NSC90-2212-E-009-049
90 8 1 91 7 31

(microtube)
( )
( )
(phononspectral) ( )

(relaxation time)
Callaway

Majumdar

(bulk system) (superlattice)

In this project, we theoretically investigate the thermal transport phenomena in microtubes. The main focus are on two subjects. One is the geometric effect (thickness and curvature) on the characteristic spectrum and heat transport by phonon. The other is the phonon heat conduction in the multilayer microtubes. Phonon is regarded as quantized energy of lattice wave. By adapting suitable boundary conditions, the phonon spectrum is solved. The relaxation time model is used to simulate the phonon scattering process. The heat transport in the microtube is examined with use of the Callaway expression for the thermal conductivity. Besides, the Equation of Phonon Radiative Transfer in association with the nodal approximation technique is used to simulate the heat transport in the multilayer microtubes. Phonon interface scattering mechanisms are considered, including diffuse and specular scattering of phonons. The results are then discussed and compared with both the bulk system and the superlattice system.

[1-3]

[4-8]

[9,10] (in)
(cross) BTE [11,12]

(Fourier law)

$$q \quad k \quad T \qquad (1)$$

[18] $k \quad \frac{1}{3} cvl$ (2)

c v l

Majumdar[11] L 1

$_L$ $\frac{L}{l}$ L l

(Boltzmann)

(equation of phonon radiative transfer)

$_L$ 1

Debye

q $k_B T_1^4$ T_2^4 (3)

q k_B T_1 T_2

Callaway's

[16,17]

k $\frac{k_B}{2^2 v}$ $\frac{k_B}{}^3 T^3 \int_0^{/T} \frac{_c x^4 e^x}{e^x 1^2} dx$ (4)

k_B h $\frac{h}{2}$

debye x $w/k_B T$ $_c$ v

(P.Debye

debye $\frac{hw_D}{k_B}$ w_D debye)

z

w w

[12]

Debye

w_1 $_1$ w_2 $_2$

w_3 $_3$

w_1 w_2 w_3 (5)

$_1$ $_2$ $_3$ (6)

$_1$ $_2$ $_3$ G (7)

(5) (6)

(5) (7)

N process

U process

Umklapp

$\frac{1}{_c}$ $\frac{1}{_U}$ $\frac{1}{_B}$ $\frac{1}{_I}$ (8)

U B I U process

U process

.

$\frac{^2U_r}{t^2}$ 2 $\frac{}{r}$ 2 $\frac{w}{z}$ (9)

$\frac{^2U_z}{t^2}$ 2 $\frac{}{z}$ $\frac{2}{r}\frac{}{r}$ rw (10)

$\frac{1}{r}\frac{rU_r}{r}$ $\frac{U_z}{z}$ (11)

$2w$ $\frac{U_r}{z}$ $\frac{U_z}{r}$ (12)

(9) (10)

r a r b

$$2A \quad \frac{}{r} J_0 h`a \quad C \; 2^{\;2} \quad \frac{w^2}{} \quad J_1 k`a \quad 0 \tag{13}$$

$$2A \quad \frac{}{r} J_0 h`b \quad C \; 2^{\;2} \quad \frac{w^2}{} \quad J_1 k`b \quad 0 \tag{14}$$

$A \quad C$

[13]

.

[11] (BTE)

Majumdar[12]

(EPRT, equation of phonon radiative transfer)

$$\frac{dI_{\;w}}{dr} \quad \frac{I_w^0(T(r)) \quad I_w}{(w,T)} \tag{15}$$

I_w^0

$$I_w^0(T) \quad \frac{1}{} \quad {}_4 \; I_w d \tag{16}$$

EPRT

$$\frac{dI}{dr} \quad \frac{\frac{1}{4} \quad Id_4 \quad I}{(T)} \tag{17}$$

(T)

(T)

(17) [14]

$$\frac{dI}{d} \quad I \quad S \tag{18}$$

dη β

S

$$S \quad \frac{1}{4} \quad {}_4 Id \tag{19}$$

$R_2 \quad R_1 \quad R_3 \quad R_2$ R_1

$T_1 \quad T_2$ Majumdar[12]

