demonstrating reliability. Reliability demonstrations use accelerated conditions to force early failure. Are these conditions valid? By definition, true reliability can be known with certainty only after the hybrid has been used in the field until it fails, and its failure history has been recorded.

Pursuing the third choice of conducting a reliability prediction can produce a major benefit: the opportunity to improve inherent reliability. A prediction made very early in the design phase, even before prototype parts have been built, allows different designs to be assessed for their impact on reliability. In this way, a reliability prediction becomes an integral part of the design cycle. Additionally, if history exists on the materials and processes to be used in a hybrid, then a prediction may be all that is necessary, thus saving the cost and time of a rigorous demonstration.

After deciding to predict reliability, it is best to use a procedure that will give consistent results.

One method is to use the reliability model in *MIL-HDBK-217*¹, a standardization handbook that covers the entire field of electronics, including hybrid microcircuits. Some people take issue with the data in this handbook, but since there are few other failure-rate models, the MIL-handbook is usually accepted, with reservations, throughout the hybrid industry. In addition, the Rome Air Development Center has been analyzing failures of hybrid circuits for a number of years and their summaries generally show good correlation of observed and predicted failure rates².

The reliability model requires many factors that, in the absence of experimental data, must be assumed. The key to meaningful predictions is substituting educated guesses for the assumptions. Substitution requires familiarity with *MIL-HDBK-217* as well as a feel for the impact of environmental and application stress factors on failure rates. These assumptions were discussed in some detail in the reliability predictions for the 2465 set of hybrids³. These calculations indicated that the predicted failure rates were quite close to the reliability goals that had been set for the hybrids. (Some excerpts from this report are given in reference 4. The procedure shown may be followed for other hybrid reliability predictions.)

The results, summarized in table 1, indicate a predicted average failure rate of 0.19% per 1000 hours at 50°C. The goal was 0.3% per 1000 hours. The vertical-output hybrid exceeded the 0.6% per 1000 hours goal for a single device due to its high operating temperature.

To repeat, there is no claim for absolute accuracy for these predictions. However, being able to study the relative failure-rate contribution of each hybrid in a set (system) is itself of great interest, and can indicate where improvements can be made with minimum effort (such as burning in one particular hybrid rather than the entire set, or reducing the operating temperature of a critical component).

Hybrid designers are encouraged to make reliability predictions using the procedures outlined here, with the provision, of course, that all assumptions are clearly defined. It is fairly simple to put the procedures on a 4050-Series graphics terminal or a programmable personal calculator.

As experience is gained in applying the variables and comparisons are made to observed failure rates, as full quality-control systems are implemented on manufacturing lines, and as reliability evaluation tests close the loop on determination of appropriate values of the factors used in the failure-rate model, our confidence in the reliability prediction model will increase.

Reliability Demonstration

To establish compliance with reliability specifications (goals), demonstration tests are frequently part of a hybrid qualification program. There are a number of methods of demonstrating that a component can meet its reliability goal. The method used most commonly is the *chi-squared* test method. This is the most convenient method when it is desirable to limit the test duration to that required for a very small number of failures.

Confidence levels

'Confidence' is merely reliability terminology for 'probability.' If an event has a 90-percent *probability* of happening, we can say we are 90-percent *confident* that it will happen. In reliability and statistical usage, *confidence* usually applies to the probability that a point or number lies within a specified region. If the region is bounded on one side only, the other boundary being at infinity or zero, the confidence interval is said to be 'one-sided.' When the region has finite boundaries on both sides, the confidence interval is said to be 'two-sided.'

Table 1
2465 HYBRID FAILURE RATE SUMMARY
(% PER 1000 HRS.)

At Instrument Ambient	25 °C	50 °C (1)	55 °C
H841 Preamp CH1 & CH2	.058	.180	.244
H842 Channel Switch	.008	.052	.077
H843 Vertical Output	.163	.960	1.338
H844 CH3/4 Preamp	.045	.196	.278
H850 Trigger	.007	.034	.048
H851 Sweep A&B	.011	.037	.050
H853 Z-AXIS	.008	.051	.071
Average for 9 Hybrids (2)	.041	.192	.267

(1) Reliability Goal Temperature

(2) Includes 2 Per Instrument for H841 & H851

A reliability test produces two parameters: total test time T_T and the number of failures N . From these two parameters, it is possible to determine two items of information.

- The observed mean time to failure (MTTF) of the component: $M_T = T_T/N$.
- The MTTF corresponding to a given level of confidence or, conversely, the confidence corresponding to a specified MTTF.

