Thermoreflectance-Based Submicron Temperature Profiling and Structure Function Analysis for Multilayer Nanostructures

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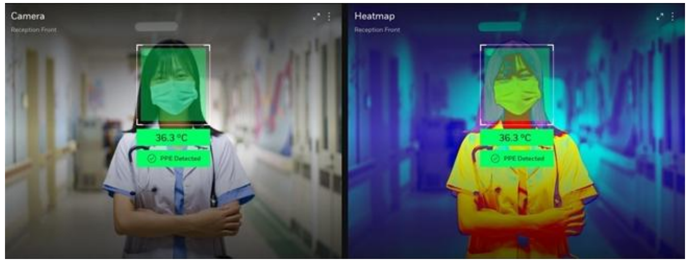
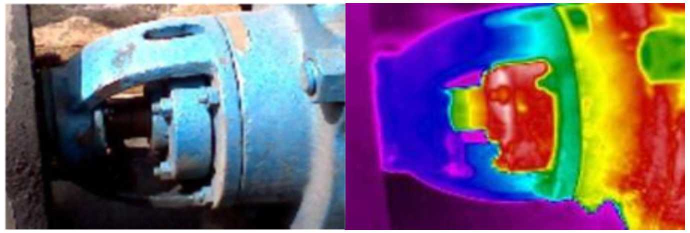
Analysis Using Thermal Imaging Measurement Technology

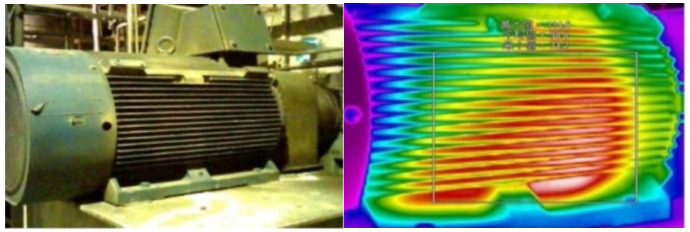
■ Various Analysis Using Temp. Measures



Covid-19 Fever Screening

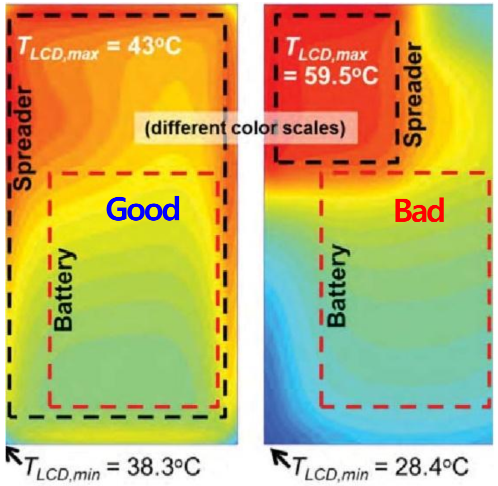


Internal Bearing



Internal Motor

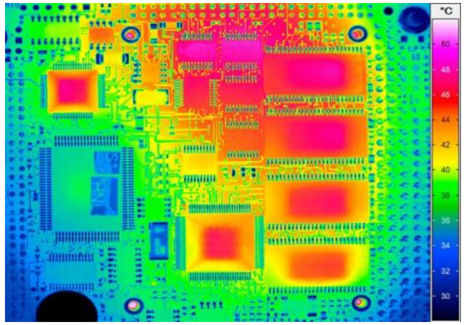
■ Analysis in the Electronics Field



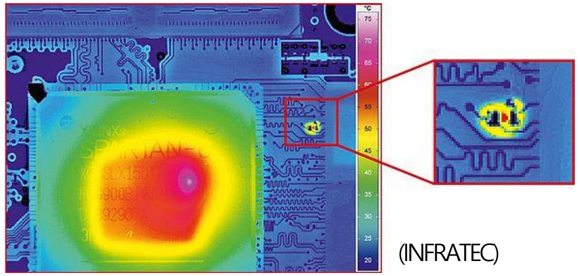
(15, Engineering, Smart Phone Thermal Management)

Thermal Distribution Optimization Design

- Improper Layout
- Improper Thermal Spreader
- …



(INFRATEC)



(INFRATEC)

Defect Analysis

- Short Circuit
- Incorrect Location (Assembly)
- Insufficient Tin for Soldering
- …

