

Thermal Transport Mediated by Non-equilibrium Surface Phonon Polaritons

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Primary CNF Tools Used: AJA Ion Mill, AJA Sputter, GCA AS200 i-line Stepper, Glen 1000 Resist Strip, Heidelberg DWL2000, Keyence VHX-7100 Digital Microscope, Oxford 82 RIE, Oxford PECVD, PT VLN Deep Silicon Etch, Woollam RC2 Spectroscopic Ellipsometer, Xactix Xenon Difluoride

Abstract:

Surface phonon polaritons (SPhPs), quasi-particles resulting from coupling between infrared photons and optically active phonons, have attracted increasing attention as energy carriers for thermal radiation and heat conduction. Recently, we have observed that a short segment of Au-coating at the end of SiC nanowires could efficiently launch SPhPs to a number density that is orders of magnitude higher than the corresponding equilibrium values [1]. These thermally stimulated high number density SPhPs could lead to novel thermal transport phenomena beyond expectations within the conventional heat transfer paradigm established upon near-equilibrium thermal transport. In this project, we fabricate microdevices with integrated resistance heaters/thermometers to experimentally measure thermal radiation from individual nanostructures and heat conduction along individual nanowires mediated by thermally excited non-equilibrium SPhPs.

Summary of Research:

During the reporting project period, Dr. Xiaomeng Zhang has performed research at Cornell Nanofabrication Facilities two times to prepare microdevices for thermal measurements to examine SPhP-mediated heat conduction along and thermal radiation from individual SiC nanowires. She was able to successfully fabricate microdevices for both heat conduction (Figure 1) and thermal radiation (Figure 2). Based on these devices, we have successfully demonstrated an approach to measure thermal emissivity from individual nanostructures [2]. In addition, we have performed measurements to explore the effect of Au-coating morphology on SPhP-mediated thermal conductivity for individual SiC nanowires.

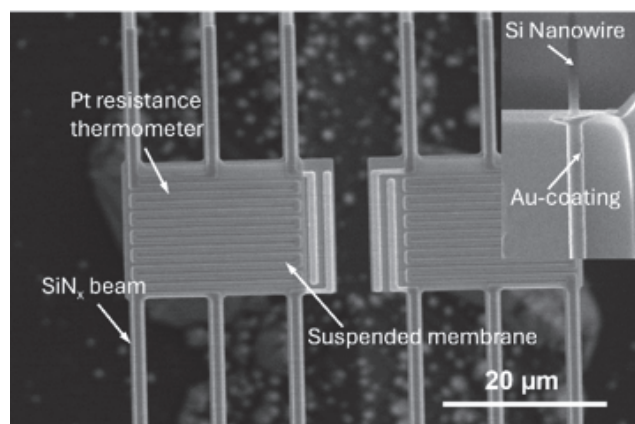


Figure 1: A scanning electron microscopy (SEM) micrograph of a microdevice fabricated at CNF for measurements of thermal transport through individual nanowires. Inset: An SEM micrograph of a SiC nanowire sample with Au-coating at the end placed on the microdevice.

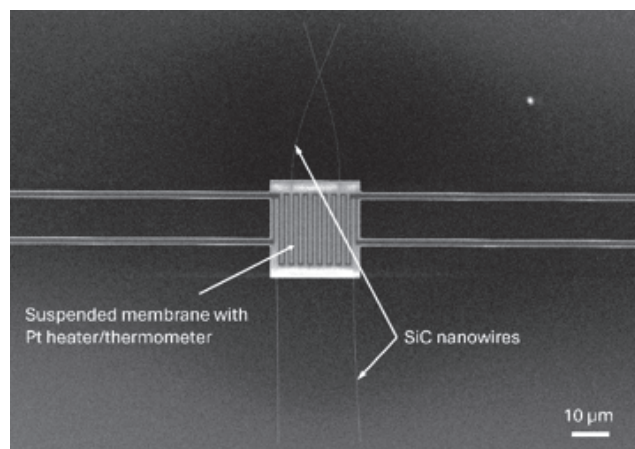


Figure 2: An SEM micrograph of a microdevice for measurement of thermal emission from individual nanowires. Individual nanowire samples have been placed on the device.

Conclusions and Future Steps:

The successful fabrication of microdevices at Cornell Nanofabrication facilities allowed for development of new thermometry techniques and currently we are conducting systematic studies to explore SPhP-mediated thermal transport. The results obtained could provide new insights into the physical properties of non-equilibrium SPhPs. We plan to design and fabricate devices with improved performance to further explore this emerging research topic.

References:

- [1] Z. Pan, G. Lu, X. Li, J. R. McBride, R. Juneja, M. Long, L. Lindsay, J. D. Caldwell, and D. Li, “Remarkable Heat Conduction Mediated by Non-Equilibrium Phonon Polaritons,” *Nature* 623, 307–312 (2023).
- [2] Z. Pan, X. Zhang, Z. Lai, M. Obst, J. D. Caldwell, and D. Li, “Differential Calorimetric Measurement of Thermal Emission from Individual Nanostructures,” *Rev. Sci. Instrum.* 96, 124902 (2025).