Thermoelectricity: From Atoms to Systems

Week 3: Thermoelectric Characterization
Lecture 3.2: Micro/Nano Scale Temperature Measurement (Part 2)

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Scanning Thermal Microscopy

- Ambient condition
- Special thermocouple or thermistor tips

Shi, Majumdar et al., *J. MEMS*

A. Shakouri, nanoHUB-U Fall 2013
UHV Scanning TE Microscopy

H.-K. Lyeo, L. Shi, and C.K. Shih. (UT Austin)

- Elastic Nano-contact between metal tip and heated sample:
  \[ T_1 > T_c > T_0 \]
- Local Temperature Gradient
  \[ \Delta T \equiv T_1 - T_c \]
- Local Thermoelectric Voltage
  \[ V = S(x, y)(T_1 - T_c) \]
- \( V \rightarrow S \) profile

Mapping S of GaAs $p-n$ Junction

- Sharp transition across the junction
- Resolution of 6 nm
- Measure both carrier concentration and types

(1) Temperature is solved by finite difference method
(2) Poisson equation is solved numerically without depletion approximation
(3) Distributed thermoelectric potential and resistor network on cubic lattice
(4) The network is solved according to Kirchoff’s current and voltage law

Measured voltage is not only an average of local Seebeck coefficients.

- Decay of resistance is much faster than that of thermoelectric voltage.
- Equivalent potential is determined by the lower resistance side.

FIG. 4. The 3D thermoelectric voltage simulation for the finite tip size and the phonon mean free path. The dots are experimental data.

Zhixi Bian et al.
87 (5), 53115, 2005
Seebeck of single molecules

STM thermopower measurements

Reddy, Jang, Segalman, Majumdar, Science 2007
Seebeck of single molecules

Electronic Structure of BDT

Reddy, Jang, Segalman, Majumdar, Science (2007)
Seebeck of single molecules

Transport in Metal-Molecule-Metal hybrids

\[ E_F \]

\[ V = -S \Delta T \]

\[ I_{1-2} = -G_0 \int_0^\infty \tau(E)(f_1 - f_2) dE \]

\[ G \sim G_0 \tau(E_F) \]

\[ S = -\frac{V}{\Delta T} = -\frac{\pi^2 k_B^2 T}{3e} \left( \frac{1}{\tau(E)} \frac{\partial \tau(E)}{\partial E} \right)_{E=E_F} \]

Calibrated infrared imaging

Micro processor

Microrefrigerator

Francisco Mesa-Martinez,
Jose Renau, UCSC

Vivek Sahu, Georgia Tech

Liquid Crystal Thermography

www.electronics-cooling.com
Thermal imaging of nanostructures with a scanning fluorescent particle as a probe

Simplicity

Infrared excitation:
emission and absorption lines well separated

Lionel Aigouy, ESPCI, Paris, France

HOW CAN WE DEDUCE THE TEMPERATURE?

Er / Yb ions

PL spectrum of Er / Yb doped particles

\[ \frac{I_{\text{green}}}{I_{\text{yellow}}} \propto \exp\left(-\frac{\Delta E}{kT}\right) \]

Lionel Aigouy, ESPCI, Paris, France
Thermal imaging using Fluorescence Nanoparticles

Lionel Aigouy, ESPCI, Paris, France

I = 50 mA

I = 0 mA

Uniform temperature (room temperature)

Optical contrast visible between different zones

Reference image

APL, 87, 184105 (2005).
Lecture 3.2: Summary

- Scanning TE Microscopy (UHV)
- Seebeck of single molecules
- Infrared Thermal Imaging
- Scanning Fluorescence Microscopy
- Liquid Crystal thermography