Thermal imaging measurement featuring advantages such as 2D analysis (location), non-contact, and real-time monitoring

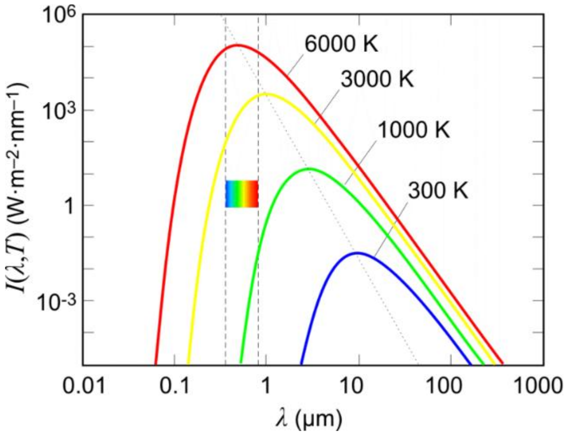
Thermal Analysis Using Infrared Measurement

■ Planck's Law(Germany, 1900) & Infrared (IR) Cam.

· All objects above absolute zero emit thermal radiation (energy).

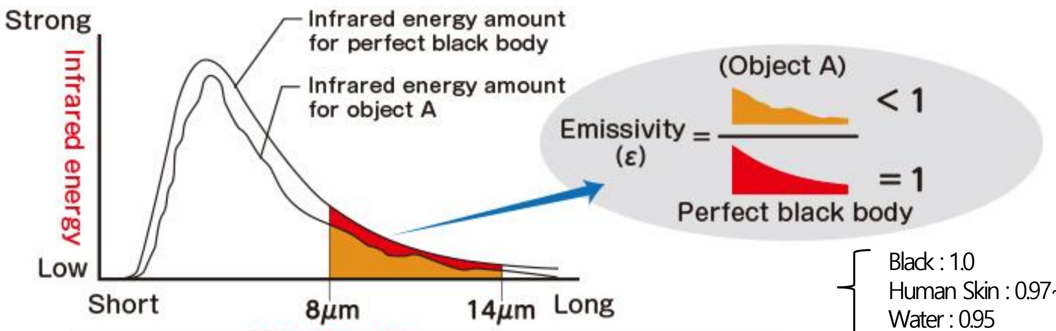
· The intensity of thermal radiation is related to 1) Object Temperature, and 2) Emissivity (Surface Condition).

· Photodetector (light-to-electricity conversion, e.g., photodiode) + Image Sensor (image processing, e.g., CCD, CMOS)



Radiation Energy According to Temperature

Visually Observable Radiant Energy



e.g., Energy(100%) = Reflection(20%) + Transmission(10%) + Emission(70%)

Black : 1.0
Human Skin : 0.97~0.99
Water : 0.95
White Cotton : 0.8
Metal : 0.25~0.7
Polished Metal : <0.05

Infrared Energy Emission Based on Emissivity

Same Temp. Diff. Emissivity   Same Temp. Diff. Reflectivity   Processing for Temp. Measurement

Infrared Measurement Results by Emissivity

IR cameras measure the amount of infrared radiation energy emitted from objects, not temperature itself

Thermal Image Measurement & Spatial Resolution

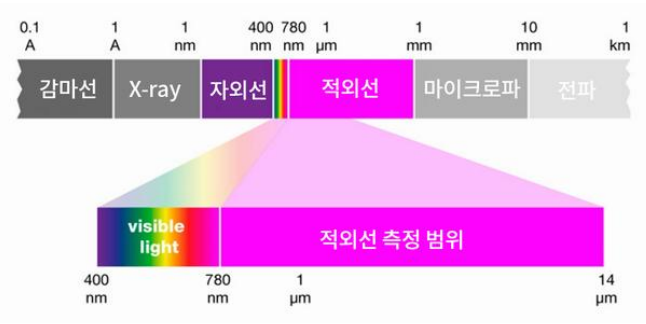
■ Spatial Resolution

· Abbe (Netherlands 1873) revealed the limit of resolution.

