A Tutorial on FA Methods and Failure Signatures

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Outline

- The Broad Knowledge Base of FA Acronyms/Tools/Trends.
- Problematic Questions.
- IV Signatures and Characterization.
- Choosing the Appropriate Analysis Path.
- Photon Emission and Thermal Emission.
- Scanning Capacitance with the AFM.
- Thermal Laser Stimulus Methods.

The Sea of Analysis Acronyms

XRF, SEM, EDX, C-SAM, TEM, AFM, AFP, SPM, TUNA, SSRM, SCM, C-AFM, EFP, MFP, PVC, FIB, EBIC, OBIC, LSM, LVP, VC, CVC, RCI, SEI, SOM, CIVA, EMMI, OBIRCH, INSB, SWIR, MWIR, LWIR, UV, FMI, SFMI, LC, TIVA, LIVA, XIVA, SQUID, SIFT, TLS, RCL, RIL, LADA, PIND, TDR, X-RAY, FTIR, ESCA, AES, SIMS, BIST, DFT, PICA, RIE, DPA …

I am the very model of a modern Major-General,
I've information vegetable, animal, and mineral…Gilbert and Sullivan

Some Passive Based Techniques

Liquid Crystal D. Burgess IRPS 1984 p. 119

Infrared Imaging MWIR or LWIR

FMI D.L. Barton ISTFA 1994 p. 87

EMMI N. Khurana IRPS 1985 p.212

PICA J.A. Kash IBM ISTFA 1998 p. 483

Some Beam Based Techniques

PVC J. Colvin ISTFA 1990 p331

OBIC K.S. Wills ISTFA 1990 p. 21

EBIC, VC, Ebeam, Ibeam FA desk ref p133

CVC J. Colvin ISTFA 1995 p305

OBIRCH NEC ISTFA 1993 p303

CIVA, LIVA, TIVA Sandia Labs

XIVA A. Faulk ISTFA 2001 p. 59

LVP W. Lo ISTFA 2001 p. 33

SIFT J. Colvin ISTFA 2002 p. 623

Contemporary Analysis Tools

- Extended CCD IR and InGaAs Photoemission Microscopy
- Moiré Thermal Pattern Analysis
- Scintillation Liquid Crystal*
- Stabilized VisGaAs/InGaAs/InSb/FMI Thermal Imaging
- Integrated Process Control Tester/Parametric Analyzer
- Laser Induced Stimulus Methods
- Magnetic SQUID
- SEM/C-SAM/X-ray

DPA Contemporary Analysis Tools

- SPM and AFP Family*
- Focused Ion Beam
- Cross Section/Lapping
- Delayering (Chemical, RIE, and lapping)
- TEM/SEM*

*Assumes the tool is used after destructive preparation

Analysis Tools Losing Ground to Scaling

- Frontside Focused Ion Beam Edits
- Photon Emission
- SEM/Voltage Contrast
- PICA
- LVP
- Liquid Crystal
- Traditional Differential Thermal Analysis

Impact of <90nm nodes on FA

- High gate oxide leakage coupled with short channel effects complicates thermal and photon emission analysis.
- The defect signal is typically no longer orders of magnitude greater than the background and is also deep submicron.

Impact of MEMS Technology on FA

- MEMS products are being analyzed most commonly with TLS or Thermal (InSb) methods for abnormal power consumption as these methods can see through the cap with minimal sample prep.
- Operational modes are evaluated stroboscopically or with interference measurements.

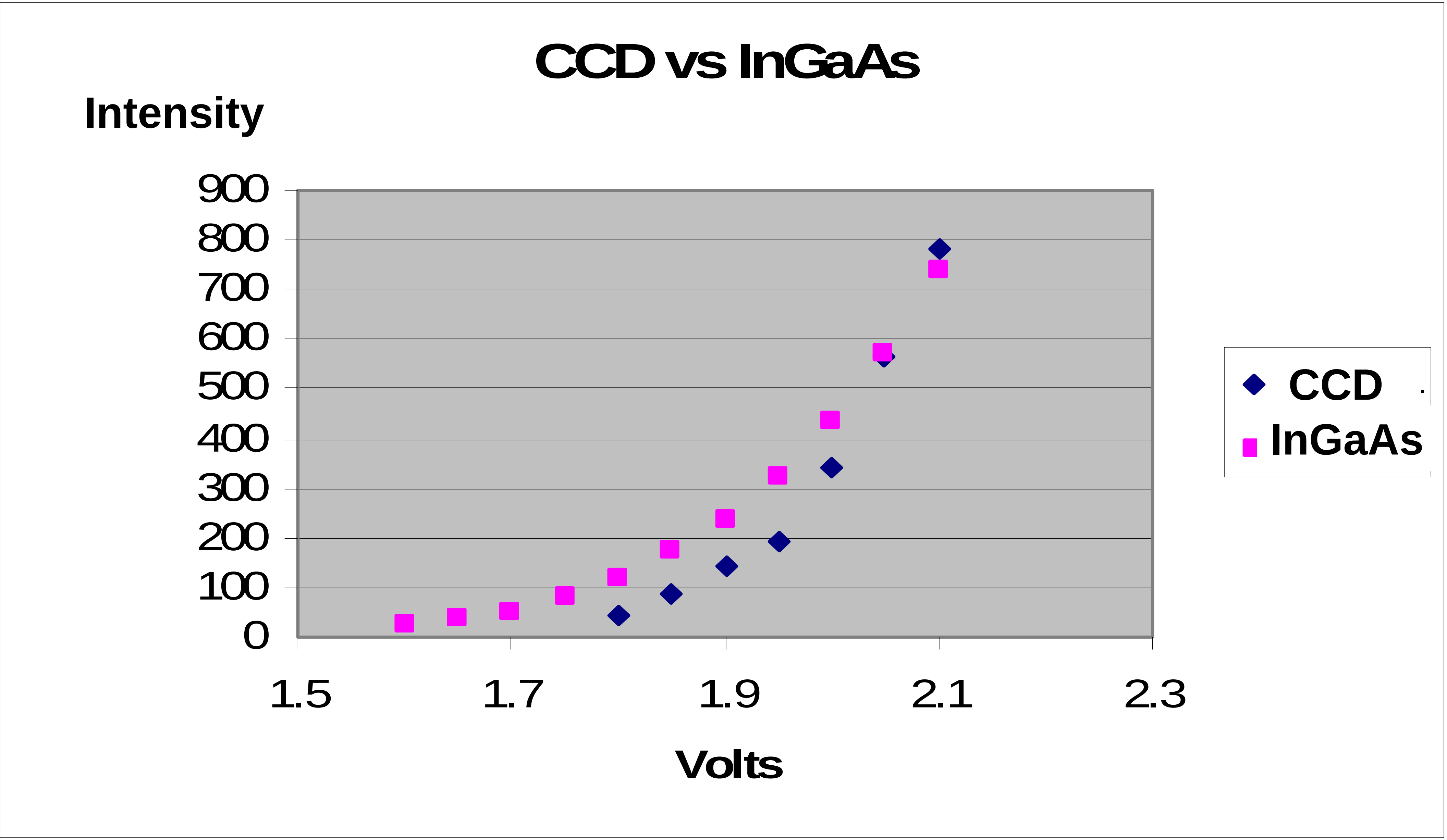
Problematic Questions

- How much current or voltage can you detect?
- How sensitive is the instrument?
- How long will the analysis take?
- My part fails, how much will it cost to analyze it?

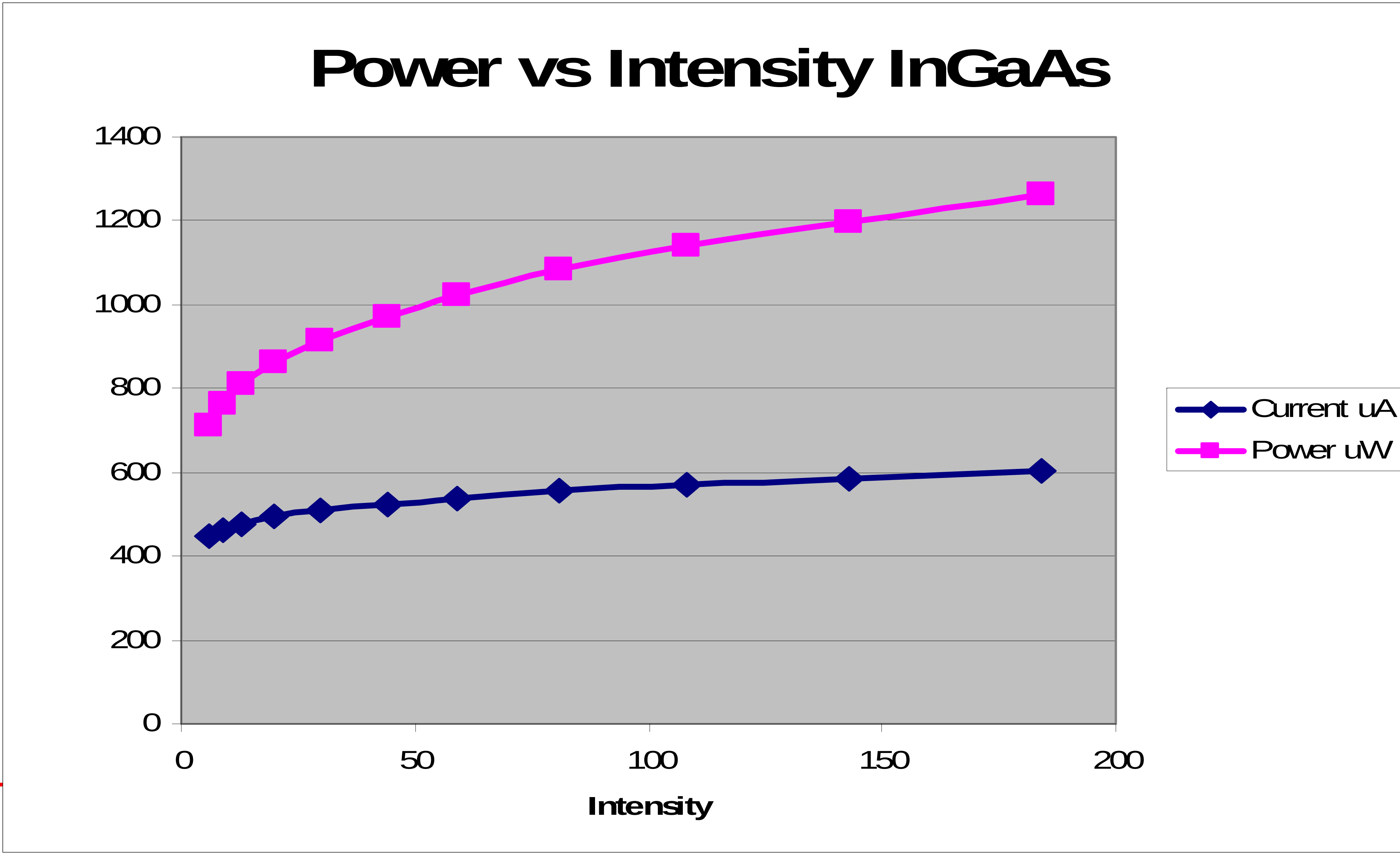
Failure Analysis, like the medical field, is an art as well as a science.

Problematic Questions

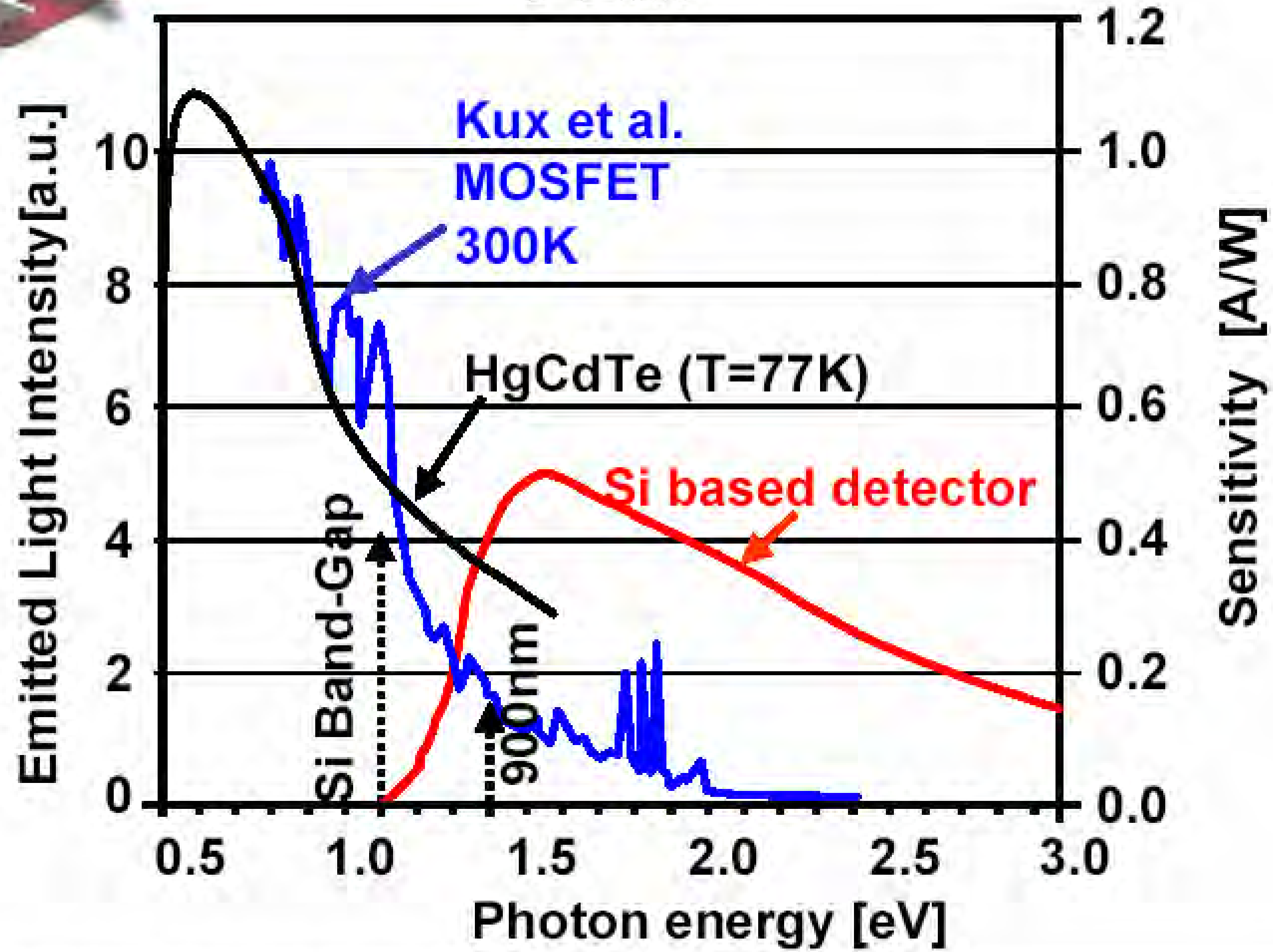
- Tell me the final root cause of failure and I'll tell you how long the analysis will take. Without the details, only a guess is possible as the failure mechanism/location is unknown. It is unrealistic to expect FA to operate in a production mode!


CCD vs InGaAs
Intensity
900
800
700
600
500
400
300
200
100
0
1.5
1.7
1.9
2.1
2.3
Volts
CCD
InGaAs

2X Intensity/13% change in power

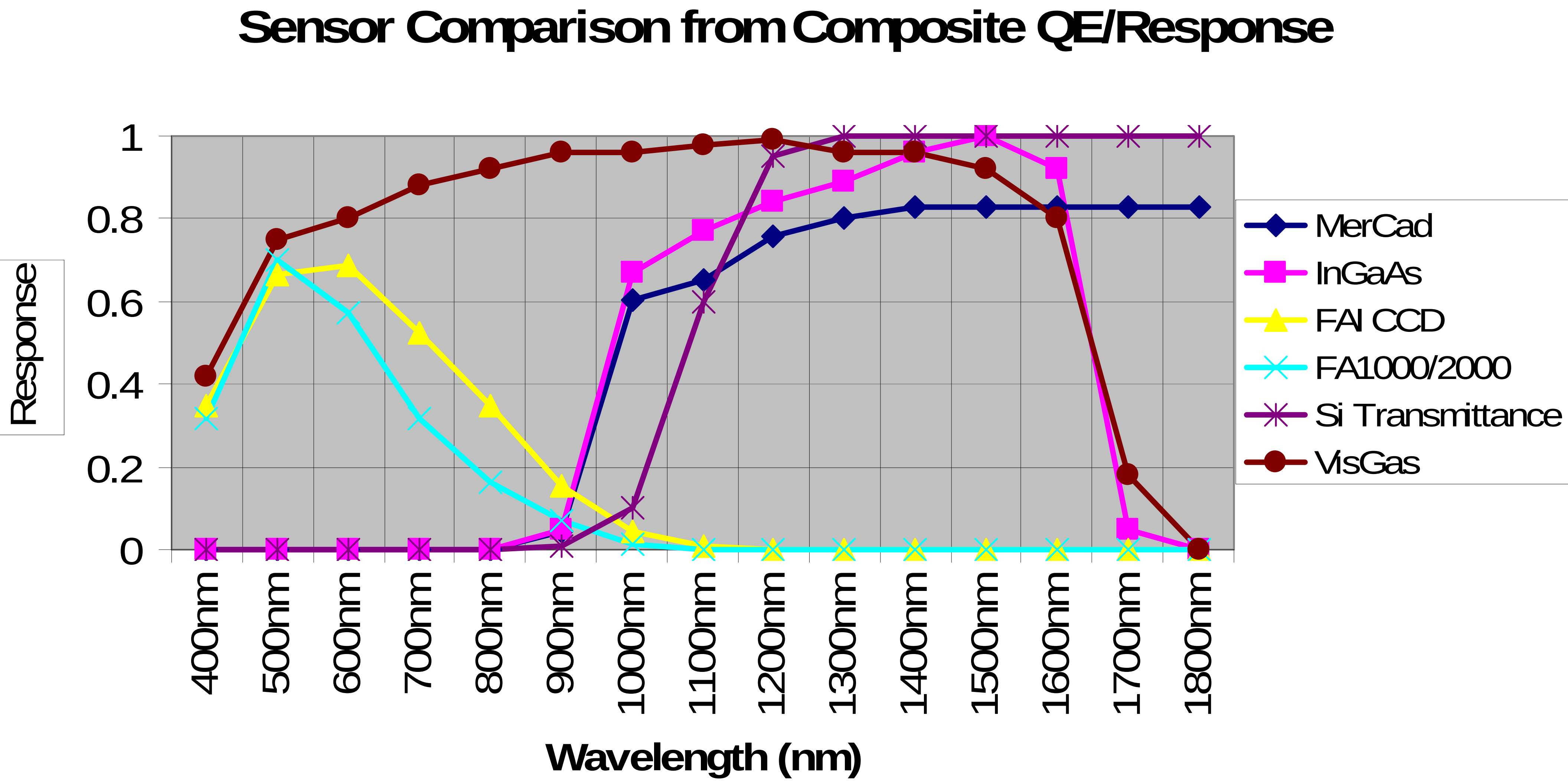


PEM



Kux et al.
MOSFET
300K
HgCdTe (T=77K)
Si based detector
Si Band-Gap
900nm
Emitted Light Intensity[a.u.]
Sensitivity [A/W]
Photon energy [eV]
0
2
4
6
8
10
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.5
1.0
1.5
2.0
2.5
3.0

The Ideal Sensor? (QE only?)



QE is not enough

QE cannot be equated to sensor responsiveness. The CCD sensor is actually around 30x more sensitive than the InGaAs sensor in its waveband, hence a VisGaAs sensor is not a universal replacement for the CCD/InGaAs system.

The Importance of Characterization

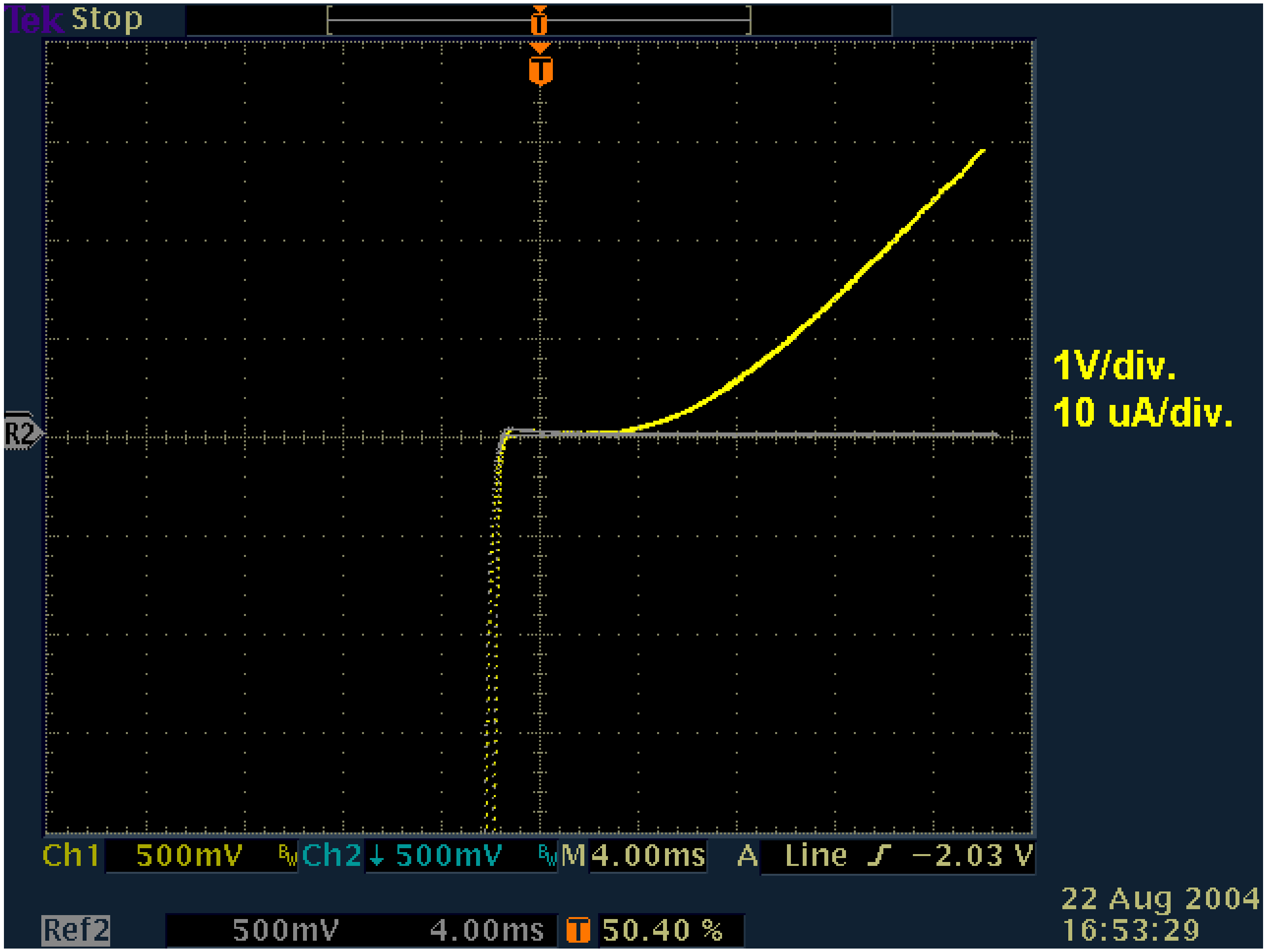
- Hot/Cold Fail?
- Voltage/Timing Dependent?
- IDD/IDDQ outside of population?
- Stable Leakage or 1/f?
- Light Sensitive?
- Field Sensitive?
- Responsiveness to Stimulus?

The Importance of IV Curve Analysis

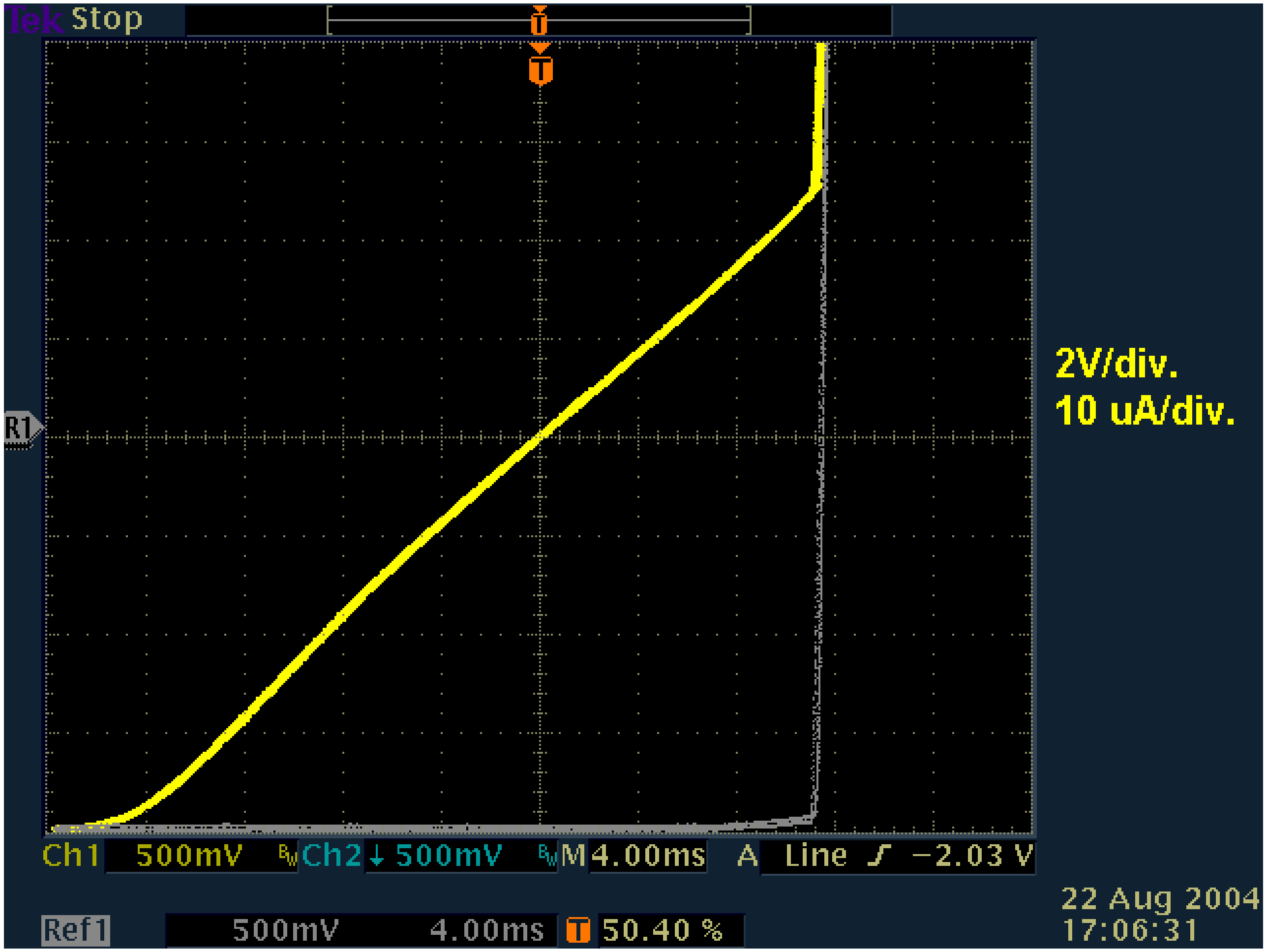
- IV curves serve as predictors for the type and likelihood of obtaining photon emission data.
- Linear responses generally are best detected with thermal methods whereas non-linear are usually photon emitters.

