Static Thermal Laser Stimulation

FIRITI Abdellatif

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TLS = OBIRCh + TIVA + SEI

OBIRCh → Optical Beam Induced Resistance Change
– Nikawa et Inoue (1993)

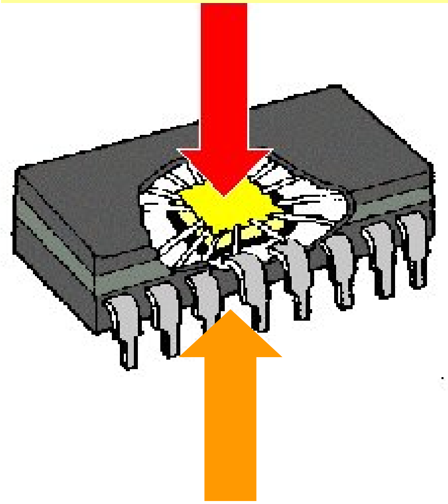
TIVA → Thermally Induced Voltage Alteration
– Cole et Al. (1998)

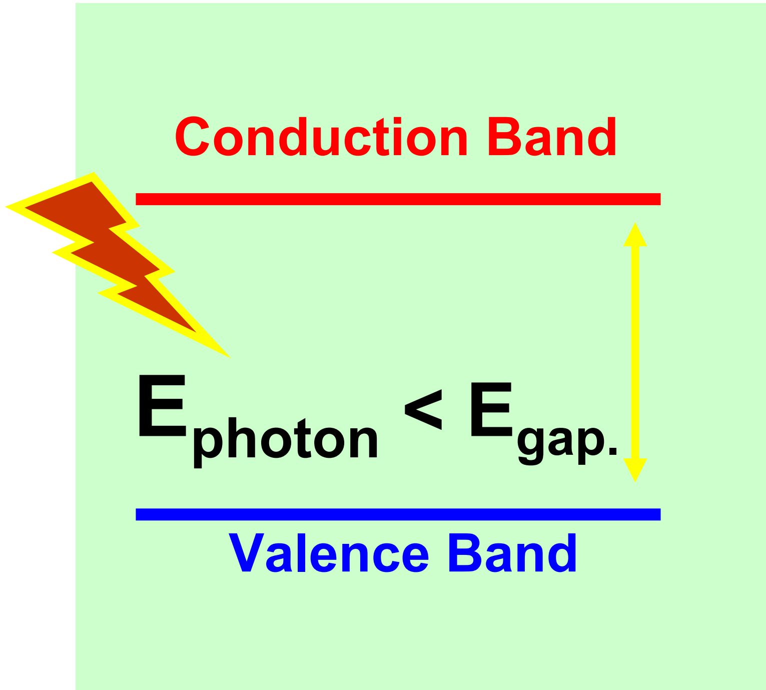
→ Defect localization in conductive materials of an IC

Semiconductors basics: Laser-Material Interaction

IR LASER
λ = 1,3 μm

Heating of die material
No photoelectric generation





High optical absorption by next material:

