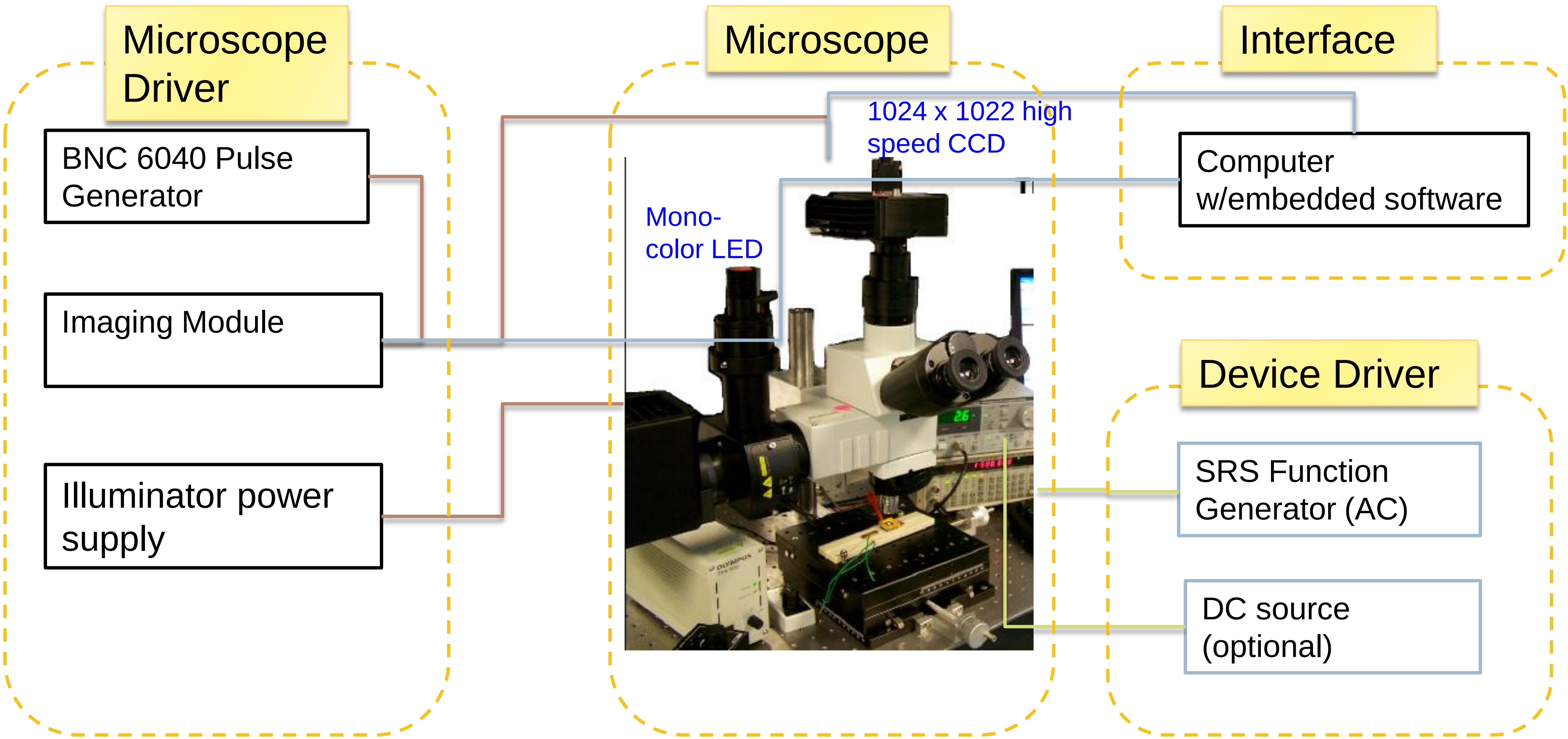
Thermoreflectance Imaging Microscope and Its Applications Part1-Thermoelectric

Xi Wang, UC Santa Barbara, Jan 20th, 2011

The Scope of This Document

- Description of Nanotherm System
- Applications of TI in Thermoelectric Research
    - Device Defect and Design Flaw Inspection
    - Thin Film Thermal Conductivity Measurement
    - In-plane (quasi-1D) Thermal Conductivity Measurement
    - Cross-plane Seebeck (Transient ZT) Measurement
- Experiment Check List
- Key System Specifications

Microsanj Nanotherm



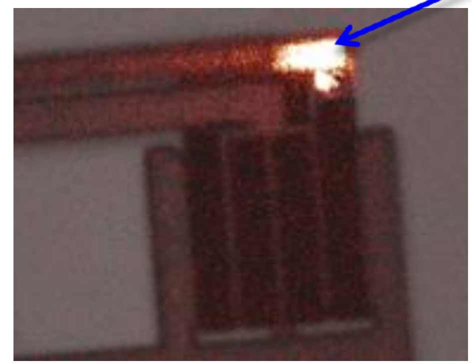
Location: ESB Bower's Lab
PI: Prof. John E. Bowers

