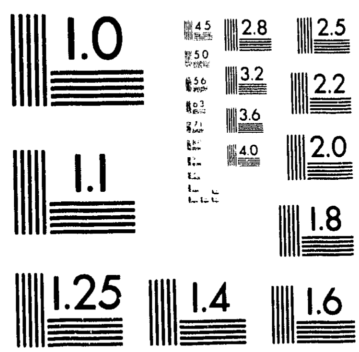
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Advanced Failure Analysis Laboratory Equipment Networking

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Introduction

Today's integrated circuits are so complex that it is often necessary to have access to the layouts and schematics when performing voltage contrast, cross sectioning, light emission, mechanical probing, optical beam induced current, and even simple SEM and Optical Examination. To deal with these issues, Sandia National Laboratories is developing an advanced failure analysis laboratory networking scheme to provide computer control, layout navigation, schematic navigation, and report generation on each of the major pieces of failure analysis equipment. This concept is known as an Integrated Diagnostic Environment or IDE.

An integrated diagnostic environment is an environment where failure analysis equipment is computer-controlled and linked by a high speed network. The network allows CAD databases to be shared between instruments, improving the failure analyst's productivity on each analysis task. At Sandia, we are implementing this concept using SUN Sparcstation computers running Schlumberger's IDE software. To date, we have incorporated our electron beam prober and light emission system into the environment. We will soon add our scanning optical microscope and focused ion beam system, and eventually add our optical microscope and microprobe station into the network. There are a number of issues to consider when implementing an Integrated Diagnostic Environment; these are discussed in detail in this paper.

I. Integrated Diagnostic Environment Basics

A. What is an Integrated Diagnostic Environment?

Historically, failure analysis equipment has been manually operated. These equipment include curve tracers, optical microscopes, scanning electron microscopes and mechanical microprobe stations. The output data from these machines were photographs and plots, and manually recorded information. In some cases, there was no ability to output any permanent data unless a camera was attached to the display of the instrument. In the mid-1980s, failure analysis equipment manufacturers began to develop computer-controlled failure analysis equipment. Some of the earliest computer controlled failure analysis equipment included the Hewlett Packard HP4145 semiconductor parameter analyzer, the KLA Light Emission Microscope and the Schlumberger IDS-5000 electron beam prober. Today, most failure analysis equipment can be computer-controlled. One can buy computer-controlled SEMs, optical microscopes, focused ion beam systems, light emission systems, IR thermal imaging systems, automatic integrated circuit testers, and even computer-controlled reactive ion etchers. Because this equipment is computer-controlled, it has the potential to be tied together via a computer network. An integrated diagnostic environment (IDE) is a term used to describe a suite of failure analysis test equipment that is linked by a computer network and is capable of sharing data.

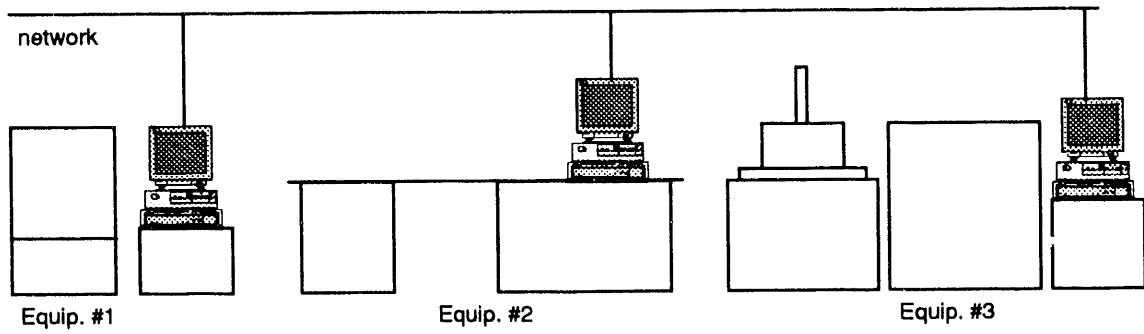

Figure 1. Drawing showing the concept of an integrated diagnostic environment.