In order to plan a test, item 'b' is usually derived from the reliability prediction or goal, as follows:

$$\text{MTTF} = 1/\lambda \text{ (failure-rate goal)}$$

The confidence level is assigned a commonly used value, such as 60 percent or 90 percent. The test time required to demonstrate the MTTF with the assigned confidence can then be estimated.

The chi-squared method

As indicated, every demonstration test produces its own (observed) MTTF; the key question is the degree of reliance that can be placed on this figure. The chi-squared method is a statistical test of fitness, in which the observed MTTF is compared with an amount that is assumed to be the true but unknown MTTF of the component. The result is a chi-squared distribution containing upper and lower limits for the true MTTF; for all practical purposes we are concerned only with the lower confidence limit.

Rather than resort to chi-squared tables, confidence curves can be drawn to cover the cases most often encountered in microelectronics. Figure 6 is a set of curves that link the test time T_T and the specified MTTF ($T_T/\text{MTTF} = S$, the statistical factor), with the number of failures occurring during the test, N , and the (lower) confidence level. For the purposes of this figure, it is always assumed a failure is about to happen (hence the zero-failure curve), and N is the number of failures that occur up to but not including the conclusion of the test. Therefore, if the test is terminated at the n th failure, then $N = (n - 1)$.

It is important to realize that the chi-squared distribution applies only to events that exhibit exponential distribution. Since time to failure has an exponential distribution when failure rate is constant, the curves are valid for most reliability applications. In microelectronic components, this assumption implies either that infant failures have been removed from the test sample by a burn-in or an equivalent screening procedure, or that the test time is sufficient so that components spend most of the test beyond their infant-mortality period.

As an example of the use of figure 6, assume that a test is terminated with its third failure ($n = 3$) after having run 520 hours. What MTTF has been demonstrated with 90-percent confidence level? Entering the curve $N = (3 - 1) = 2$ at 90-percent confidence level, we find $S = T_T/\text{MTTF} = 5.3$. Solving for MTTF,

$$\text{MTTF} = 520/5.3 = 98 \text{ hours.}$$

Thus we are 90-percent confident that the true MTTF is equal to or greater than 98 hours.

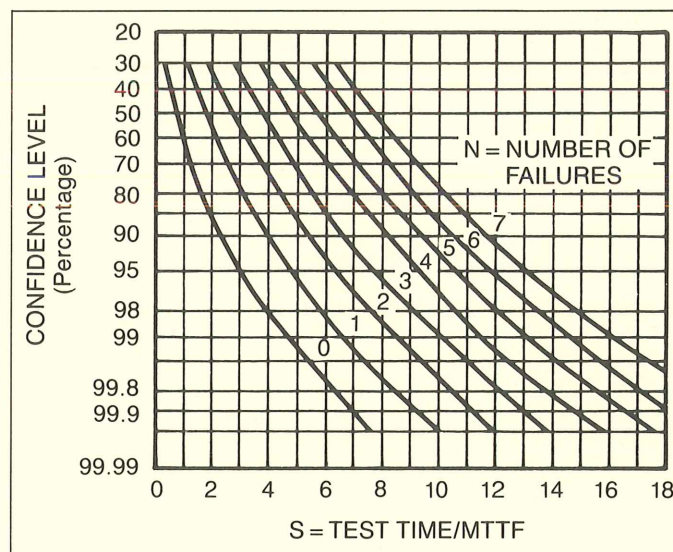


Figure 6. Mean-time-to-failure (MTTF) confidence level. S is the statistical factor.

Acceleration factor

Because life testing at the low stress levels of normal use takes too long and requires numerous samples, acceleration factors are used to achieve a more practical time scale.

As was suggested earlier, acceleration factors should be used with caution. For example, the very act of increasing the test temperature must not, in itself, introduce failure modes that would not otherwise be present in the device (such as exceeding the maximum service temperature of an epoxy, or forming a mechanically brittle intermetallic compound).

Most semiconductor failure mechanisms depend to some degree on temperature. The Arrhenius equation describes this dependence:

$$\text{failure rate, } \lambda = ae^{[-E_a/kT]}$$

where:

a = a constant.

E_a = Thermal activation energy, eV.

k = Boltzmann's constant (8.63×10^{-5} eV/K).

T = Absolute temperature, K.

From this equation, an acceleration factor due to the aging effect of an elevated temperature can be derived:

$$\text{Acceleration factor, } A = \exp \left\{ \frac{E_a}{k} \left[\frac{1}{T_1} - \frac{1}{T_2} \right] \right\}$$

where:

T_1 is the reference temperature, K.