Know the proper operating point!

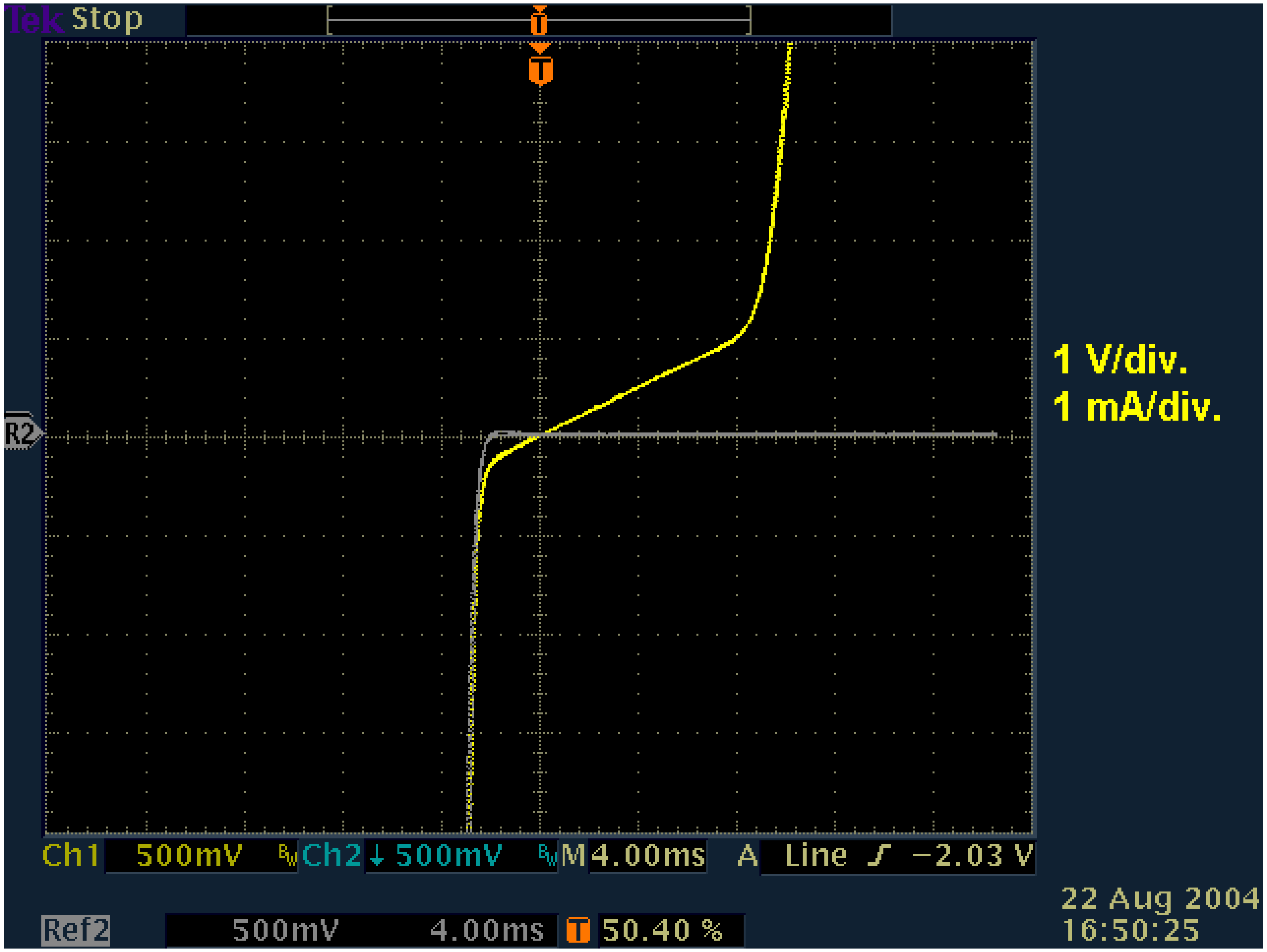
The Importance of IV Curve Analysis



The Importance of IV Curve Analysis



The Importance of IV Curve Analysis



The Analysis Path

- Do not arbitrarily assume an analysis path based on leakage or a limited pass/fail test alone unless forced to do so.
- Data collection up front is key to choosing an analysis flow with minimal wasted time/poor results.
- Requestor and FA Engineer must both be on the same page!

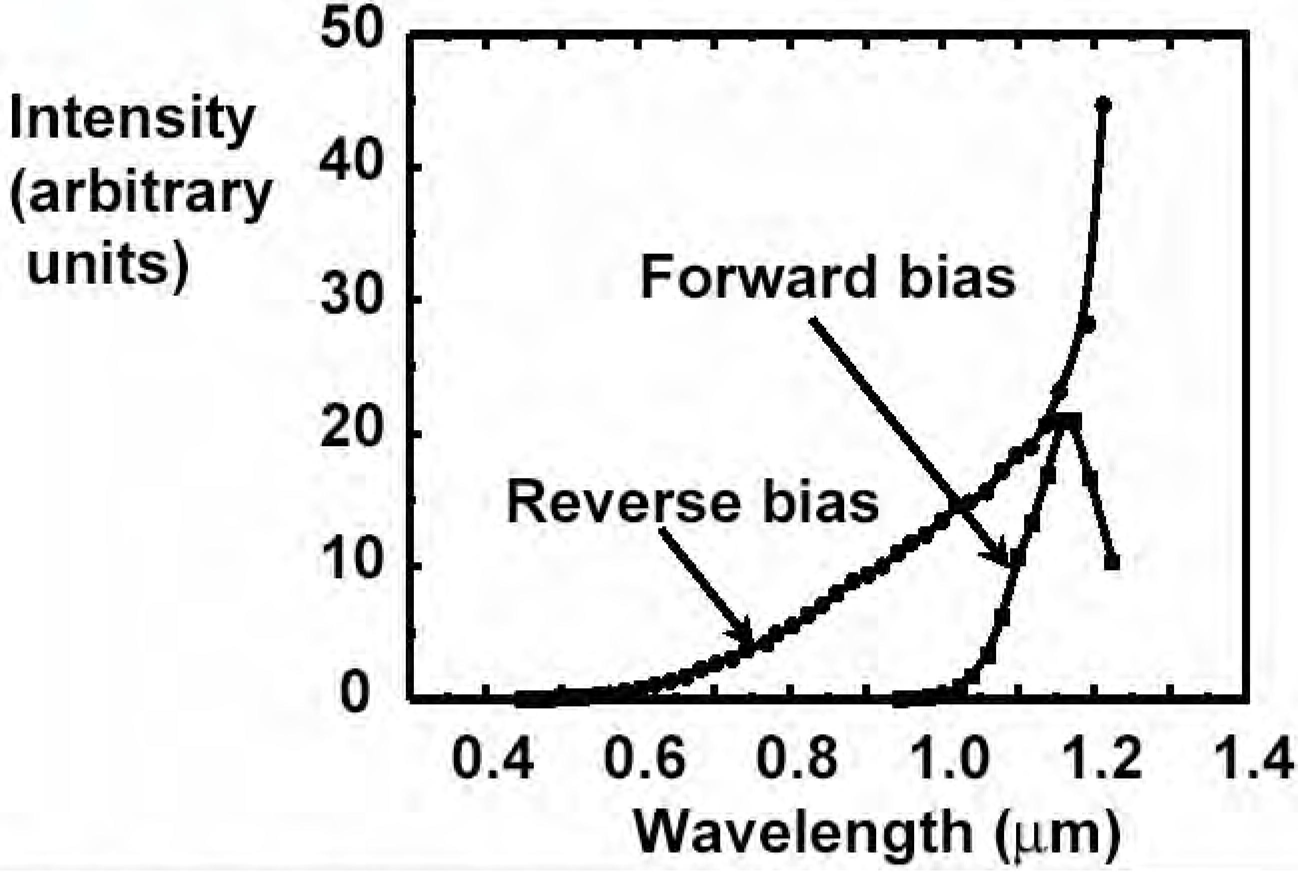
Photon Emission Detection

Photon sources from an integrated circuit are generated by several physical mechanisms:

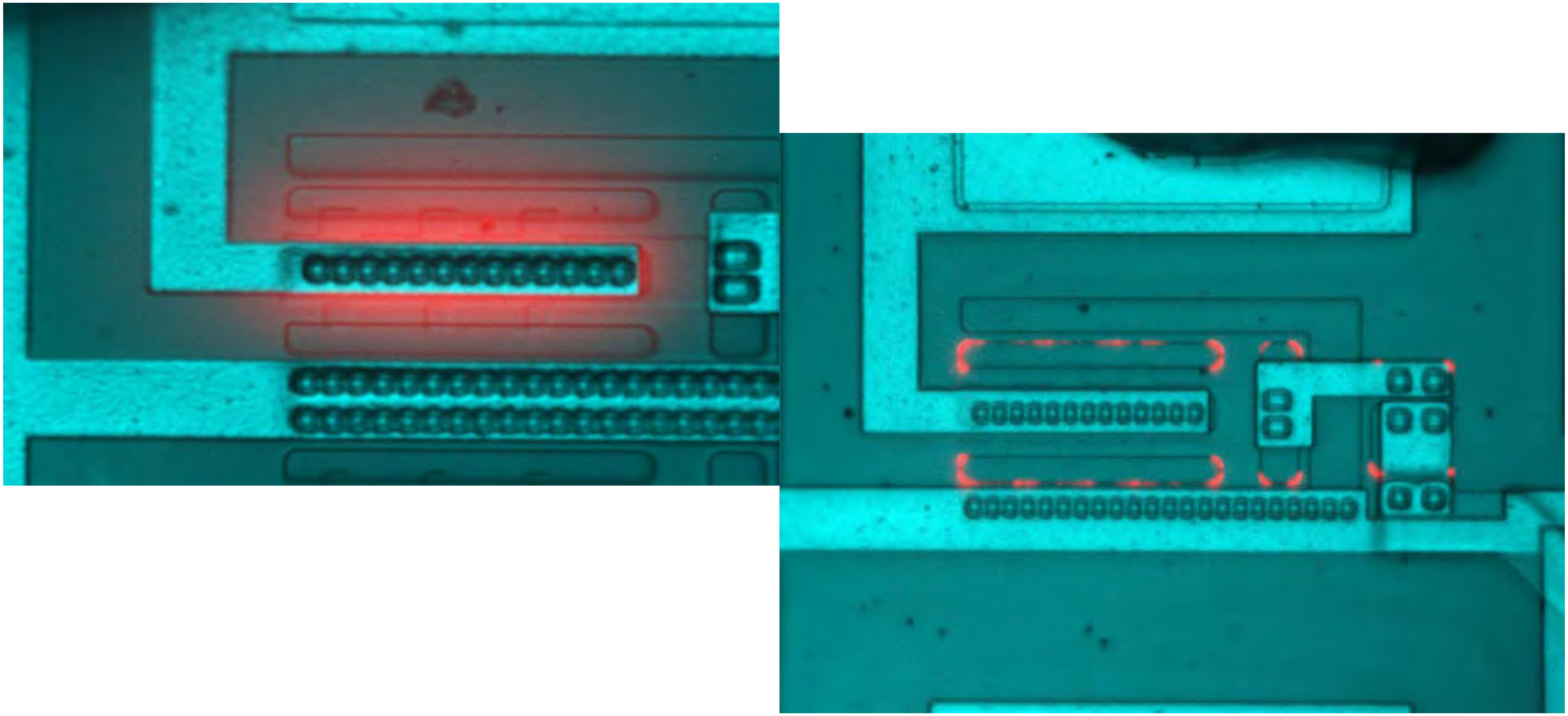
1. Hole-Electron recombination (Annihilation)
   a. Interband (Forward) 1050 nm
   b. Intraband (Avalanche) 650 nm
   c. Bremsstrahlung (Breaking radiation) Spectrum
2. Thermally generated photons (Infrared to Visible)
3. Spark Gap Phenomena (Intermittent - Spectrum)

Are spectral signatures important?

p-n Junction Emission

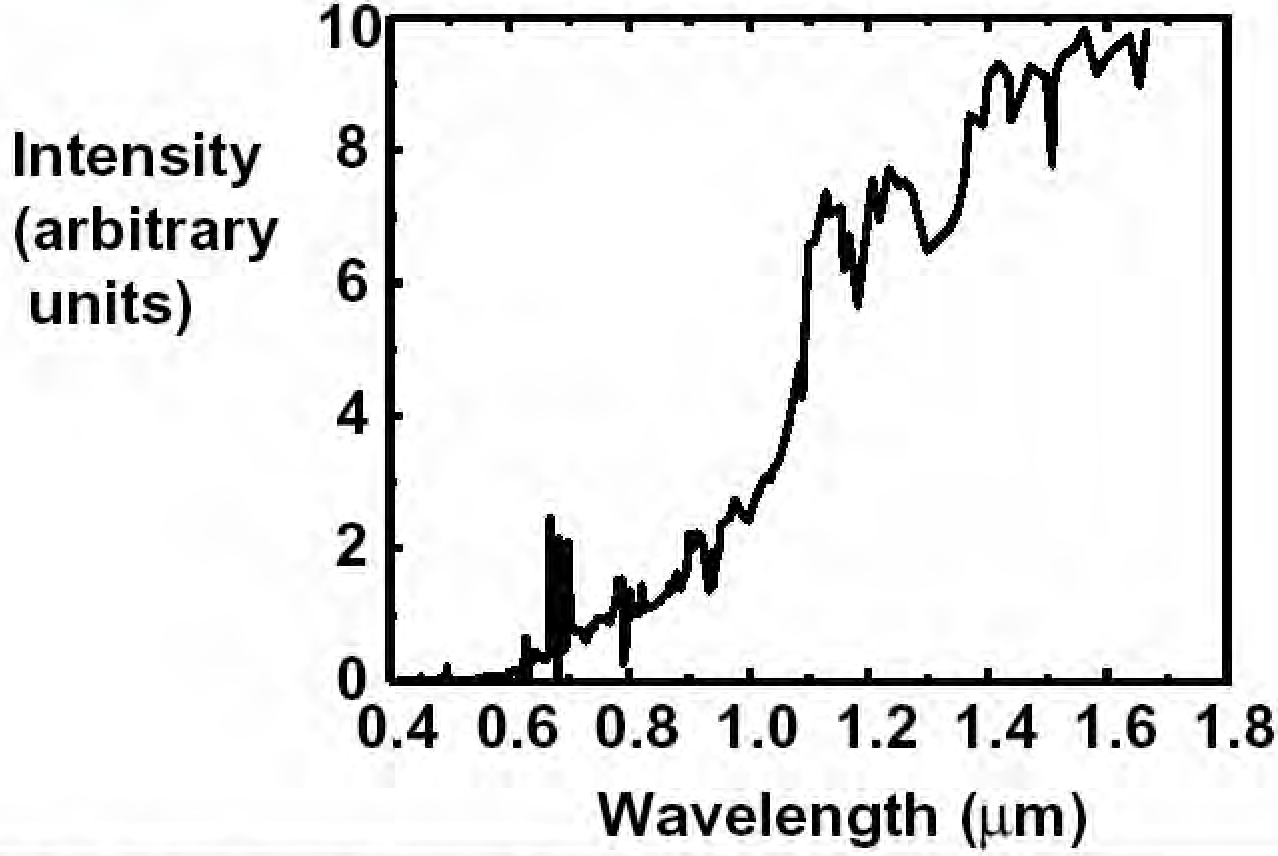


Photoemission Examples



Forward and Reverse Bias Signatures

n-MOSFET Saturation



Fundamentals of Photon Emission or:

How much current can I detect?

Photon emission occurs strictly based on the nature of the material under bias. Resistive characteristics result in no photon emission unless the energy is sufficient to produce thermally generated photons within the response of the camera. Squid microscopes detect current.

Fundamentals of Photon Emission or:

How much current can I detect?

Insufficient! Needs 2 of 3 variables to solve ohms law.

Ohms Law: V=I*R and V^2/R=Power

Power Density/Conversion Efficiency must be considered!

10nA X 1 million emission sites = 10mA!

Thermal faces similar distribution issues.

Photo Emission Microscopes
Curve Tracer/Parametric Analyzer
and
Liquid Crystal

Were traditionally the most frequently used tools in a typical FA lab.

But what about thermal analysis?

Detection Methods

There are currently four methods for thermal imaging.

1. Applied thermal film LC/FMI, etc.
2. IR focal plane array/scanning sensor.
3. Interference fringe/thermal strain.
4. SThM AFM

Fundamentals of Thermal or:

How much current can I detect?

Ohms law still applies!

Thermal phenomenon detection is based on a deltaT, not on current. The location of the thermal source and distributed area of the source are deciding factors for detection. For IR cameras, black body radiation plays a major role in sensitivity. All thermal detection methods are relative.

Stabilized Thermal Imaging

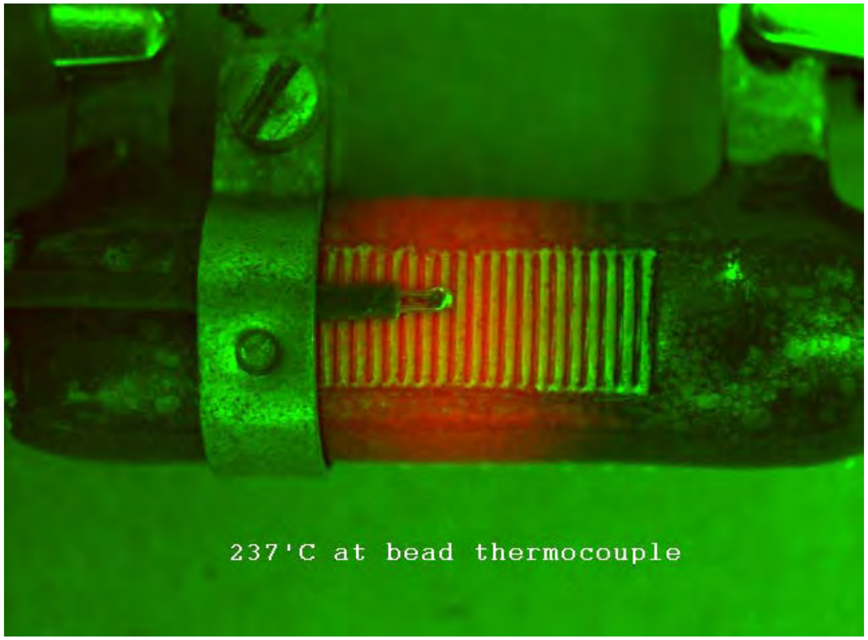
Enhances all thermal imaging techniques by frame accumulation. Differs from “lock in thermography”

- IR Cameras (InSb, InGaAs, LWIR MgCdTe)
- FMI
- Moiré
- Scintillation Liquid Crystal*

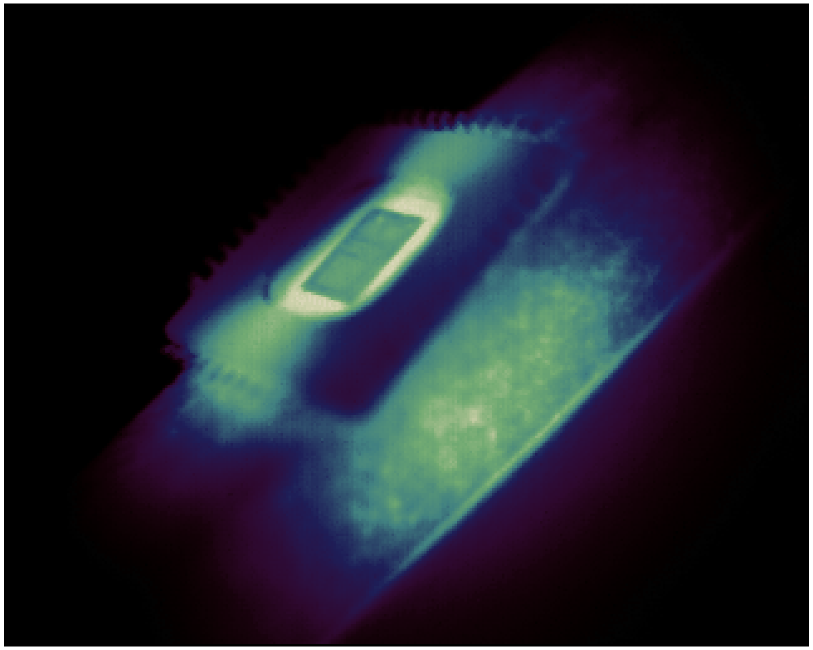
IDDQ and Emission Microscopy

1. Establishing the setup.
2. Comparing differential signatures.
    a. Differential Idd.
    b. Differential emissions.
3. Choosing appropriate fail vectors.
4. Can be run in stabilize mode.

Thermal Detection



CCD View at >240C



InGaAs view at 100C

Stabilized Thermal Control

Sequence for acquisition of 16 total frames with 8 frames biased.
All frames=1 are added to fron buffer and all frames=0 are added to froff buffer. Fron-froff=result. Gain reduction is applied to result.

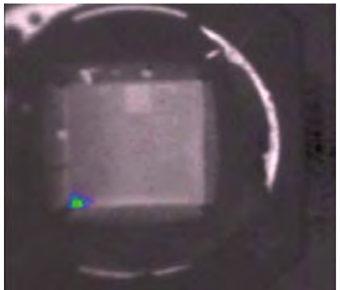
Frame	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Stabilize 1X	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
Stabilize 2X	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0
Stabilize 4X	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0
Normal	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0

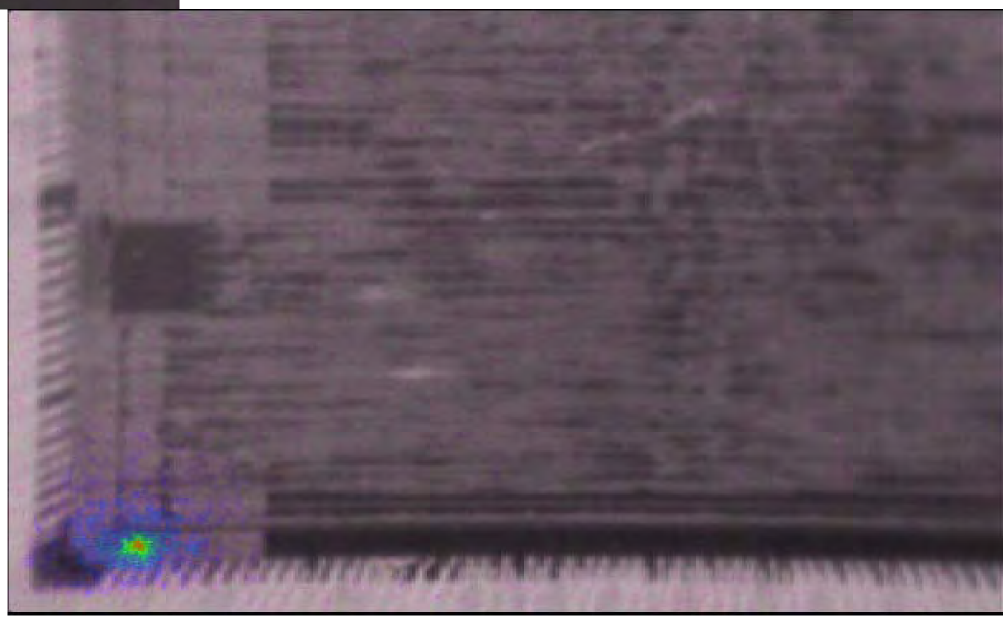
Typical Detection Limits

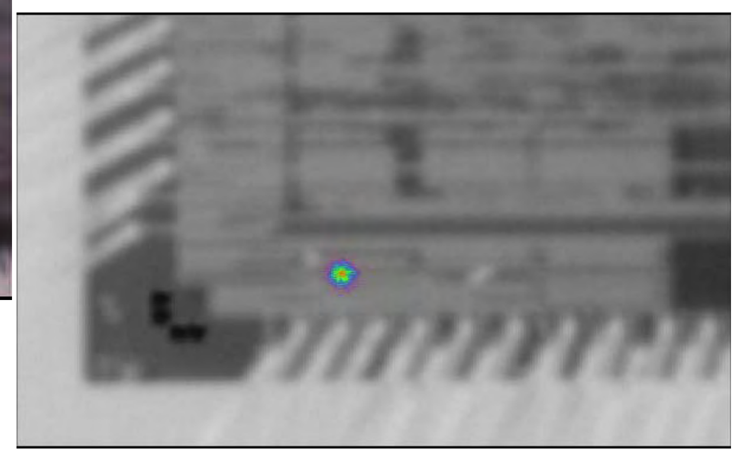
1. FMI .01C
2. SFMI .001C*
3. IR focal plane array .1C to .5C (With S_InSb .001C)
4. Liquid Crystal .1C
5. Scintillation Liquid Crystal .05C
6. Moiré .001C
7. NIR HgCdTe or InGaAs 1C

*Significant differential detection improvement

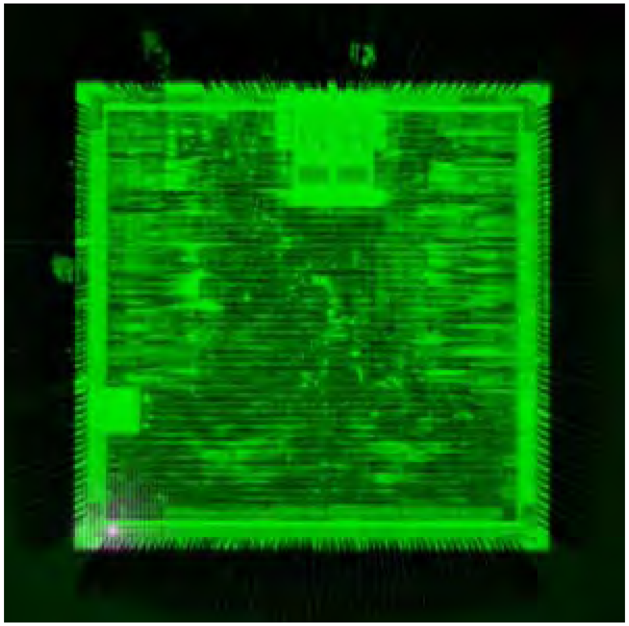
Long Wave IR Thermal Image of Ohmic Short

