フォノニック結晶ナノ構造による熱伝導制御の実現
Thermal conduction control by phononic crystal nanostructures

IIS[1], LIMMS/CNRS[2], Nanoquine[3], Univ. of Tokyo, °J. Maire[1,2], , R. Anufriev[1], M. Nomura[1,3]
E-mail: jmaire@iis.u-tokyo.ac.jp

With light, various physical effects have been achieved in the past 30 years thanks to photonic crystals (PhC). Similarly, periodic structures called phononic crystals (PnC) modify phonons transport properties and thus heat transport. However, due to the more complicated physics of phonons, thermal conductivity tuning by PnC structures is still a challenging topic.. We studied the physics of phonon transport in various Si PnCs [1,2] based on both their wave and particle descriptions. In this work, we demonstrate thermal conductivity tuning by phononic crystal structure for the first time.

The samples were fabricated from a single crystalline Silicon-on-insulator wafer. They consist of 145 nm-thick suspended membranes with circular holes arranged in a square lattice of period 300 nm drawn by electron-beam lithography. We fabricated a periodic structure with holes 135nm in diameter and then randomly modified their position within X% of the period (Fig 1a). Thermal characterization was performed thanks to our thermoreflectance system. The central Al pad is heated thanks to a laser pulse and its reflectivity is monitored while the heat flows through the PnC. The heat dissipation time that we obtain (Fig 1b, vertical axis) gives us information on the thermal properties of the PnC. Fig 1b shows the disorder dependence of the thermal decay time at room- and cryogenic temperature. At room temperature, phonon transport is purely diffusive and thus independent on disorder. However, at 4K there is a clear dependence on the disorder, due to its impact on the phononic band diagram. In the diffusive model, the relaxation time should be shorter for periodic structures. What we observe here is the opposite and can only be attributed to the wavelike behavior of phonon. This result is the first successful demonstration of heat conduction tuning based on the wave nature of phonons, and is the first step towards the development of thermal phononics.

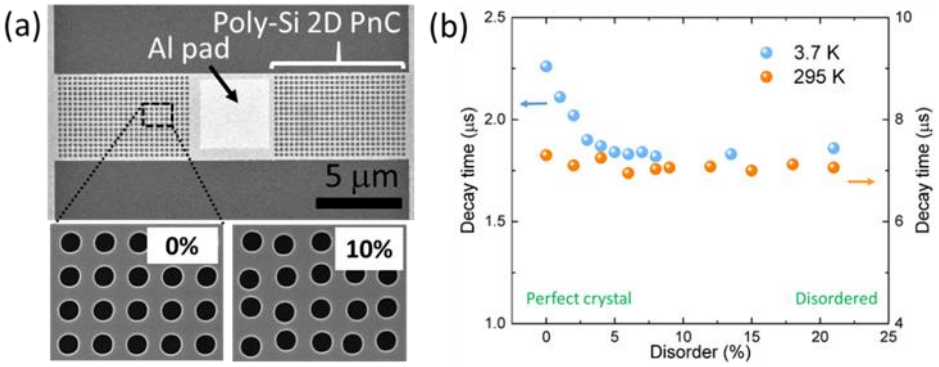

Figure 1(a) SEM image of a single crystalline phononic crystal. The lower images show close-up views of a perfectly periodic structure (left) and holes randomly moved within 10% of the period (right). (b) Dependence on disorder of the thermal decay time at room temperature (orange) and 4K (blue).

Acknowledgments: This work was supported by the Project for Developing Innovation Systems of MEXT, Japan, and of JSPS KAKENHI (Grant No. 25709090 and 15K13270).

References: [1] M. Nomura *et al*., Appl . Phys. Lett. **106**, 143102 (2015). [2] M. Nomura *et al*., Phys. Rev. B **91**, 205422 (2015). [3] J. Maire *et al*., submitted.