Evaluation of Thermal Conductivity of Single Carbon Nanotube in Liquid Using Fluorescent Micropillars

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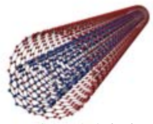
How to measure Thermal Conductivity of Individual CNT in Liquid ?

1. Background & Motivation

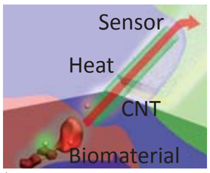
Properties of CNT



Carbon Nano Tube (CNT)

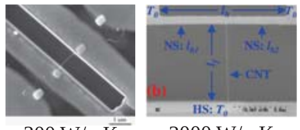
- High young modulus (～0.9TPa)
- High thermal conductivity

Biological application of CNT



Ex) Nano temperature sensor

Conventional evaluation of thermal conduction



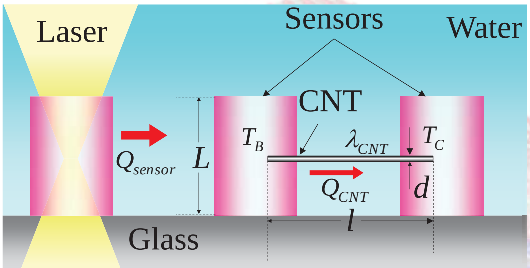
300 W/mK 2000 W/mK

T.Y. Choi, et al, NANO LETTERS, Vol. 6, No. 8, 1589-1593, 2006. M. Fujii, et al, PHYSICAL REVIEW LETTERS, 95, 065502, 2005.

These measurements is in vacuumed condition.

Evaluation of single CNT in liquid is required.

2. Evaluation Model



Evaluation model of thermal conduction of CNT

- λ_{CNT} [W/mK] : Thermal conductivity of CNT
- λ_{sensor} [W/mK] : Thermal conductivity of sensor
- T_1 [K] : Temperature at edge of CNT (heat input side)
- T_2 [K] : Temperature at edge of CNT (other side)
- Q_{CNT} [W]: Heat flow to CNT
- Q_{sensor} [W]: Heat flow to sensor
- l [m] : Length of CNT
- d [m] : Diameter of CNT

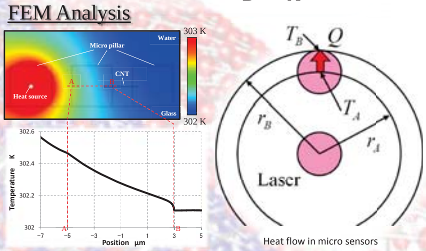
Thermal Conductivity

$$\lambda_{CNT} = \frac{l}{\pi(d/2)^2}\cdot\frac{Q_{CNT}}{T_B - T_C} \quad (1)$$

Heat flow from sensor to CNT

$$Q_{Sensor} = -\frac{2\pi\lambda_{Sensor}L(T_B - T_A)}{\ln(r_B / r_A)} \quad (2)$$