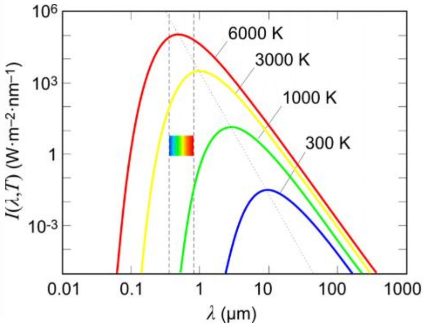
· To improve resolution, the wavelength must be shortened.

$$d = \frac{\lambda}{2n\sin\theta}$$

d : Resolution
$n\sin\theta$: Numerical Aperture (NA), max = 1
n : Refractive index
λ : Wavelength of light



Theoretical Resolution Limit: 0.36μm ~ 7μm



Resolution Limit in 300K: 5μm

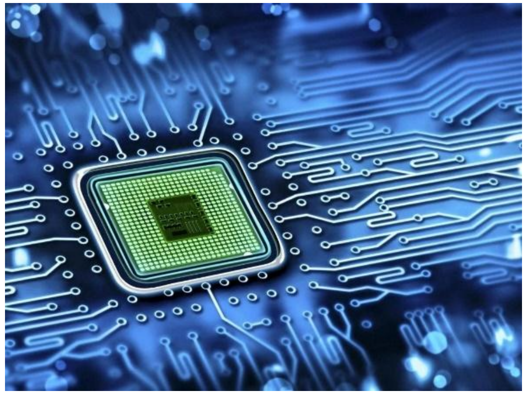
■ Thermal Reliability Issues in Integrated Circuits

· Smaller Features (10nm~100μm) → Contact is Not Possible.

· Increasing Power Density → Higher Heat / Localized Heat

· Lifetime : 15℃↑ → Lifetime 1/4↓

· High Speed Response

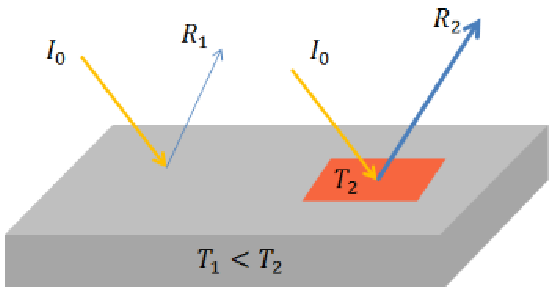


IR thermal imaging lacks sufficient resolution for dense circuit inspection in the submicron range.

Thermo-Reflectance Measurement Equipment – Spatial/Temp. Resolution

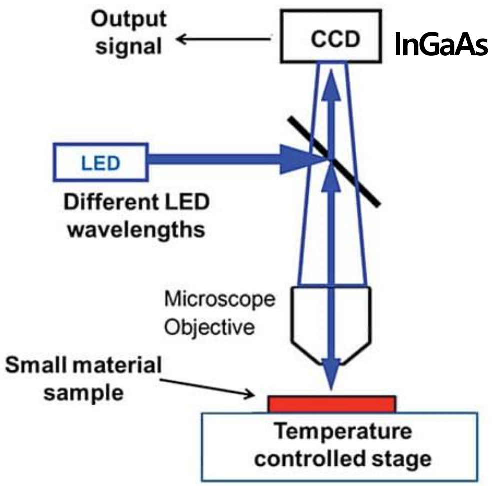
■ Principle of Thermo-Reflectance Measurement (ref., MicrosanJ / Nanoscopesystems / ALTER Tech. / Electronics Cooling)

- The optical reflectance (R) of a sample changes depending on its temperature. (1968, Thermoreflectance in Semiconductors, Phys. Rev.)
- By measuring the change in reflectance (ΔR), we can experimentally determine the temperature change (ΔT) ➔ requires the TR coefficient (C_{TR})
- When CTR is large at a specific illumination wavelength, temperature resolution improves → Proper illumination wavelength selection is required



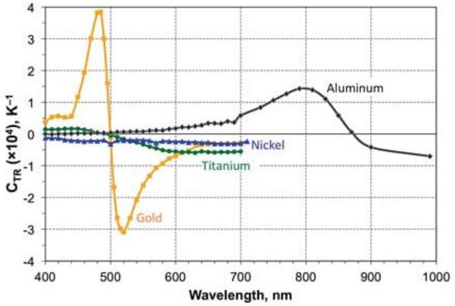
$$\frac{\Delta R}{R} = \left(\frac{1}{R}\frac{\partial R}{\partial T}\right)\Delta T = C_{TR}\Delta T$$

