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In this Issue:

Infrared Thermography Part 1

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In this article we'll begin to cover infrared thermal imaging (or infrared thermography) in more detail. Infrared thermal imaging is growing in popularity, as the detector companies continue to develop more sensitive thermal sensors and cameras.

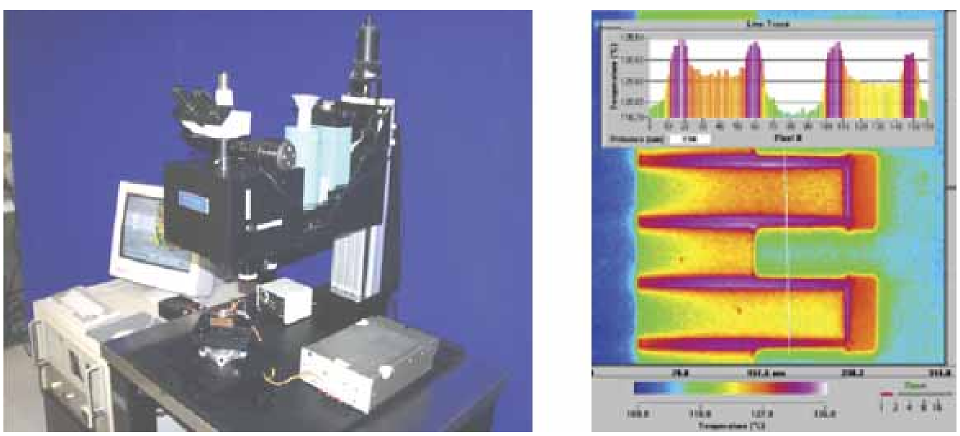


Figure 1. Infrared thermography (IRT).

Infrared thermography is based on blackbody radiation physics. A camera system detects heat, much the way our eyes can see thermal data from a very hot object like a burning log. Infrared thermography is non-contact, and doesn't require a coating or film for use. The biggest disadvantage to infrared thermography is the spatial resolution.

Let's now discuss infrared thermography. Infrared thermography is based on black body radiation physics, so let's briefly review blackbody physics. In classical physics, the spectral radiancy, $R_T(\nu)$, is the spectral distribution of energy emitted by a blackbody. It is defined so that $R_T(\nu)d\nu$ is the energy emitted per unit time in the frequency range of ν to $\nu + d\nu$ from a unit area on a surface at a temperature T. If one integrates over all of the frequencies, one gets the radiancy, given by the equation shown here:

$$R_T = \int_0^\infty R_T(\nu)\, d\nu$$

The radiancy is related to the temperature of an object by a property called Stefan's Law. It states that the radiancy is proportional to the temperature raised to the fourth power. The proportionality constant, σ, is the Stefan-Boltzmann constant, which is equal to:

$$5.67\times10^{-8} \frac{W}{m^2K^4}$$

Most objects are not blackbodies, therefore one needs to take into account the emissivity of the object. The emissivity, *e,* can be factored into Stefan's Law as follows.

$$R(T) = e \cdot \sigma T^4$$

The radiancy is equal to the emissivity times the Stefan-Boltzmann constant times T to the fourth power. Another important factor required for infrared thermography is Wein's displacement law. Wein's displacement law relates the temperature to the wavelength peak:

$$\lambda_{max} = \frac{2.898\times10^{-3}}{T}$$

The maximum in the spectrum is inversely proportional to the temperature. The higher the temperature, the shorter the peak in the wavelength, and the finer the resolution that is possible.

If one assigns an average energy kT to each mode of the spectral radiancy, one gets the classical solution called the Rayleigh-Jeans formula for blackbody radiation.

$$\rho(\nu)d\nu = \frac{8\pi\nu^2 kT}{c^2} d\nu$$

This assumes that the Equipartition Theorem holds true. The Equipartition Theorem is a principle of classical statistical mechanics which states that the internal energy of a system composed of a large number of particles will distribute itself evenly among each of the degrees of freedom allowed to the particles of the system. Unfortunately, this solution does not work for shorter wavelengths because it would assume an infinite energy density. This led to what is known as the ultraviolet catastrophe. Several years later, Max Planck examined the Rayleigh-Jeans formula in light of quantum mechanics. Planck derived a new equation based on quantized energy units, shown here.

$$\rho_T(\nu)d\nu = \frac{8\pi\nu^2}{c^3} \cdot \frac{h\nu}{e^{h\nu/kT} - 1} d\nu$$

This equation works over the entire spectrum.