The data useful to the failure analyst that could be shared from computer to computer include integrated circuit (IC) layout plots schematics, netlists, photographs, and information on how to perform particular tests.

B. Why is this type of environment necessary?

The IDE concept is an expensive proposition. Consequently, the idea may not be suitable for every failure analysis laboratory. Failure analysis laboratories that analyze discrete components or do not have access to design information would not see much benefit from such a system. Only failure analysis laboratories that analyze complex ICs and have access to the design databases would benefit from an IDE. A small gain in productivity for a failure analysis laboratory supporting a high volume IC fabrication line yields large savings for the corporation. Wafer lots are very expensive; the faster a failure analysis lab can identify the source of the failure, the fewer the number of low (or zero) yield wafer lots.

The main benefit of IDE is the CAD navigation software. The software's ability to correlate a location on a layout plot with the net on the netlist or gate on the schematic in real time can considerably reduce failure analysis time. Layout and schematic plots of complex ICs can take many hours or days to print on a plotter. Plots are also difficult to handle physically; these plots must be hung on large walls to facilitate viewing. It is time consuming to manually correlate a location on the layout plot with a gate or node on a schematic plot. This procedure must be done numerous times when troubleshooting a subtle functional failure on a complex IC. It is often necessary to go back and forth between light emission microscopes, optical microscopes, scanning electron microscopes, microprobe stations, and electron beam probers during an analysis. This situation makes the integrated diagnostic environment beneficial.

C. Example implementation of IDE on a microprobe station.

As an example, IDE is useful in an environment where both mechanical probing and electron beam probing are performed. If we are using an IDS-5000 for electron beam probing, it would be advantageous to reproduce a number of the IDS-5000 features for use with the microprobe station. Although the IDS-5000 and the microprobe station perform similar functions, the IDS-5000 is a computer-controlled instrument whereas probe stations, such as the Micromanipulator 7000, are manually controlled instruments. First, the stage of the microprobe station must be placed under computer control. To place the microprobe station under computer control, optical encoders for the microscope x, y, and z motion must be added. These encoders allow a computer to issue commands to drive the motor a specified distance. Second, a method for bringing the view seen through the lens piece of the microscope to the computer screen must be employed. This is accomplished using a TV camera mounted on top of the probe station and a video windowing system box. Schlumberger uses an RGB/View Model 1050 windowing system box. The signal from the camera is fed as an input into one of the RGB/View box low resolution inputs (typically Line A). The output video from the workstation is fed into the RGB/View high resolution input. The box then overlays the signals and produces a computer graphics screen with an overlaid video window. This high resolution output is then run to the SUN workstation monitor. Third, the CAD navigation software used on the IDS-5000 is made available to the microprobe station user on the SUN computer. Because the software driving the microprobe station is almost identical to the software driving the IDS-5000, the analyst can operate the microprobe station in the same manner as the IDS-5000. More importantly, the two systems can now share a single design database. Because they share a single design database, specific locations can be stored on one machine and quickly located on another machine.

It should be noted that this environment requires a substantial investment of time and effort up front to ensure that this process can take place smoothly. Each design must be processed before it can be used in the environment. The processing of CAD databases is not a trivial task. The linked computers must share files and communicate in a certain way. For the failure analyst unfamiliar with the UNIX operating system, this task can also be daunting.

II. Implementing IDE on a Light Emission Microscope

A. Basic Setup

The Sandia failure analysis laboratory chose KLA Model 1600 Light Emission Microscope as its first instrument to link a into the IDE environment. This instrument was chosen because of its extensive and frequent use in CMOS failure analysis work performed at Sandia [1]. The KLA Model 1600 is a computer-controlled light emission microscope. The light emission acquisition is accomplished using a sensitive microchannel plate detector connected to a frame-grabber. The frame grabber is a Matrox Imaging board that allows computer graphics overlay on video. The stage and microscope x-y motion is controlled by a custom designed board. This first generation system has several deficiencies involving acquisition speed, network connectivity and stored image formats. Sandia chose to move this instrument into the IDE environment for these reasons.