C_{TR} : Thermoreflectance Coefficient (10^{-2}/K ~ 10^{-5}/K)
C_{TR} = f(Ambient Temperature,
Illumination Wavelength [Visible LED Source],
Material & Surface Prop. [Polishing, etc.],
Optics/Microscope NI)



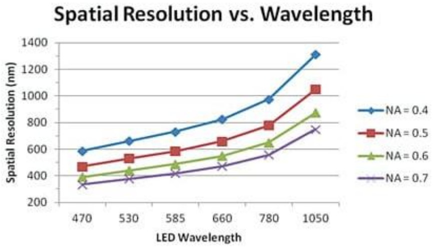
Measurement Process of Reflectance Coefficient @ Target Temperature Range

Material-specific Thermoreflectance Coefficient & Illumination Wavelengths



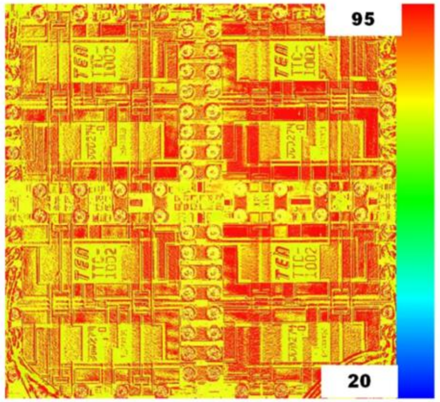
Material	Illumination Wavelength 365 nm (UV)	470 nm (Blue)	530 nm (Green)	585 nm (Yellow)	660 nm (Red)	780 nm (N-IR)	1.05-1.3 μm
Gold (Au)		■	■				
Aluminum (Al)						■	
Nickel (Ni)				■	■		
Titanium (Ti)				■	■		
Silicon (Si)		■					
Gallium Arsenide (GaAs)		■					
Gallium Nitride (GaN)	■	■	■				
Indium Phosphide (InP)		■					
Thru-the-Substrate Imaging							■

