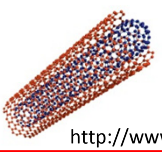
Evaluation of Thermal Conductivity of Single Carbon Nanotube Using Fluorescent Gel Temperature Sensor in Liquid

○Kyohei Tomita*, Hisataka Maruyama**, Fumihito Arai***,****
*Dept. of Mechanical Engineering, Nagoya University, JAPAN
**Dept. of Mechanical Science and Engineering, Nagoya University, JAPAN
***Dept. of Micro-Nano Systems Engineering, Nagoya University, JAPAN
****Seoul National University

What's new?: To evaluate thermal conductivity of CNT in Liquid

Background

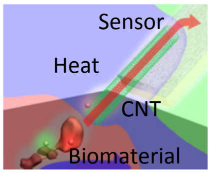
Application of properties of CNT



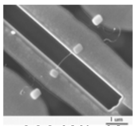
- High young modulus(～0.9TPa)
- High thermal conductivity (3000～6000 W/mK)

http://www.surf.nuqe.nagoya-u.ac.jp

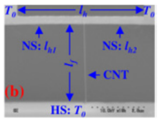
Nano-thermometer



Conventional evaluation of thermal conduction



300 W/mK
T.Y. Choi, et al, NANO LETTERS, Vol. 6, No. 8, 1589-1593, 2006.



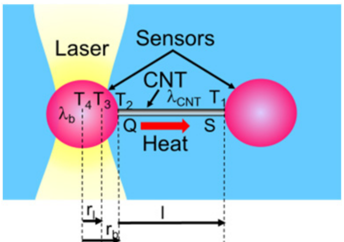
2000 W/mK
M. Fujii, et al, PHYSICAL REVIEW LETTERS, 95, 065502, 2005.

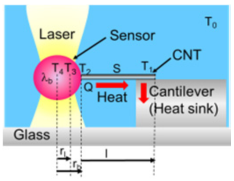
These measurements is in vacuumed condition.

Evaluation of single CNT in liquid is required.

Evaluation Model

Evaluation model using polymer temperature sensor





※Assumption: $T_0=T_1$

Thermal conductivity

$$\lambda_{CNT}=\frac{l}{S}\cdot\frac{\alpha\lambda_b Q}{\alpha\lambda_b(T_4-T_1)-Q}\qquad \alpha=\frac{4\pi}{\frac{1}{r_l}-\frac{1}{r_b}}$$

Sensing value: T_4 and T_1

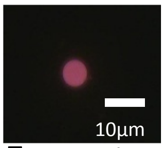
Assumptions:
$T_4=T_3$,
Heat does not escape to water.

Inside the sensor
$$Q=\frac{4\pi\lambda_b}{\frac{1}{r_l}-\frac{1}{r_b}}(T_3-T_2)\quad (1)$$

Inside the CNT
$$Q=\frac{S\lambda_{CNT}}{l}(T_2-T_1)\quad (2)$$

λ_{CNT} [W/mK]: Thermal conductivity of CNT
λ_b [W/mK] : Thermal conductivity of sensor
T_1 [K]: Temperature at edge of sensor
T_2 [K]: Temperature at edge of CNT(Heat input side)
T_3 [K]: Temperature at the edge of laser spot
T_4 [K]: Temperature at the center of sensor
Q_{in} [W]: Heat input Q [W]: Heat flow to CNT
r_l[m]: Radius of laser spot r_b[m]: Radius of sensor
l [m]: Length of CNT S [m²]: Cross-section area of CNT

Polymer temperature sensor

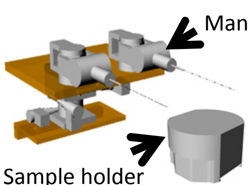


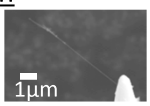
Materials
- Photo-crosslinkable resin
  → Connection to CNT
- Quantum Dot (Lumidot590)
  → Temperature sensitive

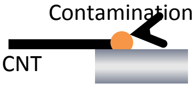
Temperature measurement
- Fluorescent intensity
  Major method,
- Peak wavelength
  High precision, Low sensitivity
- Fluorescent lifetime
  High precision, Low sensitivity

Fabrication Process of Model:

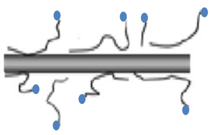
SEM Nanomanipulation System

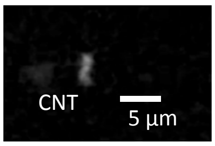




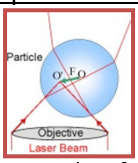


Fluorescence Stain of CNT for OM Observation

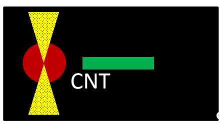


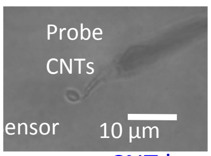


Optical Tweezers



Principle of Optical tweezers

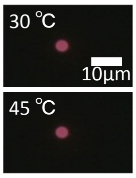


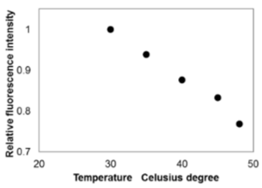


Connection of sensor to CNT by optical tweezers

Error Evaluation of Model:

Temperature calibration: Sensor





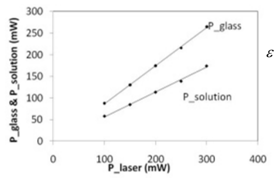
$$T=-8.0\times10^1\times I/I_{30}+1.1\times10^2$$

Sensitivity: -1.1 %/K
Accuracy: ±0.5 K

Temperature calibration: Chamber

Chamber: ZILCOS (Tokai Hit. Co. LTD.)
Accuracy: ±0.3 K

Laser heat absorption



$$\varepsilon=\frac{\frac{P_{glass}-P_{solution}}{18000}}{P_{laser}-\frac{P_{laser}-P_{glass}}{2}}\times100$$

Accuracy: 5%

Absorption rate of sensor
$1.81\times10^{-3}\ \%/\mu m$

Simulation of evaluation error

Errors: Q: ±5% T_0 : ±0.3 K T_1 : ±0.5K

T0=30 K, T1=60 K, T2=77 K, T3=77 K, $l=3\times10^{-6}$ m, $S=1962\times10^{-18}$ m², $r_l=0.7\times10^{-6}$ m, $r_b=2.5\times10^{-6}$ m, $\lambda_{CNT}=3000$ W/mK, $\lambda_b=0.287$ W/mK

From (1), $\Delta\lambda_b=7.9\%$

$$\lambda_{CNT}=\frac{l}{S}\cdot\frac{\alpha\lambda_b Q}{\alpha\lambda_b(T_1-T_0)-Q}$$

$$\Delta\lambda_{CNT}\fallingdotseq 20\%$$

Conclusions:

Evaluation model for thermal conduction in liquid using polymer temperature sensor was proposed.(Error of this model is 20 %).
Measurement of heat conductivity using this model is future work.

Reference: Kyohei Tomita, Hisataka Maruyama, Fumihito Arai, The 40th Commemorative Fullerenes-Nanotube General Symposium, p.208, 2011

Contact: Kyohei Tomita
E-mail: k.tomita@biorobotics.mech.nagoya-u.ac.jp,
URL: http://www.biorobotics.mech.nagoya-u.ac.jp/,
TEL: 052-789-4510, FAX : 052-789-521

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