The Sandia hardware configuration is shown in Figure 2 on the following page. The basic IDE setup places the live video seen on the light emission screen in a window on the SUN workstation. This is accomplished on the SUN using an RGB/View Model 1050 Video Windowing System. The window on the SUN displaying the live video is known as the "Emission Microscope Tool". In this first level of integration the stage and microscope x-y motion remains under the control of the KLA computer (a Compaq 286 DeskPro). This basic IDE setup addresses the issue of stored image formats and network connectivity, but does not address the problem of slow acquisition speed. This is accomplished using a more advanced integration of IDE software with the KLA hardware.

B. Advanced Integration

A higher level of integration between the IDE environment and the emission microscope can be achieved by placing the microscope x-y motion under SUN workstation control. The x, y and rotation movements for the stage and the x and y movements for the microscope are controlled by Superior Electric Model 230T translation drive modules. The z movement of the stage and microscope and the rotation of the microscope objective turret are controlled by Parker CompuMotor DB drive units. The most straightforward method of implementation is to control the x and y motion of the stage and microscope and the z motion of the stage and microscope with a Controller from Delta Tau. Once these motors are under the control of the SUN workstation, the user can control the field of view, position, and magnification from the SUN workstation.

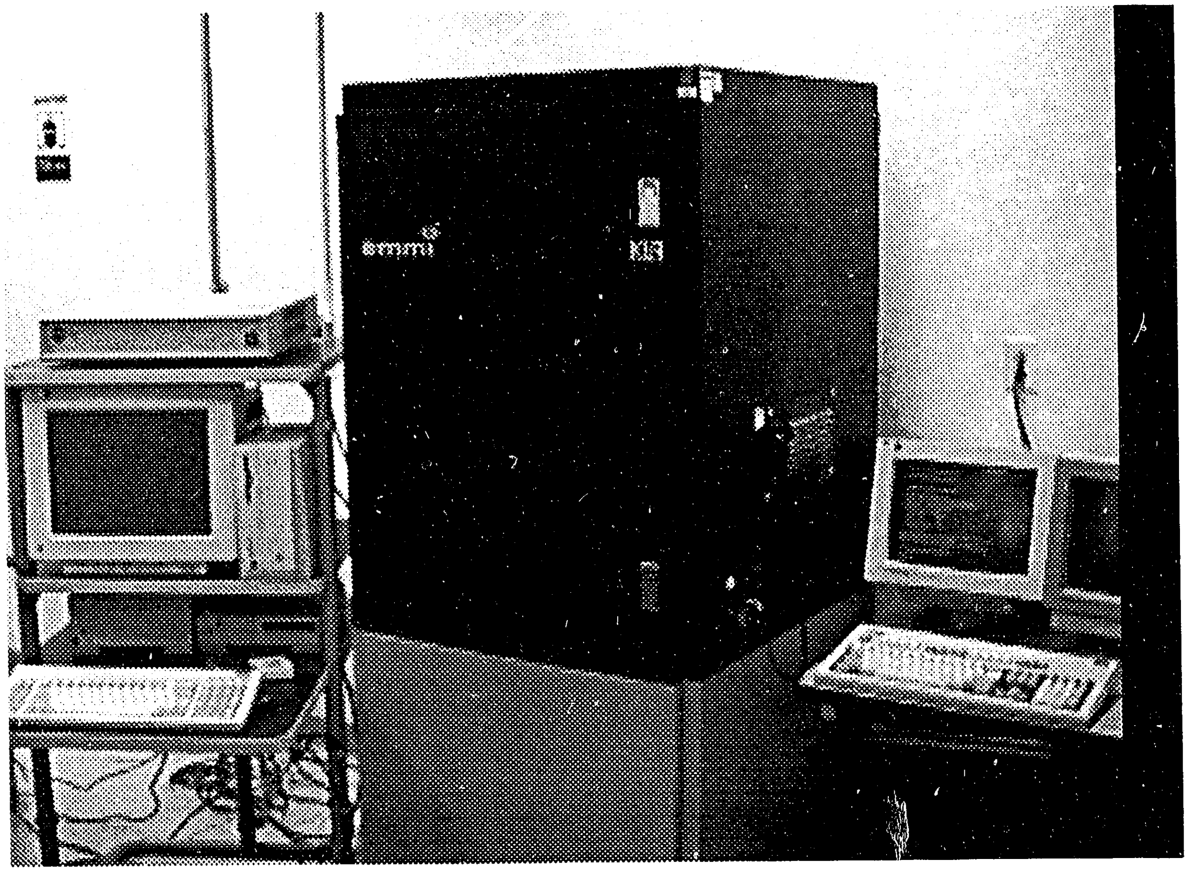

Figure 2. KLA EMMI Model 1600 system and SUN Sparcstation IPC for IDE integration.