1

2 Lin[14,15]

(18) (19)

$$S_1(r_1) \quad \frac{1}{\pi} \; {}_{R_1} \; {}_0^{\cos^1(\frac{R_2}{r_1})} \; {}_0^{\cos^1(\frac{R_3}{r_1})} S_1(r_1')\kappa_1(\sqrt{r_1^2 \quad r_1'^2 \quad 2r_1r_1'\cos\vartheta})r_1' d \; dr_1'$$

$$\frac{1}{\pi} \; {}_0^{\cos^1(\frac{R_1}{r_1})} I_{\Gamma 1}(R_1)\kappa_2(\sqrt{r_1^2 \quad R_1^2 \quad 2r_1R_1\cos\vartheta})(r_1\cos\vartheta \quad R_1)R_1 d\theta$$

$$\frac{1}{\pi} \; {}_0^{\cos^1(\frac{R_1}{r_1})} {}_0^{\cos^1(\frac{R_1}{R_2})} \kappa_2(\sqrt{r_1^2 \quad R_2^2 \quad 2r_1R_2\cos\vartheta})(R_2 \quad r_1\cos\;)R_2 d$$

$$\{[\frac{4(1 \quad {}_2)}{} \; {}_{R_2} \; {}_0^{\cos^1(\frac{R_2}{r_2})} S_2(r_2')\kappa_2(\sqrt{R_2^2 \quad r_2'^2 \quad 2R_2r_2'\cos\vartheta})(r_2'\cos \quad R_2)r_2' d \; dr_2'$$

$$\frac{4}{} \; {}_{R_1}^{\;1} \; {}_0^{\cos^1(\frac{R_2}{r_1})} {}_0^{\cos^1(\frac{R_2}{R_2})} S_1(r_1')\kappa_2(\sqrt{R_2^2 \quad r_1'^2 \quad 2R_2r_1'\cos\vartheta})(R_2 \quad r_1'\cos\;)r_1' d \; dr_1'$$

$$\frac{4(1 \quad {}_2)}{\pi} \; {}_0^{\cos^1(\frac{R_2}{R_3})} I_{\Gamma 3}(R_3)\kappa_3(\sqrt{R_2^2 \quad R_3^2 \quad 2R_2R_3\cos\vartheta})(R_3\cos\vartheta \quad R_2)(R_3 \quad R_2\cos\;)R_3 d\theta$$

$$\frac{4}{\pi} \; {}_0^{\cos^1(\frac{R_1}{R_2})} I_{\Gamma 1}(R_1)\kappa_3(\sqrt{R_2^2 \quad R_1^2 \quad 2R_2R_1\cos\vartheta})(R_2\cos\vartheta \quad R_1)(R_2 \quad R_1\cos\;)R_1 d\theta]$$

$$/[1 \quad \frac{4}{} \; {}_0^{2\cos^1(\frac{R_1}{R_2})} \kappa_3(\sqrt{R_2^2 \quad R_2^2 \quad 2R_2R_2\cos\vartheta})(R_2 \quad R_2\cos\;)^2 R_2 d\theta]\} \tag{20}$$

$$S_2(r_2) \quad \frac{1}{\pi} \; {}_{R_2} \; {}_0^{\cos^1(\frac{R_3}{r_2})} \; {}_0^{\cos^1(\frac{R_3}{r_2})} S_2(r_2')\kappa_1(\sqrt{r_2^2 \quad r_2'^2 \quad 2r_2r_2'\cos\vartheta})r_2' d \; dr_2'$$

$$\frac{1}{\pi} \; {}_0^{\cos^1(\frac{R_2}{r_2})} {}_0^{\cos^1(\frac{R_2}{R_3})} I_{\Gamma 3}(R_3)\kappa_2(\sqrt{r_2^2 \quad R_3^2 \quad 2r_2R_3\cos\vartheta})(R_3 \quad r_2\cos\;)R_3 d\theta$$

$$\frac{1}{\pi} \; {}_0^{\cos^1(\frac{R_2}{r_2})} \kappa_2(\sqrt{r_2^2 \quad R_2^2 \quad 2r_2R_2\cos\vartheta})(r_2\cos \quad R_2)R_2 d$$

