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# Quantized thermal conductance: measurements in nanostructures

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## Abstract

We are performing experiments to probe directly the thermal conductance of suspended nanostructures with lateral dimensions  $\approx 100$  nm. It has been recently predicted that at low temperatures, thermal conductance in such a structure approaches a universal value of  $\pi^2 k_B^2 T/3h$  for each massless, ballistic phonon channel, independent of material characteristics. We have developed ultra-sensitive, low dissipation DC-SQUID-based noise thermometry, and extreme isolation from the electronic environment in order to perform this measurement at temperatures below 70 mK. © 2000 Elsevier Science B.V. All rights reserved.

*Keywords:* Mesoscopic transport; Nanostructures; Quantized thermal conductance

It has recently been predicted [1,2] that the phonon thermal conductance through a single ballistic quantum channel should be quantized to a value of  $K = \pi^2 k_B^2 T/3h$ . This result is independent of material characteristics and even of particle type (electrons, phonons, photons, etc.) which carry the heat current [3]. Results from past experiments which intended to enter this regime for phonon thermal conductance have been obscured by parasitic electronic thermal conduction [4,5] or the inability to determine the number of thermally conducting channels [6]. The experiment that we describe here intends to overcome these difficulties and to provide the first clear measurement of phonon thermal conduction through a one-dimensional channel.

Fig. 1 shows the device we have fabricated in our laboratory to probe the thermal conductance. The device is patterned from a suspended 60 nm thick silicon nitride membrane. The center square is 4  $\mu\text{m}$  on a side and is connected to the membrane through four channels with minimum size of 150 nm  $\times$  85 nm. Deposited onto the central square are two 30 nm thick Au resistors, of which

one is used as a heater and the other as a noise thermometer. A 25 nm thick Nb film is deposited onto the four channels. This superconducting film provides electronic contact to the Au resistors without the parasitic thermal conduction of a normal electron gas.

For temperatures below  $\approx 150$  mK, we expect to observe the thermal conductance of four acoustic channels for each leg of the sample (one longitudinal, two transverse, and one torsional mode) [7]. Recent measurements of the thermal conductance of silicon nitride show that for temperatures  $< 200$  mK ballistic transport is realized [8,9]. To provide adiabatic coupling from the central square to the outside thermal bath, the shape of the channels follows  $\cosh^2(x/\lambda)$  where  $\lambda = 1$   $\mu\text{m}$ , as modeled in Ref. [2]. This should allow the thermal conductance to approach the maximum allowed value which is the thermal conductance quantum per channel.

Thermometry at these low temperatures with such a microscopic sample is complicated by the severe electron-phonon thermal resistance [10]. We employ DC-SQUID based noise thermometry [11] because of the extremely low back-action dissipated into the thermometer. We have tested our noise thermometry on a microscopic Au resistor (30 nm  $\times$  300 nm  $\times$  30  $\mu\text{m}$ ) and have shown that we can measure the temperature down to 70 mK (noise temperature of SQUID system is

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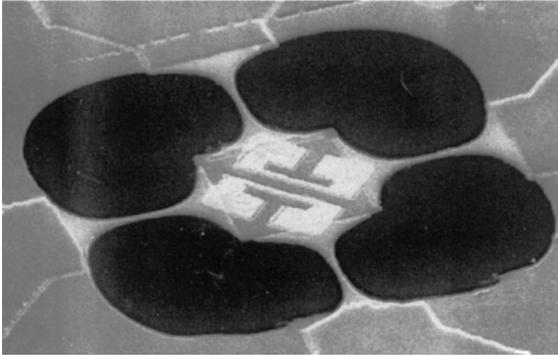


Fig. 1. SEM micrograph of suspended nanostructure designed to isolate and measure the four one-dimensional acoustic modes of thermal transport. See text for description.

$< 1 \text{ mK}^1$ ). For temperatures below 70 mK, the microscopic resistor no longer follows the refrigerator temperature which could be caused by an unknown spurious power source of  $\approx 10^{-17} \text{ W}$ .

The twisted pair connected to the nanostructure heater requires extensive electronic filtering. This is to attenuate the heat load from radio and microwave frequency black-body radiation generated by the Johnson noise of resistors at higher temperatures. We have installed two sets of filters, one set at 1 K and the other set at the mixing chamber. Each filter comprises of a 10-pole RC network and a separate stainless-steel powder filter. With this system we attain an effective passband of only 140 Hz from 300 K and over 200 db of attenuation from 1 MHz to  $> 20 \text{ GHz}$ . This limits the total power radiated down the heater wires to  $< 10^{-18} \text{ W}$ .

We have demonstrated all of the essential techniques to measure the phonon thermal conduction through one-dimensional channels and expect to confirm the recent prediction of a universal thermal conductance.

These experiments are the beginning of a very exciting new realm which may lead to the measurement of the quantum nature of thermal transport involving single phonons [12].

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