Next, a scheme for providing light emission acquisition must be developed. The light emission acquisition is controlled by two basic parameters: the analog integration time and the number of digital integrations. The analog integration time (analogt) controls the number of video frames that will be integrated together to capture an image of the device under test. The number of digital integrations (digitalt) controls the number of integrated images that will be averaged together. These two parameters must be controlled from the SUN computer. Finally, there are several pneumatic operations that are controlled by a vacuum logic switch. These include turning the microscope objective turret and switching between the macro lens and the higher magnification objectives. These two signals can also be controlled from the Delta Tau controller.

There are several difficulties with implementing IDE on the KLA EMMI. First, software must be written to perform video frame integration and averaging. This software would be relatively easy to write. Second, a number of wires must be disconnected from the KLA EMMI's internal logic boards and routed out to the Delta Tau controller. This change is not a trivial task. And third, some amount of software must be written to control the Delta Tau controller to replicate x, y, and z motion for both the stage and optics, w (rotation) motion for the stage, and the vacuum logic. It may be time consuming to implement the full set of operations that are available in the KLA EMMI software.

III. Implementing IDE on a Scanning Optical Microscope

A. Basic Setup

A scanning optical microscope (SOM) is a versatile instrument. A laser SOM or laser scan microscope (LSM) can be used perform optical beam induced current, layer extraction, very high magnification examination (greater than 10,000X), light emission, and infrared microscopy [2]. At Sandia National Laboratories, we use a Zeiss LSM 21 system. This system presently uses a HeNe laser at 633 nm and an additional HeNe laser at 1152 nm for IR imaging.