- Metallization (Al / W…)
- Polysilicon
- Active silicon highly doped

$$\alpha_{\text{Aluminium}} = 1{,}1x10^{6}\,cm^{-1}$$

Principle of Thermal laser Stimulation

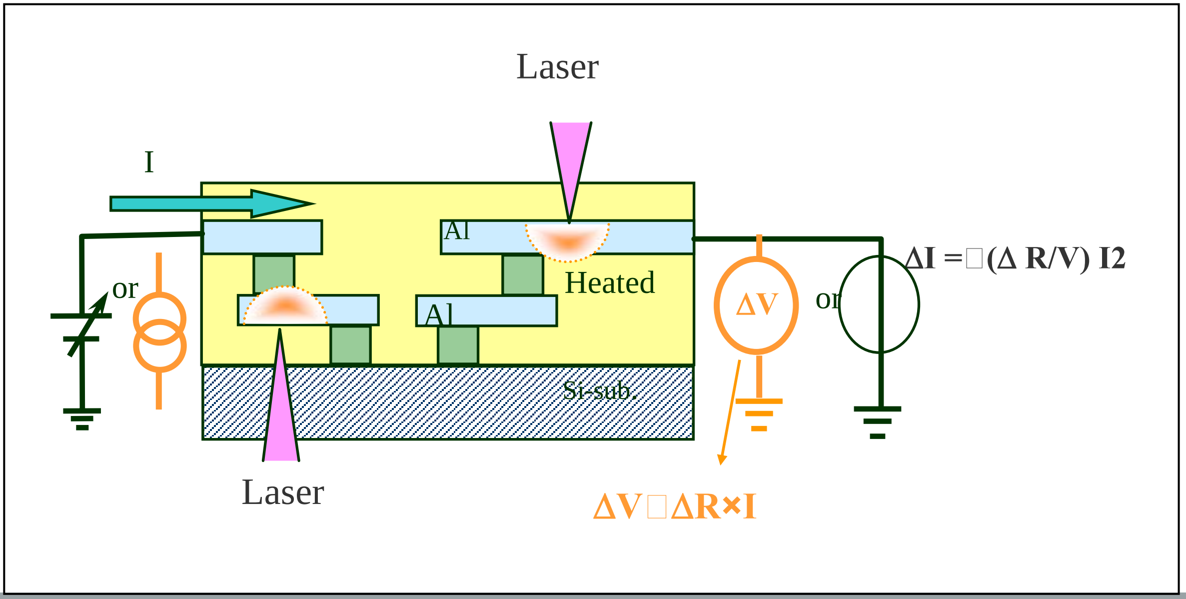
General Principle

Laser scanning ⇒ Thermal gradient → Local ΔR induced inside metallizations tracks

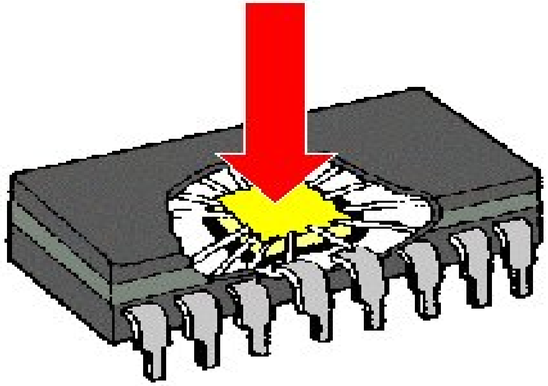
⇒ Modification of current consumption of the IC

⇒ Correlation between laser position and measured variations ΔI or ΔV

⇒ Defect localization (resistive/short circuit/leakage)



IR Laser beam **1.3 µm** ⇒ Frontside & Backside analysis



Heating of metallic elements

Resistivity variation

$$\Delta\rho = \rho_0 \alpha_{TCR}(\Delta T)$$

Current variation

$\Delta I = -(\Delta R/R^2)\, V$ @ constant V

OBIRCh

Voltage Variation

$\Delta V = \Delta R\, I$ @ constant I

TIVA

Localization of discontinuity inside metallic material and abnormal current paths observation

Electrical current density :

