Asymmetric thermal properties observed for nanomesh patterned locally on a suspended graphene

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Thermal rectification is a behavior that is similar to the electric diode, where heat transport highly relies on the directions. Most of the systems are based on the graded structure or heterostructure. The phenomena usually are contributed to the temperature dependence of the thermal conductivity [1]. Nowadays, the research interests for thermal rectification has been extended from bulk materials to nanosize materials. Phonon behavior is suggested to play more roles in heat transport [2]. As graphene has its unique 2D structure, it is an ideal simplified platform to understand the phonon transport. Recently, both the experimental and theoretical results for thermal rectification based on monolayer graphene have been reported [3-4]. However, the thermal rectification based on the structure-controlled graphene phononic crystal has not been demonstrated yet. In this work, we used the helium ion beam milling technique to build structure-controlled suspended graphene nanomesh devices. By combining with the pristine graphene part, we observed asymmetric thermal transport properties in this kind of homogeneous structure.

The suspended graphene nanomesh devices were fabricated by milling periodic nanopores on the suspended large area (500 nm long and 1200 nm wide) graphene nanoribbon devices (Fig. 1). The nanopore diameter was fixed around 6 nm [5]. We patterned the nanopores on half of the suspended graphene (half-meshed) to introduce the asymmetric structure as shown in Fig. 1. In order to avoid the thermal noise from the environment, the device was measured in the cryostat from 100K to 300K. We used the "thermal bridge method" to evaluate heat transport from both directions. The thermal bridge method compares the temperature difference (ΔT) of the heater with the same heating power between "no bridge" condition and "have a bridge" condition, which is commonly used to measure the thermal conductivity in macro bulk materials (Fig. 2-3). We observed the different thermal transport properties between the two directions in a half-meshed device (Fig. 4). When the environment temperature was set at 150K and 250K separately, we also observed the thermal transport ratio between two directions was shrunk by increasing the environment temperatures (Fig. 5-6).

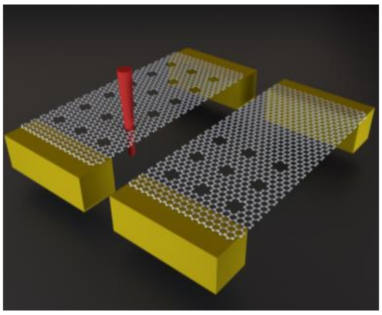

Fig. 1: Schematic illustration of the deices

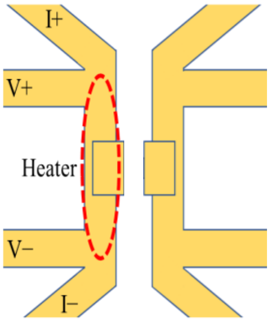

Fig. 2: "No bridge" condition

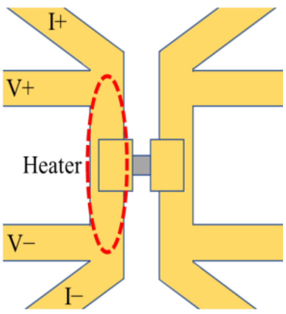

Fig. 3: "Have a bridge" condition

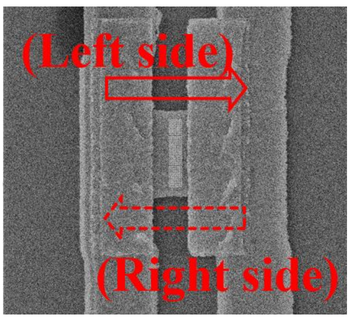

Fig. 4: 20 nm pitch half-meshed device, meshed part is in the right side.

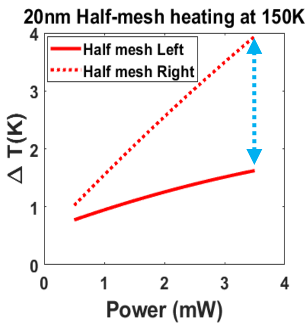

Fig. 5: Result at 150K base temperature.

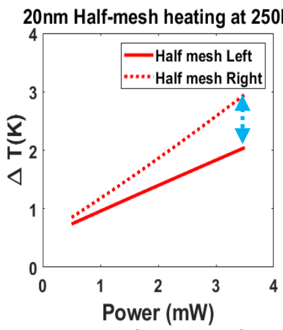

Fig. 6: Result at 250K base temperature.

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