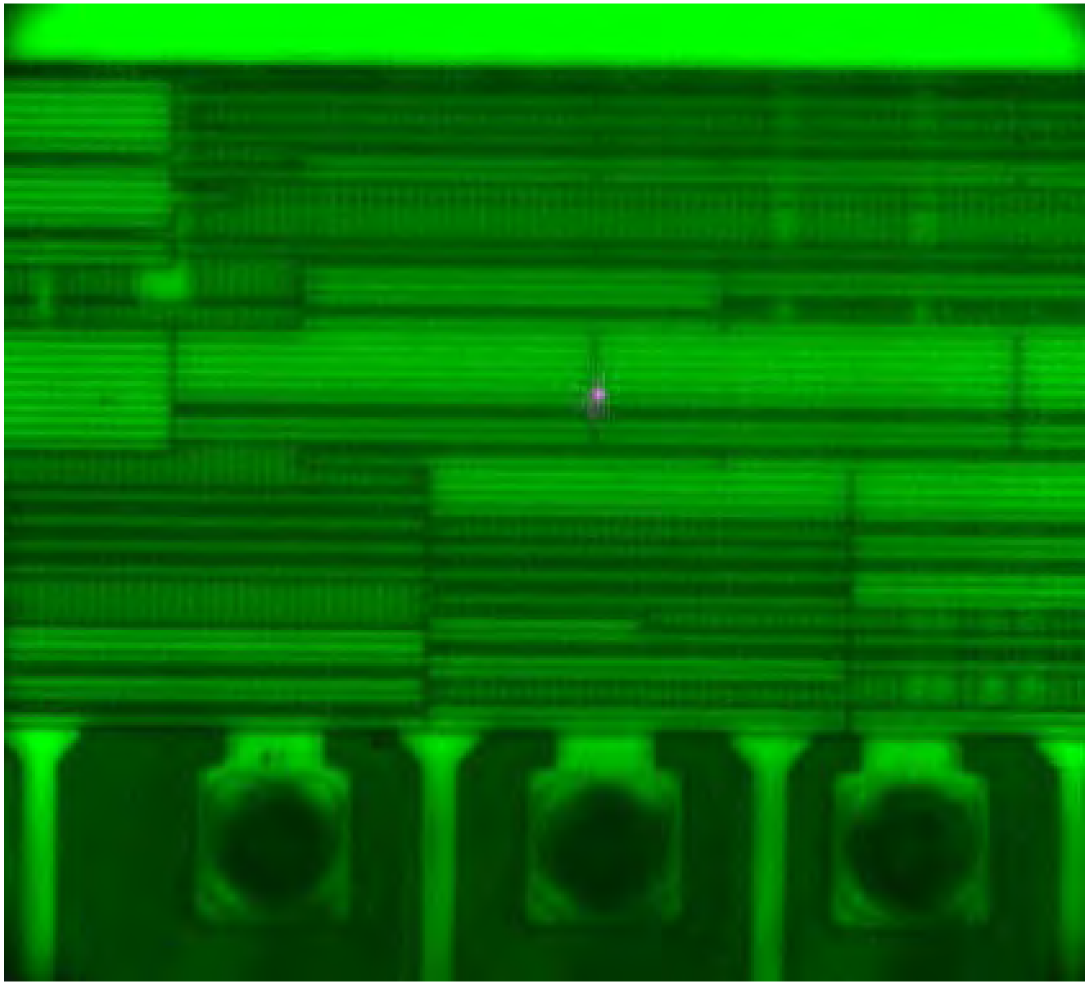




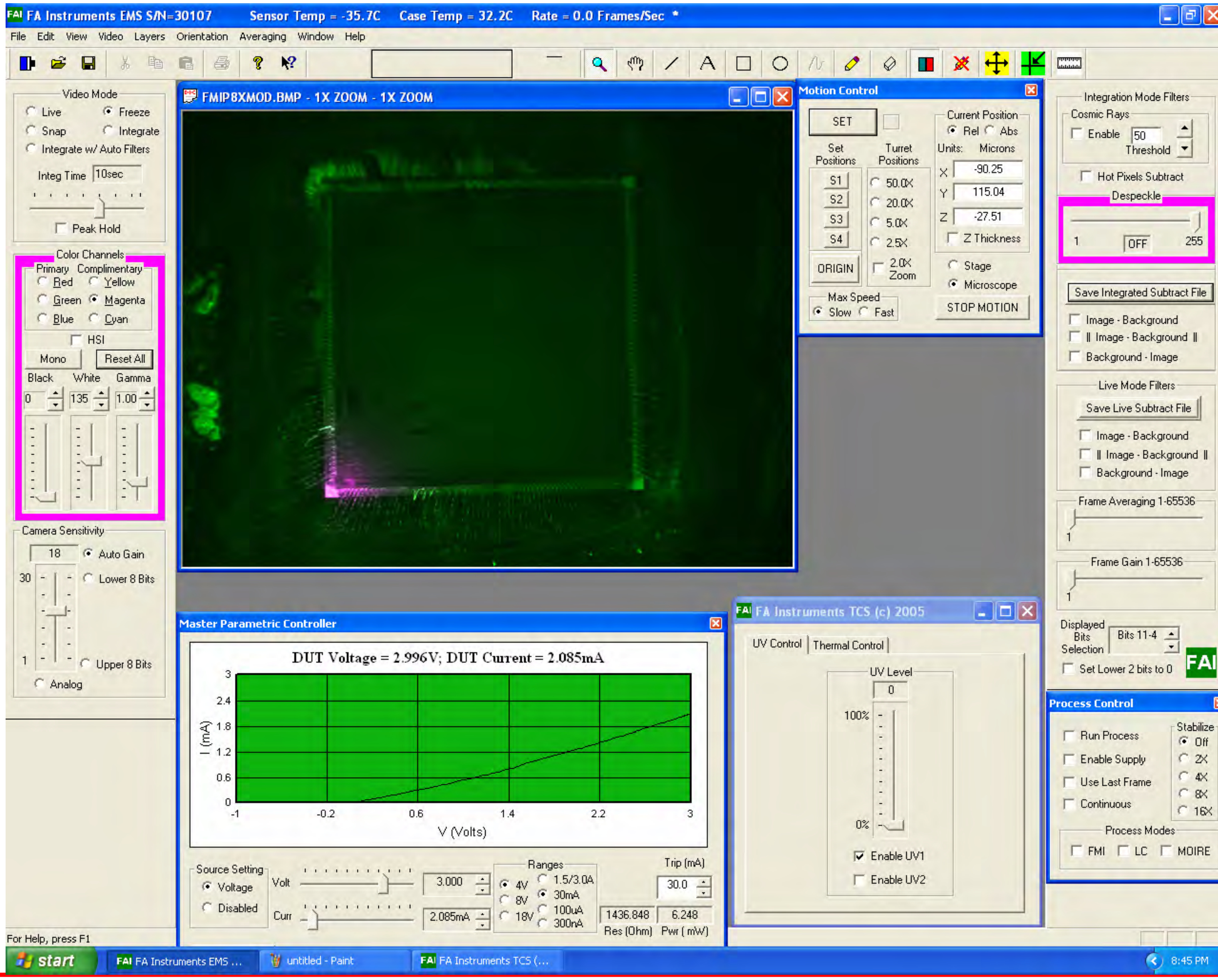


Mid Wave IR Thermal Image of Ohmic Short

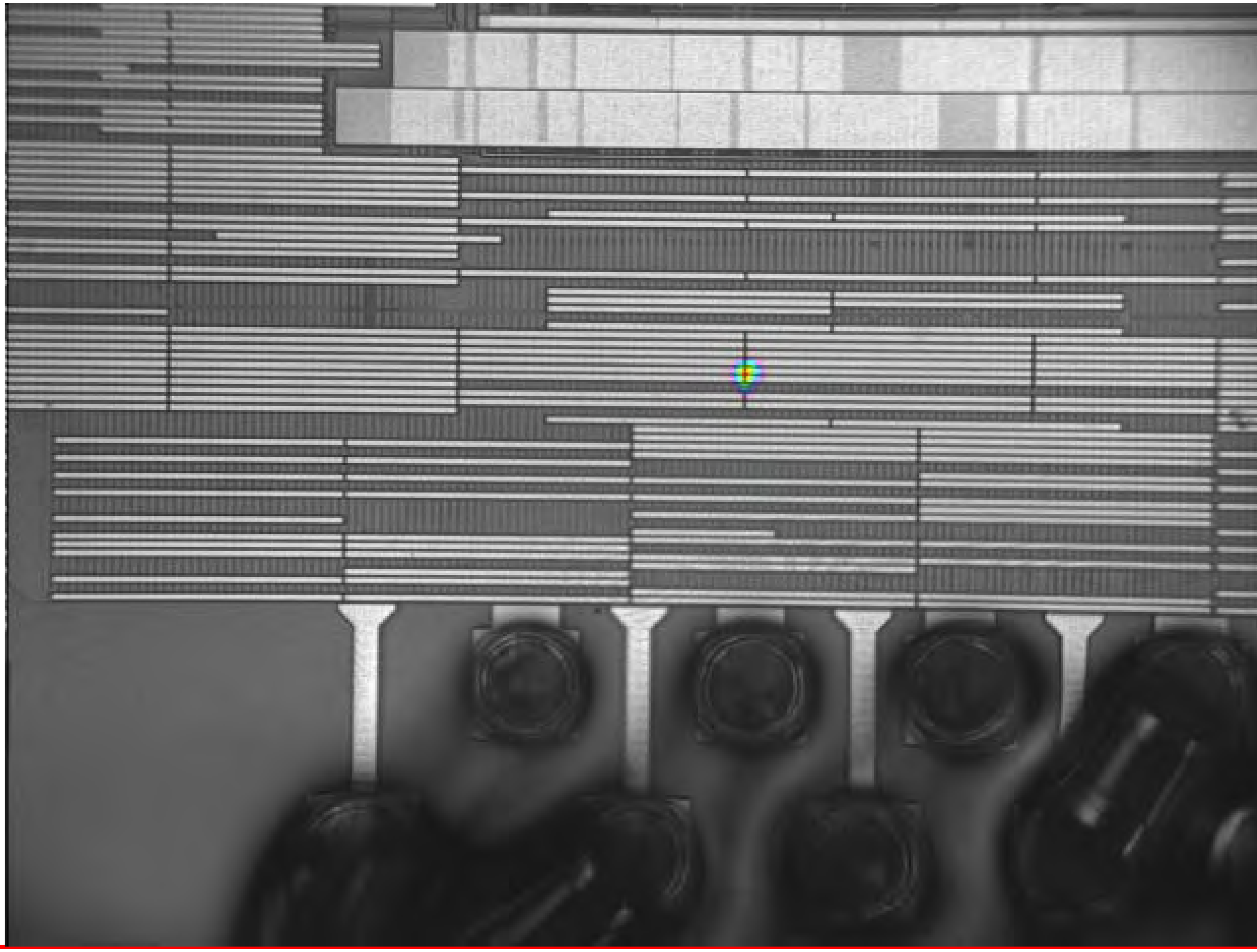




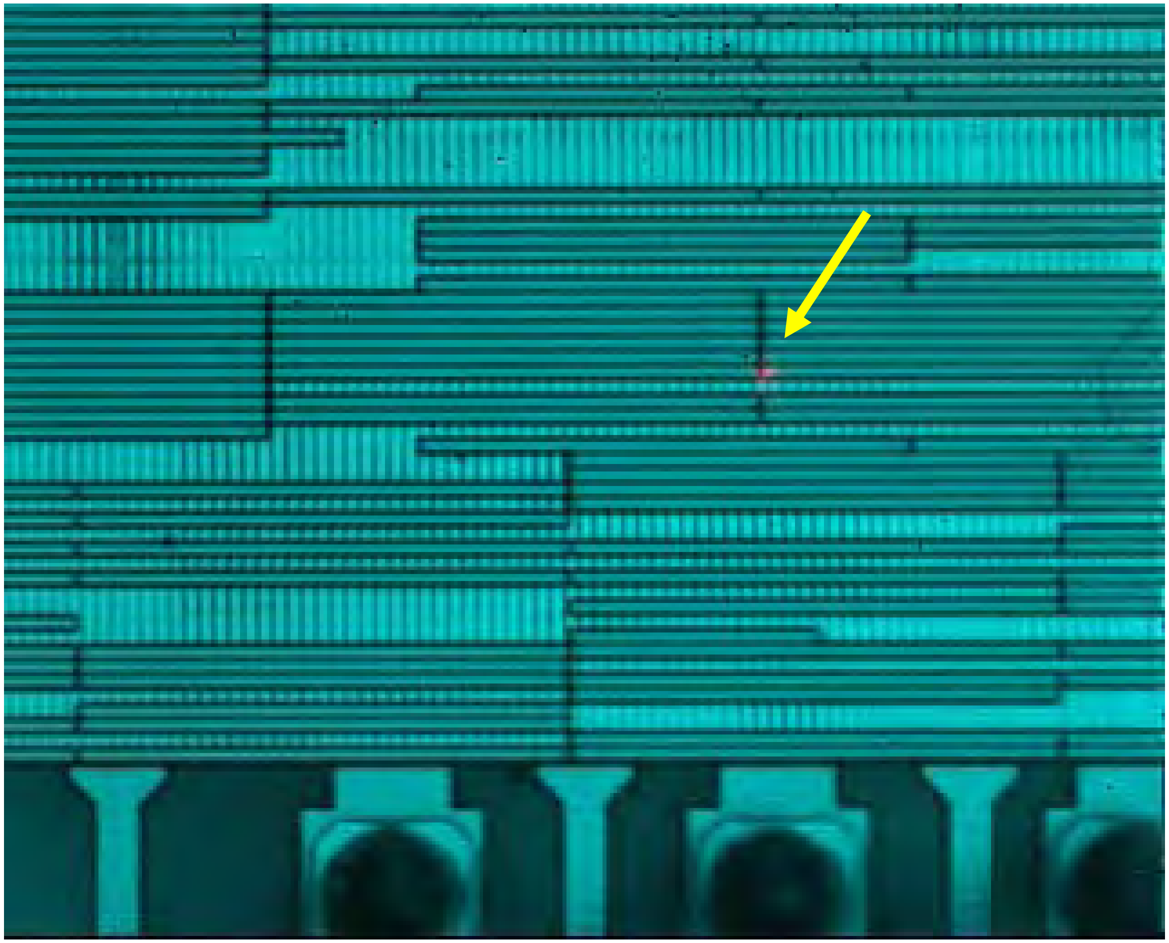
Screen shot in FMI mode with .8x macro view of thermal failure.



FMI mode with 10x obj. view of thermal failure.



InGaAs image of ohmic short. Data obtained is thermal not recombinant.

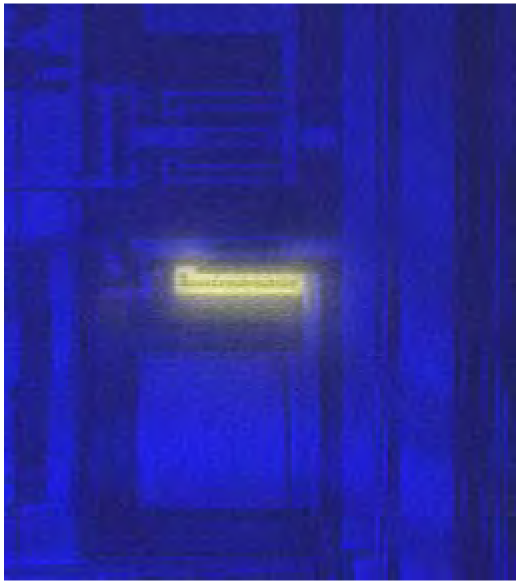


The Macro Lens and N.A.

There is a great deal of emphasis on Numeric Aperture and Pixel Binning.

1. Pixel Binning Pitfalls.
2. Are there any macro lenses with high N.A.?
3. How does CCD array size affect sensitivity?
4. Are back thinned CCD's better for backside?
5. What role does condensing the light play?

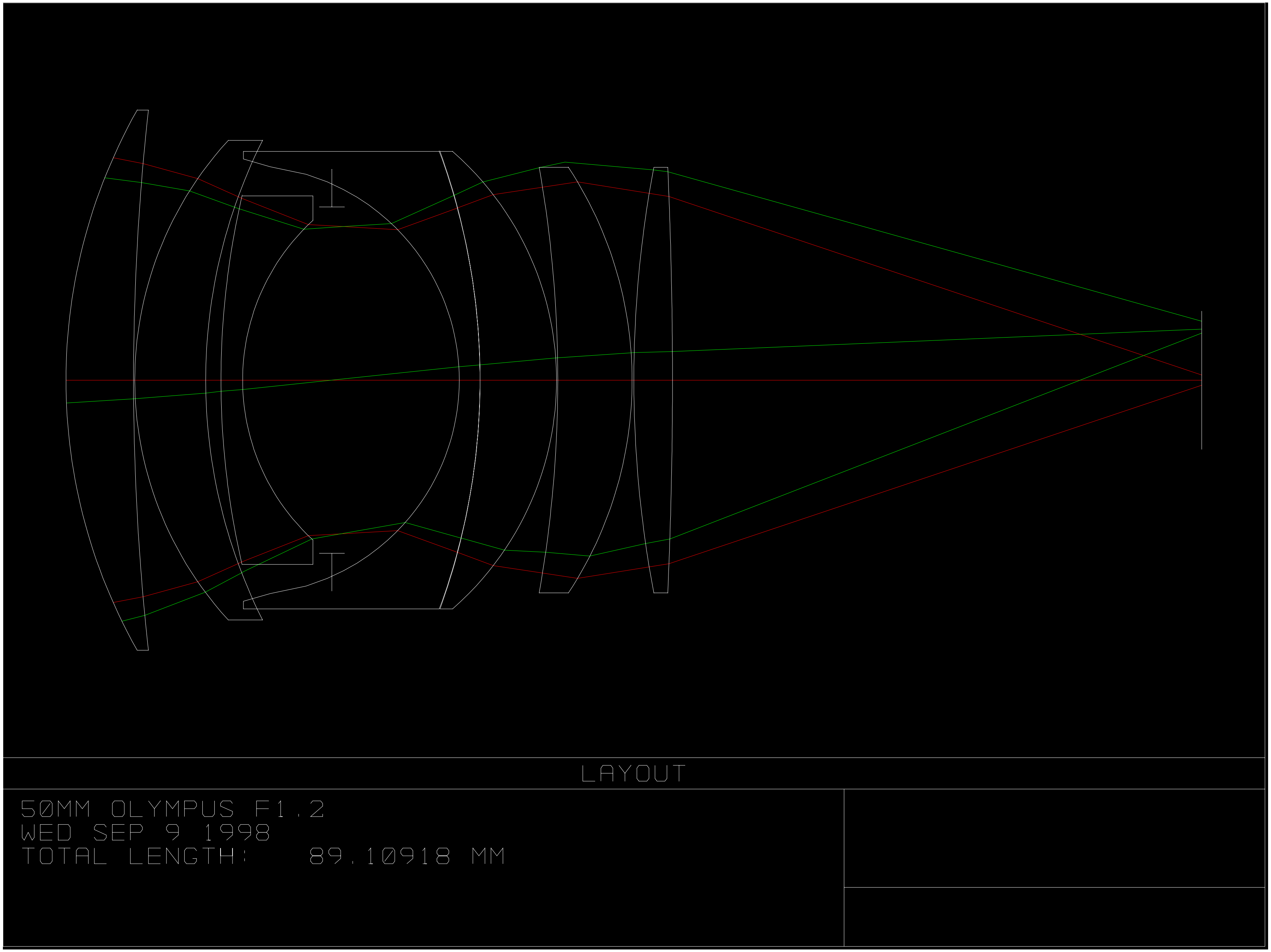
The Numeric Aperture Sensitivity Myth 1064nm backside

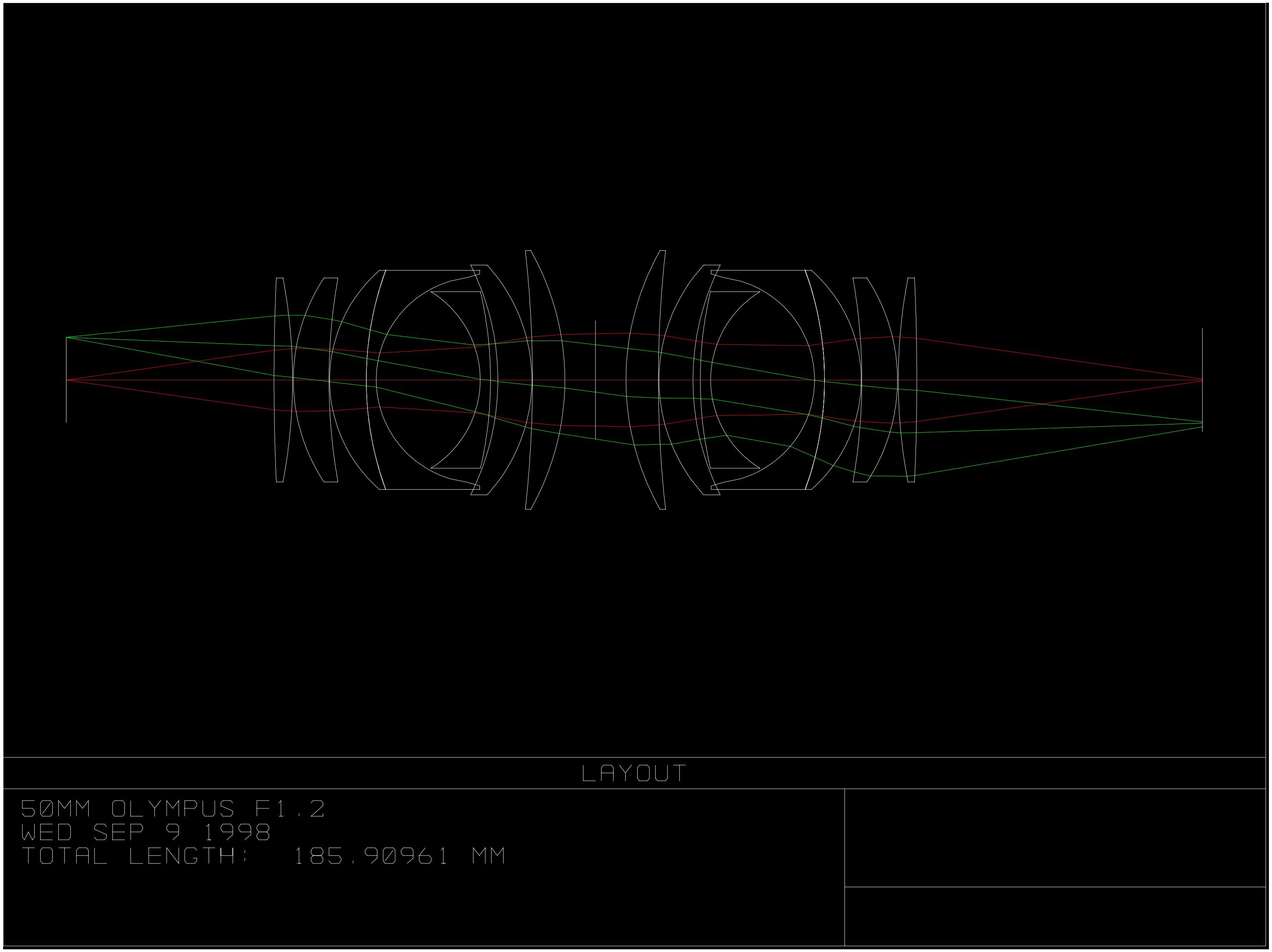


Lens	Forward	Reverse
2.5X .06 NA	3 sec	30 sec
2.5X .1 NA	1 sec	8 sec
5X .14 NA	2 sec	4 sec
20X .4 NA	4 sec	1 sec

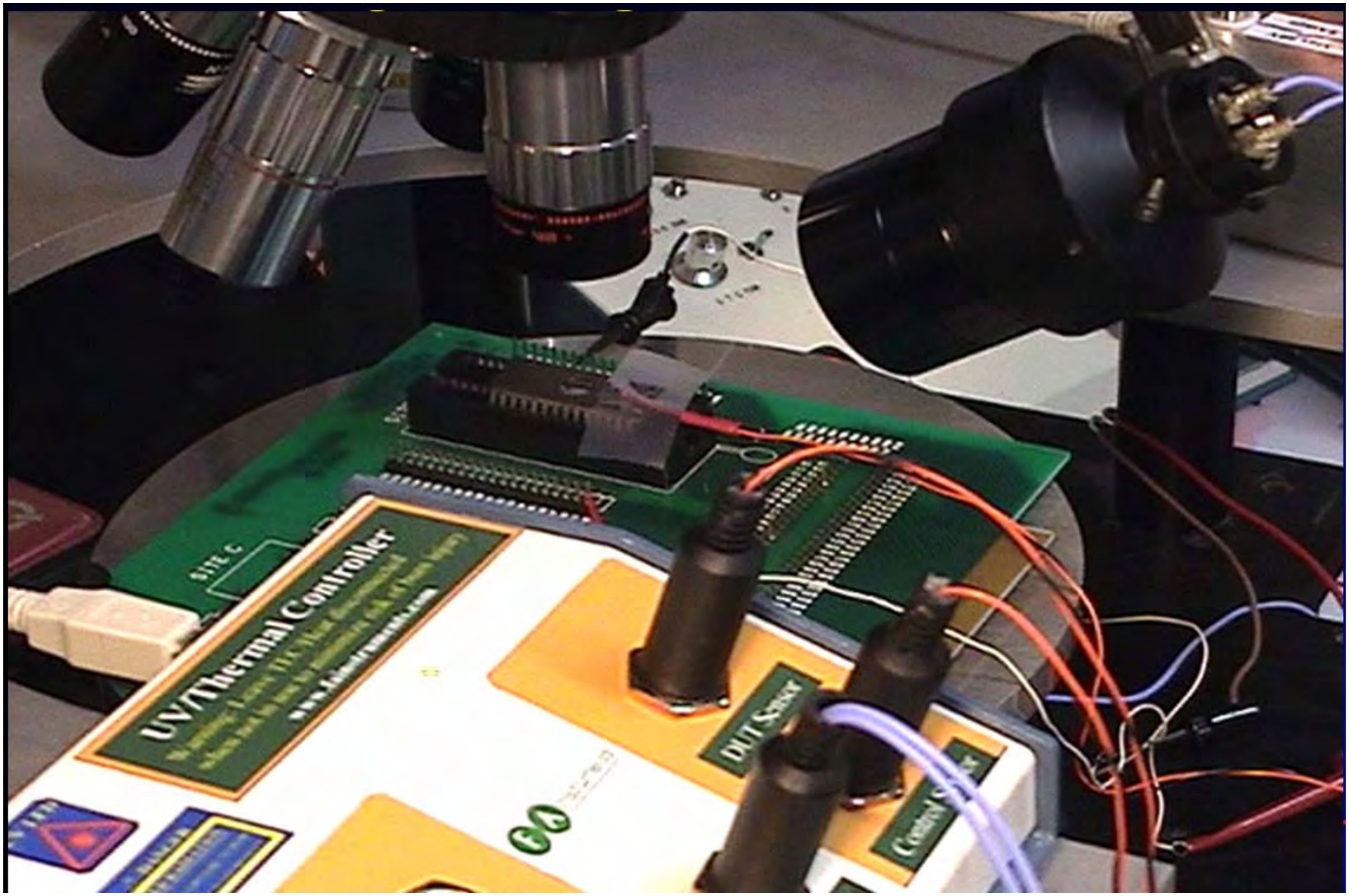
Left Image: Forward bias (1mA) to substrate on an input pin.

Right Image: Reverse (16V 10uA) breakdown on an input pin.