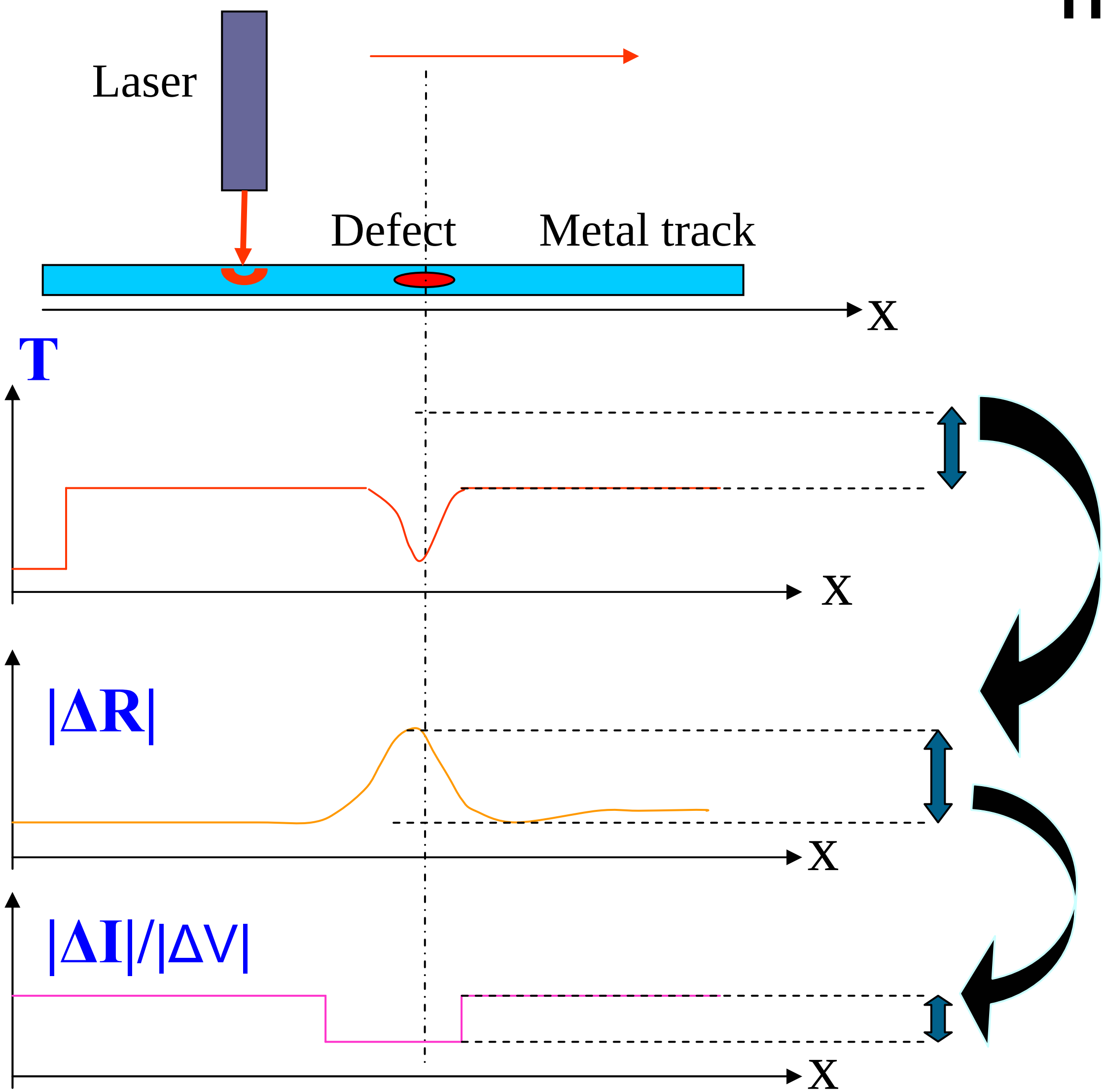
$$\mathbf{j} \cong \boldsymbol{\sigma}\left[\mathbf{E} + Q\left(-\nabla T\right)\right]$$

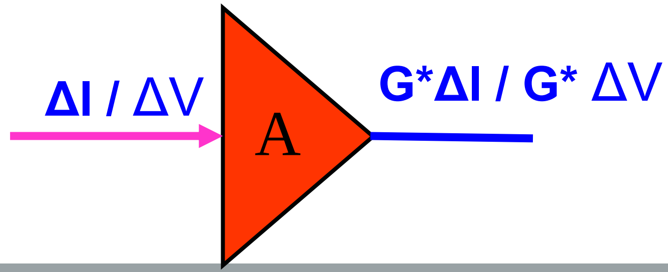
$$J = J_e + J_{stimu}$$

$\uparrow T^{\circ} \rightarrow$ Current variation

$\nabla T^{\circ} \rightarrow$ Additional current generated by stimulation

Heating of metallic materials





Heating of metallic material → Resistance variation

$$\begin{cases} \Delta R = \dfrac{\rho_0 L}{S}\left(\alpha_{TCR} - 2\delta_T\right)\Delta T \\ \dfrac{\Delta R}{R_0} = \alpha_{TCR} * \Delta T \end{cases}$$

α_{TCR} → **Temperature coefficient of resistance**

δ_T → **Linear Temperature expansion**

Aluminum

α_{TCR} = 4,29x10^{-3} °C^{-1}

δ_T = 2,36x10^{-5}

Note: Dopped Silicon & PolySi

α_{TCR} is depending on doping type and value

Temperature coefficient of resistivity

Littérature value

Matériau	Alpha TCR (°C^{-1})
Aluminium	0,0039
Cuivre	0,0068
Tungsten	0,0045
Fer	0,00651
Platine	0,003927
Manganèse	0,000002
Mercure	0,0009
Alliage Ni,Fe,Cr	0,0004
Carbone	-0,0005
Germanium	-0,048
Silicium	-0,075
Verre	