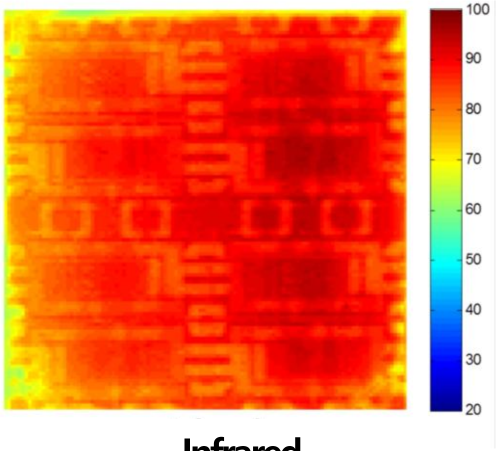
Optical System and Resolution

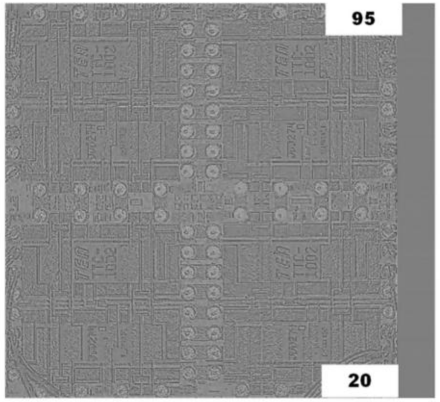


Comparison of Thermal 2D Images

■ TR(Visible Light) vs. Thermal Emission(IR) vs. Optical







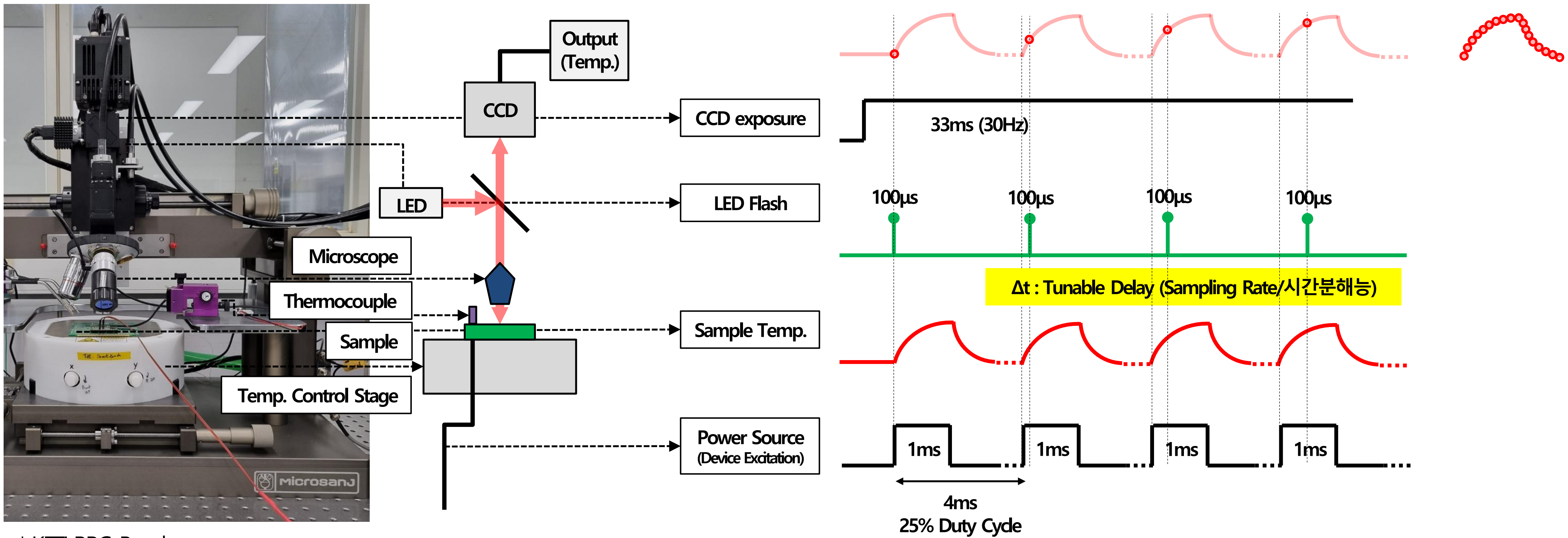
	Thermoreflectance	Infrared	Microscope
Principle	Change in reflectance by Temp.	Radiation Emissivity by Temp.	-
Coefficient	Reflectance coefficient by material	Emissivity by material	-
Spatial Resolution	0.35 ~ 0.85µm	3.0 ~ 10.0µm	0.2µm
Temp. Resolution	0.08K (Thermoreflectance Sensitivity)	0.02K (Radiative energy sensitivity)	-
Others	AC Technique W/ Lock-in	Si transparent to IR Metals are poor emitters.	-

The spatial resolution of thermo-reflectance measurement using visible light is about 10 times higher than that of IR.

Transient Thermo-Reflectance Measurement Equipment – Temporal Resolution

Transient Measurement Based on Lock-in Cycle

· Lock-in : In noisy environments, extracts Amplitude and Phase signals using a Low-Pass Filter