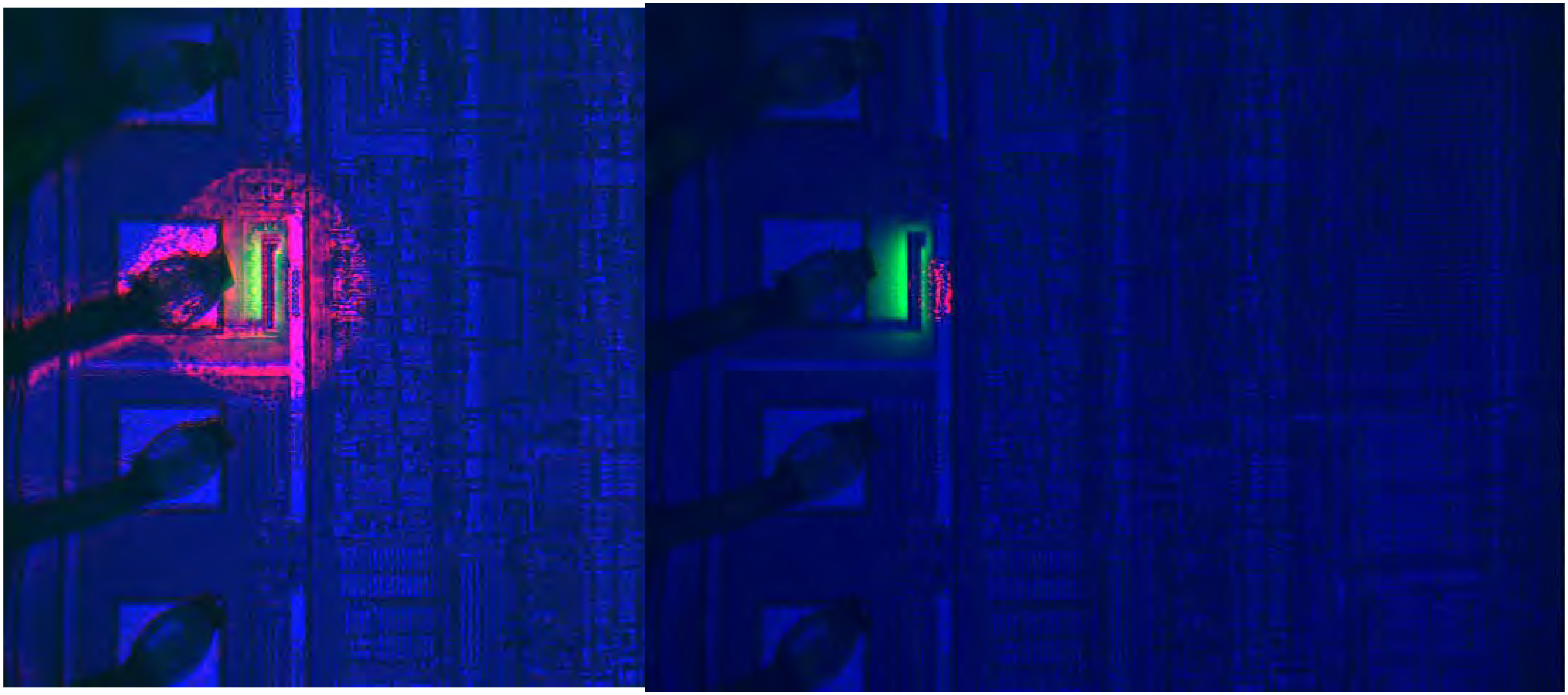

LAYOUT
50MM OLYMPUS F1.2
WED SEP 9 1998
TOTAL LENGTH: 89.10918 MM


LAYOUT
50MM OLYMPUS F1.2
WED SEP 9 1998
TOTAL LENGTH: 185.90961 MM

Liquid Crystal (Scintillation) Examples

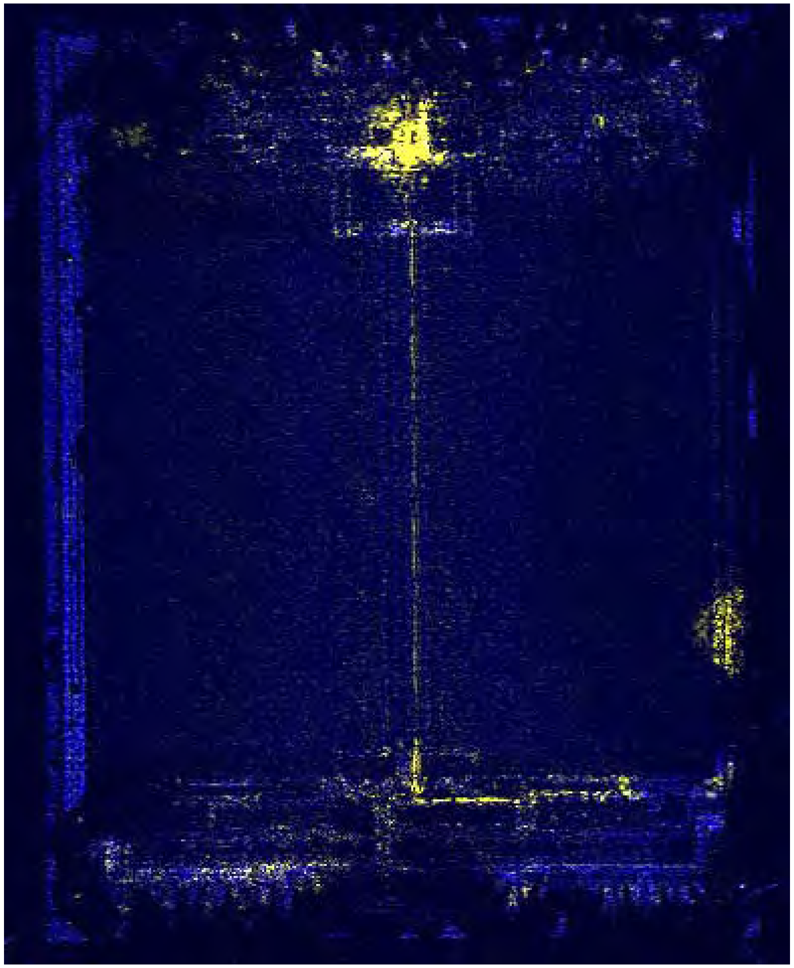


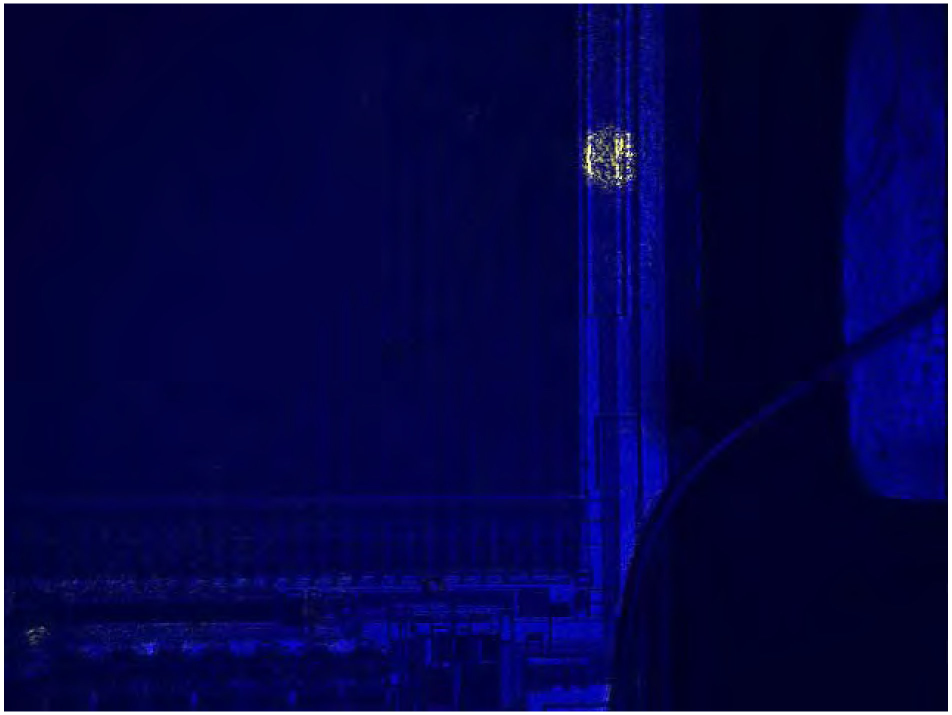
Liquid Crystal (Scintillation) Examples



|4 summed frames on-4 summed frames off|
Analyzed with bondwires present

Liquid Crystal (Scintillation) Examples





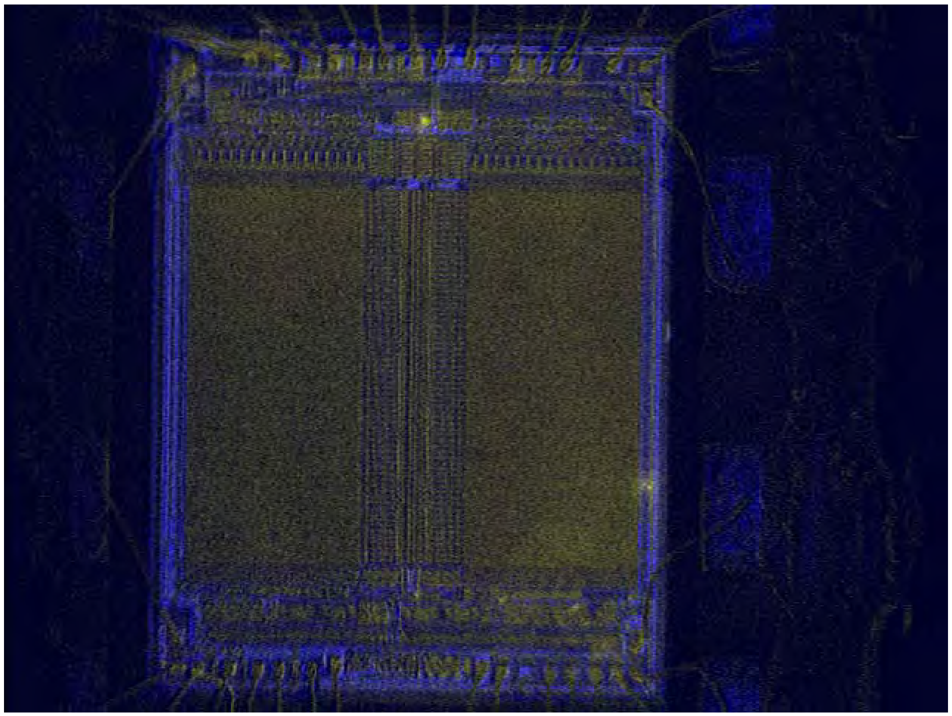
Scintillation Liquid Crystal Benefits/Shortcomings

1. Moderate spatial resolution
2. No bleaching/wearout
3. Film must be thick and stationary
4. Frontside only
5. High thermal sensitivity
6. Can image bondpad/wires!
7. Power must be modulated
8. Temperature control needed
9. No Polarizers!
10. Can use in conjunction with photoemission

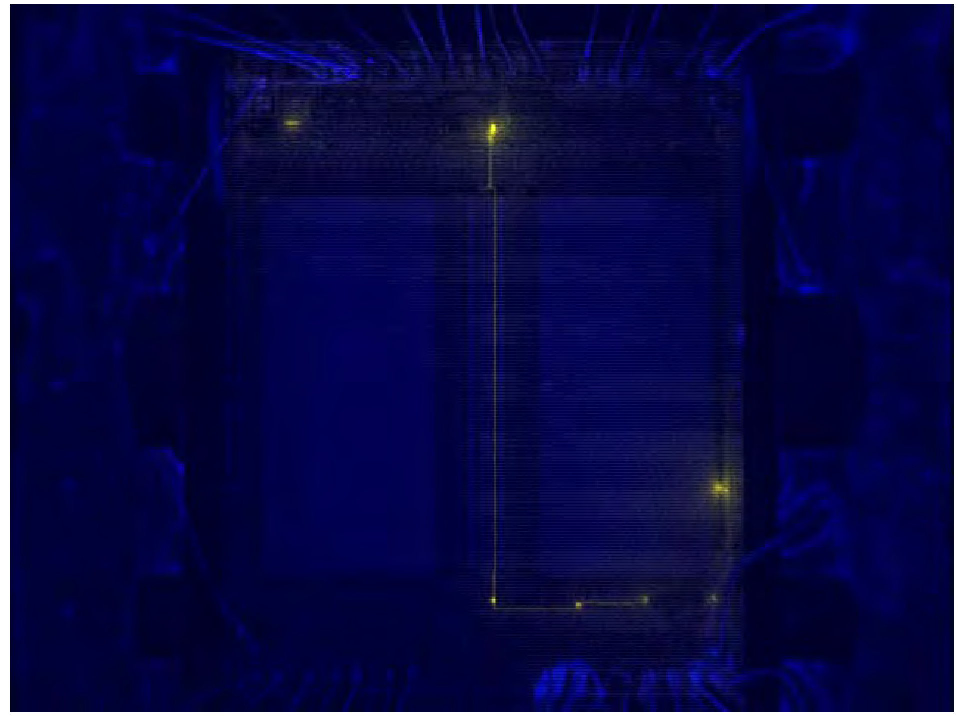
UV Setup for FMI

75mW diode source.

FMI/SFMI Examples

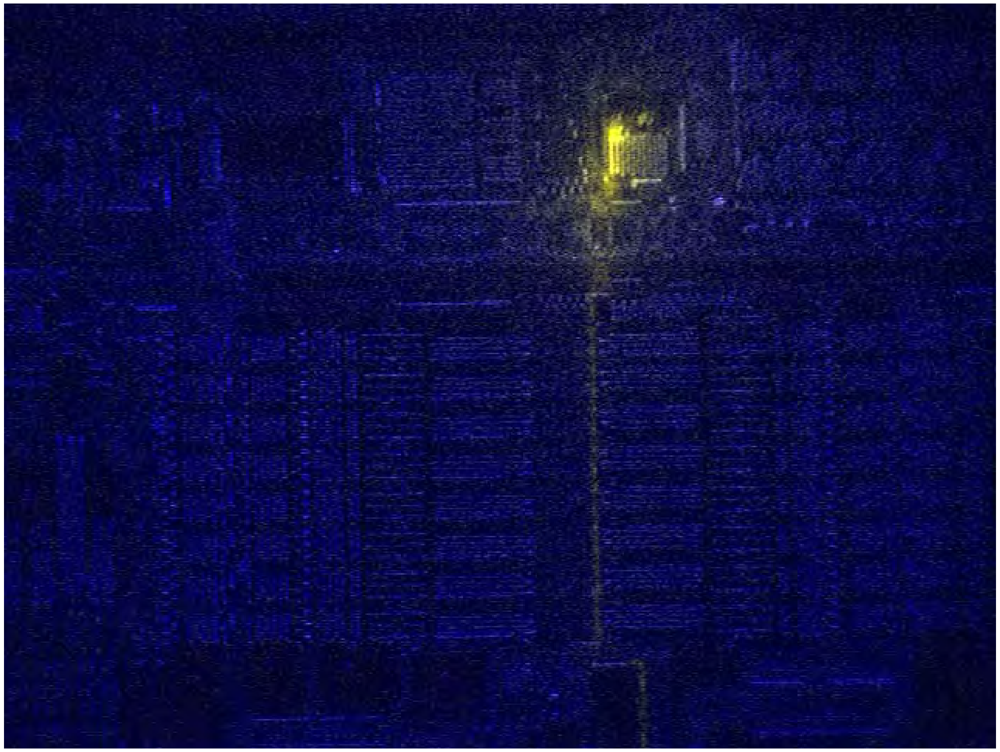


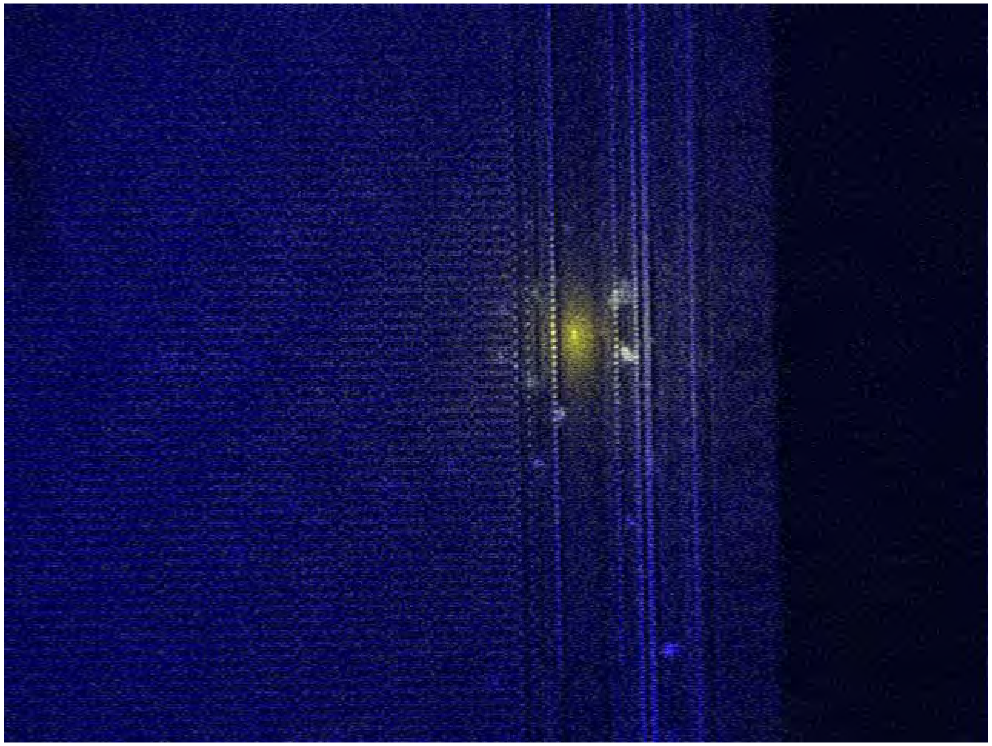
Traditional FMI



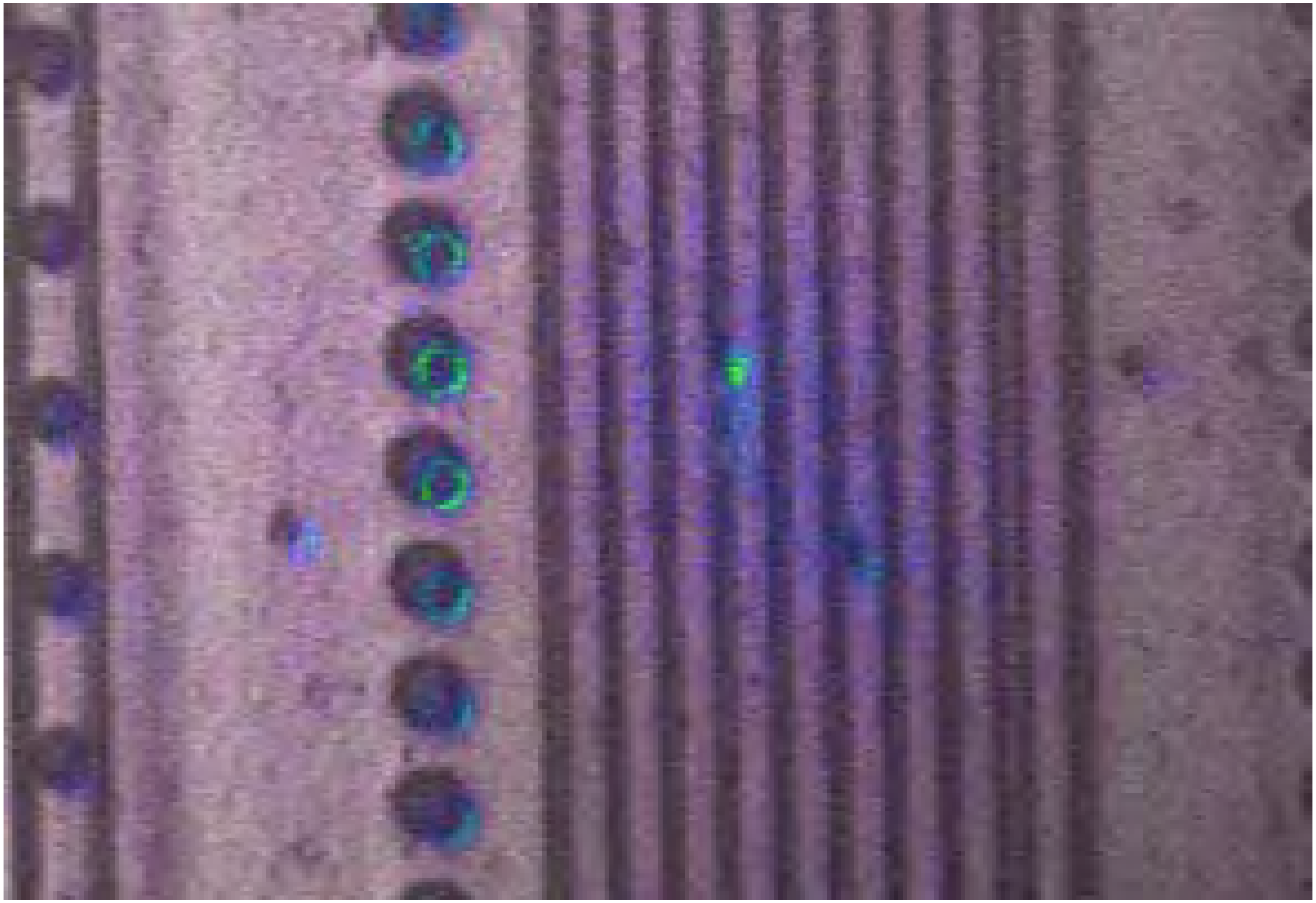
128FramesX32XGain 4X SFMI

SFMI Examples

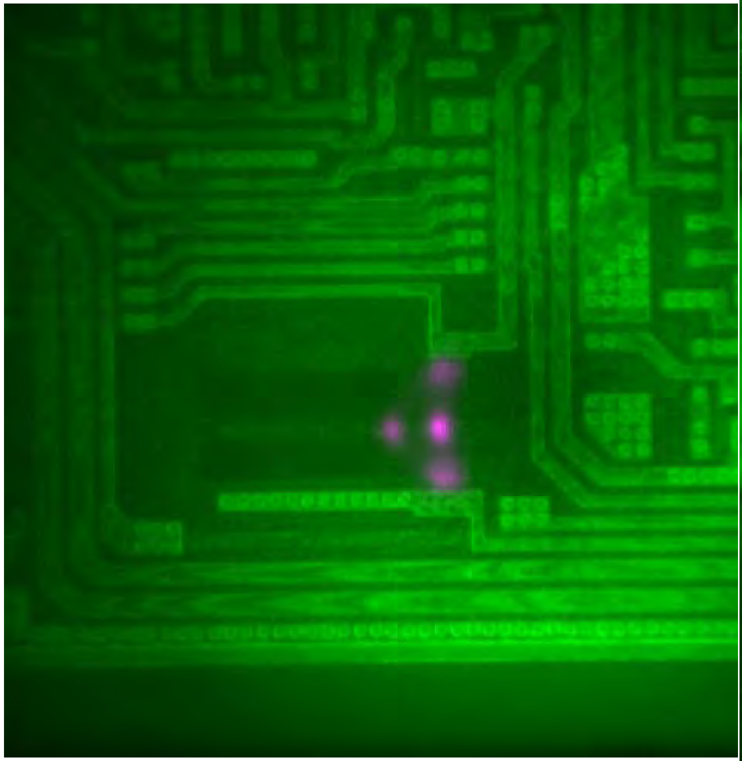


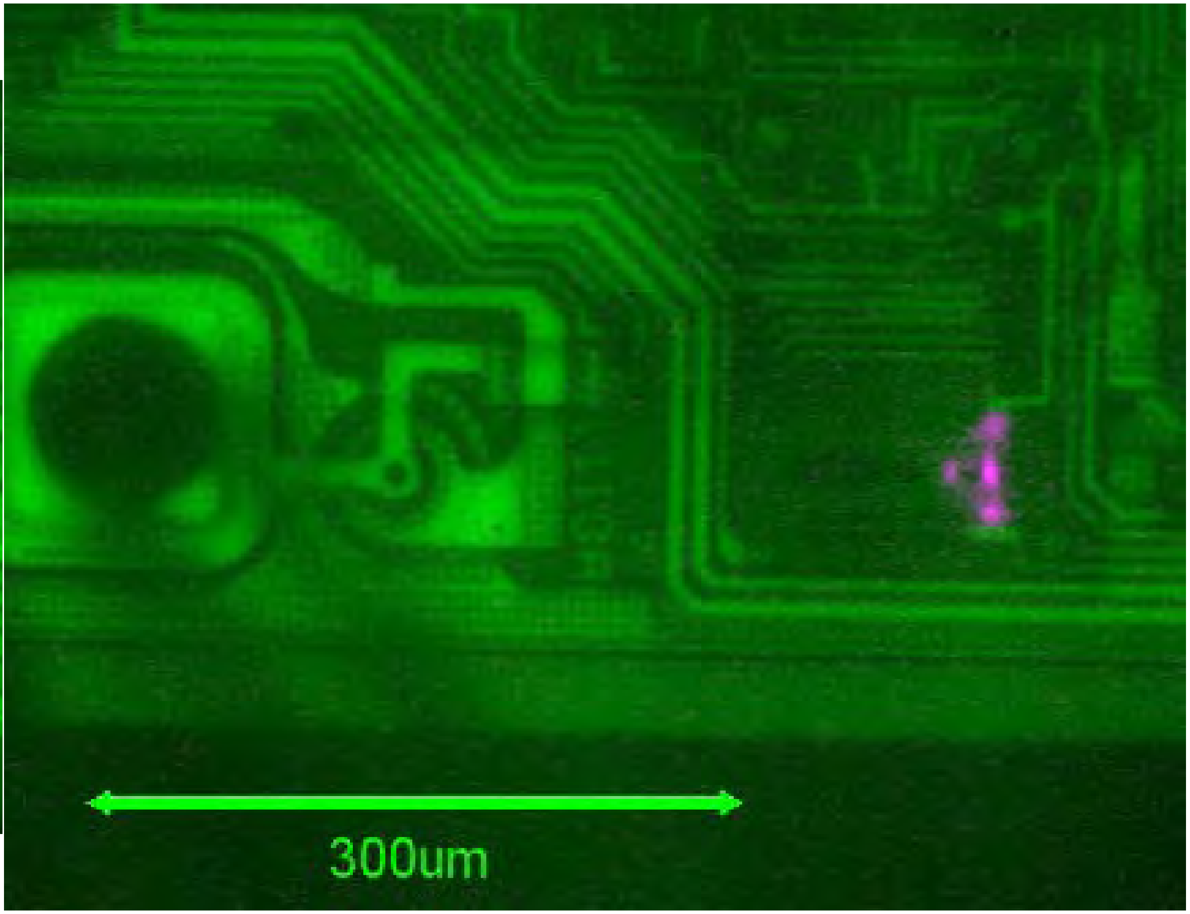


SFMI Examples



SFMI of 10K Ohm Leakage vs InSb

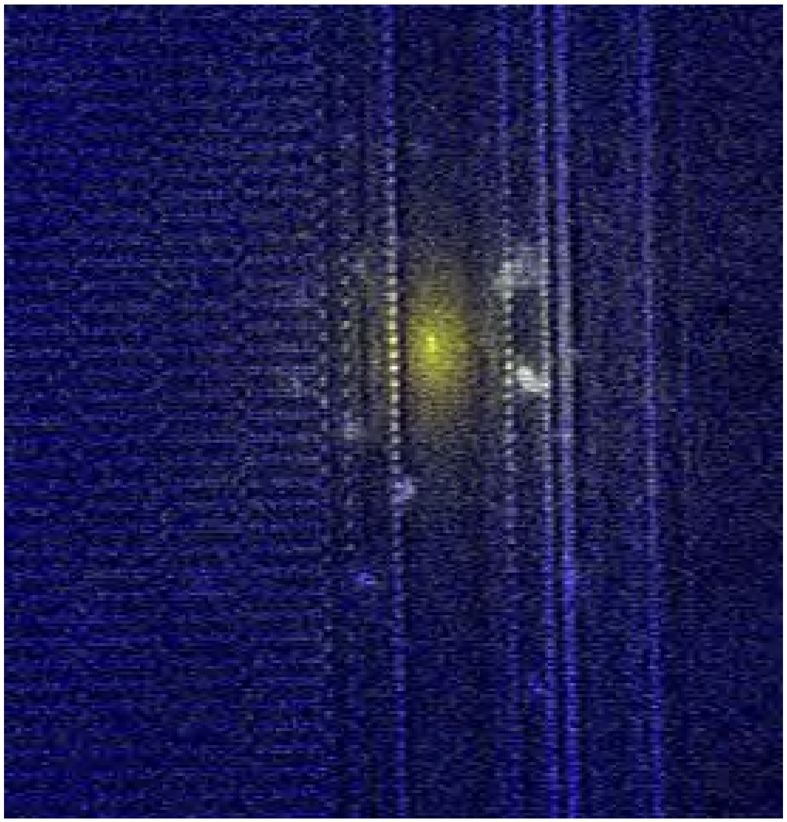


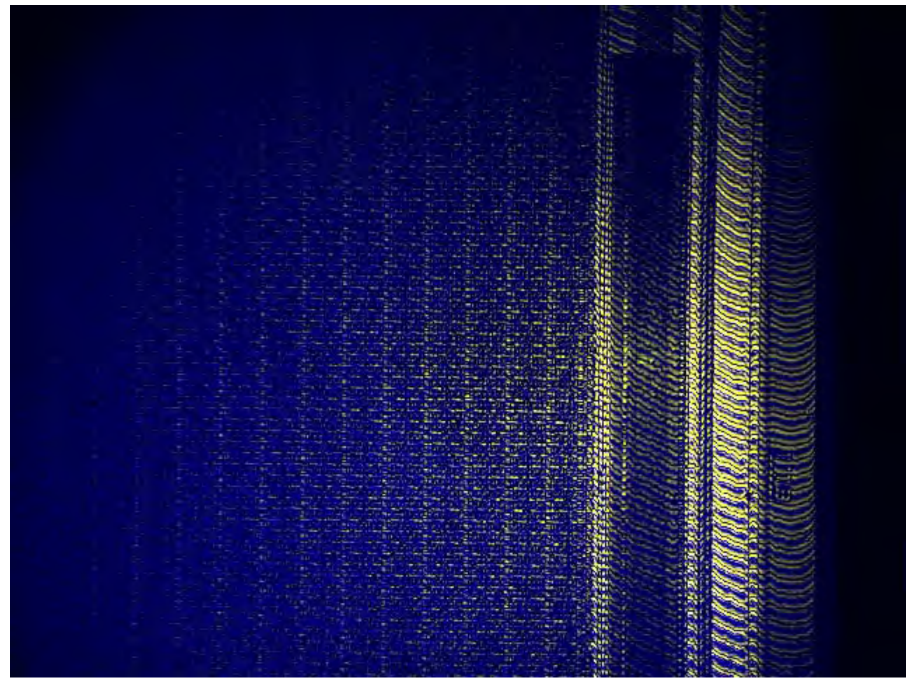


SFMI Benefits/Shortcomings

1. High spatial resolution
2. Bleaching 3dB/6min
3. Film uniformity
4. Frontside only
5. High thermal sensitivity
6. Not all FMI chemistries are equivalent
7. Power must be modulated
8. No temperature control needed
9. Improved signal discrimination over traditional FMI