Metal layer

Semi conductors

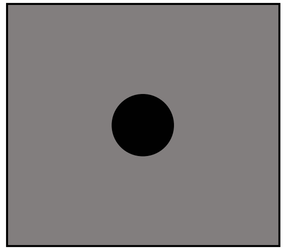
Experimengtal values

Matériaux	Alpha TCR (°C)
Al/Cu (1%)	0,0035
W	0,0015
TiTiN	-0.01357
Poly (4.1015cm-3)	-0.006
Poly (N+)	0,00075

Sign of resistance change

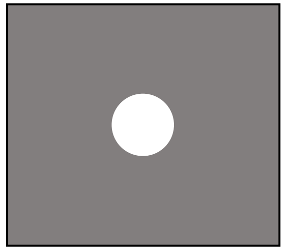
Case of metals and alloys materials :

$\alpha_{TCR} > 0$; $\frac{\Delta R}{R} \Uparrow$; $\Delta i \Downarrow$; BLACK



Case of semiconductors materials :

$\alpha_{TCR} < 0$; $\frac{\Delta R}{R} \Downarrow$; $\Delta i \Uparrow$; WHITE



Synthesis of mapping color

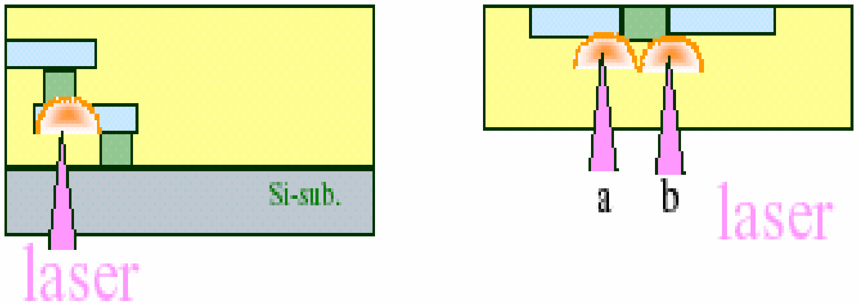
Matériau	α_{TCR}	$\Delta R/R$	ΔI	Signal OBIRCH	Signal superimposé
Métal	> 0	Augmentation	Diminution	NOIR	VERT
Semiconducteur	< 0	Diminution	Augmentation	BLANC	ROUGE

NOTE:
The circuitry of a silicon die is compoosed by multiple and differents materials involving naturals thermocouples.

Principle :

An electromotive force (e) appears at interfaces of two differents materials under heating:

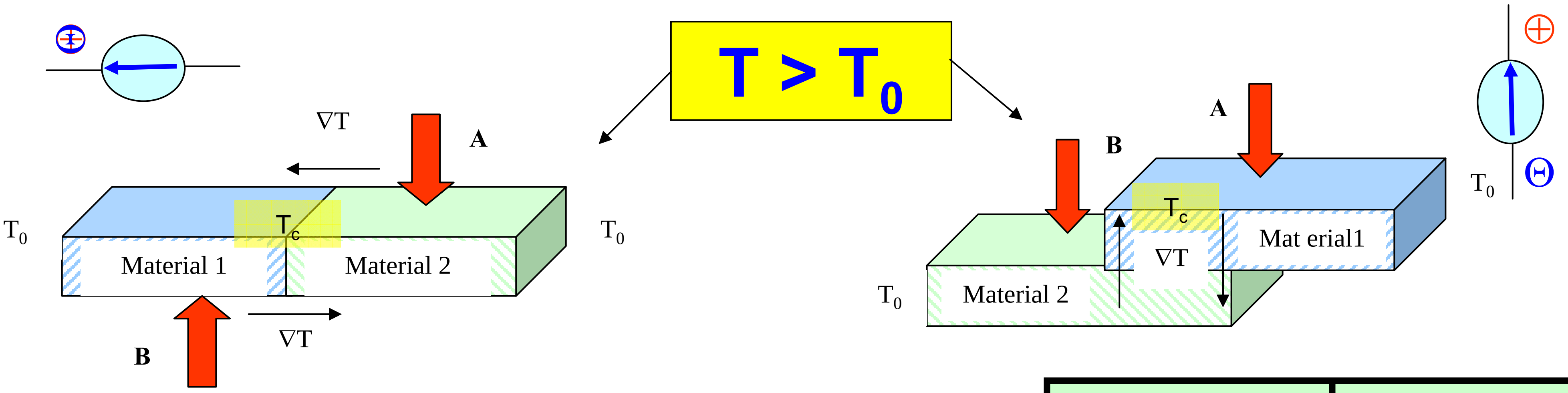
e = ΔS*ΔT



This internal voltage source appears also when the die is not biased: but has to be maintained electrically connected.