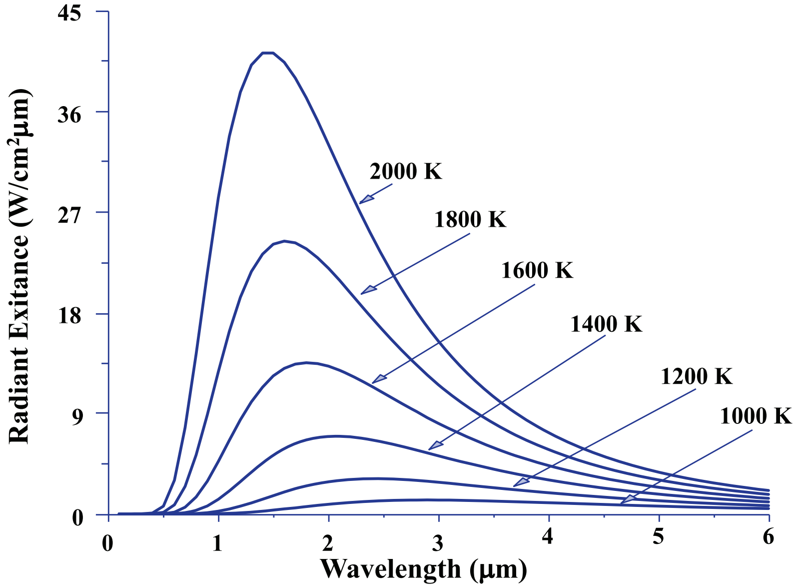


Figure 2. Blackbody radiation: 1000°K to 2000°K.

If one plots the radiancy vs. wavelength, the relationship can be seen. Notice that as the temperature increases, the peak in the radiancy moves toward shorter wavelengths.

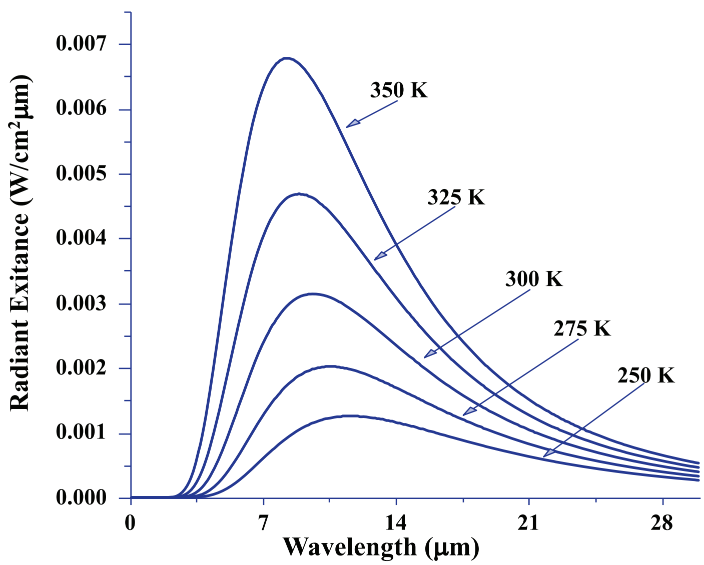


Figure 3. Blackbody radiation: 250°K to 350°K.

One normally performs thermal imaging of semiconductor components at temperatures near room temperature. This graph in Figure 3 shows the radiancy as a function of wavelength for temperatures closer to room temperature. Notice that the radiancy is about a factor of four less. More importantly, notice that the peak wavelengths are between 7 and 14 µm. This means that infrared thermography is effectively limited to around 7 µm spatial resolution.

As we discussed earlier, the radiancy of a body is related to the radiancy of a blackbody by the emissivity, $R_T = e \cdot R_{TBB}$. In order to obtain a correct temperature reading, the radiance reflected by the sample must be taken into account, $R_{Total} = R_T + (1 - e)R_0$. If we combine the two equations, we can obtain an equation that gives an accurate measurement of any particular body, $R_{Total} = e \cdot R_{TBB} + (1 - e)R_0$.