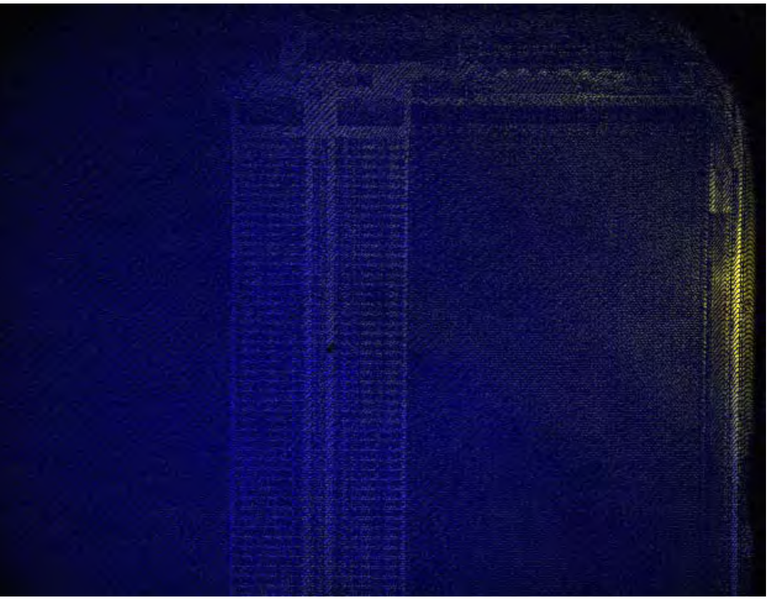
Moiré Thermal Pattern (Backside)

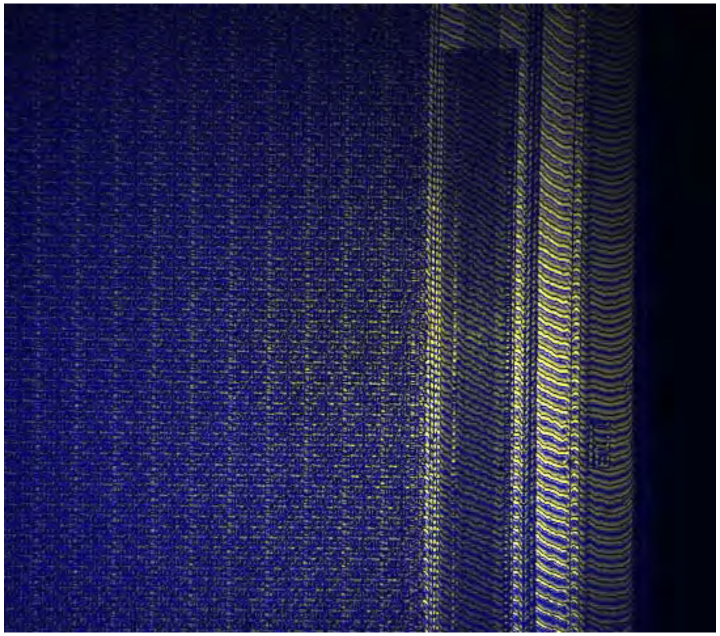


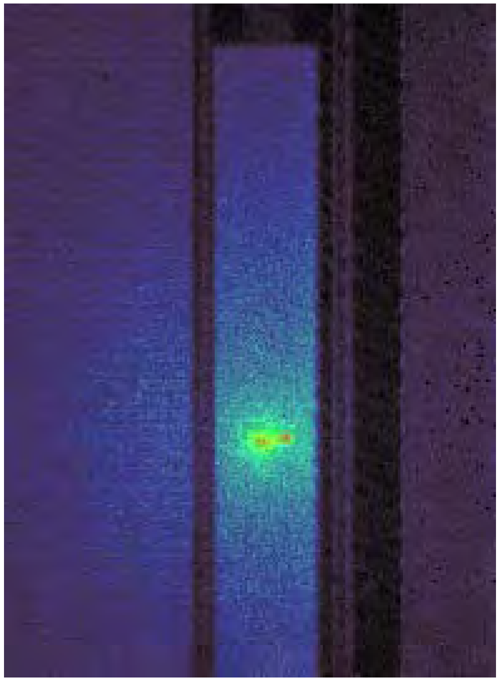


Frontside SFMI vs. Backside Moiré

Moiré Thermal Pattern (Backside)





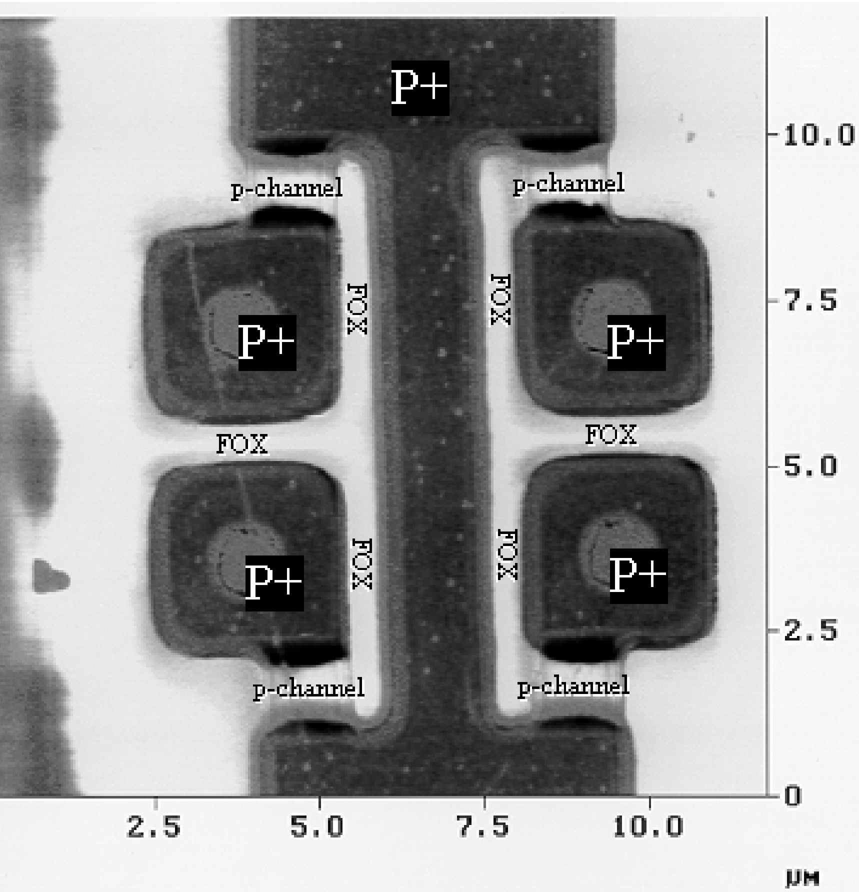


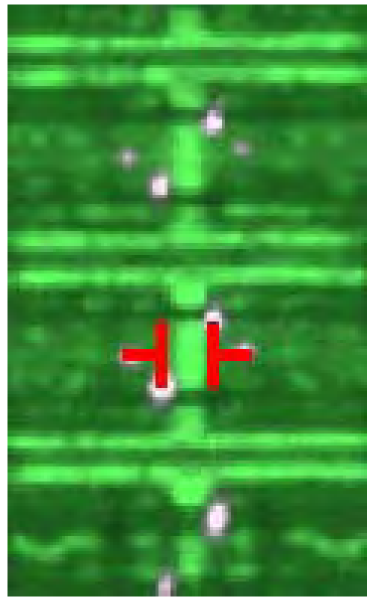
Moiré vs Stabilized InGaAs Thermal

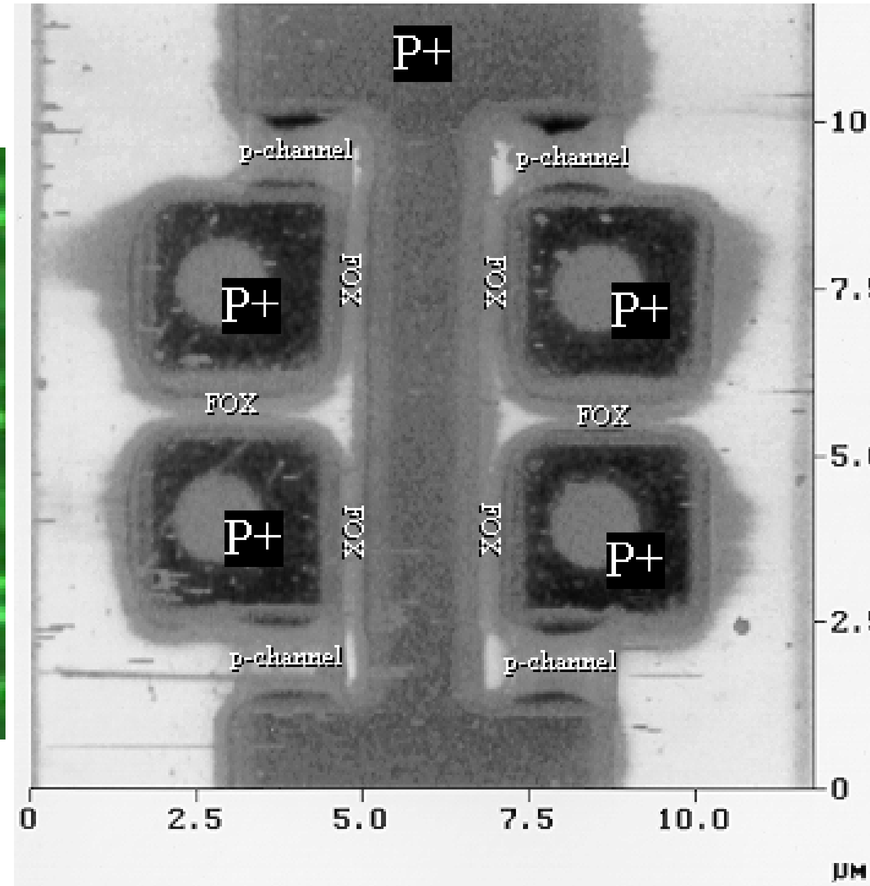
Moiré Benefits/Shortcomings

1. Lower spatial resolution: 10-50 um
2. No films needed
3. Must thin sample to 150um or less
4. Backside only
5. High thermal sensitivity… especially for circuit block/array diagnosis
6. Circuit features affect intensity
7. Power must be modulated
8. Must illuminate with monochromatic illumination
9. No wearout mechanism/easy to implement
10. Low irradiated power on die: <1mw. IR Bulb =100mW

Photon Emission and SCM

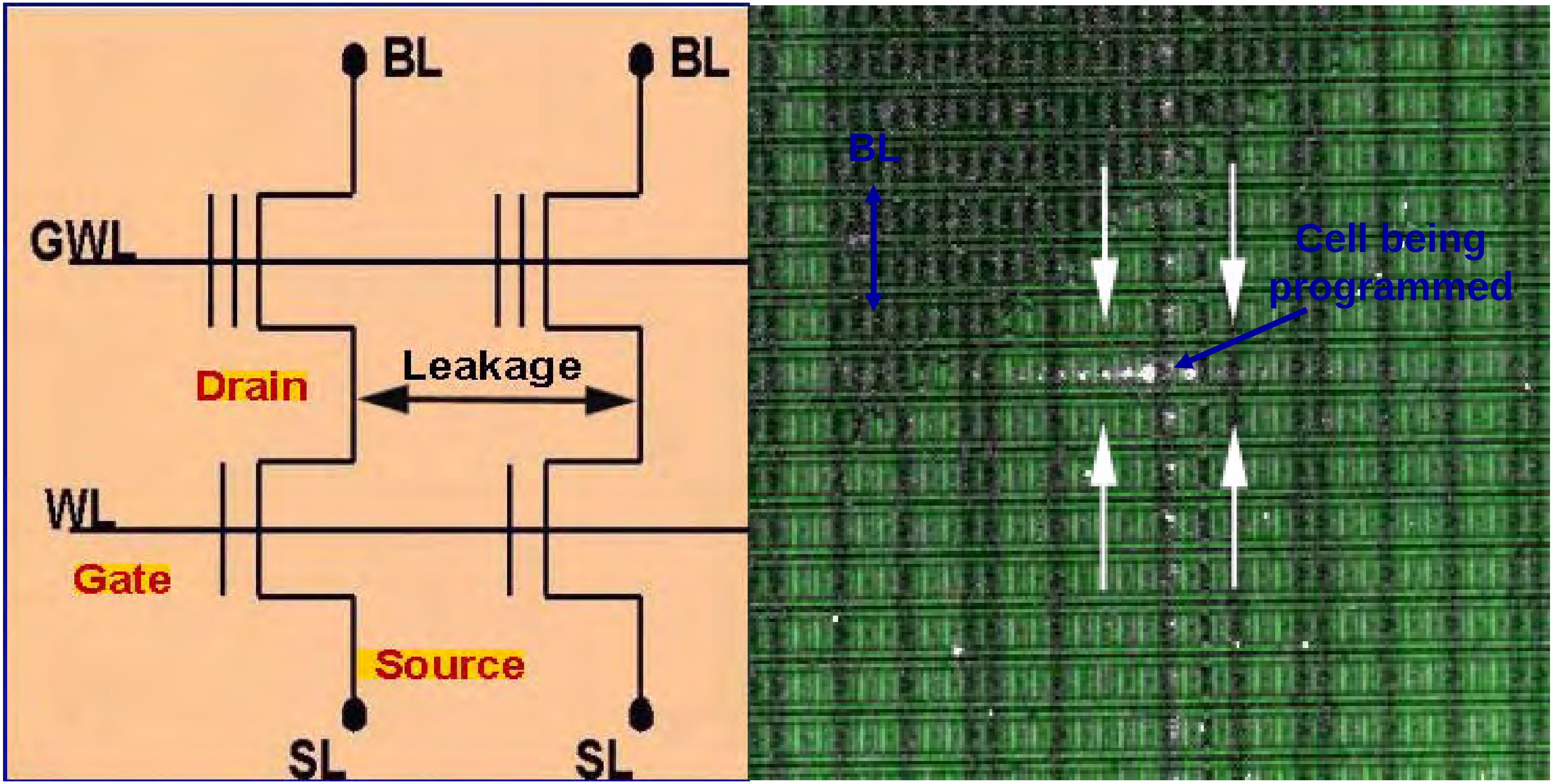






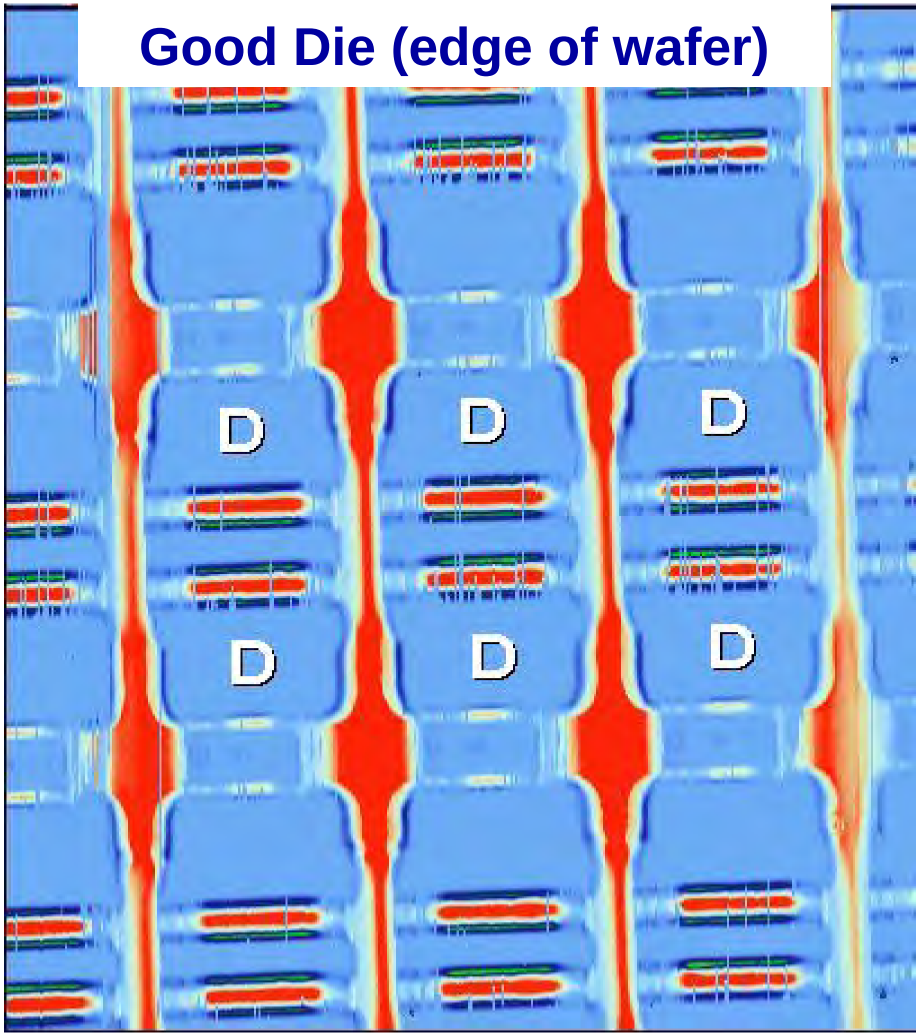
Punchthrough due to poor field isolation in SRAM.

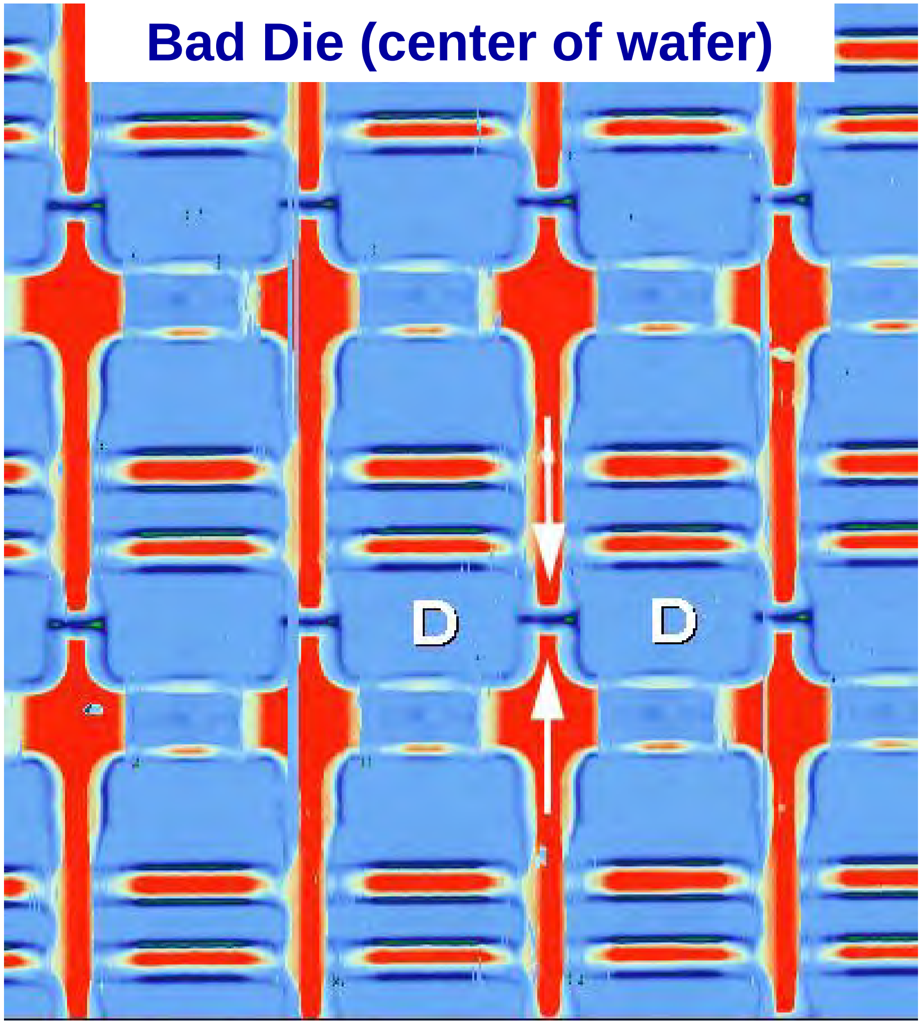
Drain-Drain Leakage



Photoemission from neighboring drain sites leakage

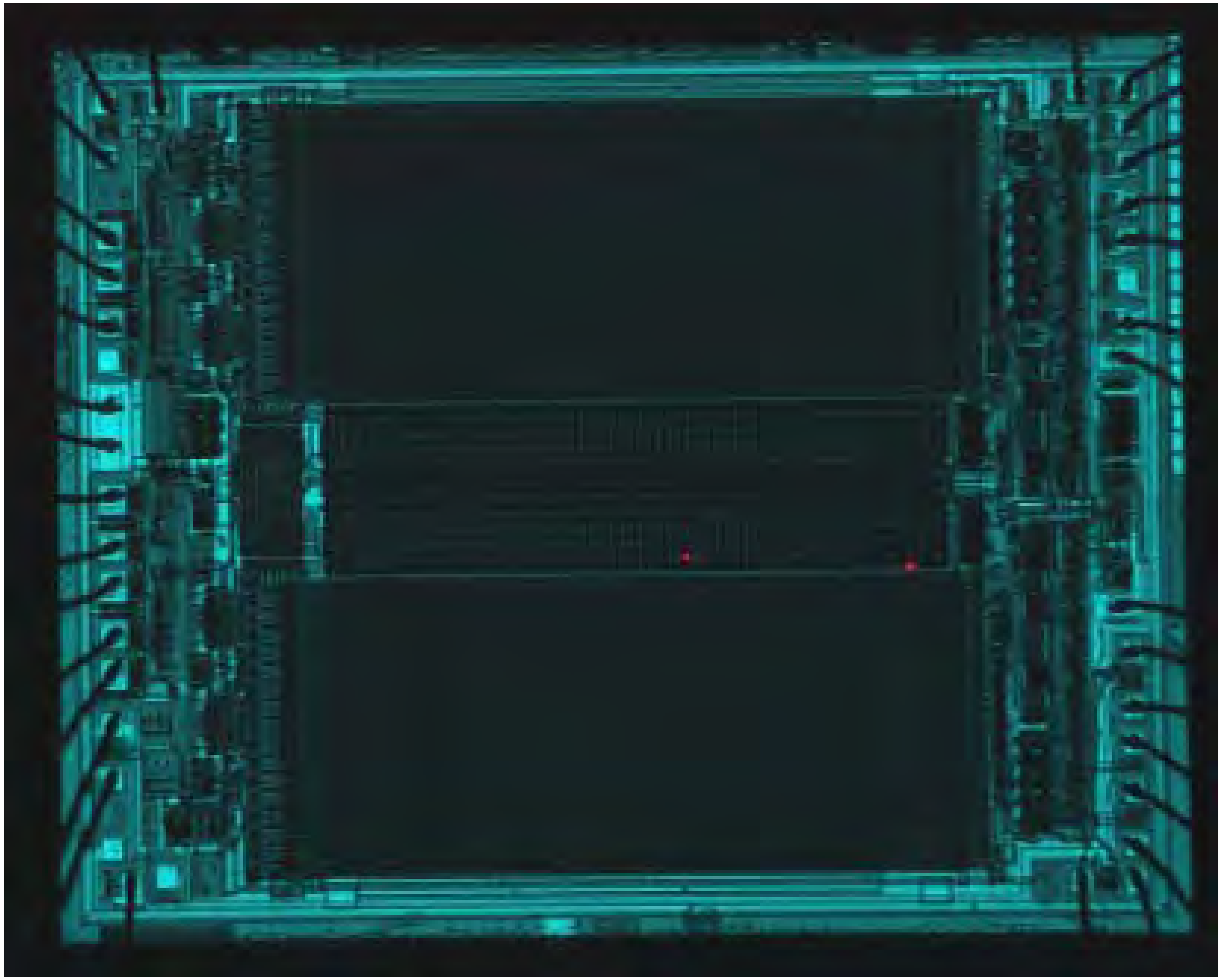
Scanning Capacitance Microscopy





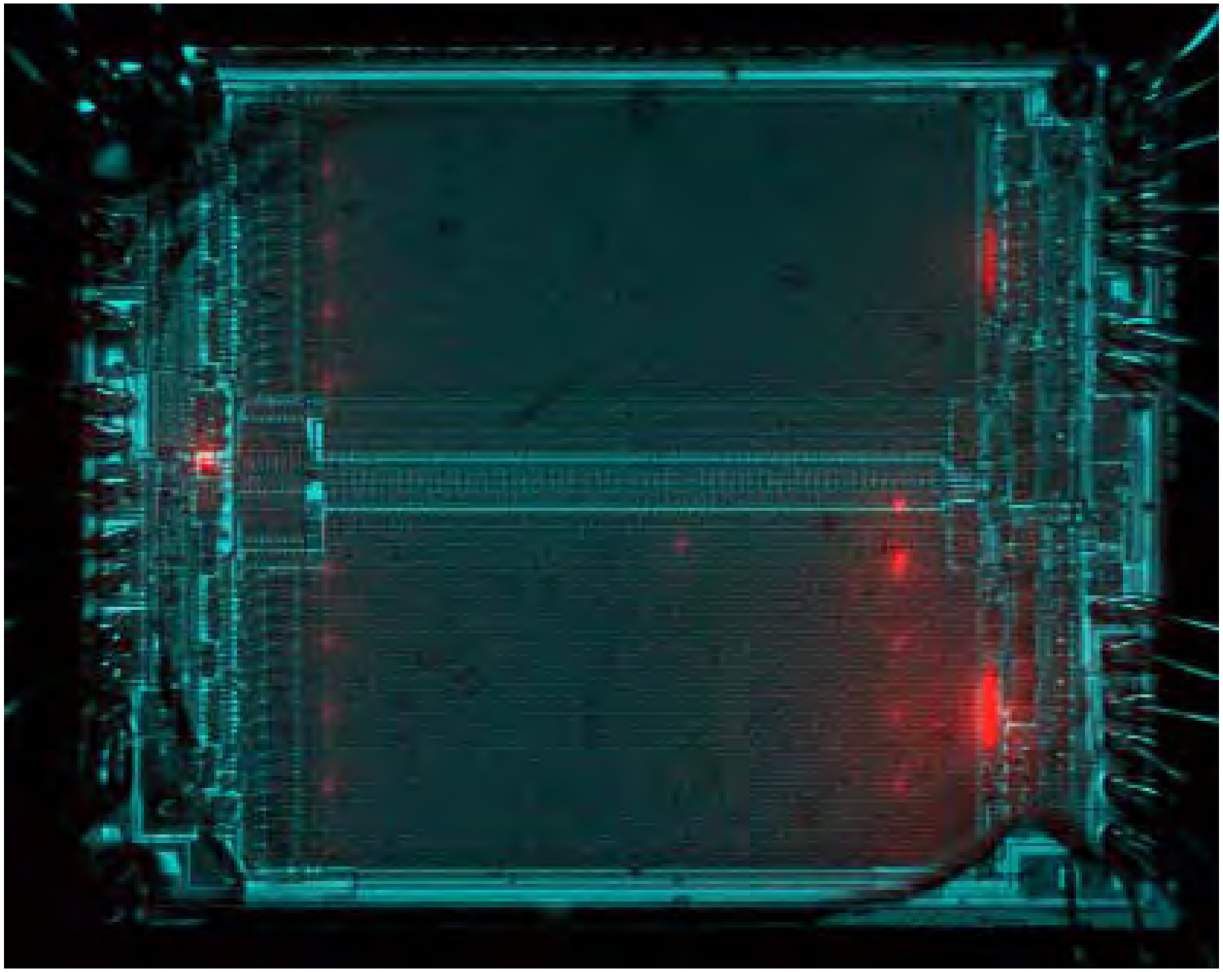
Parasitic n- dopant regions (dark blue) for bad die