Example of application :
Technic usefull to look for parasitic interfaces in Interconnect layers (vias chain, contact chain, particles, high impedance interconnect…).

Electromotive Force Generation – SEI



$$FEM \equiv V_{12} = \left(Q_1 - Q_2\right) * \left(T - T_0\right) = Q_{12}\left(T - T_0\right)$$

Q → Thermo-electrical power
or Seebeck coefficient of the element

Q_{12} → Relative Thermo-electrical power

Materials	Q_{12} (µV/°C)
Al / W	7,0
Al / n+ Poly	-121
Al / n+ Si (10^{20} cm^{-3})	-105

APPLICATIONS OF THERMAL LASER STIMULATION

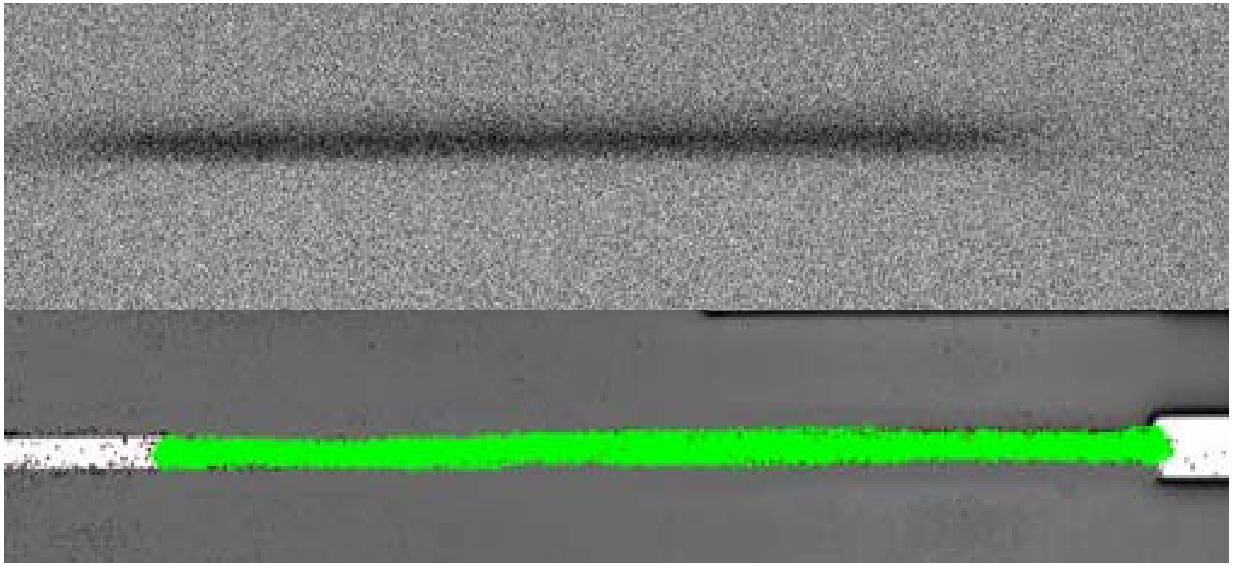
OBIRCh Analysis on constraint aluminum track (0,8µm)

V= 19,7 mV
(I = 1mA)

