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14. ABSTRACT

Our work in the last two years focused on the idea of using change in thermal strain to extract information about thermal conductivity. One experiment explores using a nanomechanical resonator made using a nanowire and measures the thermal conductivity by tracking the frequency change that results from the temperature profile inside the nanowire – this is a steady state version of the measurement. We have also explored how the plasmon mode can modify the elastic properties of a nanoscale system across a phase transition; this could imply a large change in thermal properties. In the last one year we have extended our technique to perform dynamical measurements. We see that modulation of current through the nanowire we can see a second harmonic sideband modulation in a nanomechanical system.

15. SUBJECT TERMS

thermal transport , nano materials, nano structures

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Final Report for AOARD Grant 124045

"Research Title Thermal transport and measurement of specific heat in artificially sculpted nanostructures"

Date

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Introduction: Our proposal's goal was to be able to measure thermal conductivity and specific heat in nanostructures. Measurement of thermal conductivity using techniques like 3ω are powerful means to thermal properties of bulk material. However, they present serious challenges because of electrical nonlinearities than give rise to various higher harmonics that can make the accurate measurement of the thermal conductivity challenging. In order to overcome this challenge we developed a new technique to measure the thermal conductivity of nanostructure by measuring the thermal strain that reflects accumulated thermal strain inside a NEMS device like a suspended nanowire. This technique is very general and be applied across systems. As of now we have measured the thermal conductivity by slowly modulating the heating signal. By modulating the heating current to frequencies ~ 10-100 KHz we expect to measure the specific heat of the nanostructures. (details in publication Nano Lett., 12,6432 (2012).) In order to achieve this we had to develop a new technique to measure the resonance of NEMS devices using a wide bandwith. This required the new fabrication technique to make NEMS devices on insulators, like sapphire. Following this in the last one year we have developed the modulation to see sidebands in the original resonant responses

Because of the development of the technique to study thermal conductivity we were able to extend the work to measure the elastic property of nanoscale NEMS device using a charge density wave system so that elastic property is modified due to the coupling of the elastic mode with the plasmons associated with charge density wave system. This suggests that the coupling with plasmonic mode could modify the thermal properties of the nanosctructures (details in publication Phys. Rev. Lett. 110, 166403 (2013))

Experiment: Both the experiments that we have done use the fabrication of suspended devices (figure 1) where we suspend the device to thermally isolate the material and this also enables the measurement of the thermal conductivity and elastic properties by measuring and tracking as function of various parameters the evolution of the resonant frequency of the suspended device. (details regarding the fabrication and measurement scheme provided in the publications 1 and 2).

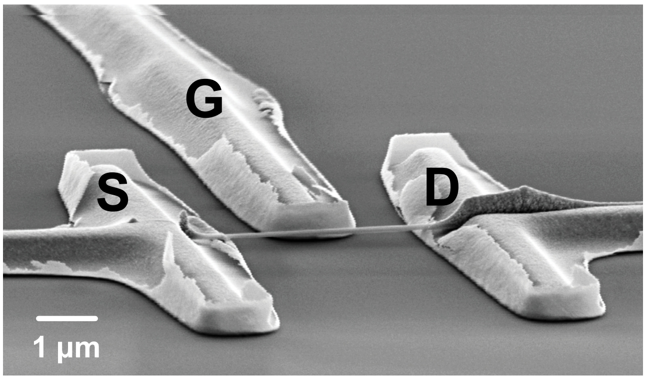

Figure 1 Scanning electron microscope image of a suspended nanowire resonator. The resonant frequency is tracked using a network analyzer Nano Lett., 12,6432 (2012).)

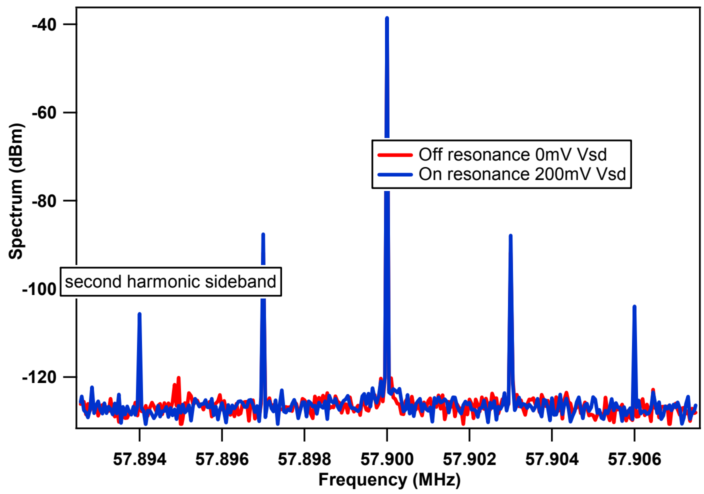

Figure 2 Frequency spectrum around the mechanical drive tone at 57.9 MHz. The sideband corresponding to the second harmonic of modulation to the left and right shows up only when the nanowire is at resonance.