Photon Emission



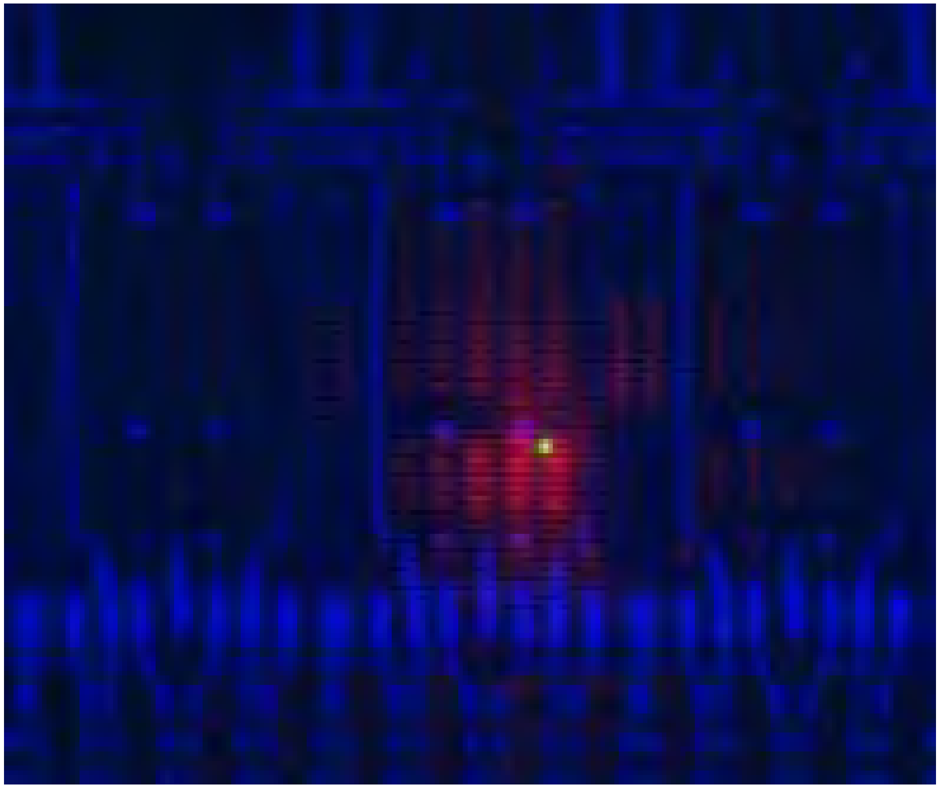
Oxide Integrity Defects

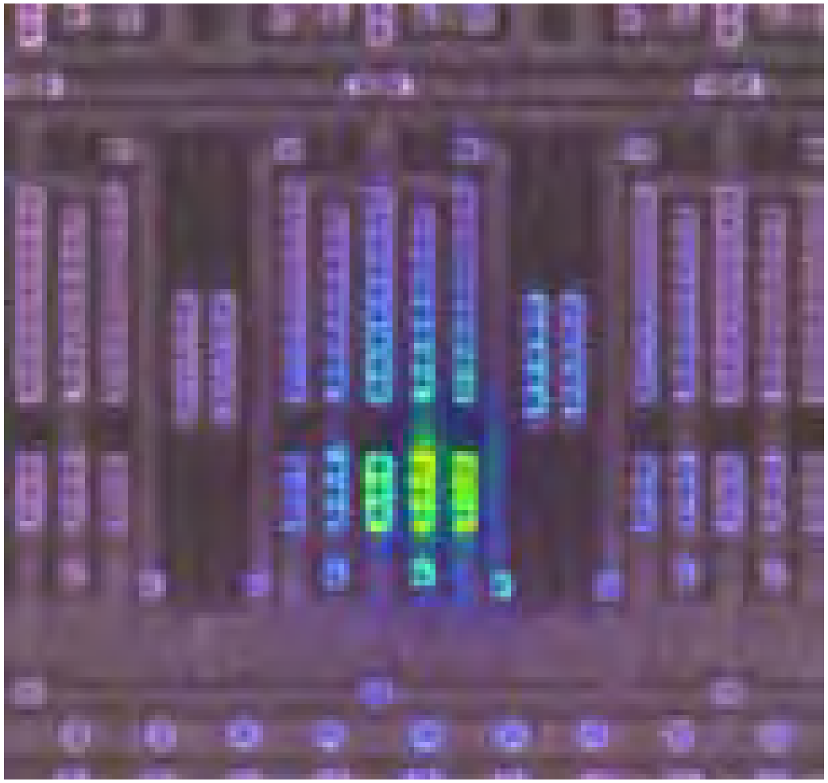
SFMI



Oxide Integrity Defects and EOS

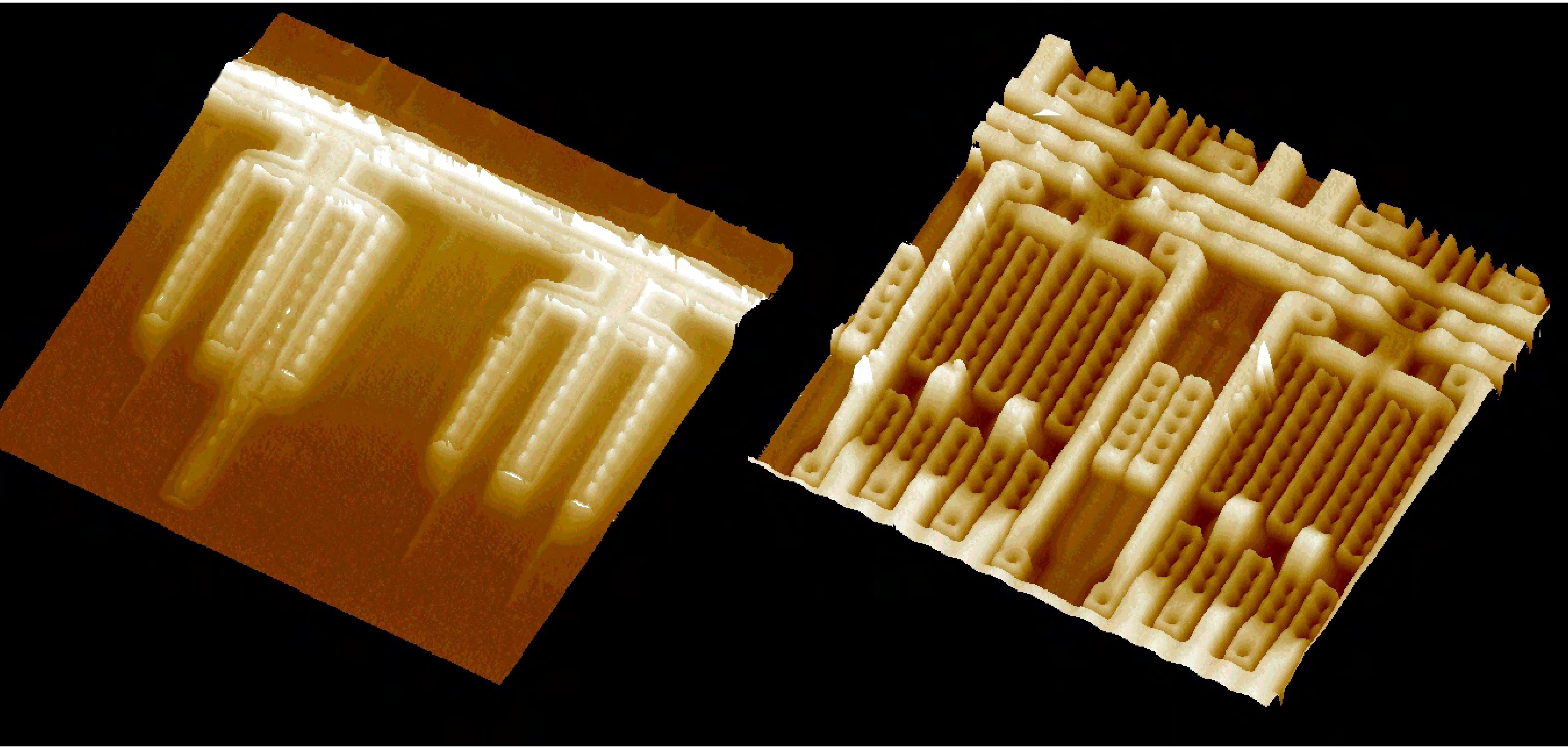
Photon Emission with SFMI





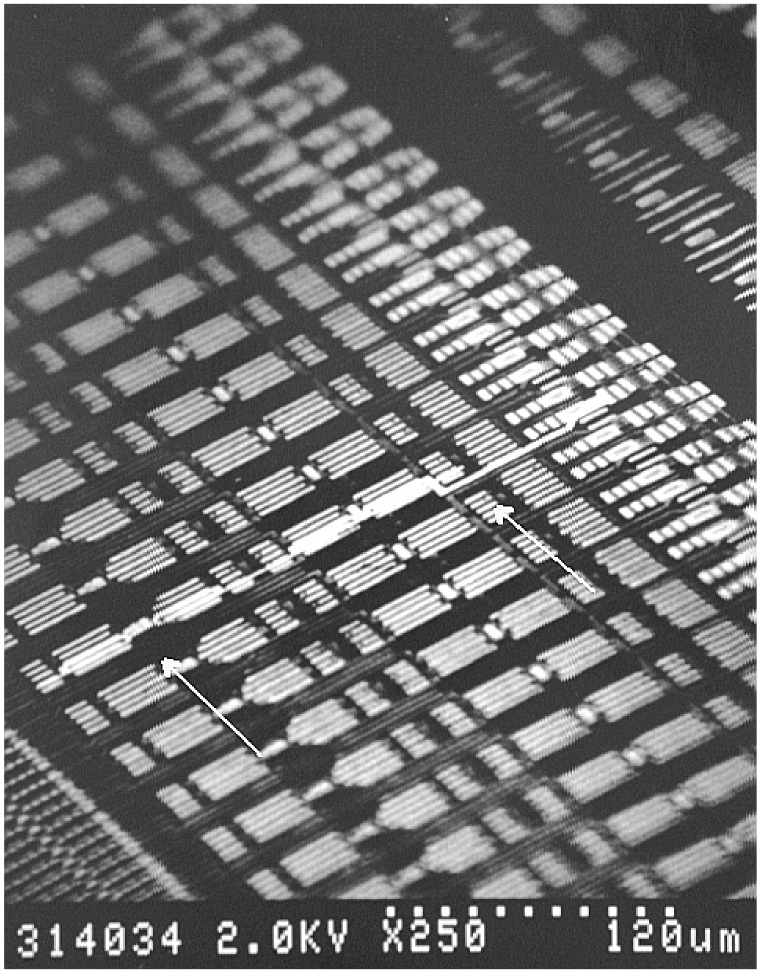
Oxide Integrity Defects

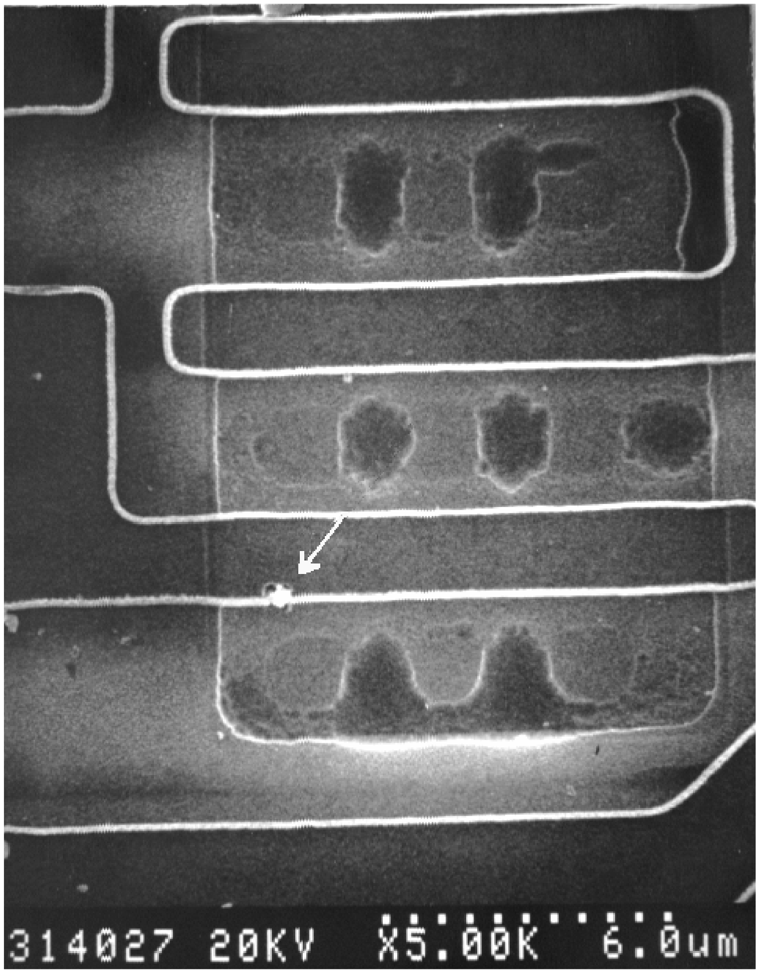
SPM Examples



EFM image of saturated NMOS transistor due to gate leak.

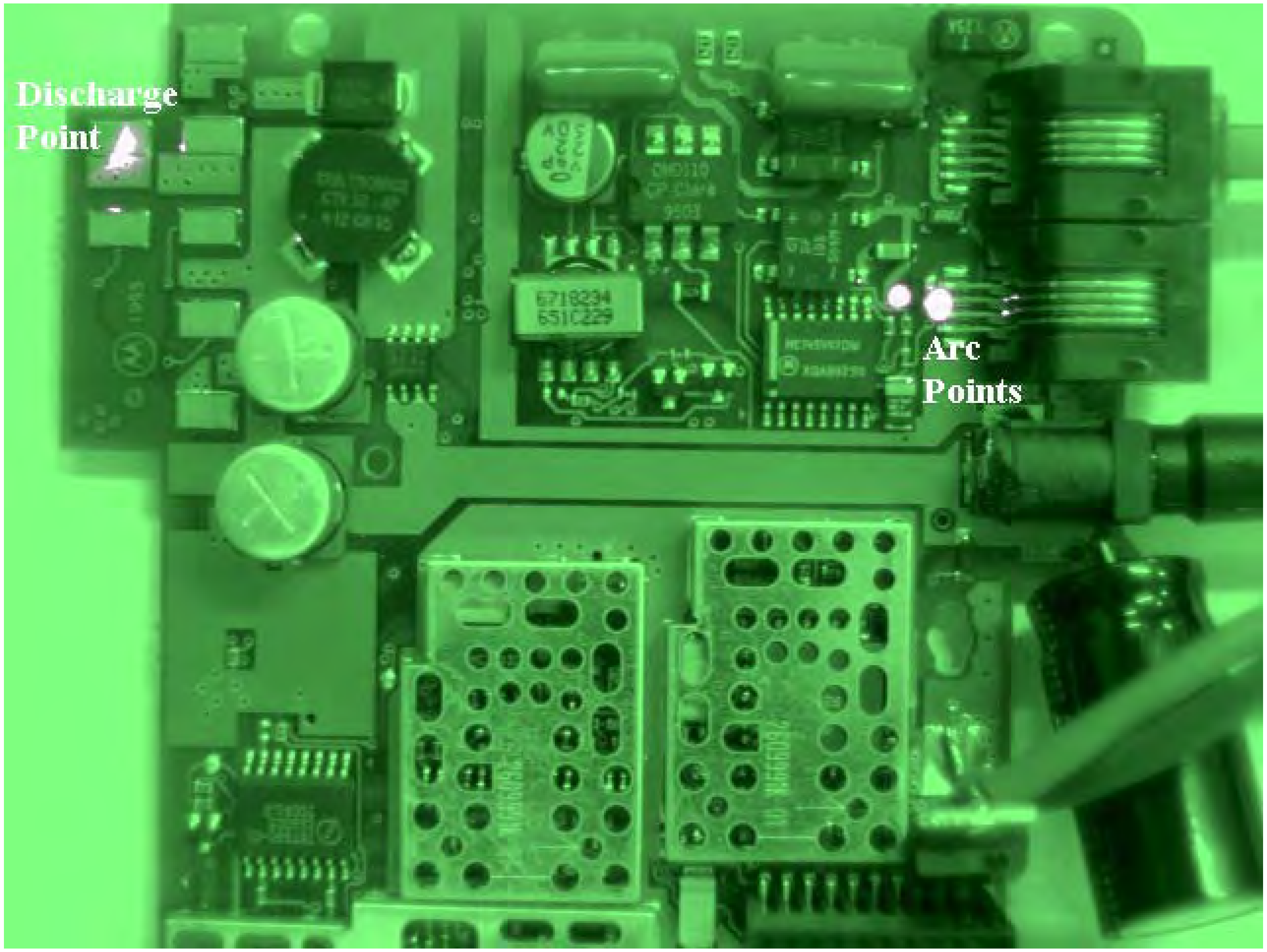
The Gate Oxide Interface and ONS





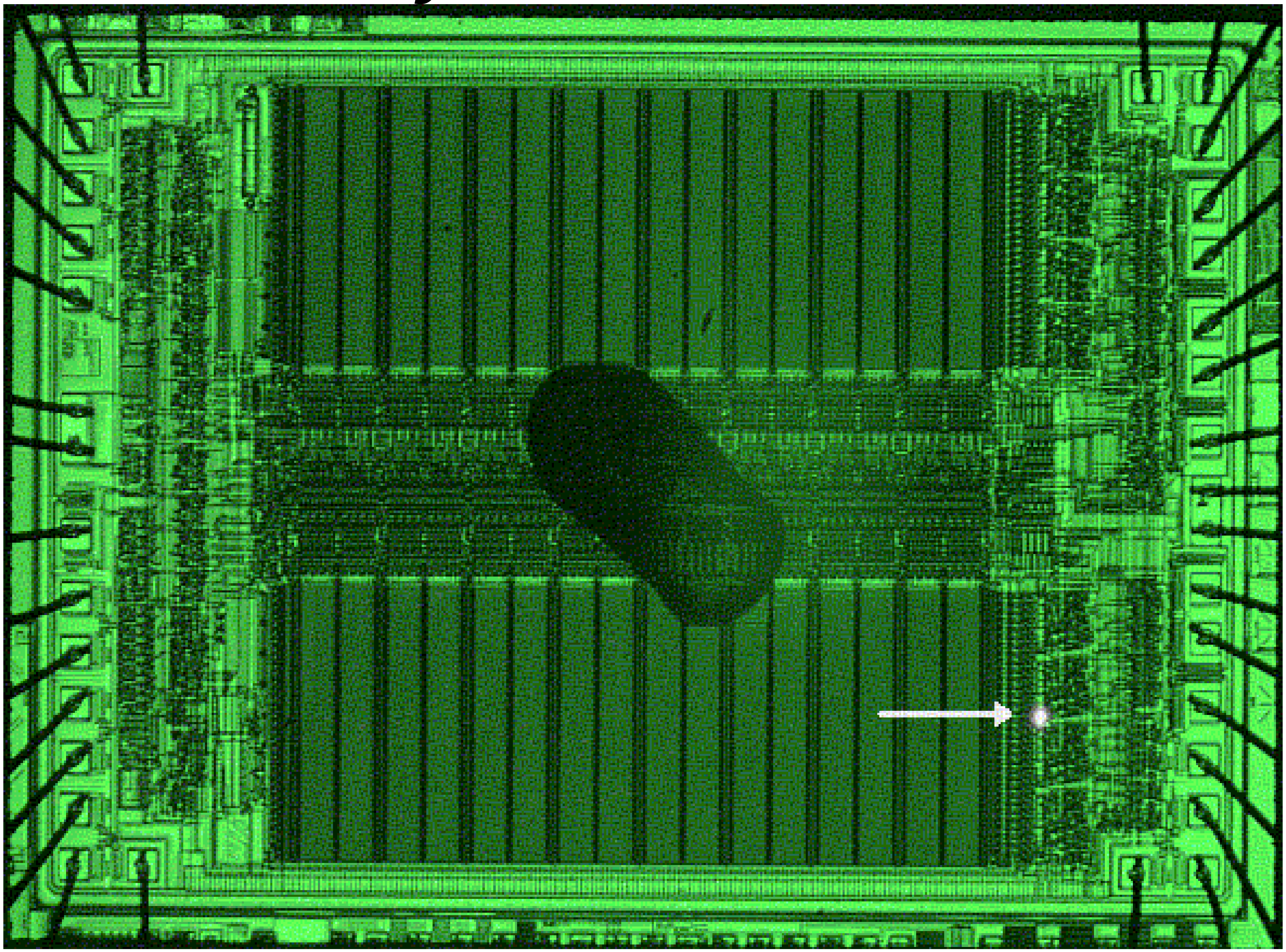
- Passive Voltage Contrast
- Gate Oxide Integrity Defect

Photon Emission

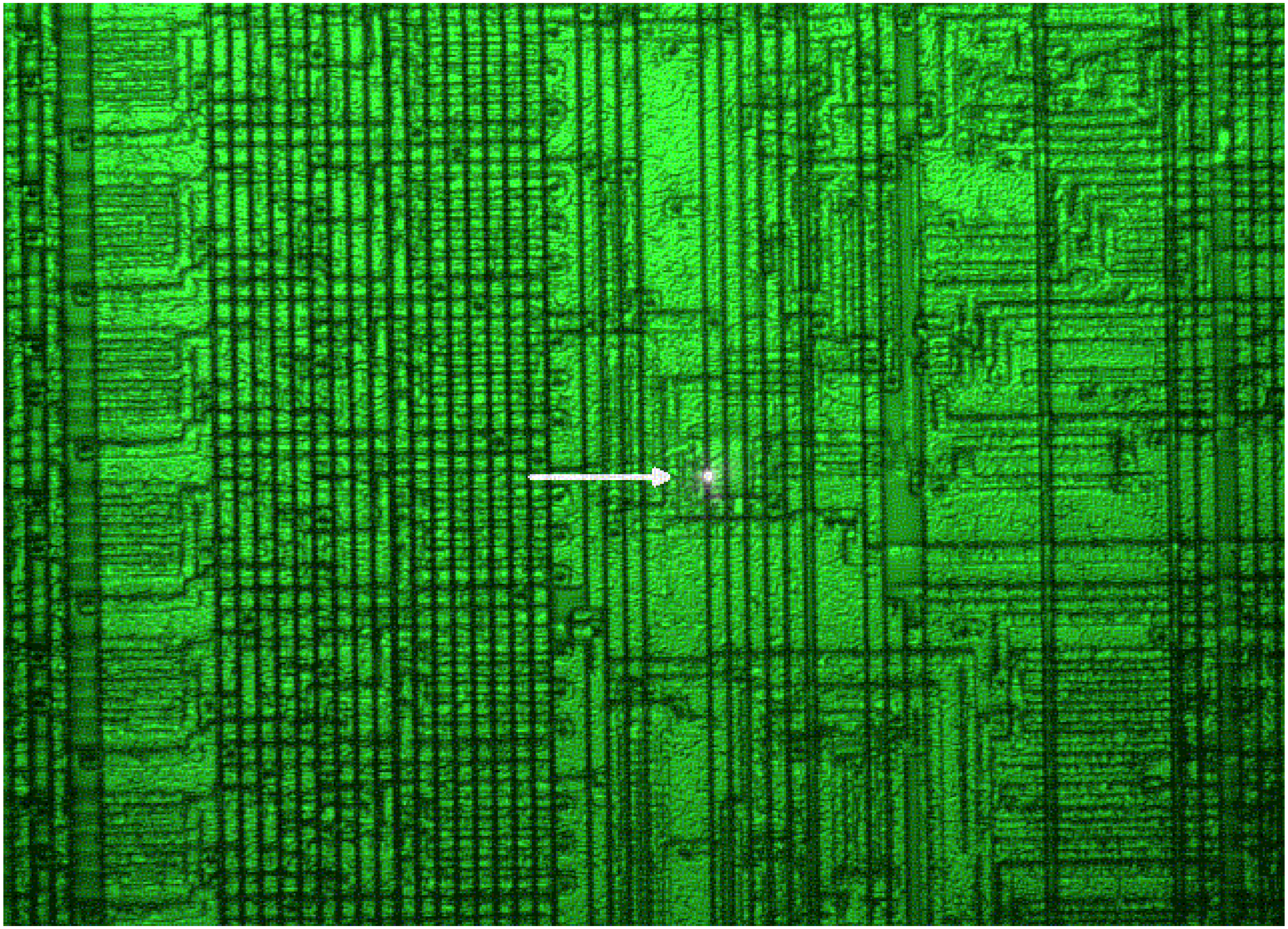


Identification of ESD arc-over points at board level.