T_2 is the acceleration temperature, K.

Also, there is a multiplicity of failure mechanisms to contend with in a hybrid circuit and each failure mechanism is associated with a specific thermal activation energy. This energy varies from 0.3 to 0.6 eV for oxide defects on an IC and metallic corrosion, to 1.3 eV for electromigration and charge injection effects. Thus, no single activation energy value can properly represent a complex component such as a hybrid.

In the case of monolithic ICs, an E_a of 1.0 eV is often used on the assumption that the dominant failure mechanisms are close to 1.0 eV. The activation energy of a hybrid circuit is usually assumed to be less than that of an IC. This assumption is reasonable since hybrids tend to contain more interconnections between circuit elements, and interconnections have been assigned fairly low activation energies in MIL-HDBK-217C, in the range 0.35 to 0.44 eV.

Activation energy can be calculated from the slope of the failure rate versus temperature curve. Figure 7 shows such a curve for the 2465 hybrid set. Five of the hybrids exhibit well-controlled behavior up to 155 degrees C; the activation energy for that group of hybrids was calculated to be 0.78 to 0.84 eV. This value, which is between the extremes of 1.0 eV for monolithic devices and the lower values expected of hybrids, could be anticipated because monolithic ICs predominate in these hybrids.

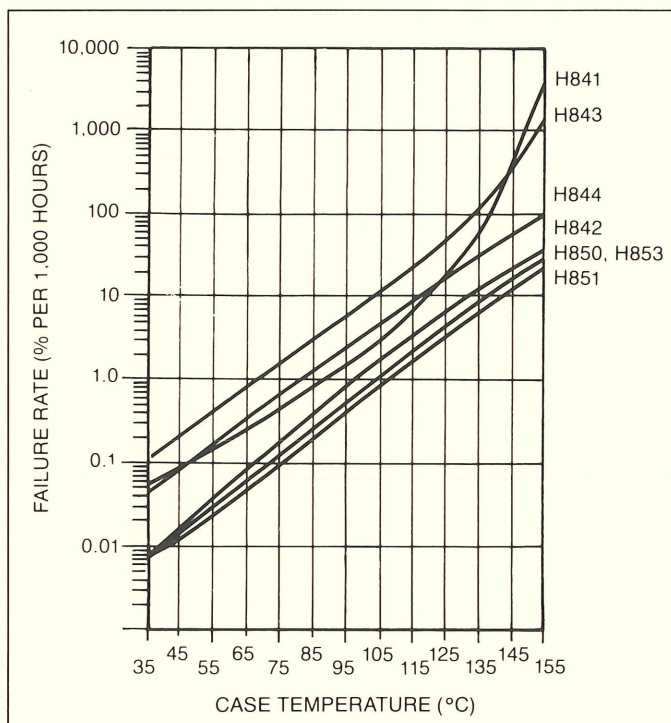


Figure 7. Failure rates – 2465 hybrid set.

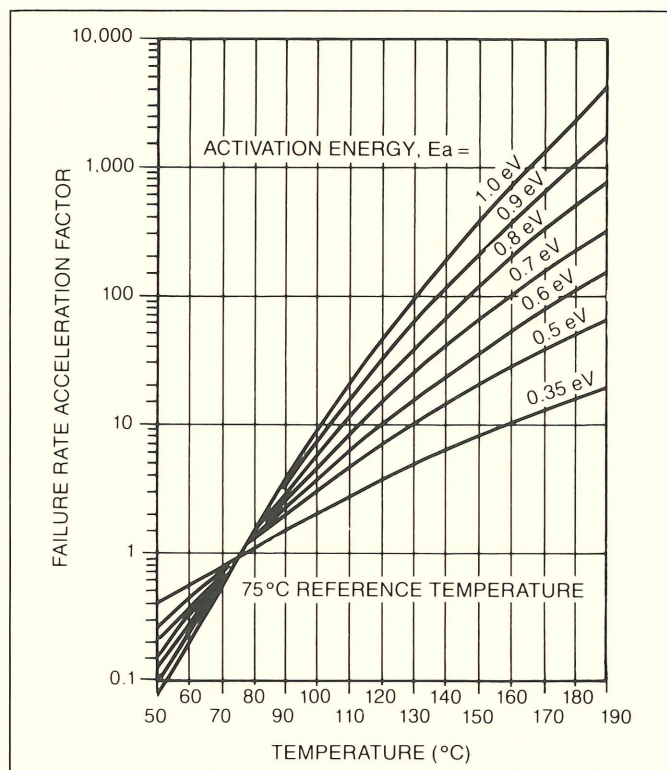


Figure 8. Activation energy curves to enable interpretation of acceleration factors.