We are now using dynamical effect to probe the time scale at which the heat is removed from a nanoscale system. The rate of heat removal from a suspended wire depends on the thermal conductivity, specific heat and geometry of the nanostructure. If we consider the modulation of heat in a system at a rate much slower than the intrinsic rate of removal of heat then after every cycle there is no net heat accumulation in the nanostructure. As we change the current through the nanowire at frequency *f* the heat is modulated into the system at frequency *2f.* Because of the heating the nanowire expands and contracts at frequency *2f* and this results in development of sidebands at around the f_m – namely the mechanical resonant frequency. This clearly seen in the figure 3.

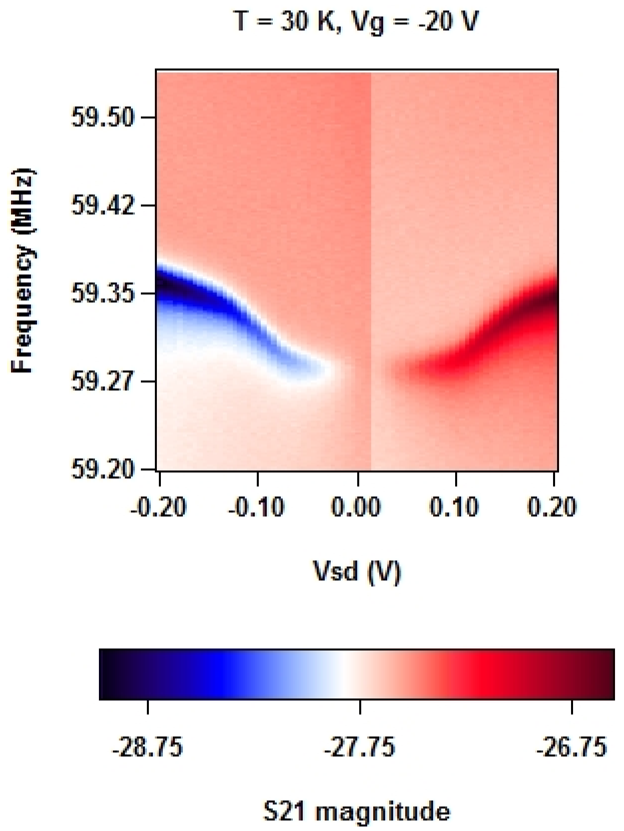

Figure 2 Change in the resonant frequency of the nanowire resonator reflecting a positive thermal coefficient.

We are in the process of using this dynamical response to get a direct measurement of the diffusivity of the system by tracking the amplitude of the second harmonic sideband. We expect a publication from this dynamical measurement of the heat tansport through a nanoelectromechanical system.

Results and Discussion:

- By tracking the resonant frequency of suspended devices we are able to determine thermal strains ~0.01% accurately and this allow determination of thermal conductivity. A new fabrication technique and measurement technique was developed to enable this.
- Using the new technique it is possible to show the plasmons affect the elastic properties of nanoscale CDW system. This imples that across phase transitions the elastic properties are modified dramatically; this may be reflected in the thermal properties as well.
- We are finishing experiments currently where we are changing the frequency of modulation to see the effect of heating.

List of Publications and Significant Collaborations that resulted from your AOARD supported project:

a) papers published in peer-reviewed journals

  - Wide Bandwidth Nanowire Electromechanics on Insulating Substrates at Room Temperature

T. S. Abhilash, John P. Mathew, Shamashis Sengupta, M. R. Gokhale, Arnab Bhattacharya, and Mandar M. Deshmukh
Nano Lett., 12,6432 (2012).

- Plasmon mode modifies the elastic response of a nanoscale charge density wave system
  Shamashis Sengupta, Niveditha Samudrala, Vibhor Singh, Arumugam Thamizhavel, Peter B. Littlewood, Vikram Tripathi, and Mandar M. Deshmukh
  Phys. Rev. Lett. 110, 166403 (2013).

- Dynamically measuring the thermal diffusivity in nanostructures. John P. Mathew et al. (in preparation).

Attachments: Publications 1 and 2