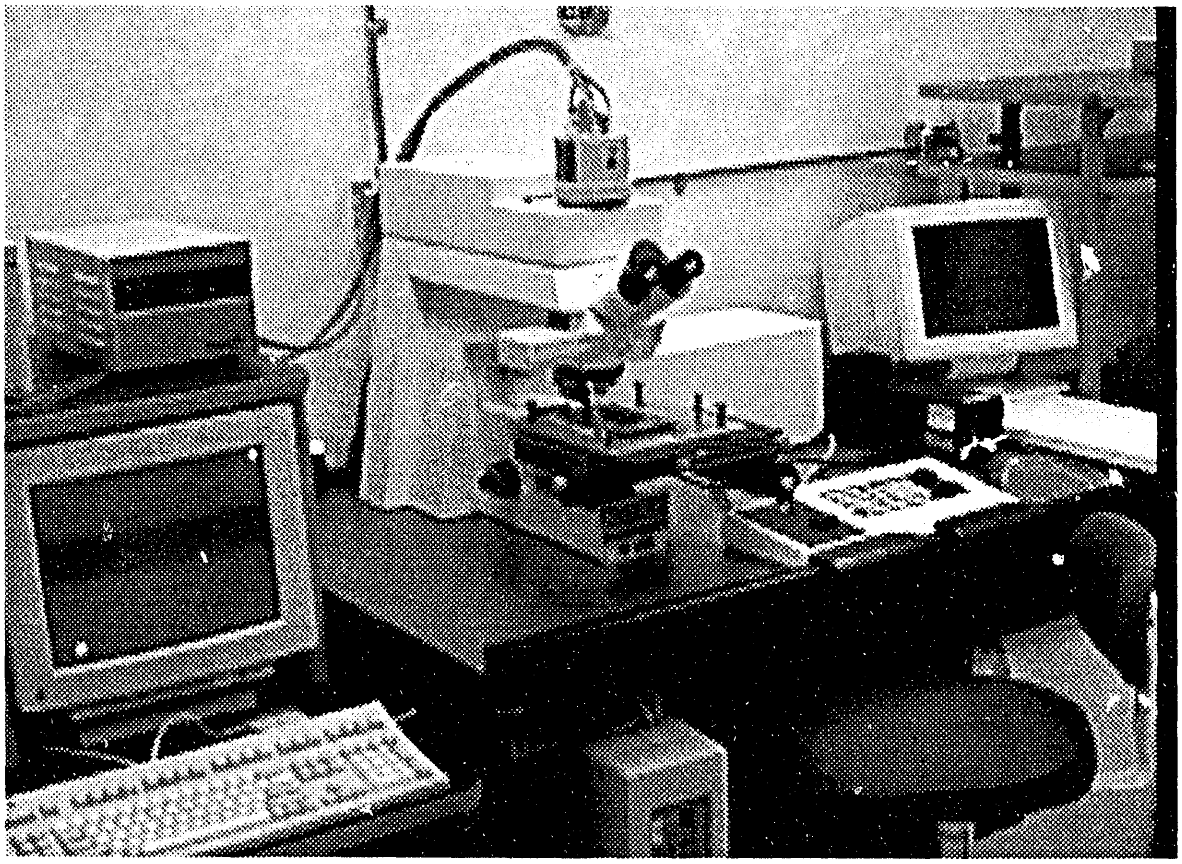

Figure 3. Zeiss LSM Model 21 system and SUN SparcStation IPX for IDE integration.

The Zeiss LSM can be remotely controlled via IEEE-488 commands. We control the Zeiss LSM from the SUN workstation using a National Instruments IEEE-488 card. Zeiss provides a rich set of IEEE-488 commands that allow complete control of the instrument optics as well as the stage. Because of this command set, the Zeiss LSM should be very easy to incorporate into the IDE environment. The LSM video can be routed to the SUN workstation RGB/View system by connecting to the Red, Green, and Blue outputs on the back of the LSM.

B. IEEE Integration

The Zeiss LSM IEEE-488 commands are robust. There are 13 motor control functions available: reset, individual selects for the motors that control x, y, and z motion, absolute motion with or without backlash compensation, set a position, read a position and limit switches, select drive mode, and several commands to regulate the drive mode (acceleration, deceleration, etc.). A simple program can be written to control the movement using these commands. There are numerous transmission and control commands that allow acquisition of images, brightness and contrast adjust, digital stepping of the laser beam, transmission of images from the host computer to the LSM computer, and control of the scan field. These commands can be integrated into a program to control the LSM image acquisition. The complexity of the program is dependent on the degree of control required over the LSM.

IV. Possible Advances in the IDE environment

A. VideoPix cards to achieve computer host independence

A major IDE limitation is the inability to run IDE software from a remote computer. This situation is attributable to the RGB/View system. Because the RGB/View System is tied to a particular monitor, there is no ability to view the video signal overlaid on a different workstation. The RGB/View System mixes the computer and video signals immediately before displaying the composite signal.

