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LATTICE THERMAL CONDUCTIVITY OF NYLONE AND POLYETHYLEN AT LOW TEMPERATURES

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Using Callaway's model, the phonon conductivity of Nylone and Polyethylen has been calculated in the temperature range 0.2–5°K and the dislocations are taken as the scaterers of phonon. Good agreement is found between the calculated values and the experimental values of the phonon conductivity.

RECENTLY Scott *et al.*[1] measured the lattice thermal conductivity of Nylone and Polyethylen at the temperatures below 5°K. They have not given its theoretical explanation. In the present note, the main interest lies in the explanation of measurements of Scott *et al.* Previous[2–4] measurements of the thermal conductivity of polymers have shown that at low temperatures, the boundary scattering and structure scattering in the amorphous region are dominant over other scattering mechanisms. Later on Scott and Giles[5] measured the lattice thermal conductivity of Teflon in the temperature range 0.17–4°K and they found a T^2-Temperature dependance below 1.2°K. In the explanation of their measurements, they have predicted that, in the lattice thermal conductivity of Teflon, the dislocation scattering plays a significant role in the determination of the phonon conductivity than either of the above mentioned scattering processes.

Following Scott and Giles and using Callaway's model,[6] the lattice thermal conductivity of Nylone and Polyethylen is calculated in the entire temperature range 0.2–5°K. According to Klemens,[7] there are two types of scattering of phonons from dislocations. First is the central core of dislocation, which produces scattering relaxation rate $\tau_{\text{dis,c}}^{-1} = b\omega^3$, and secondly the strainfield surrounding dislocation which produces scattering relaxation rate $\tau_{\text{dis,s}}^{-1} = a\omega$, where b and a are known as the scattering strength of the above stated scattering processes, respectively. These two constants, a and b can be given by

$$a = 6 \times 10^{-2} N_{\text{d}} b_1^2 \gamma^2$$
$$b = 0.55 N_{\text{d}} a_1^4 \qquad (1)$$

where b_1 is the magnitude of Burgers vectors, N_{d} is the number of dislocation lines per unit area, γ is the Gruneisen parameter and a_1^3 is the volume occupied by the vibrating unit in the crystal. Thus the combined dislocation scattering relaxation rate τ_{dis}^{-1} is given by

$$\tau_{\text{dis}}^{-1} = \tau_{\text{dis,c}}^{-1} + \tau_{\text{dis,s}}^{-1} = b\omega^3 + a\omega. \qquad (2)$$

According to the Callaway model, the lattice thermal conductivity is given by

$$K = \frac{k_{\text{B}}}{2\pi^2 v}\left(\frac{k_{\text{B}}T}{\hbar}\right)^3 \int_0^{\theta/T} \frac{x^4 e^x (e^x - 1)^{-2}\, dx}{\tau_{\text{B}}^{-1} + \tau_{\text{pt}}^{-1} + \tau_{\text{3ph}}^{-1} + \tau_{\text{dis}}^{-1}} + \text{C.F.} \qquad (3)$$

where k_{B} is the Boltzman constant, $\hbar$ is the Planck constant divided by 2π, v is the average phonon velocity, τ_{B}^{-1} is the boundary scattering relaxation rate, τ_{pt}^{-1} is the point defect scattering relaxation rate, τ_{3ph}^{-1} is the phonon–phonon scattering relaxation rate, C.F. is the correction factor due to three phonon normal processes and θ is the Debye temperature.

Since our interest lies in the low temperatures i.e. below 5°K, it is meaningless to consider C.F. and τ_{3ph}^{-1}. At the same time it is necessary to state that according to Scott and Giles, dislocation scattering is dominating over other scattering processes. Therefore one can neglect τ_{B}^{-1} and τ_{pt}^{-1} in comparison with τ_{dis}^{-1}.