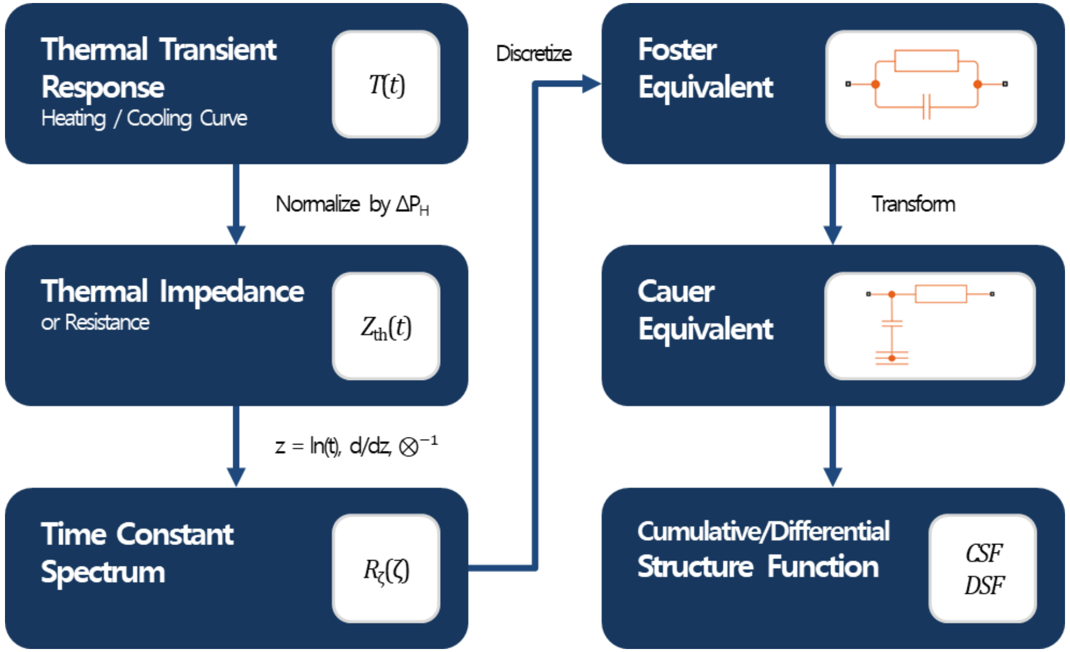
* KETI RRC, Bundang-gu

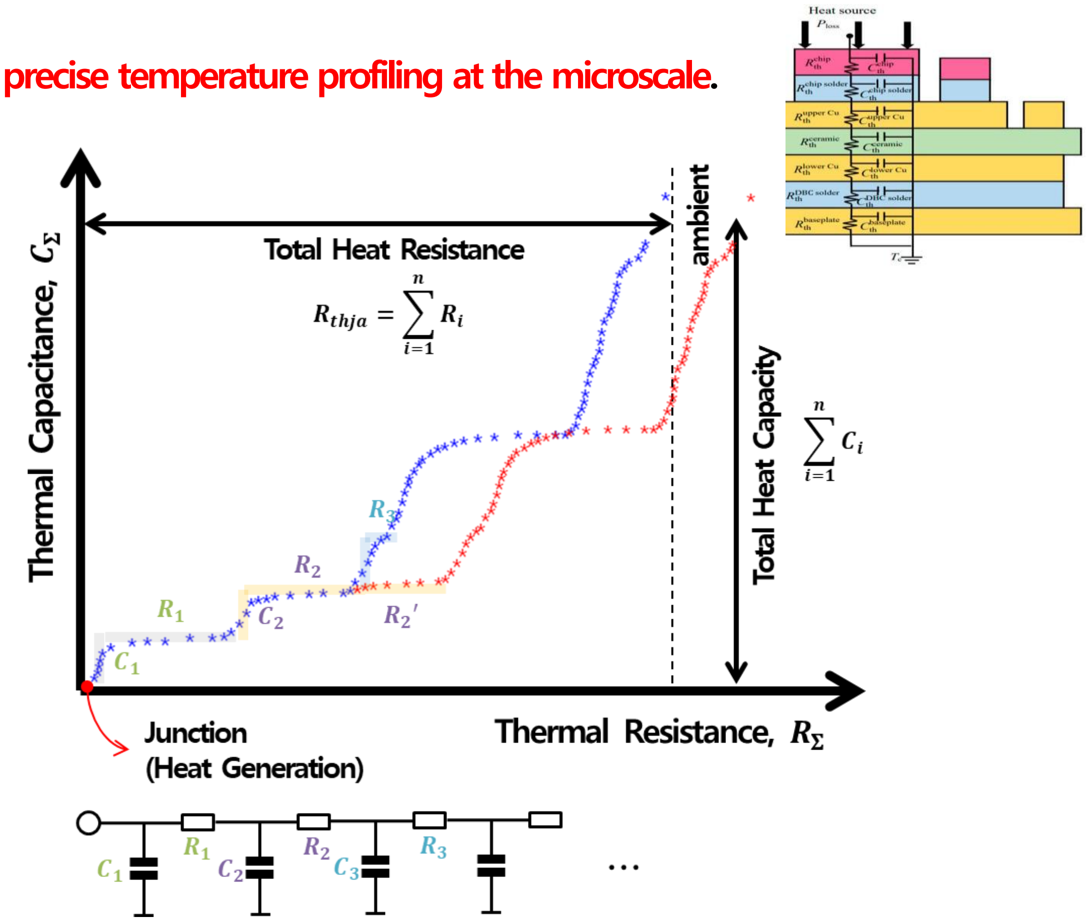
Transient characteristics can be measured through LED Flash Delay

Analysis of Multilayer Semiconductor W/ Transient Temp.