$$\{\frac{4}{} \; {}_{R_2}^{\;2} \; {}_0^{\cos^1(\frac{R_2}{r_2})} S_2(r_2')\kappa_2(\sqrt{R_2^2 \quad r_2'^2 \quad 2R_2r_2'\cos\vartheta})(r_2'\cos \quad R_2)r_2' d \; dr_2'$$

$$\frac{4(1 \quad {}_1)}{} \; {}_{R_1} \; {}_0^{\cos^1(\frac{R_2}{r_1})} {}_0^{\cos^1(\frac{R_2}{R_2})} S_1(r_1')\kappa_2(\sqrt{R_2^2 \quad r_1'^2 \quad 2R_2r_1'\cos\vartheta})(R_2 \quad r_1'\cos\;)r_1' d \; dr_1'$$

$$\frac{4}{\pi} \; {}_0^{\cos^1(\frac{R_2}{R_3})} I_{\Gamma 3}(R_3)\kappa_3(\sqrt{R_2^2 \quad R_3^2 \quad 2R_2R_3\cos\vartheta})(R_3\cos\vartheta \quad R_2)(R_3 \quad R_2\cos\;)R_3 d\theta$$

$$\frac{4(1 \quad {}_1)}{\pi} \; {}_0^{\cos^1(\frac{R_2}{R_2})} I_{\Gamma 1}(R_1)\kappa_3(\sqrt{R_2^2 \quad R_1^2 \quad 2R_2R_1\cos\vartheta})(R_2\cos\vartheta \quad R_1)(R_2 \quad R_1\cos\;)R_1 d\theta$$

$$\frac{4(1 \quad {}_1)}{\pi} \; {}_0^{2\cos^1(\frac{R_2}{R_2})} \kappa_3(\sqrt{R_2^2 \quad R_2^2 \quad 2R_2R_2\cos\vartheta})(R_2 \quad R_2\cos\;)(R_2 \quad R_2\cos\;)R_2 d\theta$$

$$[\frac{4(1 \quad {}_2)}{} \; {}_{R_2} \; {}_0^{\cos^1(\frac{R_3}{r_2})} S_2(r_2')\kappa_2(\sqrt{R_2^2 \quad r_2'^2 \quad 2R_2r_2'\cos\vartheta})(r_2'\cos \quad R_2)r_2' d \; dr_2'$$

$$\frac{4}{} \; {}_{R_1}^{\;1} \; {}_0^{\cos^1(\frac{R_2}{r_1})} {}_0^{\cos^1(\frac{R_2}{R_2})} S_1(r_1')\kappa_2(\sqrt{R_2^2 \quad r_1'^2 \quad 2R_2r_1'\cos\vartheta})(R_2 \quad r_1'\cos\;)r_1' d \; dr_1'$$

$$\frac{4(1 \quad {}_2)}{\pi} \; {}_0^{\cos^1(\frac{R_2}{R_3})} I_{\Gamma 3}(R_3)\kappa_3(\sqrt{R_2^2 \quad R_3^2 \quad 2R_2R_3\cos\vartheta})(R_3\cos\vartheta \quad R_2)(R_3 \quad R_2\cos\;)R_3 d\theta$$

$$\frac{4}{\pi} \; {}_0^{\cos^1(\frac{R_1}{R_2})} I_{\Gamma 1}(R_1)\kappa_3(\sqrt{R_2^2 \quad R_1^2 \quad 2R_2R_1\cos\vartheta})(R_2\cos\vartheta \quad R_1)(R_2 \quad R_1\cos\;)R_1 d\theta]$$

$$/[1 \quad \frac{4}{} \; {}_0^{2\cos^1(\frac{R_1}{R_2})} \kappa_3(\sqrt{R_2^2 \quad R_2^2 \quad 2R_2R_2\cos\vartheta})(R_2 \quad R_2\cos\;)^2 R_2 d\theta]\} \tag{21}$$

$I_{\Gamma 1}(R_1) \quad I_{\Gamma 3}(R_3)$ $T_1 \quad T_2$

$$K_n(x) \quad \frac{Ki_n(x)}{x^n}$$

Bickley function $Ki_n(x) \quad {}_1 \; \frac{e^{\;xt}}{t^n\sqrt{t^2 \quad 1}} dt$

20

-1 1

R_1 R_2

R_3

R_3-R_1 R_3/R_1 R_2-R_1 R_3-R_1

g*(R_3-R_1)