An interesting phenomenon is evident in the curves of the H841 and H843; above 125 degrees C, it is evident that the effects of a different failure mechanism come into play. Below 125 degrees C, the activation energy is 0.72 eV. Although these curves were generated from predicted failure rates rather than actual test results, they illustrate the usefulness of reliability predictions in giving advance warning of potential reliability problems. Figure 8 is included to assist in determining acceleration factors; this figure also illustrates the extreme sensitivity of the factor to the assigned activation energy, in the range 0.35 to 1.0 eV.

Sample size

The remaining parameter of the reliability demonstration is sample size. Enough devices should be tested to ensure a broad enough base to determine the average failure rate. We recommend at least 20 devices because the time to demonstrate a specific failure rate goes down as sample size increases.

The sample size should not, however, be too large as the test time may be reduced too much: it may span only the period of infant mortality. A basic premise of the reliability assurance test is that the test is conducted during the period of constant failure rate (see figure 2). A typical infant-mortality period for a hybrid might be 48 hours at 125 degrees C. One way to avoid this problem is to burn-in all parts prior to the life test.

Reliability assurance plan

A test plan must be developed for each new hybrid design for which a reliability demonstration is deemed necessary. This plan describes the preconditioning, or screening tests that must be conducted prior to the life test, and the sequence of those tests. The number of test parts and ambient, case, or junction temperature for the life test are established from the previously noted ground rules (see Acceleration Factor).

Since it is assumed that the devices will be electrically operating during this test, the effects of self-heating must be included when the test temperature is defined; 175 degrees C should be considered the maximum junction temperature for a life test. In addition, the acceleration factor may be determined, based upon the estimated activation energy⁵ of the hybrid. From this information, an estimate may be made of the test duration necessary to demonstrate the reliability goal of the device.

To increase data reliability, life tests should be run for a minimum of 1000 hours, regardless of the calculated duration, since a truncated test does not necessarily yield inherent reliability information, as explained earlier (see Sample Size).

In evaluating the usefulness of an accelerated life test, the following points should be considered:

- The failure mechanism(s) encountered during the tests should be the same as those occurring under normal operational stress levels. Triggering new failure mechanisms by an excessive stress level (i.e., too high a test temperature) will lead to meaningless failure-rate data.
- The acceleration factor so critically depends upon the correct estimation of the composite activation energy⁵ of all relevant failure mechanisms that every effort should be made to assure that the acceleration chosen accurately represents the hybrid under evaluation. If the hybrid incorporates new materials or processes, reliability predictions and/or step-stress testing should be considered to provide supporting data.

- The relationship between the failure rate of a device and the various electrical and thermal stresses applied to the device rely upon mathematical models that implicitly assume a constant failure rate. It is important that there not be too many failures early in the life test, indicative of a decreasing failure rate over the initial phase of the test.
- An accelerated temperature-stress test will only test failure mechanisms susceptible to thermal aging. It will not yield information about mechanisms triggered by other stresses that are also important to the application, such as humidity, mechanical, etc.

If these and similar considerations are taken into account, then the life test can meaningfully demonstrate the reliability of a device.

For More Information

For more information, call Mal Gilbert 627-4021. □

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The Software Center maintains a library of deliverables and other documents to help managers, project leaders, and engineers associated with software development. Most were recently done at Tektronix.

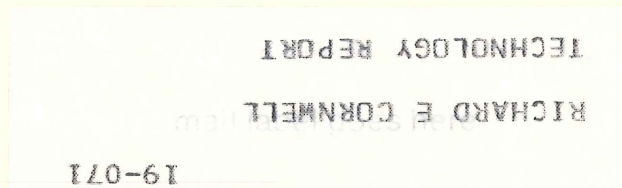
Please contact Omeda Miller on 627-6215 for a list of these documents.

If you have a document which will serve as a good example for others at Tektronix, please send it to Chuck Martiny, d.s. 50-487, or call him on 627-6834.

The library spans 21 categories:

- Ada and Related Topics
- Archiving
- Design
- Development Standards
- Disciplined Programming
- Documentation
- Estimating & Scheduling
- Evaluation & Testing
- Maintenance Technique
- Post Mortems
- Programming Environments
- Programming Languages
- Programming Methodologies
- Project Management
- Quality & Productivity Measurements
- Seminars & Conferences
- Specifications
- Tools
- UNIX
- Work Stations
- Other
- ☐

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