■ Thermal Analysis with Structure Function

· Structure function analysis requires thermal transient response – demanding precise temperature profiling at the microscale.





Using structure function for thermal dissipation, verify package design, and identify failure-related thermal anomalies.

Thank You

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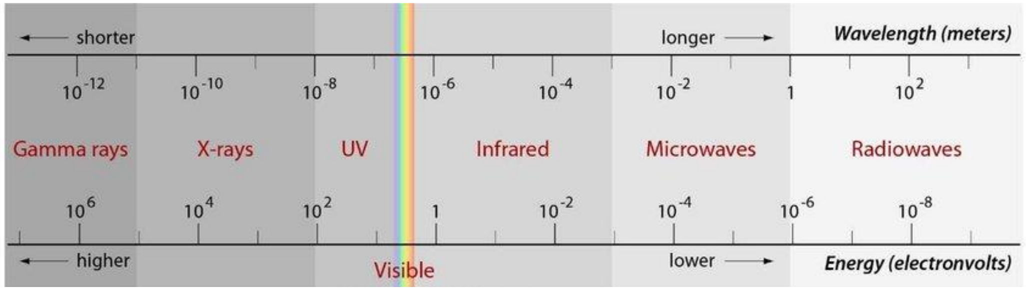
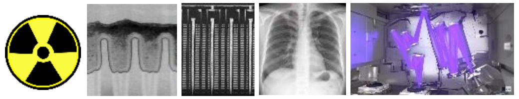
(참고) UV 기반 열 이미지 측정?

■ Electromagnetic Spectrum

출처: 10.5281/zenodo.3534245



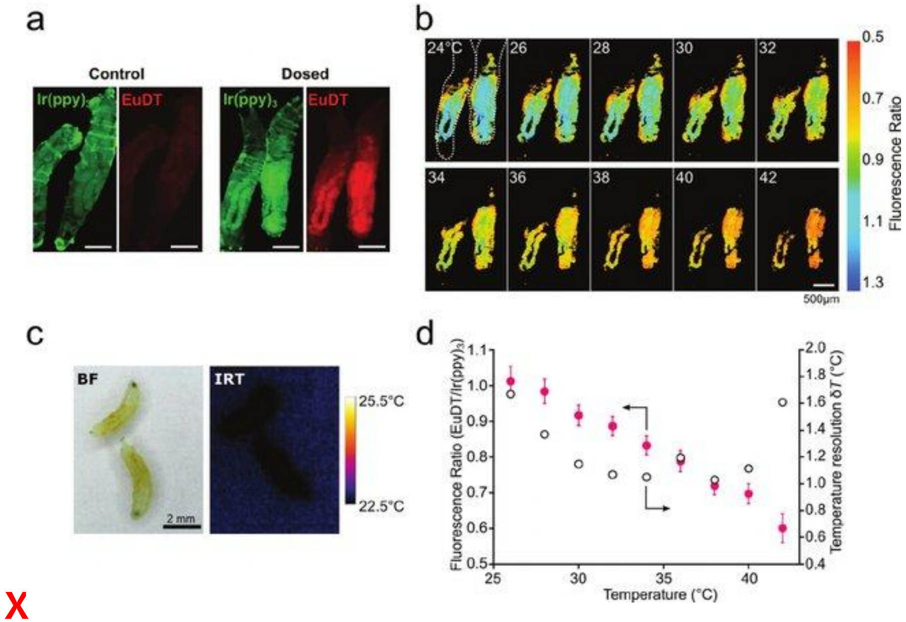


Method	Wavelength[nm]	Application	
Infrared	$700\text{-}10^5$	IR cam	3µm
Visible	400-700	TTR 광학	300nm 200nm
UV	1-400	EUV	13.5nm
X-rays	0.01-1	SEM(주사) TEM(투과)	5Å 1Å
Gamma Rays	<0.01	암치료	

* Si 원자 공유반경 : 1.11Å = 0.111nm

■ Fluorescent(형광) Micro-thermography

· 형광체 코팅 → 자외선 조사 → 적외선 검출 온도 측정



→ 재료 손상 위험

→ 온도에 대한 계수 X