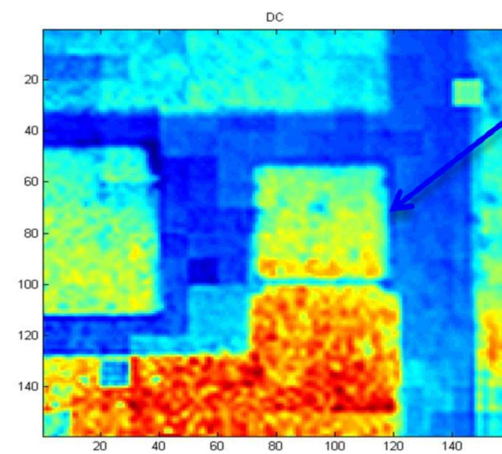
Device Defect and Design Flaw Inspection

- Most fabrication defects cause electrical current crowding or vacuuming. Most electrical field discontinuity can be reflected in forms of local temperature discontinuity

- Look at temperature, so that we know what/why is not working/ not working well.

Micrometer level local shorting





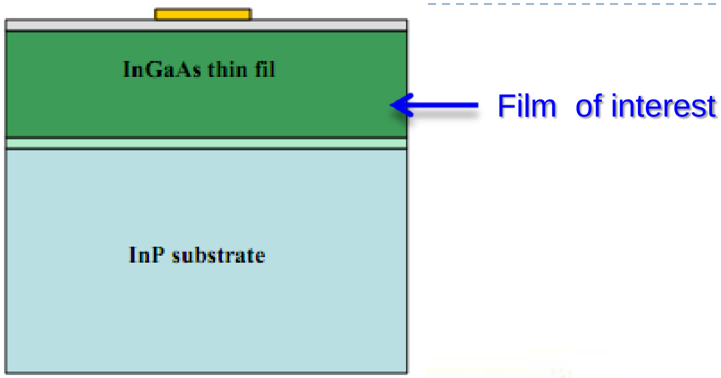
TE micro cooler overwhelmed by lead heating

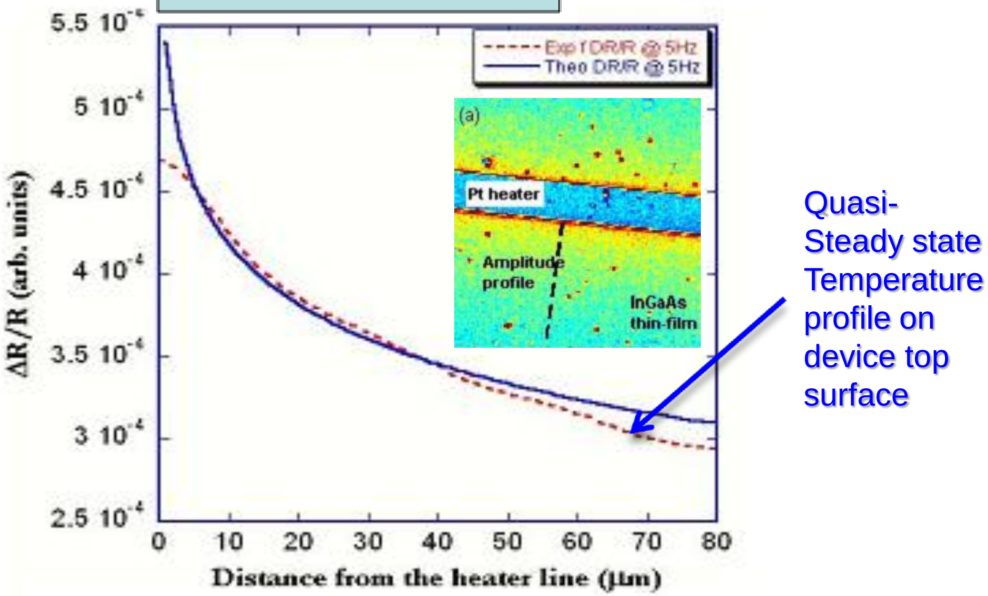
Thin Film Thermal Conductivity Measurement

- Surface temperature is a result of thin film thermal conductivity and substrate thermal conductivity

$$\Delta T_f(x) = \Delta T_T(x) - \Delta T_S(x) = \frac{P}{l}\frac{d_f}{W\beta_f}$$

- Share sample structure with 3 ω devices (Semi-infinite heat dissipation structure)
- Comparison between TI data with calculation gives film thermal conductivity
  - Steady state calculation vs Absolute Magnitude and Shape of TI profile
  - Frequency dependent calculation vs Frequency dependent TI profile shape (no absolute magnitude is need)