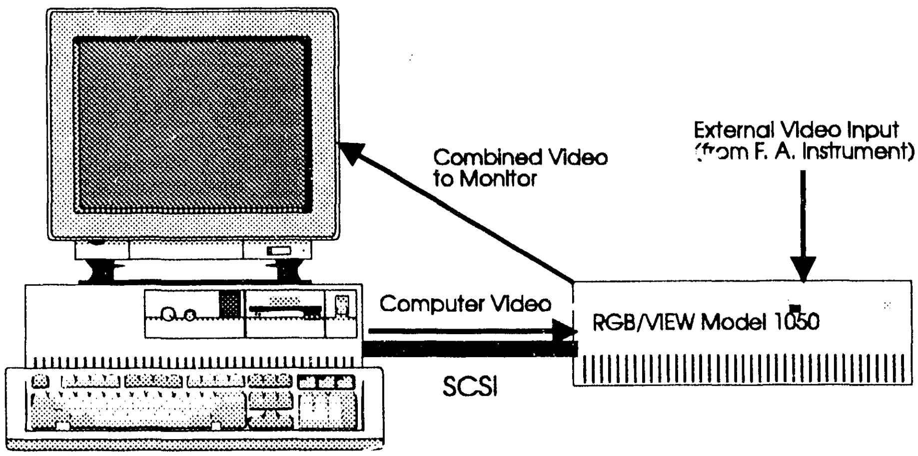

Figure 4. Diagram showing connection between SUN workstation and RGB/View System

One method for achieving computer host independence in the IDE environment is to use a multi-user frame grabber. The SUN Microsystems VideoPix board is an example of this. The VideoPix board allows the display of video and the capture of single video frames from several machines at once on a network. Using the VfcTool provided with the VideoPix board, video frames can be captured and saved on disk as Tagged Information Format, SunRaster, or Encapsulated Postscript files. The VfcTool can be run over a network, allowing multiple users to view a video stream (at a reduced number of frames per second) and grab images. Unfortunately, the VfcTool does not allow graphics overlay on the video image. In order to overlay the video and graphics, it would be necessary to write a program that makes calls to the application library. In this way, a video image can be overlaid with a graphics interface and provide support for drawing boxes on the image, four-point alignment, panning the image, etc.

B. SunVideo cards to achieve true digital imaging.

Another method for achieving computer host independence and true video-rate digital imaging is through the use of SunVideo [3]. SunVideo is a recently announced product that will perform real-time compression of video signals. These video signals are then saved into an XIL-standard file. One could then treat video as a data type like image or text. A SUN workstation attached to a piece of failure analysis equipment could then acquire and compress video at 30 frames per second and broadcast it over the network. Solaris 2 includes the ability to decompress these files in software at 30 frames per second. No hardware is required on the remote computer. Because the video is digital, it should be easier to overlay graphics to provide support for drawing boxes, four-point alignment, etc. The main disadvantage to this technique is the resulting increase in network activity. The computer network may respond slowly while video signals are broadcast over the network.

C. Report Generation

Much of the complexity in report generation is caused by the need to incorporate graphics and photographs into reports. Currently, most failure analysis report generation is done on personal computers such as Intel-based machines or Macintoshes. Unfortunately, most of the image producing equipment, such as scanning electron microscopes and optical microscopes, output images to film. This film must then be scanned or pasted manually into a report. If images are pasted electronically, translation between different file formats is sometimes necessary. It may also be necessary to transfer files from different computer platforms to bring the pieces of the report together. In our experience, this process is not always smooth. It is necessary to convert KLA images to bitmaps (custom written software), capture the HP4145 semiconductor parameter analyzer HPGL stream file and edit the file in a graphics design package, and scan photographs to generate a completely electronic report. This is a tortuous and frustrating process, at best!

The integrated diagnostic environment provides an opportunity to improve the report generation process. With all of the failure analysis equipment tied and accessible on a network, report generation should become much easier. Of course, this doesn't relieve the analyst of the burden of writing the report; he or she must still type in the text and assemble the report. Even this can be improved by using a standard template, such as the format being developed by the JEDEC 14.6 failure analysis committee.

It is relatively easy to tie such image producing equipment as optical microscopes and scanning electron microscopes into a network using frame grabbers such as the VideoPix card. Other computer-based failure analysis equipment such as the microprobe station, light emission microscope, laser scan microscope, electron beam prober, and focused ion beam system can be connected interactively with the database layouts and schematics in an IDE environment. One final instrument that produces graphical output that is widely used in failure analysis reports is the curve tracer. If the curve tracer can be controlled via IEEE-488, then the data can be ported to the SUN workstation in some type of vector format such as HPGL. With all of the data in a single computer environment in standard image formats, report generation can be performed relatively quickly. The main task of writing the report is the text generation, not the incorporation of graphics.