Table 1. Values of constants and parameters used in the calculation are given below

	Nylone	Polyethylen
a	5.98×10^{-3}	2.22×10^{-2}
b	9.48×10^{-26} sec^2	1.8×10^{-26} sec^2
v	1.79×10^{5} cm/sec	2.1×10^{5} cm/sec

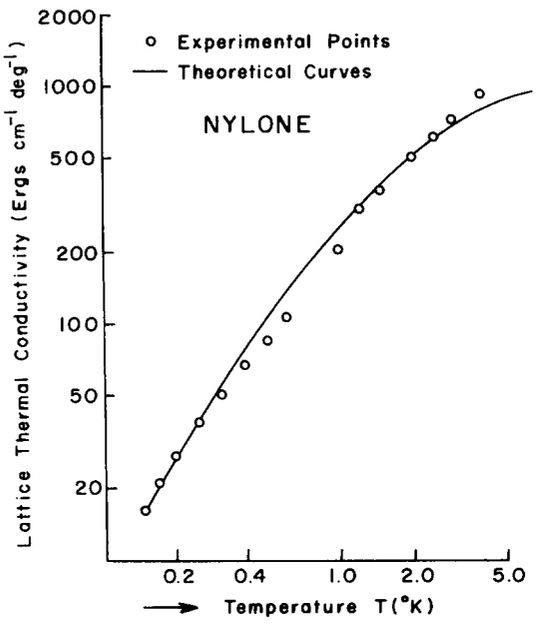

FIG. 1. Phonon conductivity of Nylone in the temperature range 0.2–5°K. Solid line is the calculated curve and circles are the experimental points.

The expression for K can be approximated as

$$K = \frac{k_B}{2\pi^2 v}\left(\frac{k_B T}{\hbar}\right)^3 \int_0^{\infty} \frac{x^4 e^x}{(e^x-1)^2} \frac{dx}{(AXT + BX^3T^3)} \quad (4)$$

where $A = a\,(k_B/\hbar)$, $B = b\,(k_B/\hbar)^3$. Here θ/T is taken as ∞ due to low value of T and high vaue of θ. The value of a and b can be calculated with the help of equation (1) but due to the lack of some constants, these are taken as adjustable parameters in the present calculation.

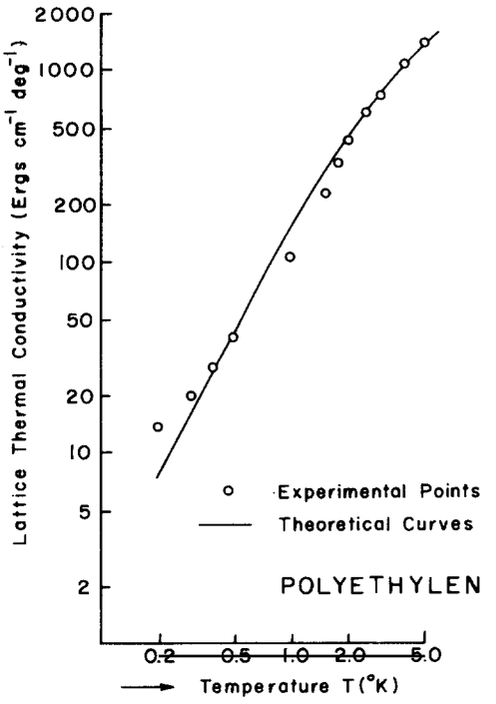

FIG. 2. Phonon conductivity of Polyethylen in the temperature range 0.2–5°K. Solid line is the calculated curve and circles are the experimental points.

Adjusting a and b, the lattice thermal conductivity of Nylone and Polyethylen has been calculated in the temperature range 0.2–5°K and is shown in Figs. 1 and 2. Constants and parameters used in the calculations are given in Table 1. From Figs. 1 and 2, it can be concluded that the agreement between the calculated values and the experimental values is good enough except at a few temperatures. The dislocation scattering is found to play a dominant role in the present work in agreement with the work of Scott and Giles.

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