Material	Emissivity
Ideal black body	1.00
Lampblack	.95
Asbestos paper	.95
White Lacquer	.95
Bronze paint	.80
Carbon, rough plate	.76
Oxidized steel	.70
Polished brass, oxidized copper	.60
Aluminum paint	.55
Oxidized monel metal	.43
Cast iron - polished	.25
Copper - polished	.15
Nickel - polished	.12
Aluminum - highly polished	.08
Platinum - highly polished	.05
Silver - highly polished	.02

Figure 4. Emissivities of common materials.

Emissivities can vary quite widely for various materials. This chart in Figure 4 shows some common materials and their emissivities. An object that absorbs light has a high emissivity like lampblack, while an object that reflects light has a low emissivity like highly polished silver. Notice that materials used in semiconductor devices, like aluminum and copper, have low emissivities. One needs to take this into account when examining these devices.

Company/Models	Detector (std/opt)	Max. IR spectral range in um(std/opt)	Temperature range (low/high ºC)	Temperature resolution (ºC/@ºC)	Spatial* resolution
AGEMA IR	InSb/	2-5.6	-20/1600	.1/30	15 µm
Thermovision 782LWB	HgCdTe	8-12			
Barnes Computherm	InSb	1.5-5.5	amb/600	0.1/75	15 µm**
RM-2A	InSb	1.5-5.5	amb/500	0.1/75	8 µm
Hughes Probeye	InSb	2-5.6			
Series 4000	HgCdTe	8-12	-40/1500	0.1/22	2.2 mrad
Inframetrics Model 600	HgCdTe	3-12	-20/1500	0.1/30	30 µm
Mikron Thermo	HgCdTe/	8-13	-50/2000	0.1/70	100 µm
Tracer 6T61	InSb	1.5-5.5			
UTI CCT-9000	HgCdTe	8-14	-50/350	0.1/75	600 e/l

notes: std = standard, opt = optional, amb = ambient, e/l = elements per line
* Spatial resolution using microscope objective ** Their latest system quotes 4 µm spatial resolution

Figure 5. IR thermography detector manufacturers.

This chart in Figure 5 shows a list of some of the more common infrared detectors on the market. Almost all IR detectors are made from either indium antimonide or mercury cadmium telluride. Although these detectors are sensitive down to about 1 µm wavelengths, there is virtually no spectral information at those wavelengths. Remember that the peak in radiancy is around 7 to 14 µm. The most popular system on the market for semiconductor failure analysis as of this writing is the Quantum Focus Infrascope II. It uses an indium antimonide detector.

(To be concluded in next month's newsletter...)

Technical Tidbit

Technology Files

An important component of a Process Design Kit, or Process Delivery Kit (PDK) is the technology file.

The technology file may be one file, or several files. For example, there might be a layer mapping file, a Library Exchange Format file, and a Tcl (pronounced "tickle") file for setup in the EDA software. The information in the file or files includes: the layer definitions and maps, units for measurement of structures, property information for sizing and spacing, and rules for allowed connection layers.

Layer Name	Description	Stream Layer	Datatype Number
NW	N-Well, P-Well assumed to be where NW is not found	1	0
ACT	Active area for fin defintion	2	0
THKOX	Thick-Oxide adjust mask	3	0
GATEA	Gate metal, Color A	10	0
GATEB	Gate metal, Color B	11	0
GATEAB	Gate metal, single color to be processed later	12	0
GATEC	Gate metal Cut	13	0
NIM	N-implant	20	0
PIM	P-implant	21	0
VTH	High Threshold adjust mask	22	0
VTL	Low Threshold adjust mask	23	0
AIL1	Active Interconnect Layer, level 1	30	0
AIL2	Active Interconnect Layer, level 2	31	0
GIL	Gate Interconnect Layer	32	0
V0	Via Zero, connecting to first level of interconnect metal	33	0
M1A	First Level of Interconnect Metal, Color A	40	0
M1B	First Level of Interconnect Metal, Color B	41	0
M1	First Level of Interconnect Metal, single color to be processed later, for	42	0
V1	Via connecting MFAn to next higher level of metal	45	0
MINTnA	Intermediate metal, Color A, n=1..5	50	0
MINTnB	Intermediate metal, Color B, n=1..5	51	0
MINTn	Intermediate metal, single color to be processed later, for import/export only, no	-	255
VINTn	Via connecting MINTn to next higher level of metal, n=1..5 (renamed from V2-6 to	-	255
MSMGn	Semi-global metal, n=1..5	-	255
VSMGn	Via connecting MSMGn to next higher level of metal	-	255
MGn	Global metal, n=1..2	-	255
VGn	Via connecting MGn to next higher level of metal	-	255

This is an example of the layer mapping file that is a part of the technology file set. This file gives the layer name, a short description of the layer, the GDSII stream layer number, and the datatype number for viewing and printing purposes. For example, 0 might indicate transparency, while 255 might indicate fully opaque.

