20p-C13-4

Thermal conductivity measurement of a 1D Si phononic crystal nanostructure

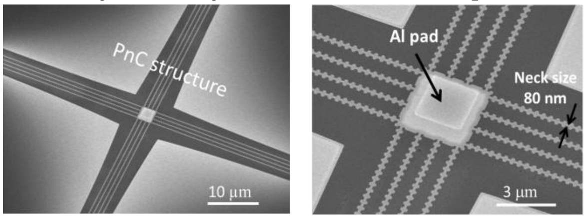
IIS[1], LIMMS[2] and Nanoquine[3], The Univ. of Tokyo, ○J.Maire[1,2] and M. Nomura[1,3]

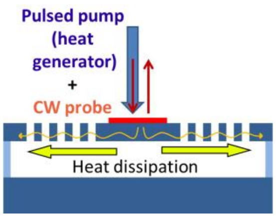
E-mail: jmaire@iis.u-tokyo.ac.jp

Improving thermoelectric efficiency, which is needed for a widespread use of the technology, can be done by decreasing the thermal conductivity. Bulk Silicon is a poor thermoelectric material, but has other enormous advantages like its easy processing and high integrability. At the nanoscale, a size effect, due to boundary scattering, studied since the study of Dresselhaus et al.[1], and further developed recently by Yu [2], reduce the thermal conductivity. In periodic structures, a coherent effect is expected to reduce the thermal conductivity even further. To reveal this phononic effect, we investigate the impact of phononic patterning on the phononic band diagram. In this contribution, we report the fabrication of 1D phononic crystal nanostructures as well as measurements with an all optical method called time domain thermoreflectance. The measured thermal conductivity in the structure is 15.8 W/mK, which is only 11% of that of bulk Si. It is considered that the reduced thermal conductivity stems from both the surface scattering and phononic effect.

After determining which phonons are of interest, namely the ones contributing the most to the thermal conductivity, we perform simulations with COMSOL Multiphysics to adapt the design of our structures to the range of phonons we want to affect. Then these structures are fabricated using a classical top-down approach, including Electron-Beam lithography steps, an example of which is shown Fig. 1. The main reason we focus on Silicon is it excellent compatibility and the possibility to integrate it directly on-chip, even if it is originally a poor thermoelectric material.

We developed a time domain thermoreflectance system able to monitor the reflectivity on scales as small as a few microns square for a wide range of thermal conductivities. A pulse laser heats the surface of a deposited metal pad that acts as a heater while a CW probe laser monitors the reflectivity of the metal pad. The reflectivity being directly linked to the temperature, follows the same variations, starting with an increase while heating and a decay to come back to its equilibrium value, with the heat flowing from the metal pad through the phononic crystal structures (Fig. 2). The heat dissipation in the same structure was simulated by COMSOL Multiphysics to obtain the thermal conductivity. The comparison between the experimental and the simulated results (Fig. 3) indicate that the thermal conductivity of the Si 1D phononic crystal is 15.8 W/mK, which is only 11% of that of bulk Si. The reduced thermal conductivity in this nanostructure seems to stem from both the surface scattering and phononic effect, but further study is necessary to clearly observe the coherent phononic effect.





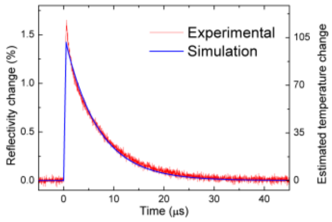


Fig. 1(left). SEM images of air-suspended 1D Si phononic crystal nanostructures. Fig. 2(middle). Measurement principle of the optical thermal conductivity measurement system. Fig. 3(right). Measured (red) and simulated results (blue) of heat dissipation through a 1D Si phononic crystal nanostructure.

Acknowledgments

This work was supported by: the Project for Developing Innovation Systems of the MEXT, Japan; by the JSPS through its Funding Program for World-Leading Innovation R&D on Science and Technology" and through Kakenhi (24656576, 25709090); and by The Murata Science Foundation.

References

[1] L. D. Hicks and M. S. Dresselhaus, Phys. Rev. B **47**, 12727 (1993).

[2] J.-K. Yu, Nat. Nanotech **5**, 718 (2010).