$\alpha_{TCR} > 0$

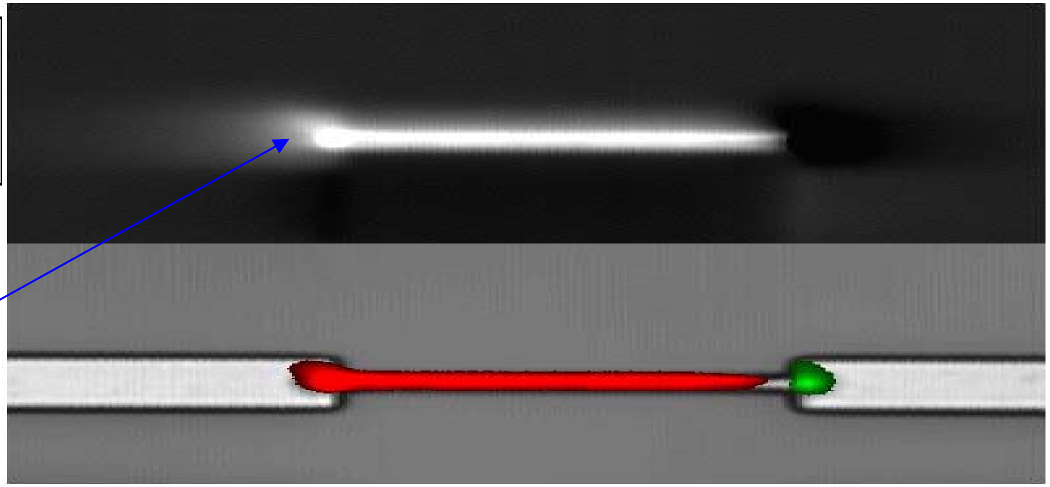
OBIRCh image

Superimposed image



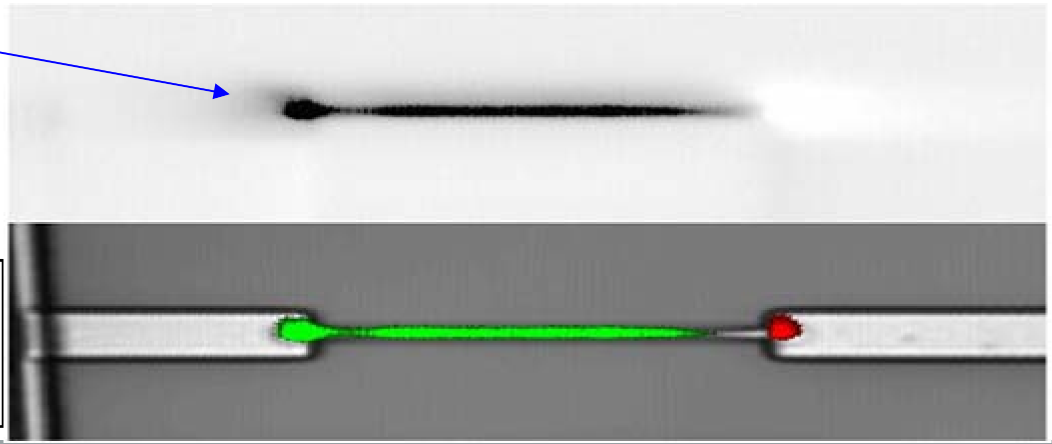
OBIRCh Analysis on Polysilicon line (0.8μm)

V= 3V
(I = 1mA)



α_{TCR} **< 0**
(Weak doping)

