VI International Conference "Condensed Matter & Low Temperature Physics 2024"

Thermal Conductivity Analysis of Composites with Superlattice Structure

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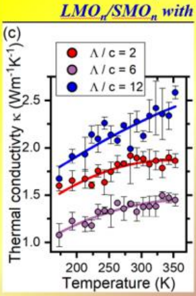
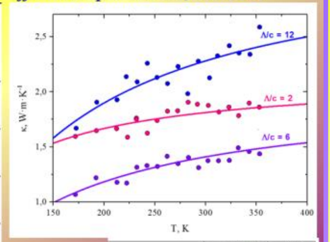
Abstract: The thermal properties studying of solids, in particular thermal conductivity, is an important direction of modern materials science, and it stimulates the creation of functional materials with specified properties. We were analyzed the temperature dependences of the thermal conductivity for thin films with different thicknesses, and they have a superlattice structures, in particular, LMOn/SMOn [1], AlN–GaN [2], $(AlN)_{4nm}$–$(GaN)_y$ [3], with different thicknesses of the GaN layer, etc. A superlattice is a structure made up of alternating layers of different materials. These layers are typically measured in nanometers, and the typical superlattice is extremely small. These structures are used in creation of new forms of semiconductors that exhibit different properties than their included materials [3]. It was shown that all temperature dependences of thermal conductivity demonstrate an exponential growth κ(T) with temperature increasing as $\kappa_C = \kappa_0 \exp(-E/T)$, where κ_0 is a pre-exponential factor which characterizes the intensity of the heat transfer process, and E is the energy of the dominant excitations.

Temperature dependences of thermal conductivity for SLs LMO_n/SMO_n with different SL period c = 2; 6 and 12.

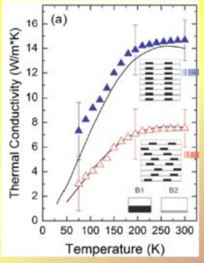


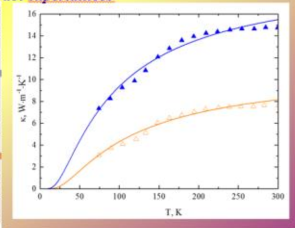


Meyer, D., Metternich, D., Henning, P., Bange, J. P., Gruhl, R., Bruchmann-Bamberg, V., ... & Ulrichs, H. (2021). Coherent phonon transport and minimum of thermal conductivity in $(LaMnO_3)_n/(SrMnO_3)_n$ superlattices. *arXiv preprint arXiv:2108.05860.*

Substance:	κ₀, Вт/м*К	E, K
$LaMnO_3/SrMnO_3$ Superlattices, period 2	2.14	50
$LaMnO_3/SrMnO_3$ Superlattices, period 6	2	105
$LaMnO_3/SrMnO_3$ Superlattices, period 12	3.29	110

Temperature dependences of thermal conductivity of Ge quantum dot superlattices

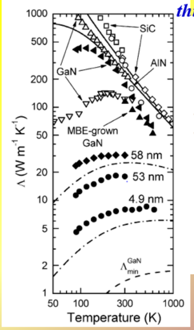


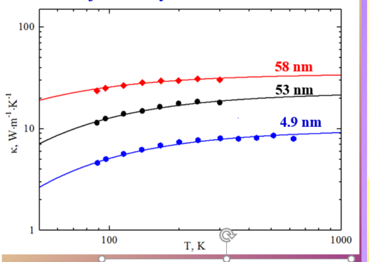


Alvarez-Quintana, J., Alvarez, X., Rodriguez-Viejo, J., Jou, D., Lacharmoise, P. D., Bernardi, A., ... & Alonso, M. I. (2008). Cross-plane thermal conductivity reduction of vertically uncorrelated Ge/Si quantum dot superlattices. *Applied physics letters*, *93*(1), 013112.

Substance:	κ₀, Вт/м*К	E, K
cross-plane thermal conductivity reduction of vertically uncorrelated Ge/Si quantum dot superlattices: with vertically aligned dots (52)	19.9	75
Without vertical correlation	11.2	95

Thermal conductivity analysis of $(AlN)_{4\,nm}$–$(GaN)_y$ with different thicknesses of GaN-layers.

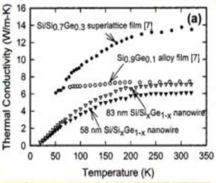


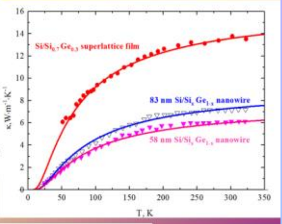


Koh, Y. K., Cao, Y., Cahill, D. G., & Jena, D. (2009). ***Heat-transport mechanisms in superlattices***. *Advanced Functional Materials*, *19*(4), 610-615.

Substance:	κ₀, Вт/м*К	E, K
GaN-layers: 4,9 nm	9.78	65
GaN-layers: 53 nm	22.76	58
GaN-layers: 58 nm	34.8	30

Thermal conductivity analysis of Si/SiGe superlattice nanowires.

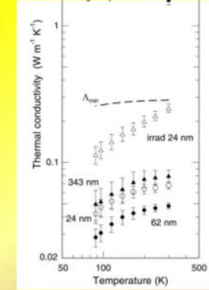


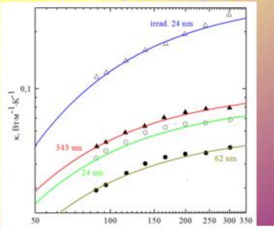


LI, Deyu, et al. ***Thermal conductivity of Si/SiGe superlattice nanowires***. *Applied Physics Letters*, 2003, 83.15: 3186-3188.

	Substance:	κ₀, Вт/м*К	E, K
1.	$Si/Si_{0.7}Ge_{0.3}$ SPL	16.47	58
2.	83 nm Si/Si_xGe_{1-x} nanowire	9.3	72
3.	58 nm Si/Si_xGe_{1-x} nanowire	7.67	72

Thermal conductivity analysis in disordered, layered WSe_2 crystals





Chiritescu, C., Cahill, D. G., Nguyen, N., Johnson, D., Bodapati, A., Keblinski, P., & Zschack, P. (2007). ***Ultralow thermal conductivity in disordered, layered WSe_2 crystals***. *Science*, *315*(5810), 351-353.

	Substance:	κ₀, Вт/м*К	E, K
1.	superlattice WSe_2, 62 нм	0.060	62
2.	superlattice WSe_2, 24 нм	0.086	62
3.	superlattice WSe_2, 343 нм	0.1	62
4.	superlattice WSe_2, 24 нм irradiated by Kr-ions	0.305	90

Conclusion: It was shown that glass-like behavior of κ(T) can be approximated by exponentional function, and also it used for description of "coherent" contribution of thermal conductivity, or wave-like mechanism of heat transfer according to unified theory of thermal transport that declares - κ(T) consists of the sum of two contributions – particle-like propagation and wave-like tunneling of excitations in crystals.

References:

(1) Meyer, Dennis, et al. *arXiv preprint arXiv:2108 (2021): 05860.*

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(3) Koh, Yee Kan, et al. Adv. Funct. Mater. 19.4 (2009): 610-615.

(4) Li, Deyu, et al. *Appl. Phys.Lett.* 83.15 (2003): 3186-3188.

(5) Chiritescu, Catalin, et al. *Science* 315.5810 (2007): 351-353.

(6) Simoncelli, Michele, et al., *Nature Physics* 15.8 (2019): 809-813.

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