Ask the Experts

Q: To avoid Weff (effective channel width) fails at the WAT, we have enlarged the final Critical Dimension (CD) target of Active Area mask, or Oxide Diffusion mask (OD) by 10nm. I am curious…is there any impact on the device transconductances with respect to OD CD change?

A: The transconductance would go up, as you would be making Weff larger when you increase the oxide diffusion mask (assuming this mask blocks the etch of the SiN during formation of the STI regions). This effect is sometimes known as the Narrow Channel Effect. Most of the time, engineers think about the narrow channel effect as one that increases the threshold voltage when the channel width becomes narrower, but at the same time, it will decrease the transconductance. So the opposite should be occurring in the example you are describing.

Spotlight: Failure and Yield Analysis

OVERVIEW

Failure and Yield Analysis is an increasingly difficult and complex process. Today, engineers are required to locate defects on complex integrated circuits. In many ways, this is akin to locating a needle in a haystack, where the needles get smaller and the haystack gets bigger every year. Engineers are required to understand a variety of disciplines in order to effectively perform failure analysis. This requires knowledge of subjects like: design, testing, technology, processing, materials science, chemistry, and even optics! Failed devices and low yields can lead to customer returns and idle manufacturing lines that can cost a company millions of dollars a day. Your industry needs competent analysts to help solve these problems. ***Advanced Failure and Yield Analysis*** is a four-day course that offers detailed instruction on a variety of effective tools, as well as the overall process flow for locating and characterizing the defect responsible for the failure. This course is designed for every manager, engineer, and technician working in the semiconductor field, using semiconductor components or supplying tools to the industry.

By focusing on a ***Do It Right the First Time*** approach to the analysis, participants will learn the appropriate methodology to successfully locate defects, characterize them, and determine the root cause of failure.

Participants learn to develop the skills to determine what tools and techniques should be applied, and when they should be applied. This skill-building series is divided into three segments:

1. **The Process of Failure and Yield Analysis.**Participants learn to recognize correct philosophical principles that lead to a successful analysis. This includes concepts like destructive vs. non-destructive techniques, fast techniques vs. brute force techniques, and correct verification.
2. **The Tools and Techniques.** Participants learn the strengths and weaknesses of a variety of tools used for analysis, including electrical testing techniques, package analysis tools, light emission, electron beam tools, optical beam tools, decapping and sample preparation, and surface science tools.
3. **Case Histories.** Participants identify how to use their knowledge through the case histories. They learn to identify key pieces of information that allow them to determine the possible cause of failure and how to proceed.

COURSE OBJECTIVES

1. The seminar will provide participants with an in-depth understanding of the tools, techniques and processes used in failure and yield analysis.
2. Participants will be able to determine how to proceed with a submitted request for analysis, ensuring that the analysis is done with the greatest probability of success.
3. The seminar will identify the advantages and disadvantages of a wide variety of tools and techniques that are used for failure and yield analysis.
4. The seminar offers a wide variety of video demonstrations of analysis techniques, so the analyst can get an understanding of the types of results they might expect to see with their equipment.
5. Participants will be able to identify basic technology features on semiconductor devices.
6. Participants will be able to identify a variety of different failure mechanisms and how they manifest themselves.
7. Participants will be able to identify appropriate tools to purchase when starting or expanding a laboratory.

INSTRUCTIONAL STRATEGY

By using a combination of instruction by lecture, video, and question/answer sessions, participants will learn practical approaches to the failure analysis process. From the very first moments of the seminar until the last sentence of the training, the driving instructional factor is **application**. We use instructors who are internationally recognized experts in their fields that have years of experience (both current and relevant) in this field. The handbook offers hundreds of pages of additional reference material the participants can use back at their daily activities.