R_3/R_1 2.0 0.5

0.3 ( )

g $\frac{2}{1}$ $_1$ $\frac{1}{_1(T)}$ $_2$ $\frac{1}{_2(T)}$

$_1(T)$ $_2(T)$

. ( )

0.5

1.5 0.5 10

2.0

. SiO_2 / Si

g*(R_3-R_1)=0.1 R_1 *Si*

R_2

g*(R_3-R_1)=2.0 *Si* 0.1844

R_1 R_2 R_2 R_3

SiO_2

: 0.8156

0.1 ( )

0.025 0.05 0.075

0.075 0.05 0.025

.

g 1

: *Si* SiO_2

:

2.0 0.1

R_1 R_2 R_2 R_3

R_3/R_1=1.5

R_3/R_1=10.0

0.025

0.05 0.075 0.075 0.05 0.025

1. N. Mori and Y. Ando, Phys. Rev. B 40, 6175(1989).

2. H. Rucker, E. Molinari, and P. Lugli, Phys. Rev. B 45, 6747(1992).

3. M. A. Stroscio, G. J. Iafrate, K. W. Kim, M. A. Littlejohn, A. R. Bhatt, and M. Dutta, in Integrated Optics and Optoelectronc, Vol.CR45, p. 341 (1993).

4. B. Hillebrands, S. Lee, G. I. Stegeman, H. Cheng, J. E. Potts, and F. Nizzoli, Phys. Rev. Lett. 60, 832 (1988).

5. J. Seyler, and M. N. Wybourne, Phys. Rev. Lett.69, 1427 (1992).

6. Z. V. Popvic, J. Spitzer, T. Ruf, M. Cardona, and K. Ploog, Phys. Rev. B 48, 1659 (1993).

7. R. Bhadra, M. Grimsditch, I. K. Schuller, and F. Nizzoli, Phys. Rev. B39, 12456 (1989).

8. M. Grimsditch, R. Bhadra, and I. K. Schuller, Phys. Rev. Lett.58, 1216 (1987).

9. D. G. Cahill, H. E. Fischer, T. Klitsner, E. T. Swartz, and R. O. Pohl, J. Vac. Sci. Technol.A, 7, pp. 1259-1266 (1988).

10. G. Chen, and C. L. Tien, J. Thermophys. Heat Transfer, 7, pp.311-318 (1993).

11. A.Majumdar, J. Heat Transfer, Vol.115, p.7-16 (1993).

12. C. Kittel, Introduction to Solid State Physics, 6th ed., (1986).

13. , , (2001).

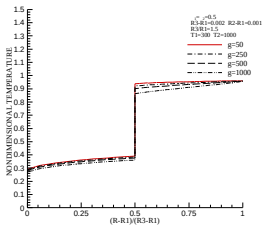
14. J. D. Lin, J. Quantitative Spectroscopy and Radiative Transfer, Vol.37, pp.591-601 (1987).

15. J. D. Lin, J. Thermophysics and Heat Transfer, Vol.2, pp.68-74 (1988).

16 J. E. Parrott and A. D. Stuckes, "Thermal Conductivity of Solids," (Methen, New York, 1975).

17 Bell Telephone Laboratories, Murray Hill, New Jersey, Rev. Modern Phys.Vol.33, 1(1961).

18 J. M. Ziman, Electrons and Phonons, (1960).



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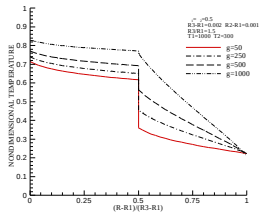

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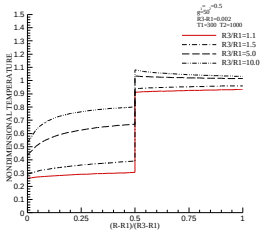

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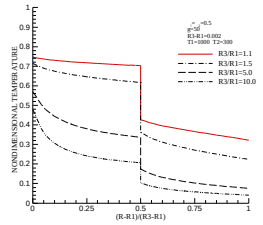

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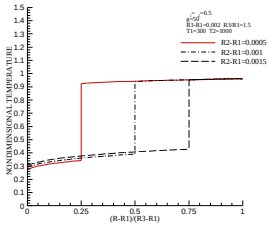