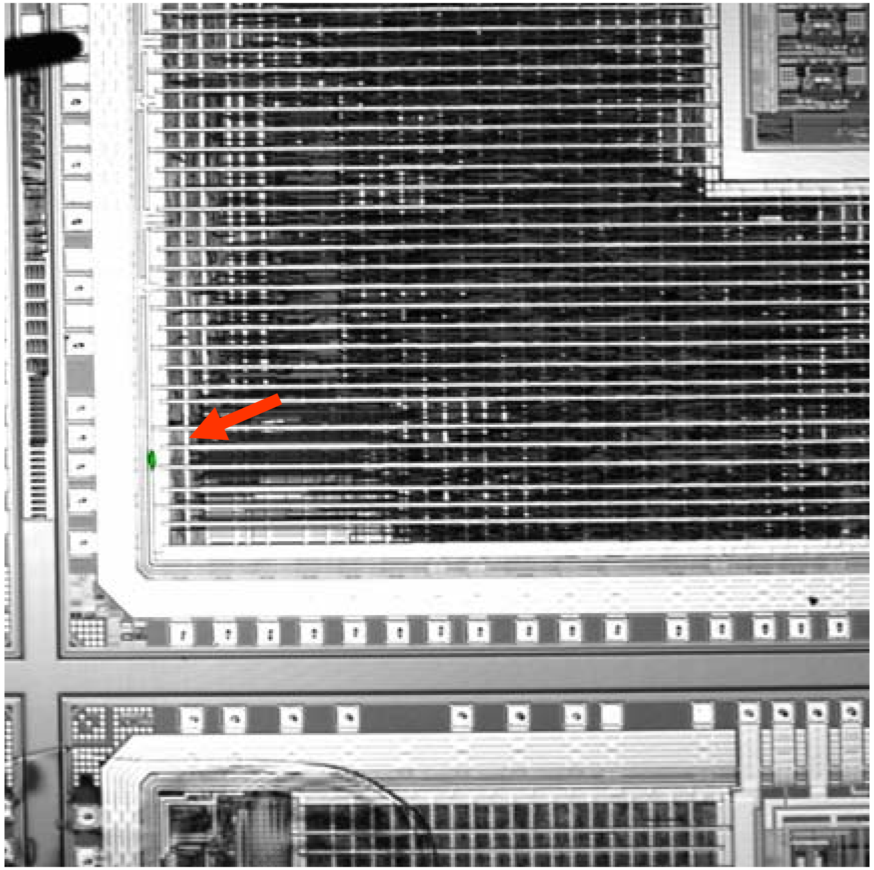
OBIRCh
Image

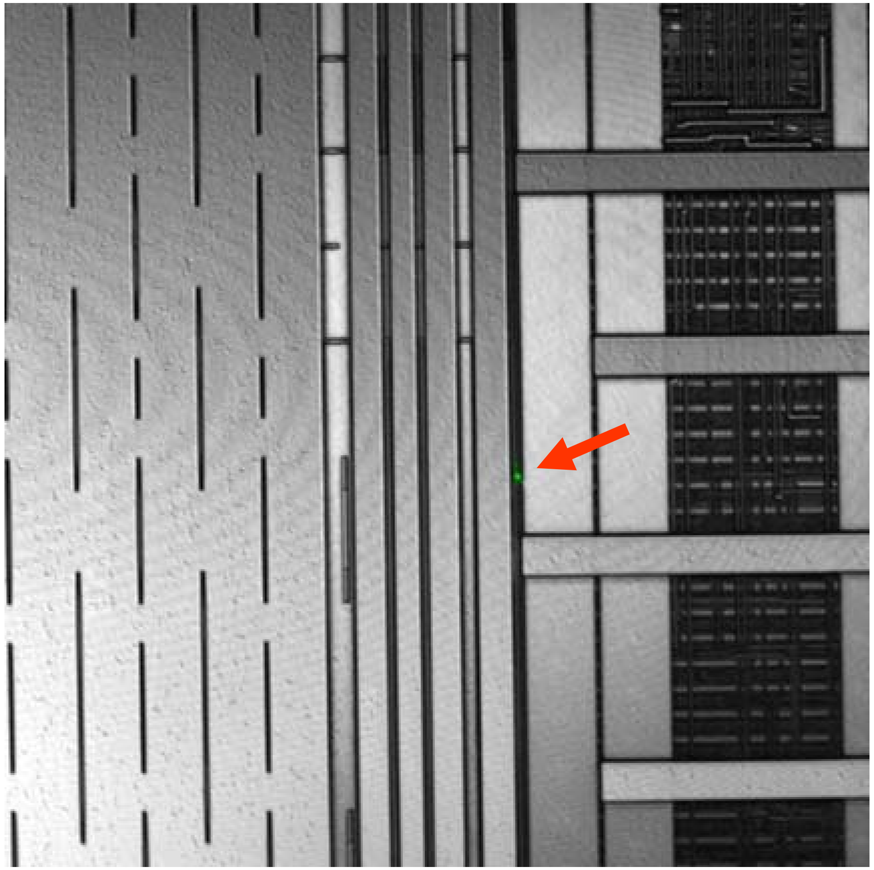


V= 940 mV
(I = 1mA)

α_{TCR} **> 0**
(High doping)