V. The Future of the Integrated Diagnostic Environment

A. Database management

There are a number of different data types that must be managed by the failure analyst. First, there are the standard database items such as date started, date completed, analyst, part type, etc. Second, there are data types such as images, waveforms, graphics, and text data. Third, there are layouts, schematics, netlists, and other engineering drawings that are pertinent to the failure analysis. And fourth, there are the final reports. Currently, this information is stored in disparate locations. For example, at Sandia National Laboratories, the first group of data items is stored in a Microsoft Access database on a personal computer. The second group of data items is stored on a variety of different machines including PCs, Macintoshes, DEC computers, and SUN workstations. The third group of data items is stored in a file structure on the IDS-5000. The fourth group of items is stored in ring binders in a file cabinet. It is nearly an impossible task to manage all of these data (protect it, back it up, etc.). The network file system implemented on the SUN workstation, coupled with the power of an object-oriented database, should provide a solution to the database management problem.

B. Interactive Help

The power of the integrated diagnostic environment can also provide interactive help for the failure analyst. It is possible to provide not only textual help for a procedure or operation of equipment, but also provide high quality graphics, audio and even video using IDE. Textual help can be made more powerful using the hypertext features available in the help viewer. Hypertext allows for non-linear observation of text. With hypertext, the user can jump from topic to topic quickly because the text is marked and linked to related subjects. This type of help is quite common today in word processors, spreadsheets, etc. High resolution graphics with hypertext can be provided by using an electronic publishing program such as FrameMaker. Hypertext documents with high resolution graphics can be created using FrameMaker and then viewed in a read-only mode using FrameReader. This type of electronic document distribution is gaining acceptance. Finally, with the advent of multimedia technologies, it is now possible to create audio and even visual help. The hardware and software mentioned previously (SunVideo), can be used to deliver such help. For example, if failure analysts need help performing an operation such as setting the reactive ion etcher to remove a layer of the IC, one simply films the expert performing the operation, captures the video using a video compression card, and incorporates the video clip into the help file as a data type. The end user can then click on the hot button in the help file to view the procedure.

C. Expert Level Advice

Finally, the integrated diagnostic environment can provide the basis for expert level advice during the analysis. Several companies have already designed expert systems to aid in failure analysis [4, 5]. These systems could act as a front-end to IDE to provide top-level guidance to the novice failure analyst, freeing up the experienced analysts to work on the more difficult analyses. The systems could also provide a means of documenting failure analysis procedures for the stringent requirements of military and ISO-9000 guidelines. Finally, these systems can provide the experienced user with a second opinion as additional input into the failure analysis process.

VI. Conclusion

The integrated diagnostic environment is a powerful concept for standardizing and centralizing failure analysis techniques and increasing productivity. The power of the SUN workstation, coupled with the common user interface provided by the IDS software, makes the integrated diagnostic environment easy to use. The incorporation of new failure analysis tools into IDE is not always a straightforward task. Instruments such as the KLA EMMI can be quite difficult to integrate completely into the environment, requiring both software development and hardware modification. Other instruments such as the Zeiss LSM can be controlled readily from an external computer, making the job of integration easier.

One drawback to an IDE is its expense. The cost of integrating a laboratory can be prohibitive for some failure analysis laboratories. Fortunately, as computing costs continue to tumble, it will be less expensive to buy the hardware necessary to implement IDE. This expense can be justified if the need is present. Another perceived drawback to IDE is the time required to learn the software. Most failure analysts claim that they are too busy and do not have the time to spend on learning to use an IDE. A second, more reasonable concern is the need to use a more complex operating system (UNIX). These concerns can be alleviated by constructing the software to be as easy to use as possible and hiding the operating system from the end user. One impetus might be to tie all failure analysis equipment into IDE. Failure analysts would then be required to become familiar with IDE and the CAD navigation software.

It is reasonable to assume that as technology complexity increases, the difficulty in performing failure analysis increases. The integrated diagnostic environment provides a framework for managing the increasing complexity of failure analysis equipment control and data management.

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