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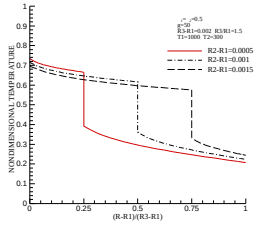

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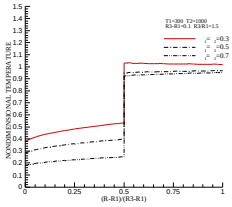

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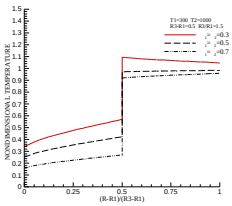

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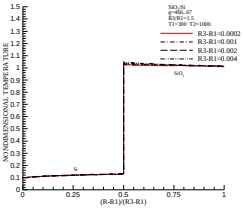
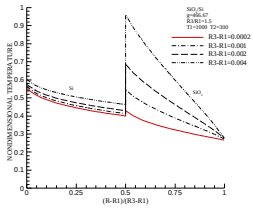


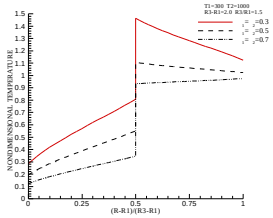
SiO_2/Si

1.5



SiO_2/Si

1.5



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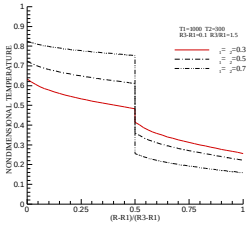
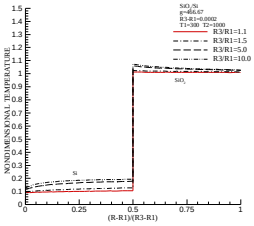


0.1

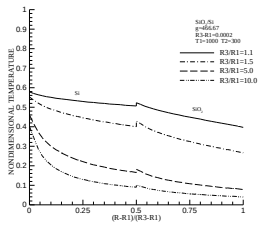
Si

Si



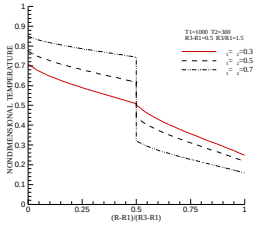
SiO_2/Si

0.0002



SiO_2/Si

0.0002



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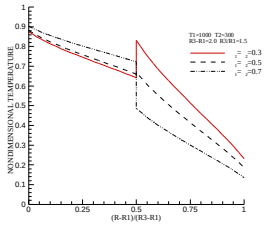
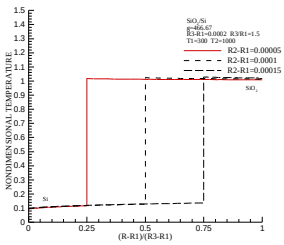


2.0

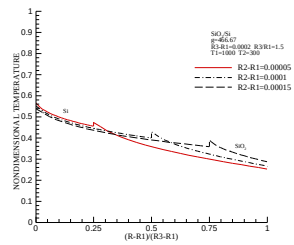
Si

Si



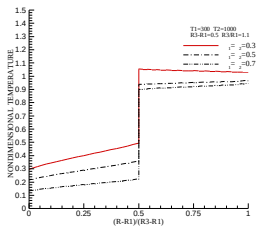
SiO_2/Si

1.5



SiO_2/Si

1.5



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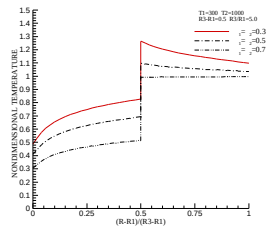

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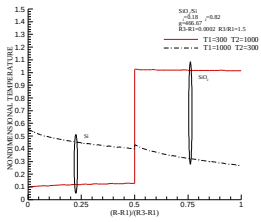
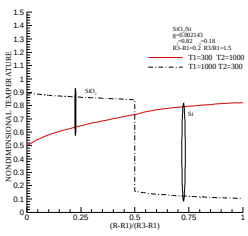


SiO_2/Si

1.5

Si



SiO_2/Si

1.5

SiO_2