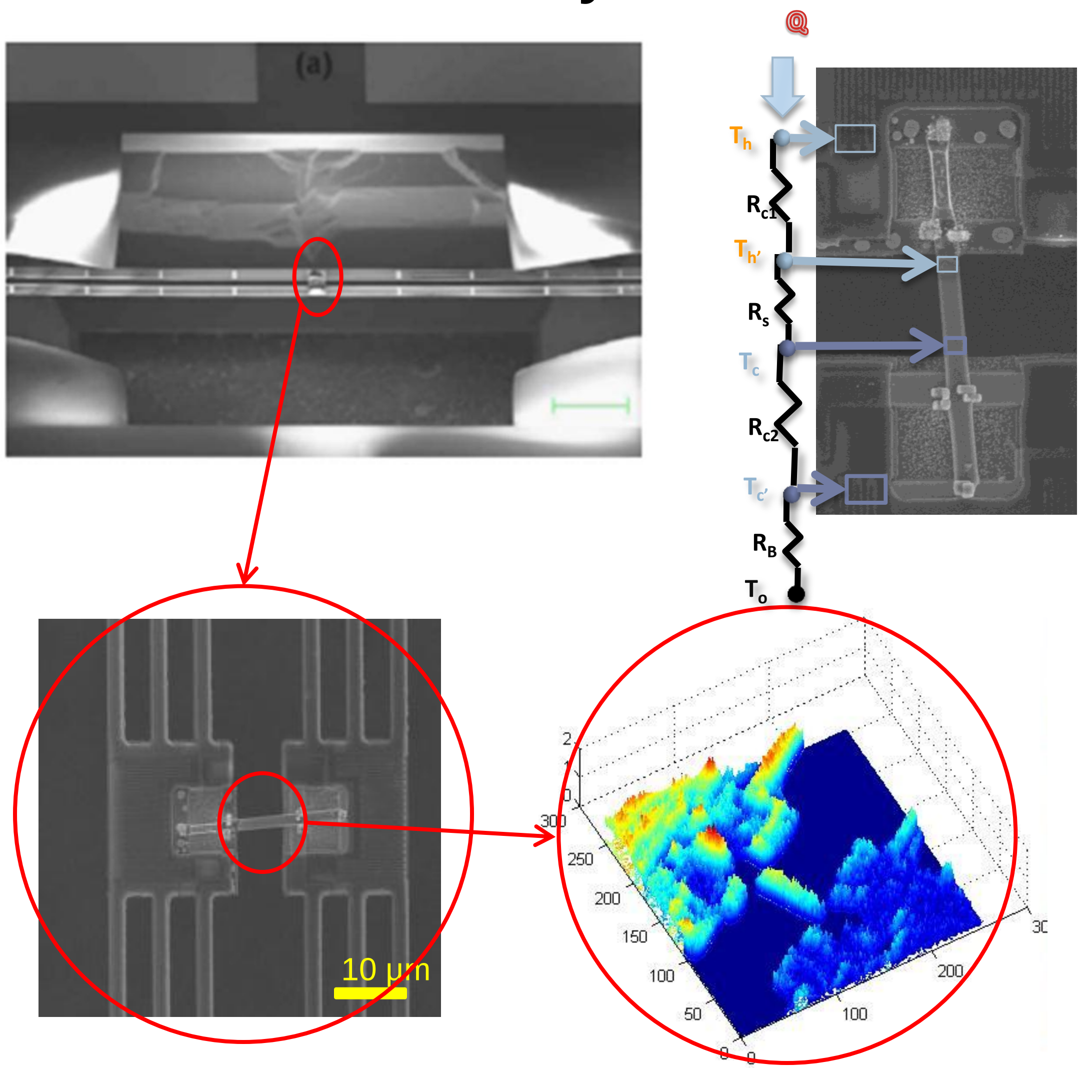


K. Maize, Y. Ezzahri, X. Wang, S. Singer, A. Majumdar, A. Shakouri, "Measurement of thin film isotropic and anisotropic thermal conductivity using three omega and thermoreflectance imaging", Proc. 24th IEEE SEMI-THERM, March 16-20, pp. 185-190, 2008.

