熱フォノニクスによる熱伝導制御の実現とそのメカニズム

Thermal conduction control by thermal phononics and its mechanisms

IIS[1], LIMMS/CNRS[2], Nanoquine[3], Univ. of Tokyo, EM2C CNRS[4], and JST PRESTO[5]
°J. Maire[1,2], R. Anufriev[1], R. Yanagisawa[1], S. Volz[4], M. Nomura[1,3,5]
E-mail: jmaire@iis.u-tokyo.ac.jp

Phononic crystals are able to alter phonon transport properties just like photonic crystals do for light. While various effects have been achieved with photonic crystals (PhC), the more complicated physics of phonons renders thermal conduction control more challenging. Phonon transport has been investigated in Si PnCs [1-3] and coherent scattering appeared at cryogenic temperatures. In this work, we elucidate the mechanisms of thermal conduction change in phononic crystals due to the wave nature of phonons.

Samples were fabricated from a single crystalline Silicon-on-insulator wafer. Suspended membranes (Fig 1a) and nanobeams (Fig 1b) of thickness 145 nm are patterned with circular holes drawn by electron-beam lithography. The pitch between holes is 300 nm and their arrangement on the membrane is that of a square lattice. They are then randomly moved from their initial position within X% of the pitch (Fig 1a). Thermal characterization was performed with our thermoreflectance system [1]. The thermal decay rate points to a reduced thermal conductivity in periodic structures compared to the disordered ones (Fig 1b) at 3.7 K. Since phonon transport is purely diffusive at room temperature, we could verify that incoherent scattering mechanisms are not affected by disorder, thus the difference observed stems from coherent mechanisms, which is further supported by the thermal dependence of this effect – its disappearance as temperature increases and the anomalous behavior of the periodic structure at very low temperatures. We performed FDTD simulations at different frequencies and observed, in the periodic structures, weaker propagation for intermediate frequencies. We believe that out of the three types of phonons, non-propagating locons in periodic structures become diffusons with no well-defined wavevector in disordered PnCs, which is supported by our observation of the polarizations. This result is the first step towards the development of the concept of thermocrystals and the understanding of wave phononics.

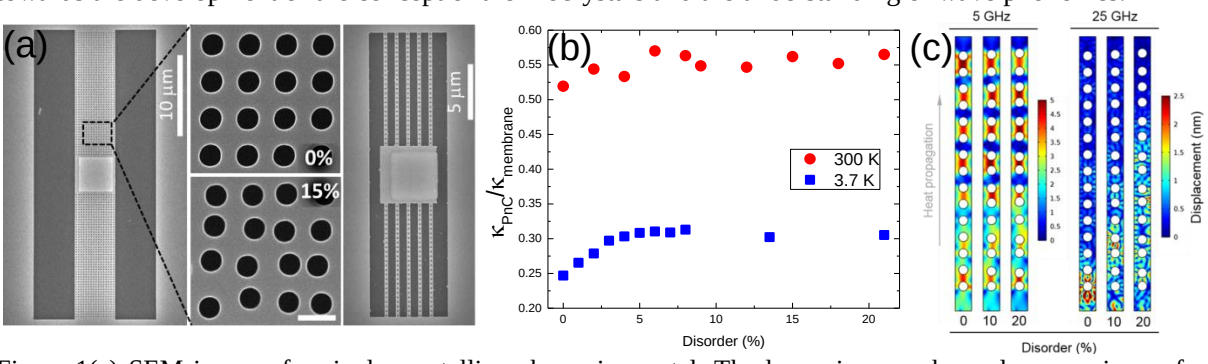

Figure 1(a) SEM image of a single crystalline phononic crystal. The lower images show close-up views of a perfectly periodic structure (left) and holes randomly moved within 10% of the period (right). (b) Dependence on disorder of the thermal decay time at room temperature (orange) and 4K (blue).

Acknowledgments: This work was supported by the Project for Developing Innovation Systems of MEXT, Japan, JST PRESTO, and of JSPS KAKENHI (Grant No. 25709090, 15H05869, 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.*, arXiv:1508.04574.