Semiconductor Device & Analysis Center Berlin

Scope:

• **Research:** FA Techniques for Faster Turnaround
  - Edit techniques on devices
  - Physical interactions of devices for localization
  - Standard solutions (cook book etc.)
  - Device Design & Characterization

• **Education:** Full Device Development Process
  - Semiconductor Devices in Basic Curriculum
  - Full Microelectronic Business Process (FET)
  - Failure Analysis, Power & Special Devices

• **Service:** Commercial-like Application Lab
  - Lab unique for service of design verification and failure analysis processes from chip backside
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Resources:
- 1 Lead Engineer (permanent)
- 3 PhD Students based on educational track
- 4 Technical Staff (permanent contracts)
- More PhD Students per cooperation contracts
- State of the Art tools Hamamatsu Phemos 1000, NPTest OPTIFIB, Agilent 83000 Tester
- Device Simulation & Know How (FET, Power, PV)
- Sample Preparation Mech, Chem Wet &Dry
- 1000 sqft Small Clean Room Technology
- More than 5000 sqft lab and office space
Who we are

Device Dynamics Make the Difference in Functional Analysis
Challenges of Backside Approach
Device Localization with Laser Stimulation
Device Repair (Circuit Edit) with FIB

Where we want to go
Photon Emission Basics: Electroluminescence

The Two Basic Mechanisms of Photon Emission in IC

P/N Junction:

Reverse Bias
1) Deceleration: Radiant loss of energy gained in electrical field

Forward Bias
2) Injection: Radiant Interband Recombination

Detection Limit
Leakage Current
I
V
Photon Emission Microscopy

Direct defect identification: Gate oxide defect

Emission images at magnification:
Correlation of MOSFET Light Emission to Electrical Operation Mode

Light emission and substrate current vs. gate voltage

Substrate Current

Light Intensity

Gate voltage [V]  
Substrate current  
Drain

$I_{sub}$  
$[\mu A]$  
$[mA]$  

$ID$  

Gate voltage [V]
Dynamic Photon Emission in CMOS

- Photon Emission in Switching Phase of FET
- Required Time Resolution: 30 - 40 ps
- Measurement Challenge: ~ 1 photon / $10^5$ events
- Stroboscopic Imaging: IC Signal Tracing

All figures from J.C. Tsng, Picosecond imaging circuit analysis
Design Verification: Signal Propagation in IC visualized with Dynamic Photon Emission

Example: ring oscillator:

Three optical waveforms of switching induced light emission from neighbouring inverters of the ring oscillator:
Vdd -> 0V: high intensity
0V -> Vdd: low intensity

Emission from a ring oscillator at various times.

All figures from J.C. Tsng, Picosecond imaging circuit analysis
Design Verification & Failure Analysis: Identification and Localization of Erratic Device

Time integrated image of light from a register file while running a test pattern producing a fail

'optical waveform' from normal and faulty latch pair

All figures from J.C. Tsng, Picosecond imaging circuit analysis
Why FA through Backside of the Die?

Multi-Level Metallization

New Packages

LOC (Lead On Chip)

Flip-Chip

Data taken from Fujitsu
Observability of Signals with Beam Techniques Drastically Reduced by Multi Layer Wiring

Data taken from N. Kuji et al., NTT, ESREF97

Image taken from IBM Research Labs
Challenge of Analysis Techniques Through Chip Backside: IR Optics Resolution vs. Feature Size

Spatial resolution >0.7 μm (λ>1 μm) (Backside analysis)

Minimum Pitch [μm]

0.2 0.4 0.6 0.8 1.0

0.18 μm 0.15 μm 0.13 μm 90 nm

Technology Node

Gate line

Metal line
Resolution of different immersion media
gas, air (a), liquid, oil(b), solid, Si (c)
Paradigm Shift in Functional Analysis of Semiconductor Devices

Functional Analysis through Chip Backside

- Gain of material pervasive techniques
- Re invent full analysis process
- Systematic understanding of effects lacking = techniques not yet employed to their potential
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Where we want to go
Beam Induced Device Stimulation

Set Up:

- Device
- Signal-Processing
- Computer
- LSM
- IR Laser
- Image overlay
- Deflection signal
Principle of Laser Induced Thermal Stimulation