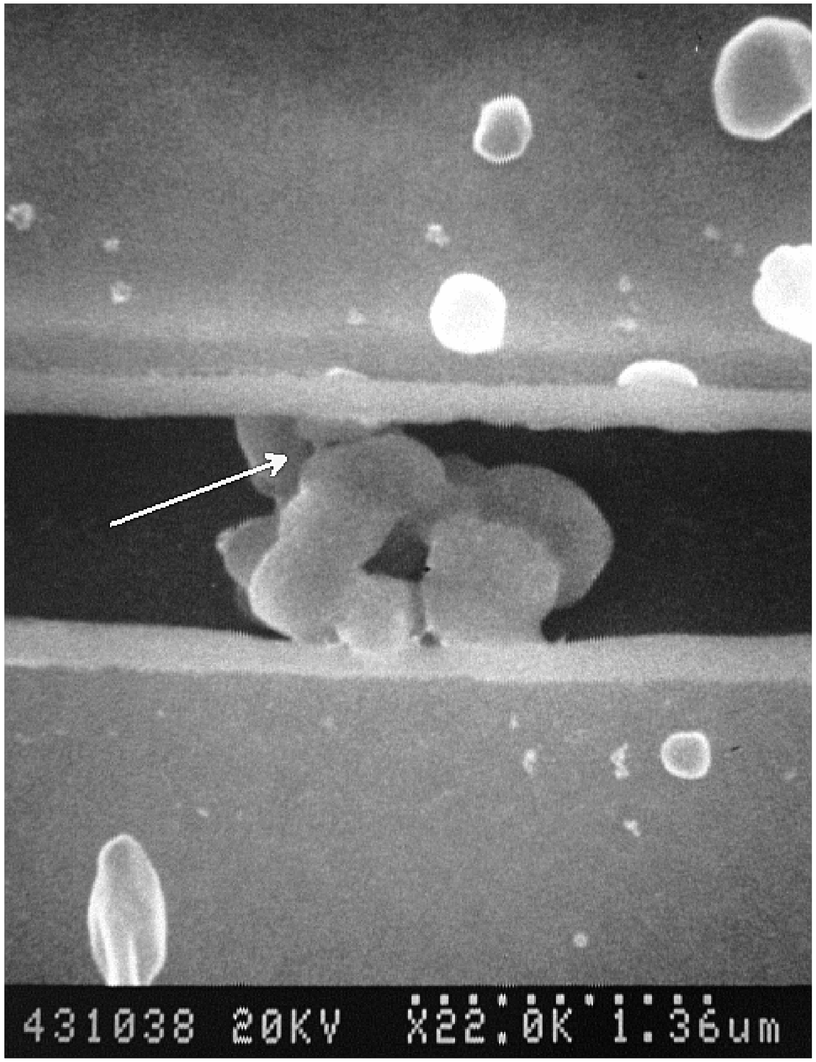
Yield Analysis of MTM Failures



MTM Failures - Spark Gap

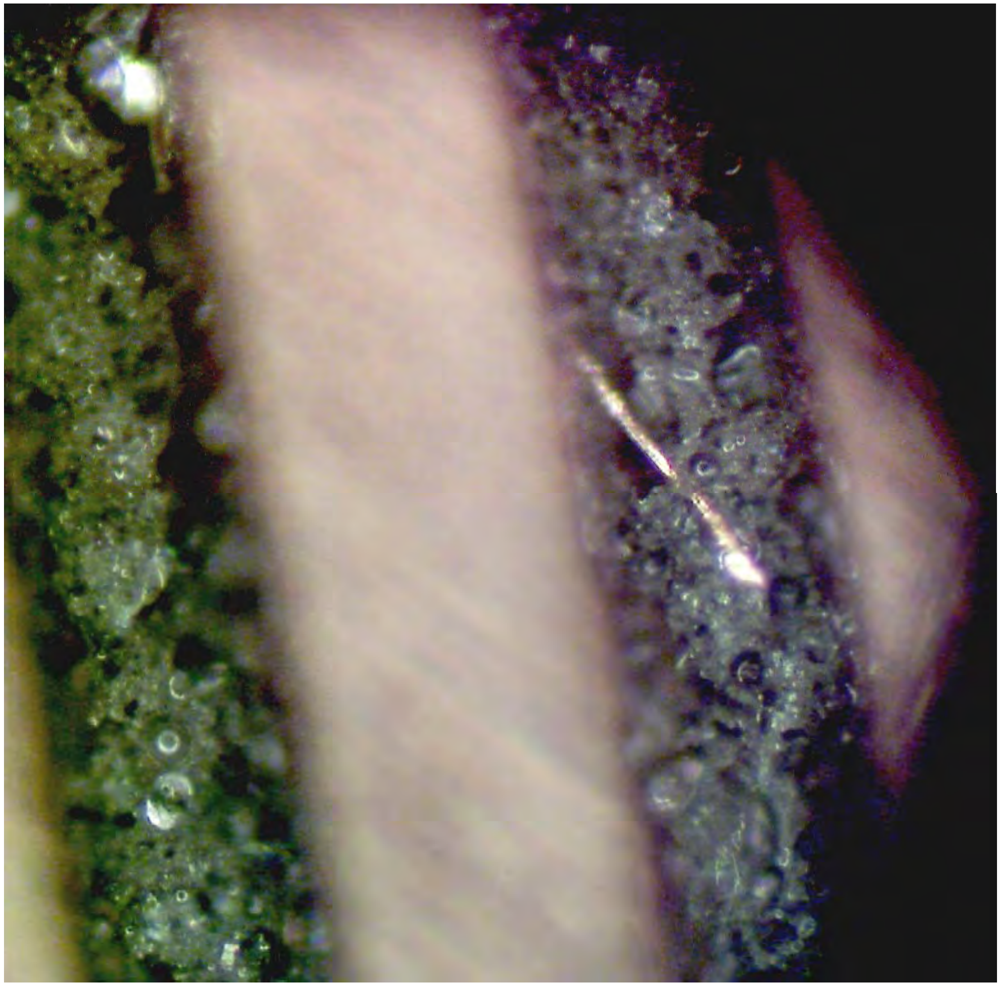


Yield Analysis of MTM Failures

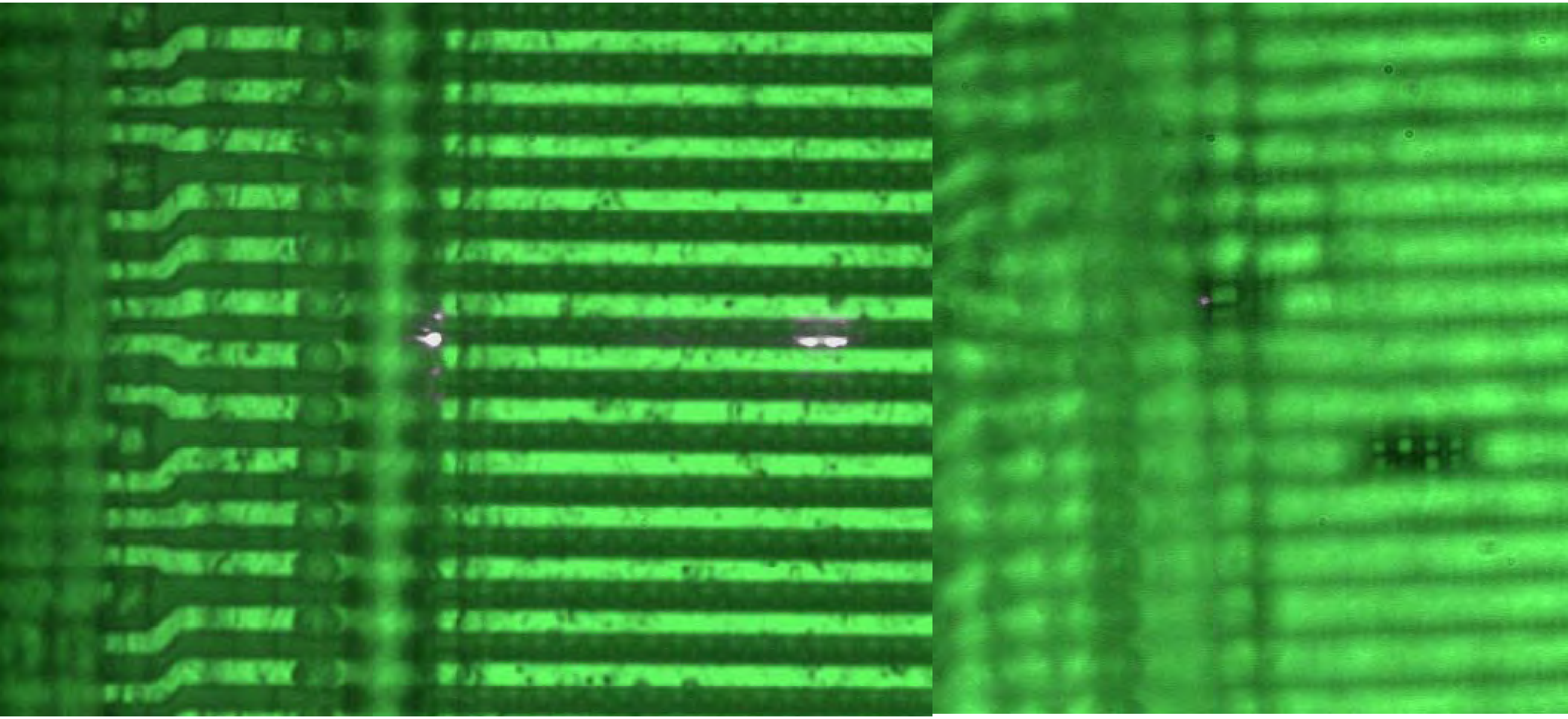


- SEM image of the metal particle responsible for the metal to metal intermittent as identified by ONS and Emission Microscopy.

O2 Plasma Exposed Leadframe Short



Photoemission Examples



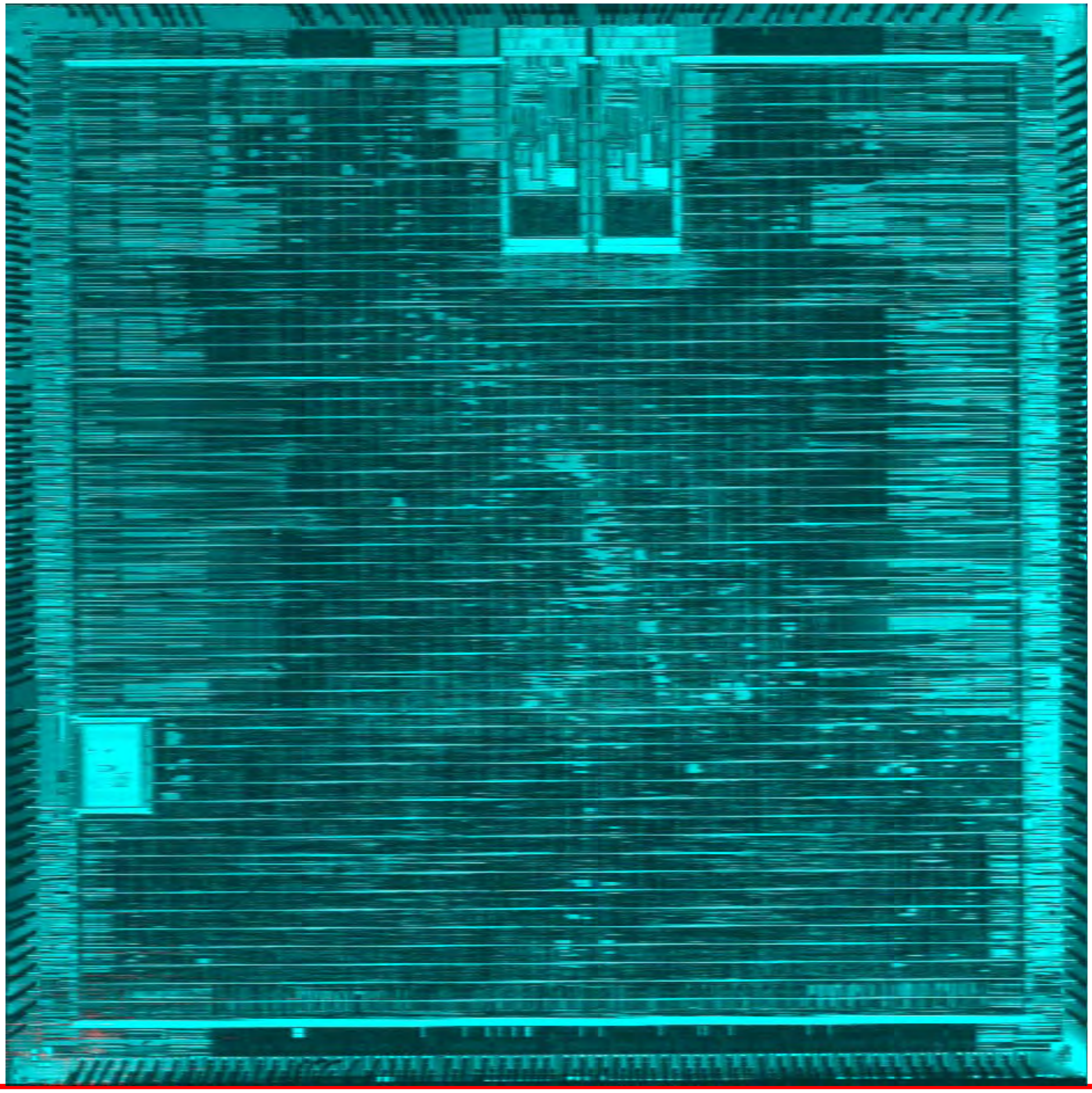
EPROM select cell failure before and after FIB cut.

Stimulus Induced Fault Test (SIFT/TLS)

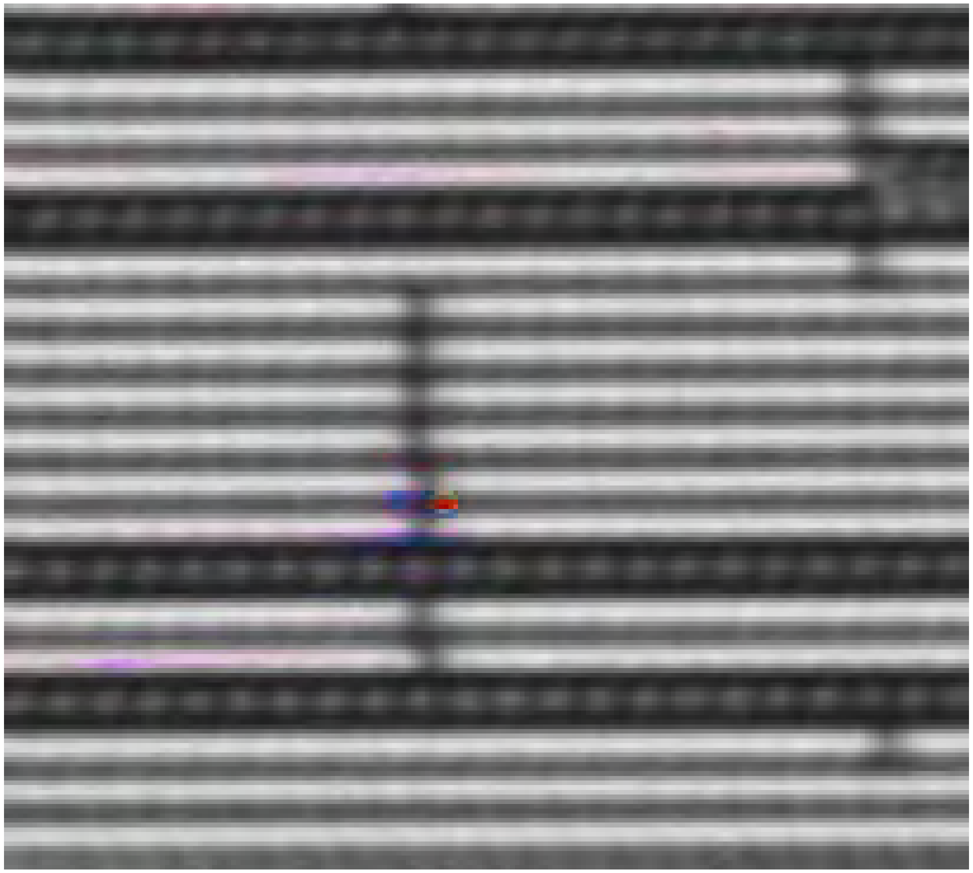
- Thermal Laser Stimulus
- Optical Injection
- Electrostatic Coupling
- Magnetic Mapping
- Logic Fault Mapping
- Raster head or stage for coordinate and constant power control without moving beam in optics but is slow compared to LSM.

- Raster Beam for traditional LSM like operation.
- Scan sample beam position rates: 250 KHz to DC.
- Contiguous full die scan (No image stitching if in SIFT mode).
- Accomodation for die tilt during scan to compensate focus.
- Variable stimulus spot size.
- Defineable scan window in camera view and for full die.

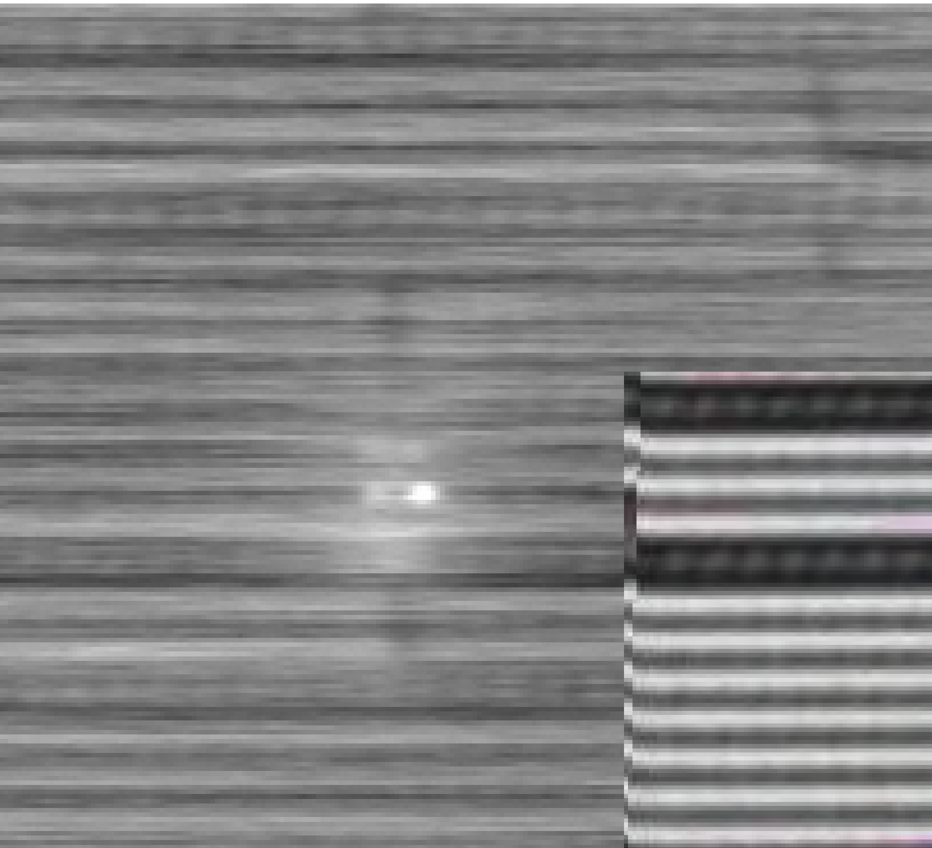
Full die SIFT scan overlay at 1480nm with a 10X NIR objective. Note the signal in red in the lower left. 0.3V bias

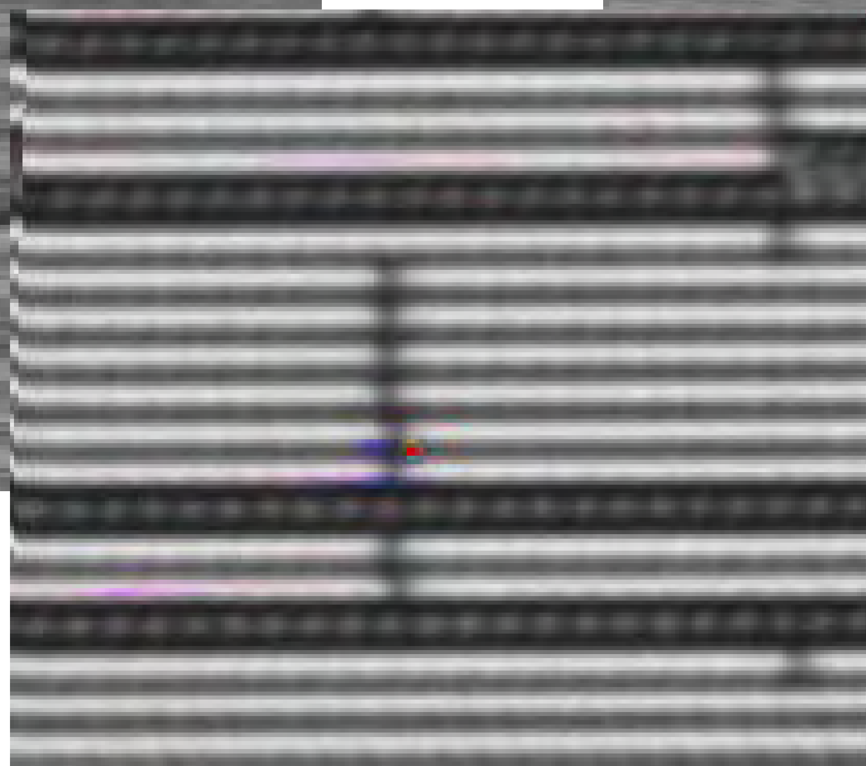


(SIFT 1340nm) Left no filter at 3.3V right with noise filter. (0V bias was best/SEI/Peltier defect) Scan at 1 um step. 20xNIR objective used.

