Semi-analytical method for extrapolating phonon mean free path distribution for thin dielectric films

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Background: Thin suspended films have many applications in photonic, electronic, and phononic systems. One very important application is for the making of phononic crystals (PnCs), used to manipulate the phonon behavior in a given system. PnCs work by creating geometries that enhance phonon boundary scattering. This impacts strongly the phonon mean free paths (MFP) in the film. Until now, there has been no experimental way to determine the phonon MFP distribution in thin films. Thus as a modification of a method proposed by Hao et al. [1], here we create a general method to determine the phonon MFP distribution in any thin film.

Results: There are certain accumulated data in the literature on PnCs, from which we can readily extract the phonon MFP distributions. As such, we apply the model to crystalline Si membranes and poly-crystalline $Si_{0.5}Ge_{0.5}$ membranes from the PnC studies done by Anufriev et. al [2] and Nomura et. al [3]. Here F represents the cumulative function of the thermal conductivity (k_{BT}). We see from Fig.1 that in both Si and SiGe thin films the average MFP is about ≈120 nm. With the majority of the contribution to k_{BT} is between 20-250 nm for Si and 5-250 nm for SiGe. Also, above around 300 nm for Si and 400 nm for SiGe the phonon MFP contribution to k_{BT} becomes negligible. There is some uncertainty in the distribution, which is due to the amount of experimental data points.

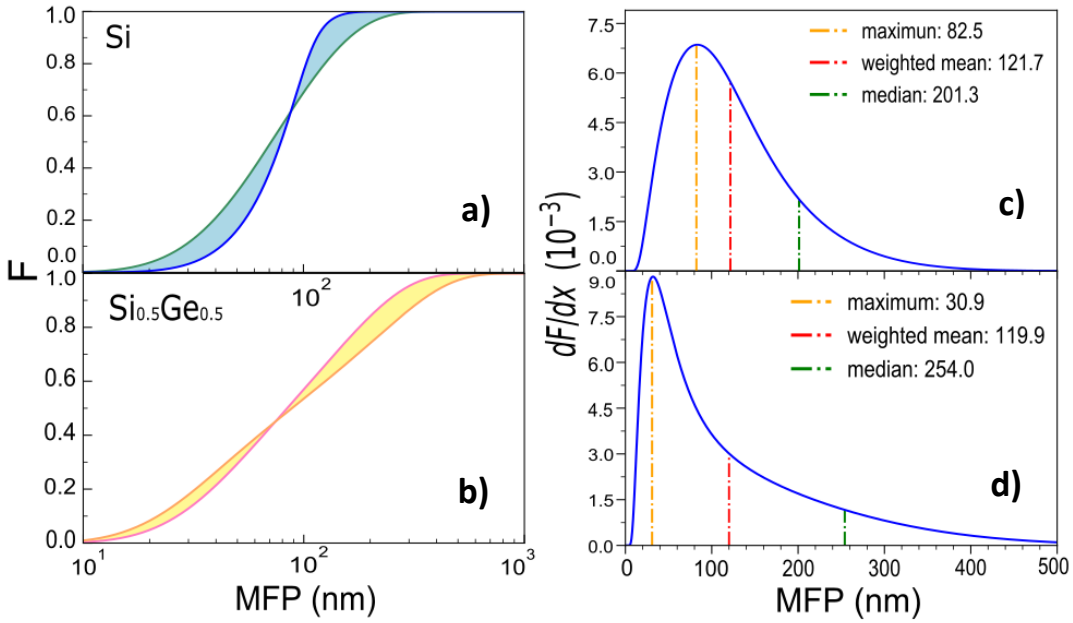

Fig.1. Cumulative function of thermal conductivity F, as a function of the mean free path. (a) Si film 145nm thick. (b) SiGe film 150nm thick. Derivative function, illustrating the impact to k_{BT} on the mean free path of (c) Si and (d) SiGe

Reference:[1] Q. Hao, Y. Xiao, and Q. Chen, *Mater. Today Phys.*, vol. 10, p. 100126, 2019.
[2] R. Anufriev, A. Ramiere, J. Maire, and M. Nomura, *Nat. Commun.*, vol. 8, no. May, pp. 1–8, 2017.
[3] M. Nomura, J. Nakagawa, K. Sawano, and S. Volz, *Appl. Phys. Lett.*, vol. 109, no. 17, pp. 1–5, 2016.