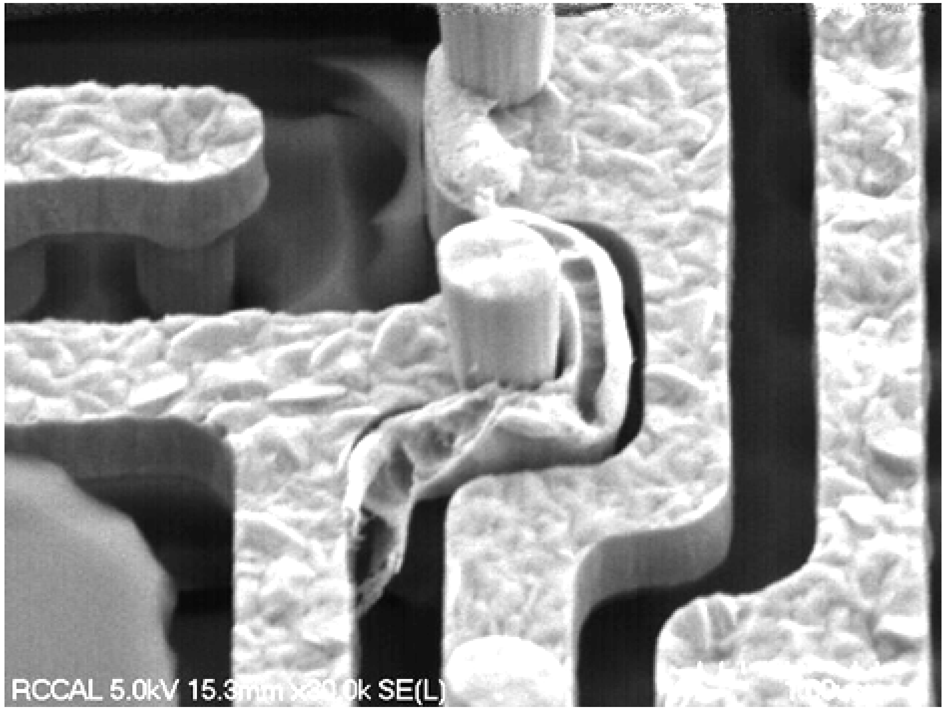
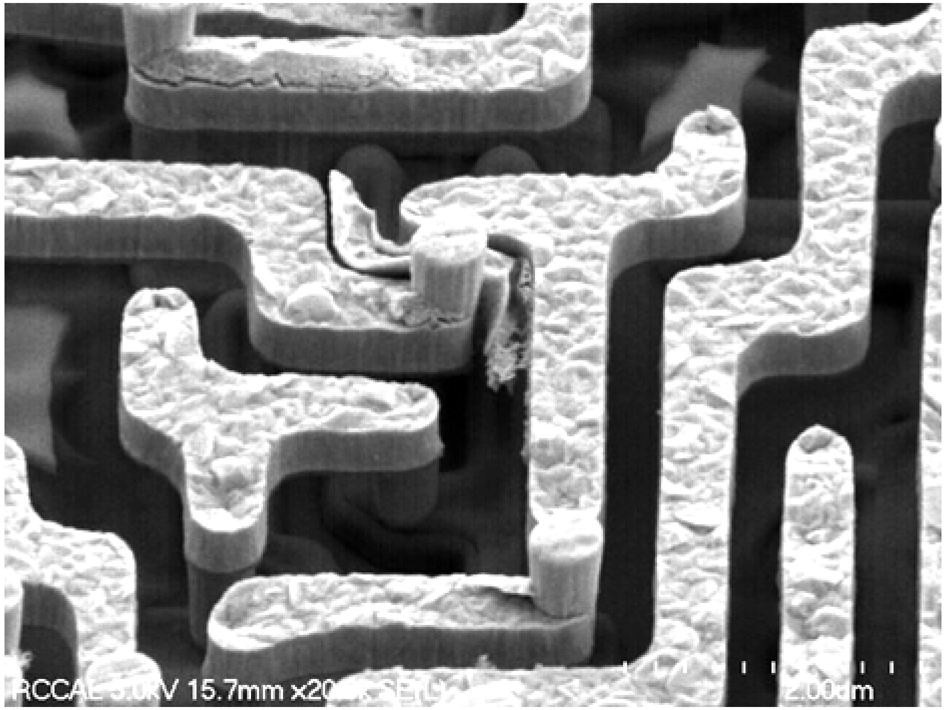
TLS application on shorted device





Technology: 0.25µm – 6 metal layers

Physical analysis: SEM observation

<u>Conclusion:</u>

Root cause of failure on this product was a **short LIL (W).**

NB: Defect found in front-end level has been detected and localized **through 6 metal layers**

SUMMARY OF STATIC TLS TECHNIQUES

Interaction between IR laser beam and the IC material will generate:

- Optical to thermal transformation,
- Heating of conductive materials

→ modification of IC current consumption

OBIRCh

$$\Delta i = -\alpha_{TCR} * \Delta T * (\frac{U}{R})$$

ΔI = -(ΔR/R)*I

TIVA

$$\Delta V = \alpha_{TCR} * \Delta T * R_0 * I$$

ΔV = ΔR*I

SEI

ΔV= (Q1-Q2)*∇T= Q1-2* ∇T

Resistivity change detection

Thermocouple detection

Conclusion

Thermal Laser Stimulation allows :

- Localizing accurrately metallic shorts via fronstide and backside of IC,
  - No shift of defect position,
  - Weak thermal expansion (~30μm).

- Localizing non metallic defect
  - Polysilicon bridging or melted silicon,
  - Bridging active area,
  - Implants defects, ..
  - Spiking defects,
  - Interface defects of vias/contact.