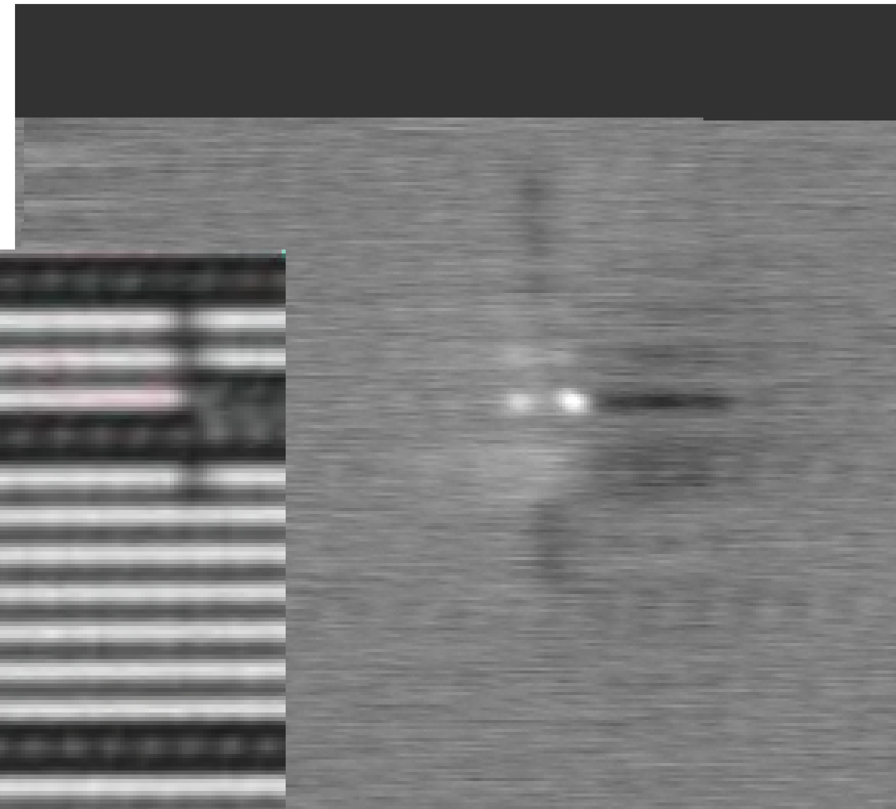


SIFT Image

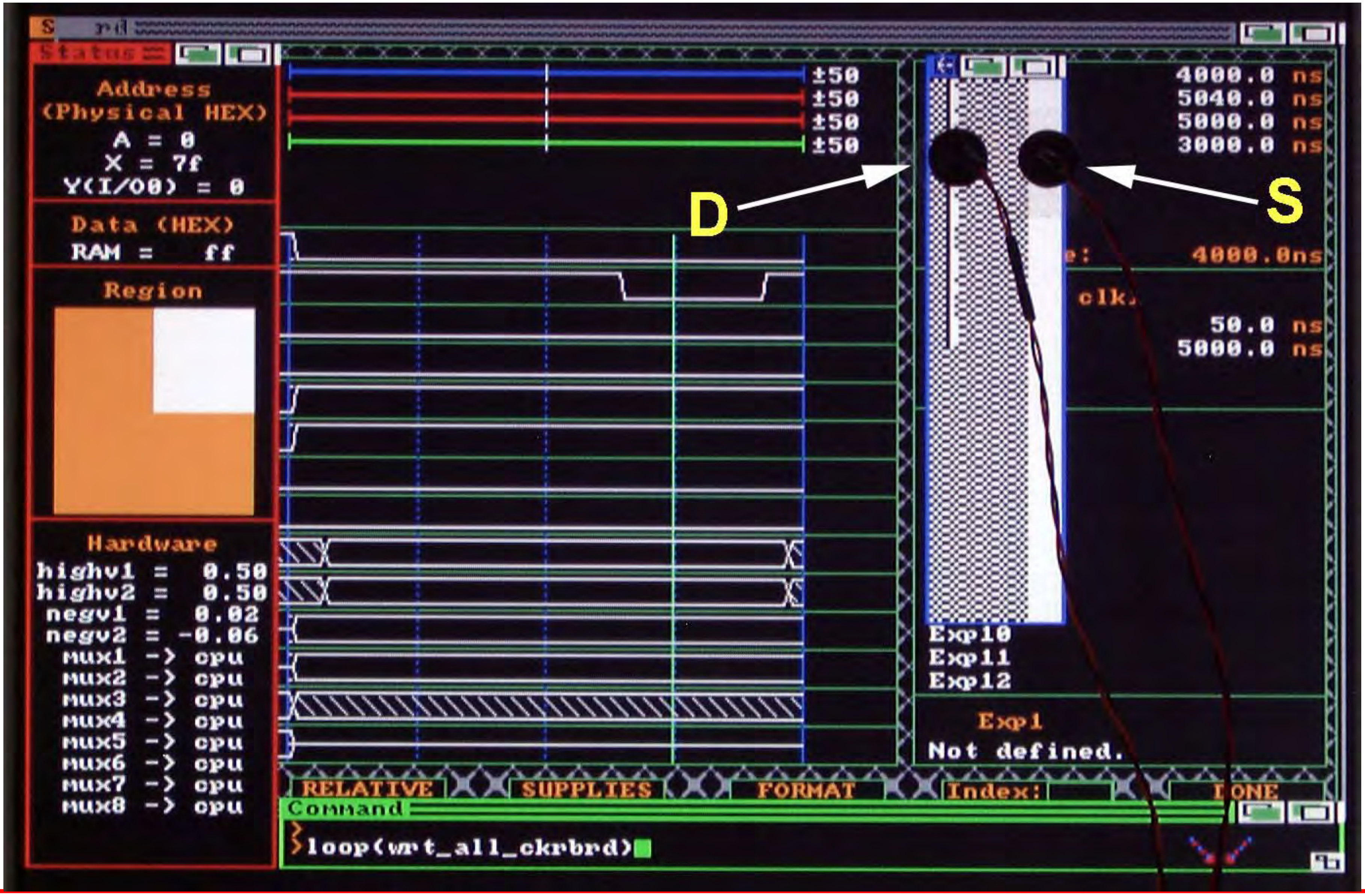




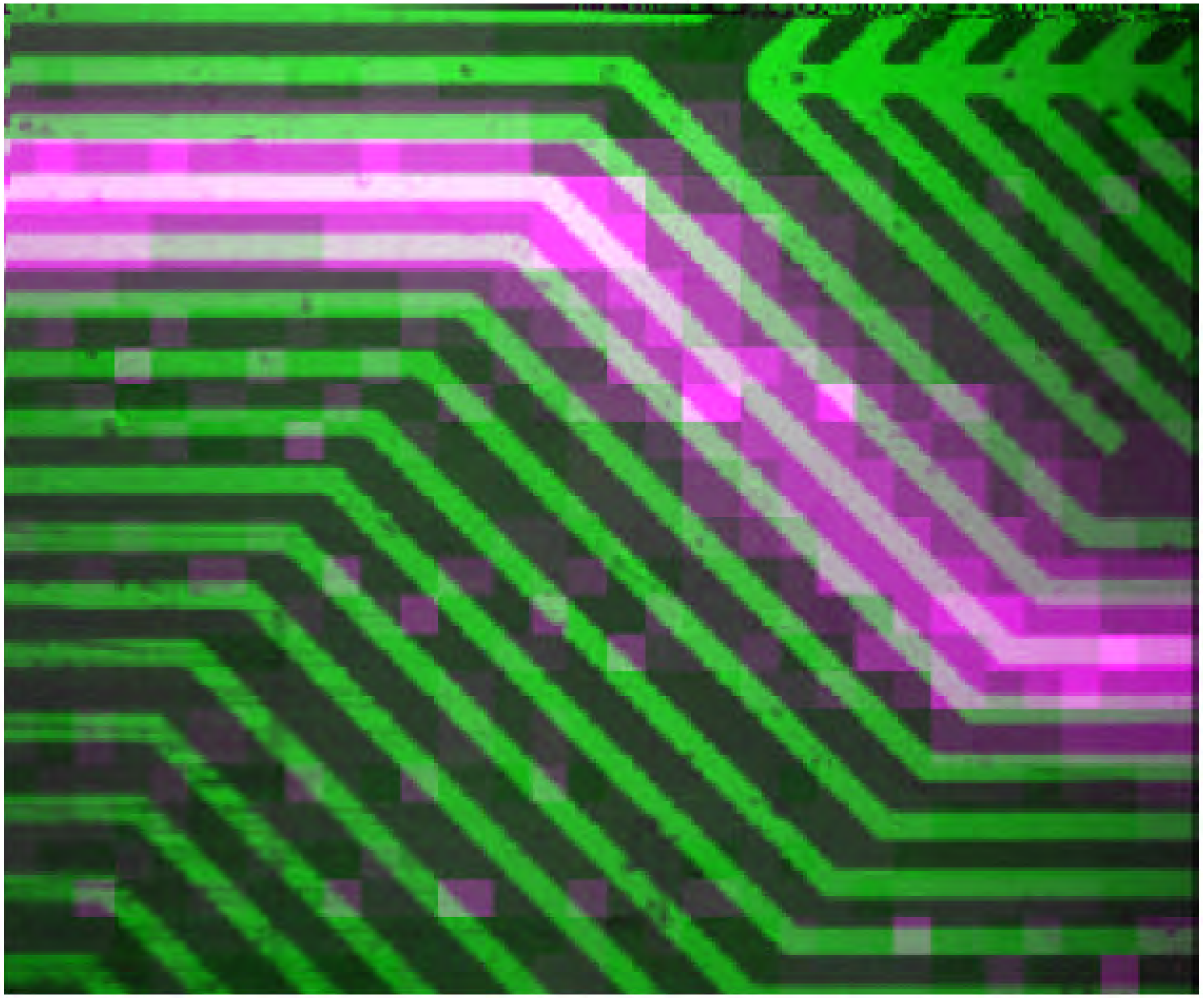
“IVA” Image



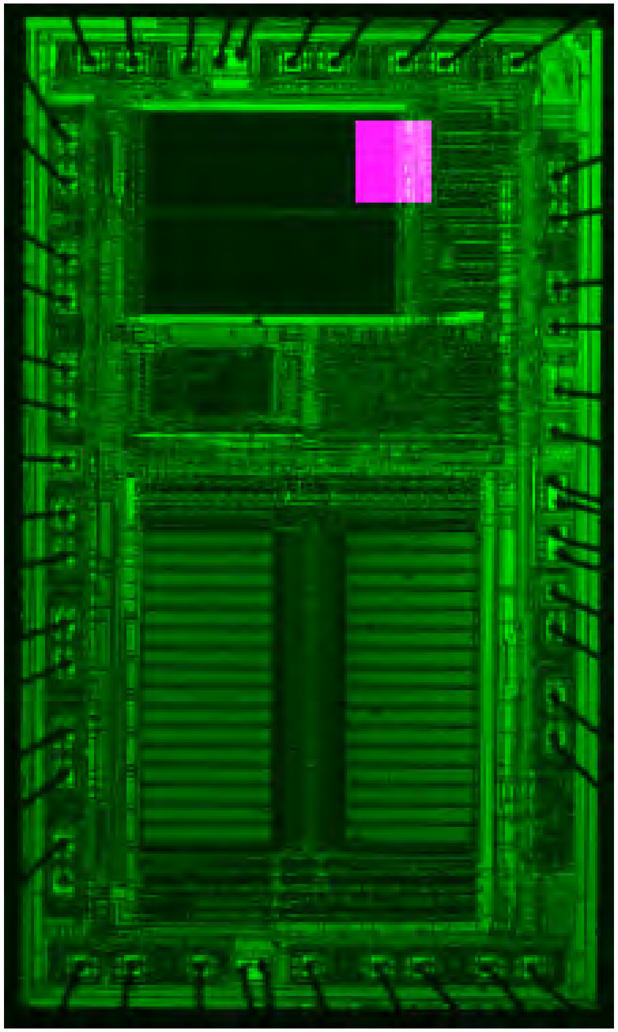
SIFT Configuration on Tester Screen

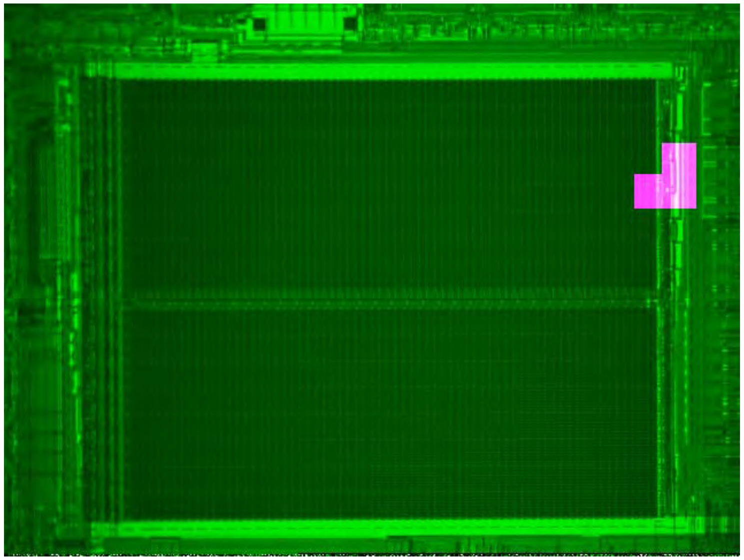


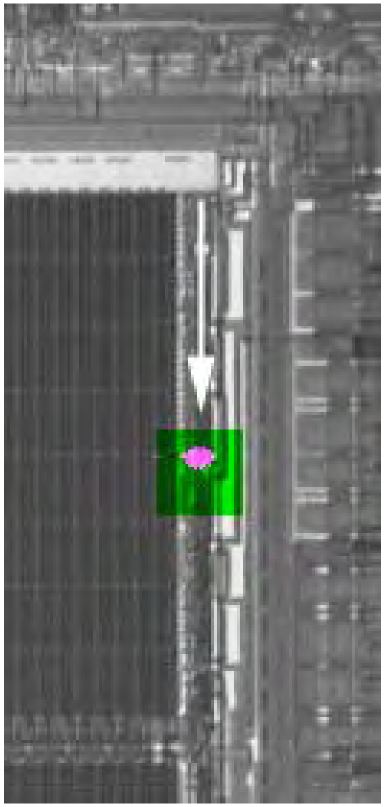
SIFT in Electrostatic Probe Mode 100KHz



SIFT Analysis of Light Sensitive Column Decoder Failure
Recently referred to also as LADA







Arrow points to location of identified channel leakage

Backside Preparation

I. Sample Prep + ARC

II. Silicon Refraction and Spectral response

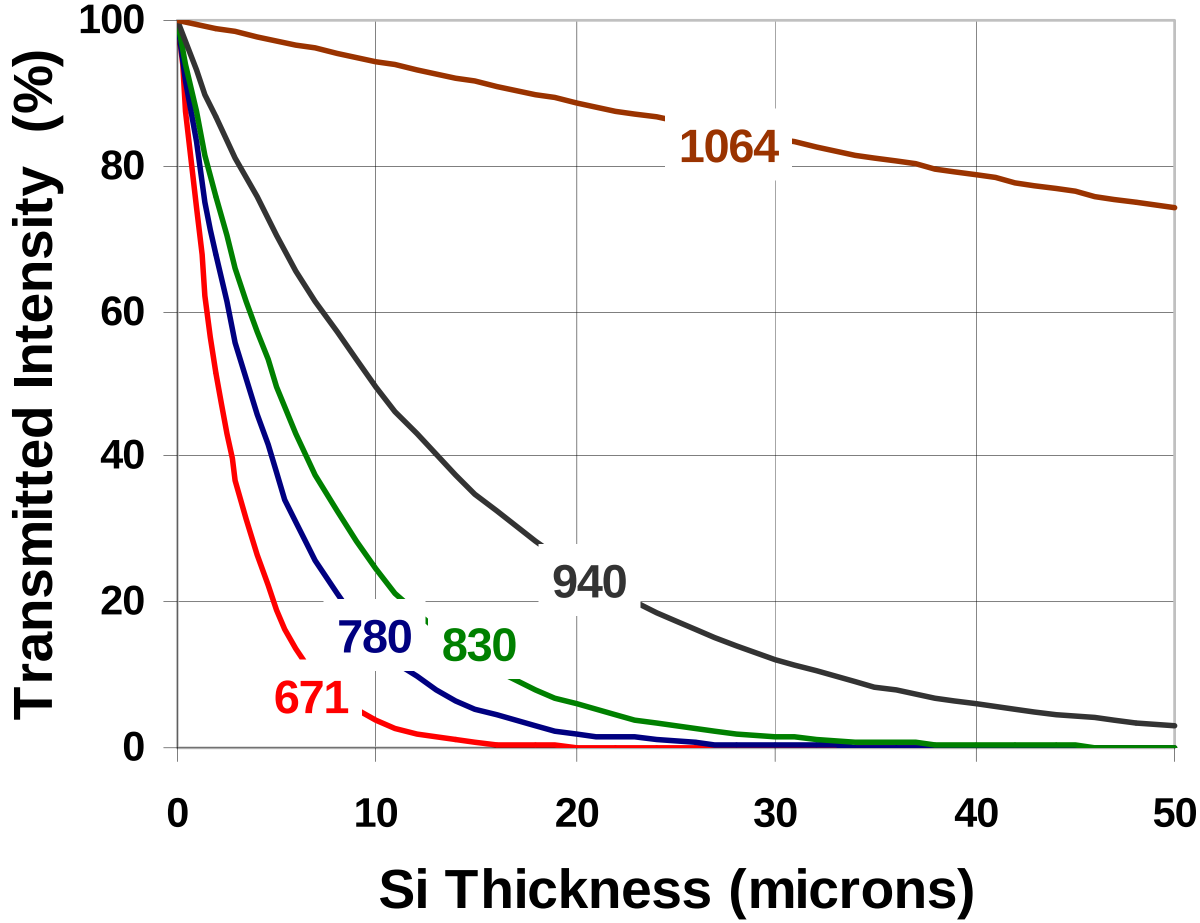
III. Shortcomings
    a. Heat dissipation
    b. Socket complications

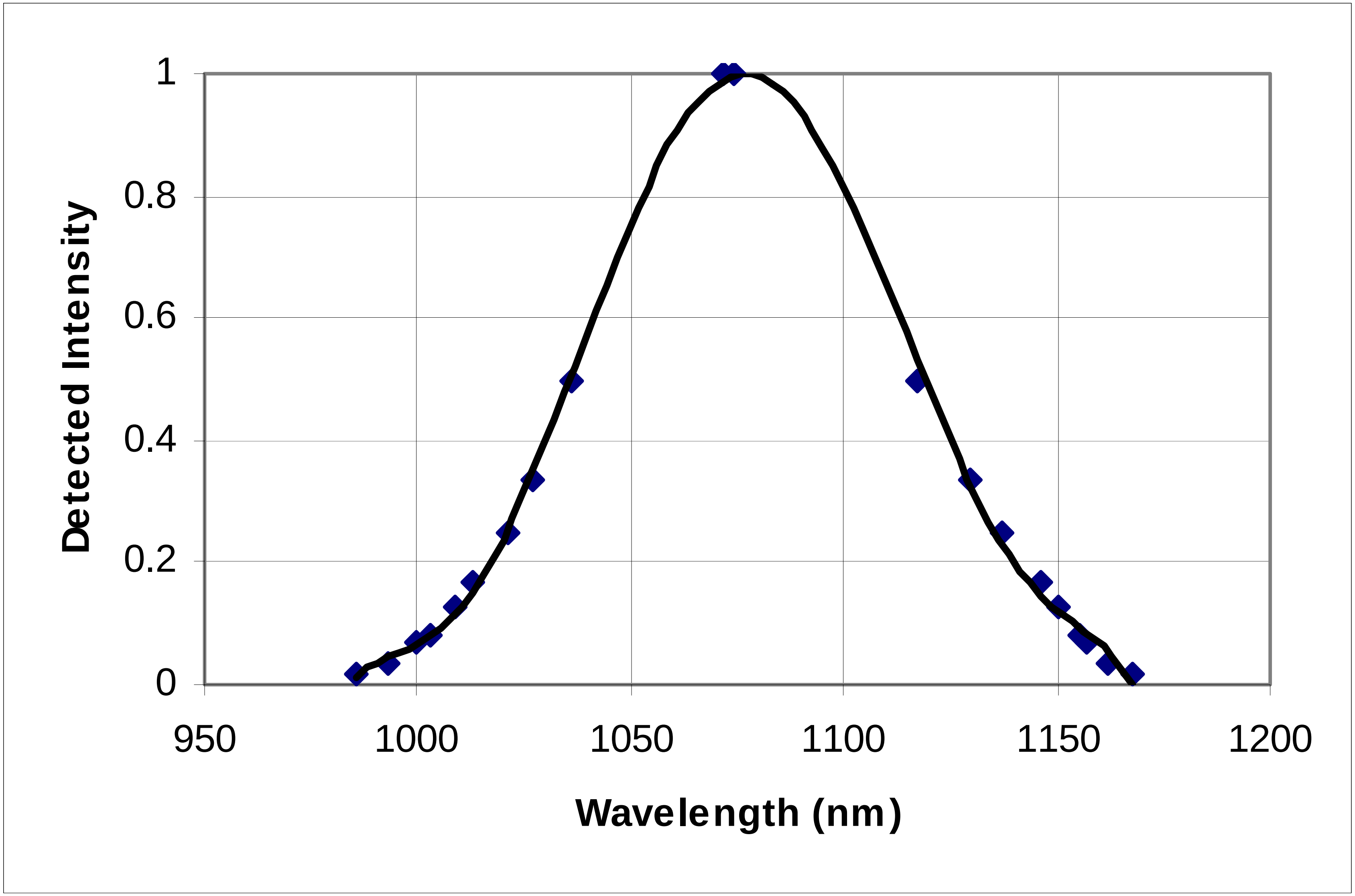
How much does thinning improve spectral response?

As the substrate is thinned, the spectral response shifts to higher energies.

When the substrate is 50 um thick or less, 940nm wavelengths can more easily illuminate the underlying circuitry.

How much does thinning improve spectral response?



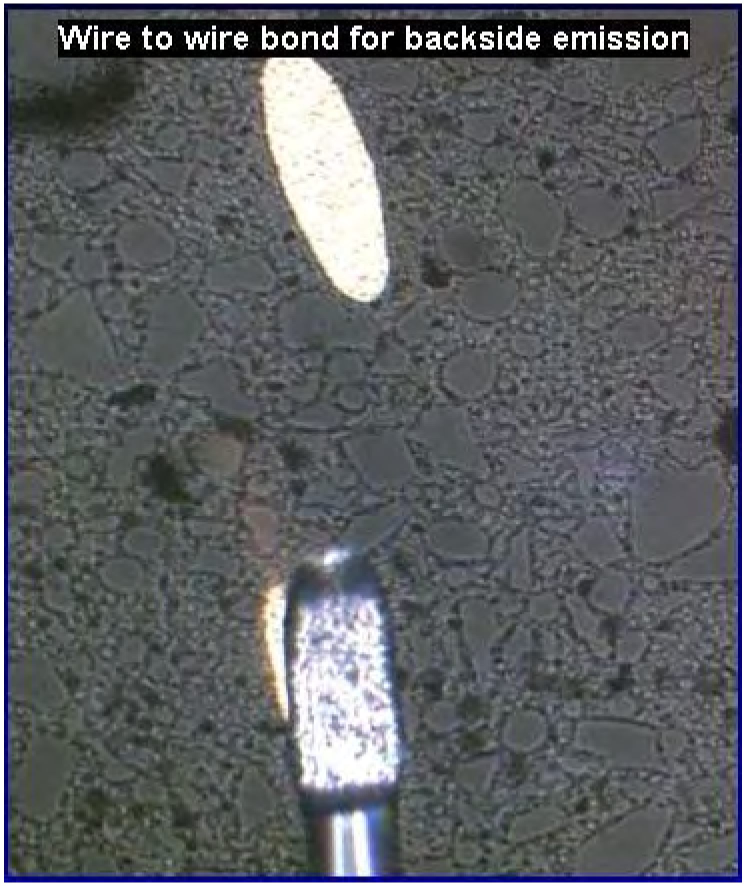

1
0.8
0.6
0.4
0.2
0
950
1000
1050
1100
1150
1200
Detected Intensity
Wavelength (nm)

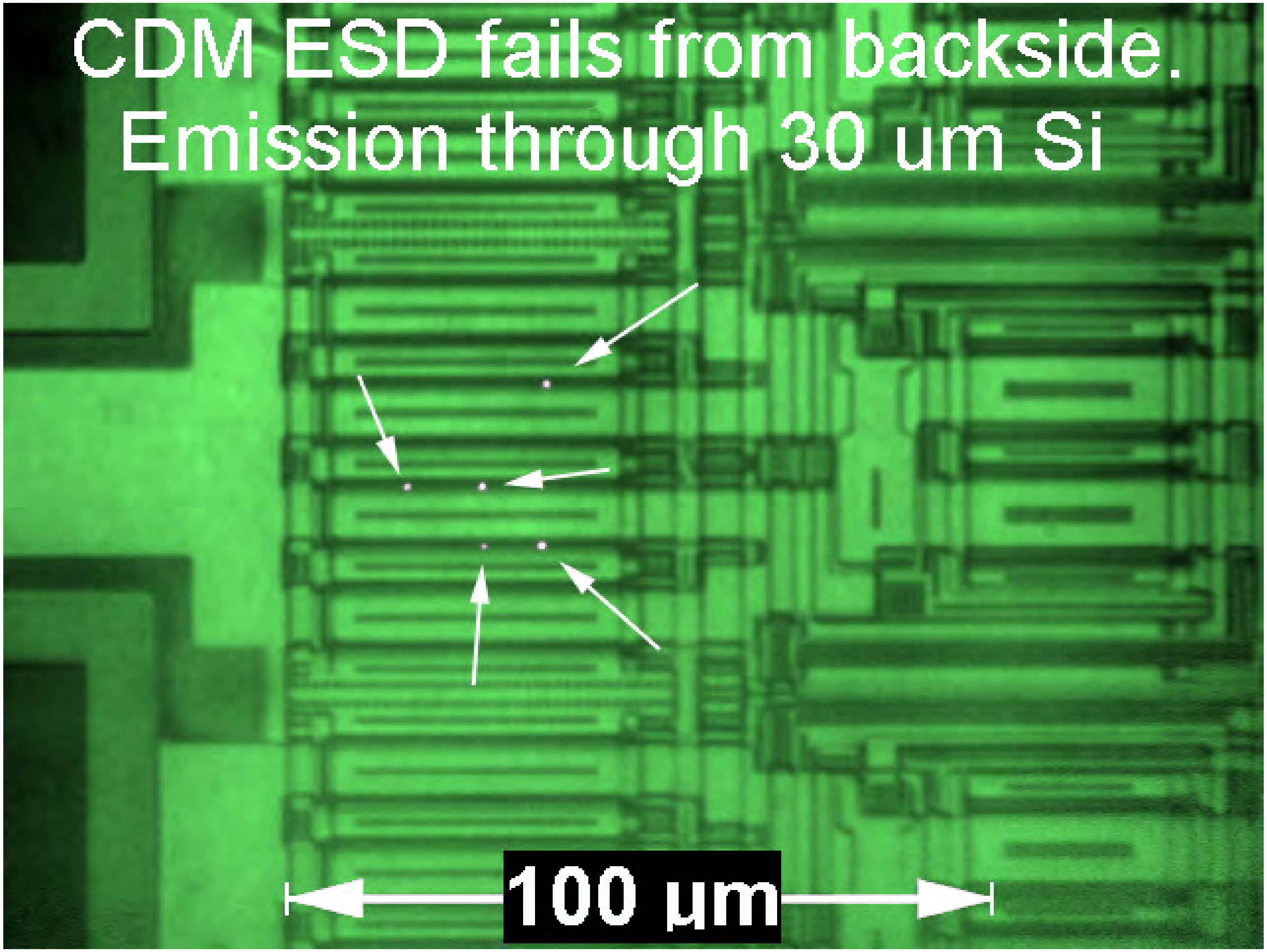
How Thin Should the Sample Be?

The required thickness will vary based on the following factors:

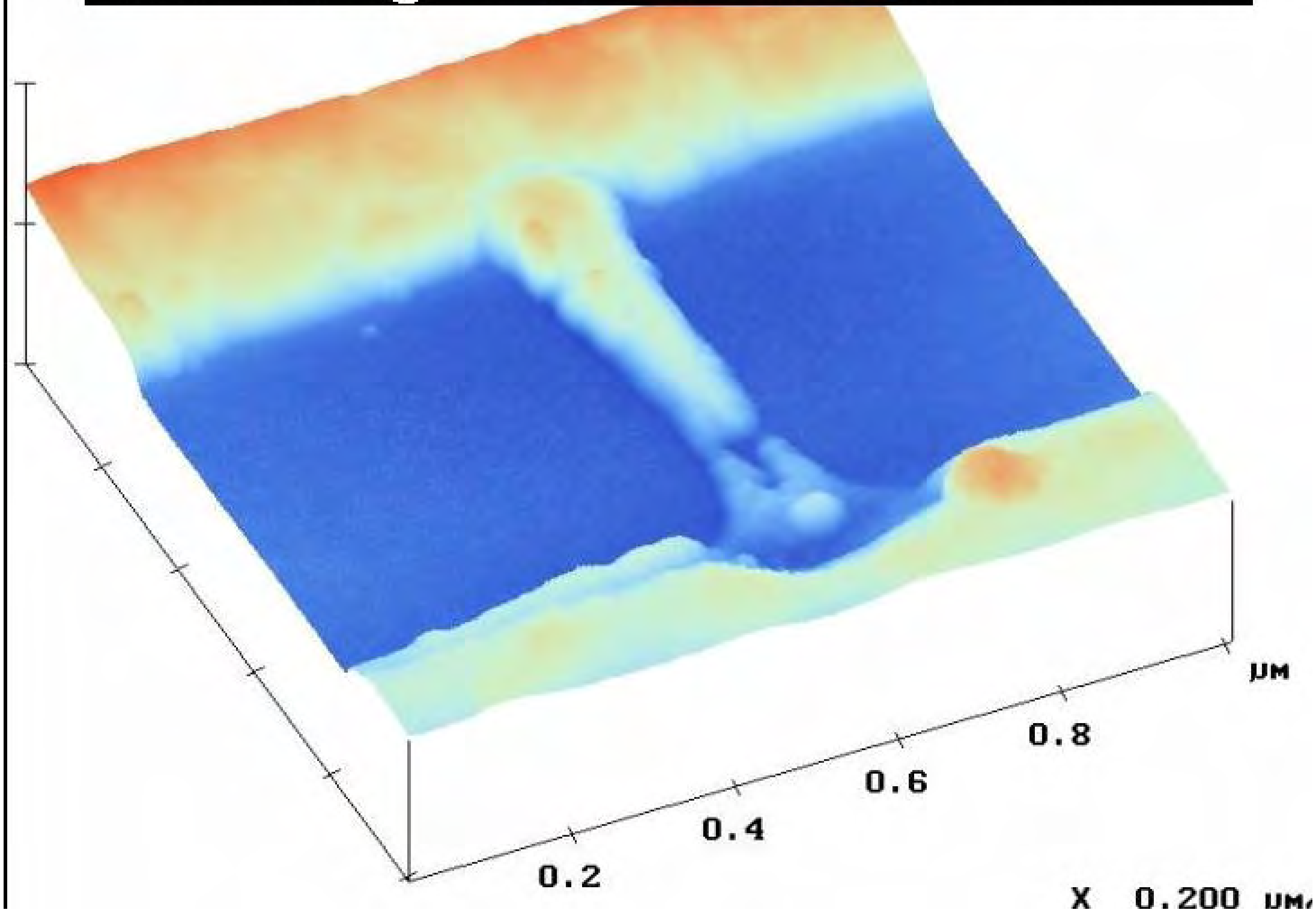
1. Latchup stability of the thin substrate.
2. Heat dissipation of the thin substrate.
3. Package dimensions.
4. Substrate dopant levels (CCD best for highly doped substrates)

Backside Emission Microscopy with WTW Bonding




CDM ESD fails from backside.
Emission through 30 um Si
100 µm

AFM image of ESD from backside



Conclusion

A number of different defects were shown using different FA tools to show the strengths and weaknesses of selected methods. An important part of Failure Analysis is to cross correlate the failure data whenever possible. The validity of your data is greatly reinforced to drive the corrective action. Efficient FA labs operate best in engineering mode rather than production mode.

Profile

Jim Colvin, CEO

- Mr. Colvin comes from the Midwest with a background in Electrical Engineering from Purdue University . He has 21 years of contributions to the Failure Analysis community through committee organizations for ISTFA, EOS/ESD, and IRPS and has published numerous award-winning papers on Failure Analysis techniques. Colvin has also been working as a Consultant for over 15 years and originated the Passive Voltage Contrast technique, the first portable Emission Microscope, the Vibration coupler, and the laser illuminator, to name a few. Currently he is the CEO of FA Instruments, Inc. founded to provide leading edge tools for Failure Analysis. Jim currently holds 7 patents for products relating to the semiconductor field and is recognized as a contributor to the advancement of semiconductor technologies.
  - Best Paper award from the EOS/ESD Symposium for his paper titled "The Identification and Analysis of Latent ESD Damage on CMOS Input Gates" 1993.
  - Outstanding paper award from ISTFA for his paper titled" Color Voltage Contrast: A New Method of Implementing Fault Contrast with Color Imaging Software" 1995.