THE SEMITRACKS ANALYSIS INSTRUCTIONAL VIDEOS™

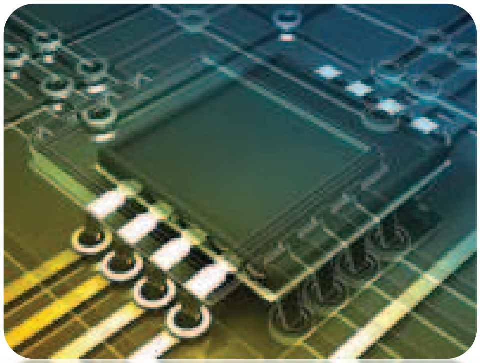
One unique feature of this workshop is the video segments used to help train the students. Failure and Yield Analysis is a visual discipline. The ability to identify nuances and subtleties in images is critical to locating and understanding the defect. Many tools output video images that must be interpreted by analysts. No other course of this type uses this medium to help train the participants. These videos allow the analysts to directly compare material they learn in this course with real analysis work they do in their daily activities.

COURSE OUTLINE

1. Introduction
2. Failure Analysis Principles/Procedures
   a. Philosophy of Failure Analysis
   b. Flowcharts
3. Gathering Information
4. Package Level Testing
   a. Optical Microscopy
   b. Acoustic Microscopy
   c. X-Ray Radiography
   d. Hermetic Seal Testing
   e. Residual Gas Analysis
5. Electrical Testing
   a. Basics of Circuit Operation
   b. Curve Tracer/Parameter Analyzer Operation
   c. Quiescent Power Supply Current
   d. Parametric Tests (Input Leakage, Output voltage levels, Output current levels, etc.)
   e. Timing Tests (Propagation Delay, Rise/Fall Times, etc.)
   f. Automatic Test Equipment
   g. Basics of Digital Circuit Troubleshooting
   h. Basics of Analog Circuit Troubleshooting

6. Decapsulation/Backside Sample Preparation
    a. Mechanical Delidding Techniques
    b. Chemical Delidding Techniques
    c. Backside Sample Preparation Techniques
7. Die Inspection
    a. Optical Microscopy
    b. Scanning Electron Microscopy
8. Photon Emission Microscopy
    a. Mechanisms for Photon Emission
    b. Instrumentation
    c. Frontside
    d. Backside
    e. Interpretation
9. Electron Beam Tools
    a. Voltage Contrast
        i. Passive Voltage Contrast
        ii. Static Voltage Contrast
        iii. Capacitive Coupled Voltage Contrast
        iv. Introduction to Electron Beam Probing
    b. Electron Beam Induced Current
    c. Resistive Contrast Imaging
    d. Charge-Induced Voltage Alteration
10. Optical Beam Tools
    a. Optical Beam Induced Current
    b. Light-Induced Voltage Alteration
    c. Thermally-Induced Voltage Alteration
    d. Seebeck Effect Imaging
    e. Electro-optical Probing
11. Thermal Detection Techniques
    a. Infrared Thermal Imaging
    b. Liquid Crystal Hot Spot Detection
    c. Fluorescent Microthermal Imaging
12. Chemical Unlayering
    a. Wet Chemical Etching
    b. Reactive Ion Etching
    c. Parallel Polishing

13. Analytical Techniques
    a. TEM
    b. SIMS
    c. Auger
    d. ESCA/XPS
14. Focused Ion Beam Technology
    a. Physics of Operation
    b. Instrumentation
    c. Examples
    d. Gas-Assisted Etching
    e. Insulator Deposition
    f. Electrical Circuit Effects
15. Case Histories



Feedback

If you have a suggestion or a comment regarding our courses, online training, discussion forums, or reference materials, or if you wish to suggest a new course or location, please call us at 1-505-858-0454 or Email us (info@semitracks.com).

To submit questions to the Q&A section, inquire about an article, or suggest a topic you would like to see covered in the next newsletter, please contact Jeremy Henderson by Email (jeremy.henderson@semitracks.com).

We are always looking for ways to enhance our courses and educational materials.

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To post, read, or answer a question, visit our forums.
We look forward to hearing from you!

Upcoming Courses

(Click on each item for details)

Wafer Fab Processing

April 14 – 17, 2020 (Tue – Fri)
Munich, Germany

Semiconductor Reliability / Product Qualification

April 14 – 17, 2020 (Tue – Fri)
Munich, Germany

Failure and Yield Analysis

April 20 – 23, 2020 (Mon – Thur)
Munich, Germany

IC Packaging Technology

April 27 – 28, 2020 (Mon – Tue)
Munich, Germany

Advanced CMOS/FinFET Fabrication

April 30, 2020 (Thur)
Munich, Germany