High ΔR if R high: sensitive to high R interconnects
Local thermovoltage at high currents: sensitive to low R sections
Problem: Signal Path from excitation to terminal not well defined

Source: Nikawa
Thermal Stimulation of Silicon Device by IR Laser Intraband Free Carrier Absorption:

IR Absorption in Highly Doped Layers: 0.1 to 0.05% of 1.3μm Laser power

Local Heating of Active Device

- Si thickness: 625μm
- Dopant Concentration: x10^{16} cm^{-3}
  - (a) 1.5
  - (b) 33
  - (c) 120
  - (d) 730

Si indirect bandgap
Thermal Laser Stimulation in Metal Wire & in Semiconductor Device

Interactions:

Wiring:

Device:

M1

M1

S/D, typ. $10^{19}/\text{cm}^3$

well, typ. $10^{17}/\text{cm}^3$

Si-Substrate, typ. $10^{15}-10^{16}/\text{cm}^3$

Cap

Silicide

Poly-Si

typ. $10^{19}-10^{20}/\text{cm}^3$

M2

S/D
Thermal Laser Stimulation in Metal Wire & in Semiconductor Device

Interactions:
Wiring:
- Voltage Alteration
- Resistive Change

Device:

Heat

$\lambda=1.3\mu m$ laser illumination
Thermal Laser Stimulation
in Metal Wire & in Semiconductor Device

Interactions:

Wiring:
- Voltage Alteration
- Resistive Change

Device:
- Performance Reduction
  - Mobility
  - $V\tau$
  - Speed

laser illumination, $\lambda=1.3\mu m$
Thermal Laser Stimulation
in Metal Wire & in Semiconductor Device

Interactions:

Wiring:
- Voltage Alteration
- Resistive Change

Device:
- Performance Reduction
  - Mobility
  - $V\tau$
  - Speed

$\Delta t = 1$ ms
Soft Defect Localization - FET

Ring Oscillator frequency vs. VDD

Frequency (MHz)

VDD (V)

Source: Ed Cole
Soft Defect Localization

Soft Defect: Test Fail occurring only in special Environment

Source: Ed Cole

TUB Research Result: Quantitative Investigation of FET Device Parametrics with Thermal Laser Stimulation to be submitted 10/03
TLS Thermal Laser Stimulation of Soft Defects:

Will be important Innovation in Localization of IC Device Functionality and Failures

- Probe = parametric modification of device
- Signal path for detection defined by tester
- Can determine gradual device performance
- Understanding of effects scattered

=> research necessary for proper use in industry
Next Generation Localization Techniques
- Key: further improvement of turnaround
- Detection of further signals emitted by device, i.e. magnetic field (SQUID)
- Interaction of circuitry time delay and propagation of induced signal
- Signal tracing with all available dynamic techniques (Laser induced, photon emission, other?)
Outline:

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Where we want to go
Device Repair (Circuit Edit) with FIB: Short Redesign Loop and Access to Cells

FIB Deposition of Probing Pads for SRAM Cell on Via 1 level (Prep: surface parallel polishing)
The OptiFIB Column

Coaxial Photon-Ion Microscope

Photon Beam

Ion Beam

Simultaneous Imaging & Editing

Photon Image

Ion Editing

100nm FIB Placement Accuracy
FIB Editing of ICs through Si Backside

- Very thin remaining bulk Si
- Risks: Flatness, Endpoint, Navigation
Voltage Contrast by Silicon Active Volume

TUB Research Result:

FIB Image Contrast of n-Wells for
- Endpoint Control and
- Navigation
to be presented at ESREF & ISTFA 03
Endpoint Detection for Active Si Volume

- Ion Beam removes material
Ion Beam removes material and implants Ga ions into the back surface.
Ion Beam removes material and implants Ga ions into the back surface. Influence of SCR causes contrast of secondary particle emission rate.

Endpoint Detection for Active Si Volume
Semiconductor Device & Analysis Center Berlin: Where we want to go

- Establish TUB as Solution Center for Advanced Analysis Problems in Electronic Devices

Microelectronics:
- Dynamics of Device and Analysis
- Pervasive Techniques (i.e. SQUID)
- Focused Ion Beam Processes for Edit in Si

Power Devices & Compound Semiconductors:
- Adaption of Localization Techniques to Discrete Devices, Band Gap and Mechanisms of Direct SC
- Adaption of FIB processes to Material Components