Application in Thermoelectric Research

In-Plane / Quasi-1D Thermal Conductivity Measurement

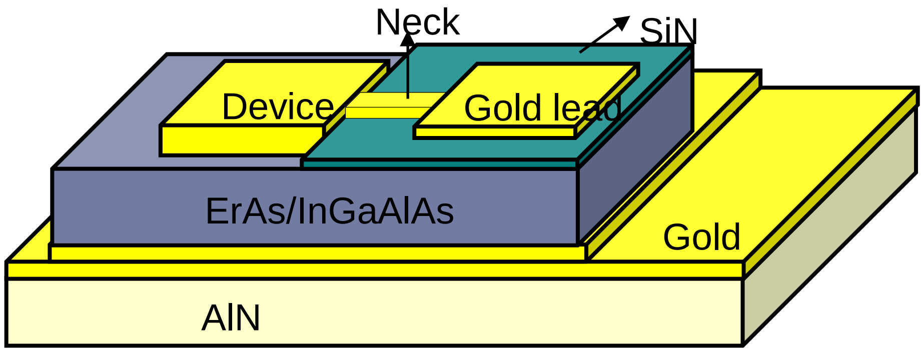
- In-plane and quasi-1D (nanowire,-belt, -tube) thermal conductivity measurement is extremely sensitive to parasitic heat flows (substrate leakage, convection loss)
- TI allows direct probing of temperature on a suspended film (no substrate leakage, no contact thermal resistance)
- In-plane thermal conductivity is given by temperature on ends of thin film, on both sides of suspended device, and inputting power.

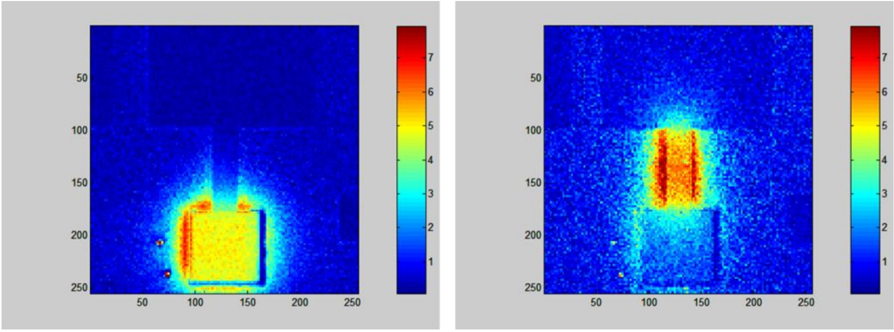


X. Wang, A. Shakouri, A. Mavrokefalos, Y. L., H. Kong, L. Shi H. Lu, A. C. Gossard, and J. E. Bowers "In-plane Thermal Characterization of a Thin-film Sample Suspended between two Micro-thermometers using Thermoreflectance Thermal Imaging ", Submitted to Nanotechnology, Dec. 2010.

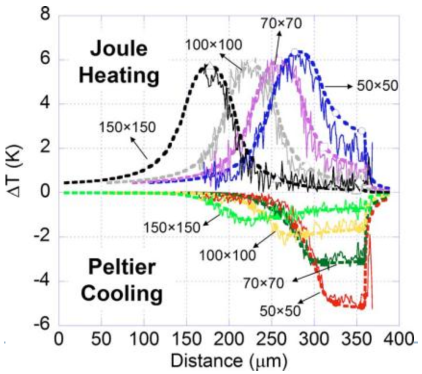
Cross-plane Seebeck /Transient ZT Measurement

- Peltier effect and Joule effect coexist in material under bias
- Tracking signal at different frequencies (1st and 2nd harmonic) allows viewing the Peltier and Joule contribution of temperature separately.
- Signal separation can be done in frequency domain or in time domain (forward biasing+/- reward biasing)
- TI is also useful in transient ZT (Harman) measurement for experiment validation





Peltier Effect (100mA)   Joule Effect (100mA)



R. Singh, Z. Bian, A. Shakouri, G. Zeng, J.H. Bahk, J.E. Bowers, J.M.O Zide, A.C. Gossard, "Direct measurement of thin-filmed thermoelectric figure of merit", Appl. Phys. Lett. 2009 May; 94: 212508.

Experiment Checklist

Experiment	Is the thermal signal your are interested in in 5~200M Hz range?	Is your sample surface reflective to 450~900nm wavelength?	Is your substrate much more thermally insulating than your film?	Do you have in hand a lens in the correct spectrum range with >80X magnification?	Can you pin signal at different frequency? Or your device bias is revertible?	Is your inputting signal Sinusoidal?
Defect/ Performance Inspection	Yes	Yes				
Thin film Thermal Conductivity	Yes	Yes	Yes			
In-plan/quasi-1D Thermal Conductivity	Yes	Yes		Yes		
Cross-plane Seebeck /Transient ZT	Yes	Yes			Yes	Yes if signal separation is performed in frequency domain

System Spec

- Spatial Resolution ~200nm (diffraction limited)
- Temperature resolution ~0.1 degree C
- Active Thermal Pixels 1024 x 1022
- Thermal Image Frame Rate 1Hz (Recommend to use in 5~200M Hz range for good S/N)
- On Site objective lens: 5X, 20X 50X