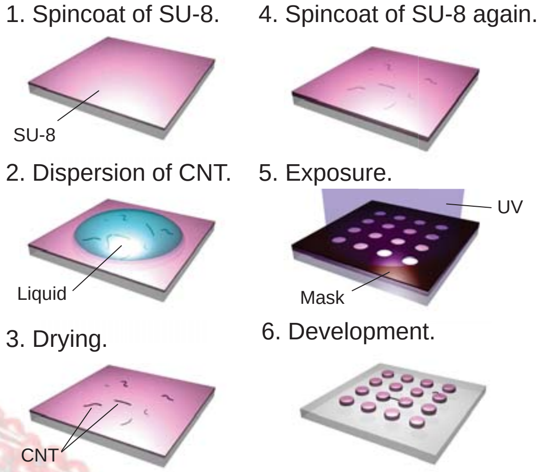
FEM Analysis



Temperature distribution in sensors

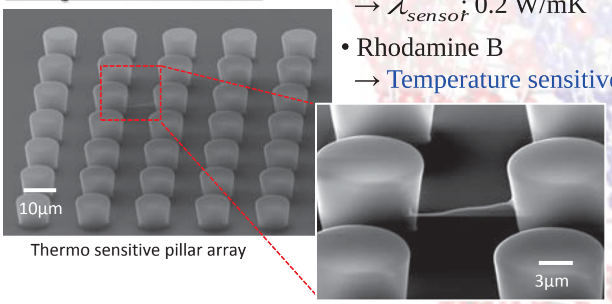
Heat flow in micro sensors

3. Fabrication Process



4. Experiments

Temperature Sensor



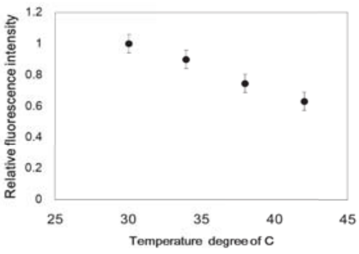
Thermo sensitive pillar array

CNT bridge

Materials

- SU-8 3005
  → λ_{sensor}: 0.2 W/mK
- Rhodamine B
  → Temperature sensitive

Sensitivity of Sensor



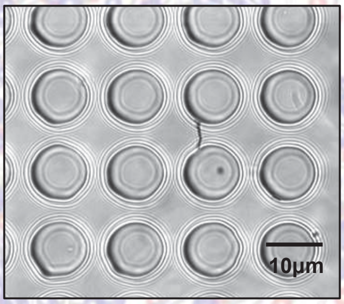
Calibration of temperature sensor

Measurement system

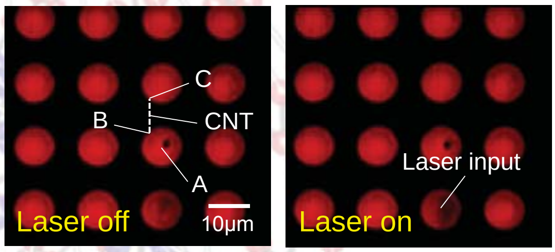
- EM CCD (iXon,Andor)
- Confocal scanning system (CSU-X1,Yokogawa)

Sensitivity: -3.0 %/K
Accuracy: ±1.0 K

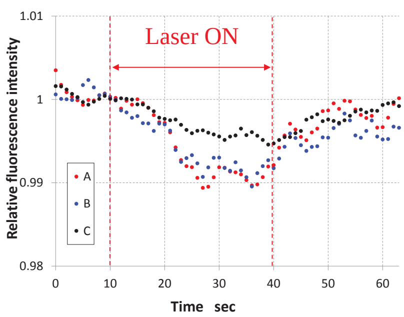
Measurement of Thermal conductivity of CNT



Optical image of measurement system



Fluorescent image of measurement system



Relative fluorescent intensity of temperature sensor

Correction of discoloring

$$I = I_{sensor} - \Delta I_{discolored}$$

- I : Relative fluorescent intensity (RFI)
- I_{sensor} : RFI of sensor
- $\Delta I_{discolored}$: Variation of RFI by discoloring

Laser Power : 5.4W
Wavelength : 1064nm

$l = 5.5[\mu m]$
$d = 0.14[\mu m]$

Heat flow Q (from Eq.2)

$$Q = 1.1\times10^{-5}[W]$$

Thermal Conductivity λ_{CNT}

$$\lambda_{CNT} = 1.2 \pm 0.3[kW/mK]$$

(N = 6)

5. Conclusions

We proposed evaluation method of thermal conductivity of individual CNT in liquid using temperature sensitive micro pillars. We succeeded in measuring the thermal conductivity of individual CNT in liquid. As a result, thermal conductivity of that was 1.2 ± 0.3 kW/mK. In the future, we can apply this method to evaluate the thermal conduction of individual CNT with different diameter in different condition such as air and vacuumed condition.

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References
1. H. Maruyama, et. al., IEEE 12th International Conference on Nanotechnology (IEEE NANO 2012), TuA26-2,2012
2. R. Kariya, et. al., 23rd Micro-NanoMechatronics and Human Science (MHS 2012), pp. 215-217,2012