Thermal rectification in suspended monolayer graphene

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Thermal rectification is a phenomenon that the heat flow changes by reversing the direction of temperature gradient. This is a fundamental behavior of the thermal rectifiers, which can be used for the active heat flow control, thermally driven computer, efficient energy harvesting, etc. The key challenge is how to increase the thermal rectification ratio, which is defined as the relative change of thermal conductivities in different heat flow directions. Due to the significant size effect and unique heat transfer mechanisms, nanomaterials (such as carbon nanotubes, nanowires, graphene, etc.) are suggested to have high thermal rectification ratio. However, the experiment result showed that the ratio of the single carbon nanotube thermal rectifier was only 7%.

In the past decade, many theoretical researches and molecular dynamics simulations have shown that the monolayer graphene may have high thermal rectification ratio due to its unique two-dimensional heat transfer mechanism. But the experimental work is still a blank because of the difficult fabrication process of suspended graphene electronic device. In this work, we report the experimental demonstration of a suspended monolayer graphene thermal rectifier. Three different types of graphene thermal rectifiers have been fabricated with different asymmetric nanostructures, as shown in Fig. 1. The focused ion beam manufacturing, electron beam induced deposition and precise electron beam lithography were used to design and create asymmetric nanostructures on the monolayer graphene. The thermal rectification ratios were measured by using a precise H-type sensor method. The highest rectification ratio reaches 26% for the graphene with asymmetric nanopores. The asymmetric dependence of thermal conductivity on temperature and space is known to be the physical reason. For the other two kinds of thermal rectifiers, the rectification ratios are about 10%. The asymmetric phonon scattering is known to be the physical reason, which has been proved by using large-scale molecular dynamics simulation.

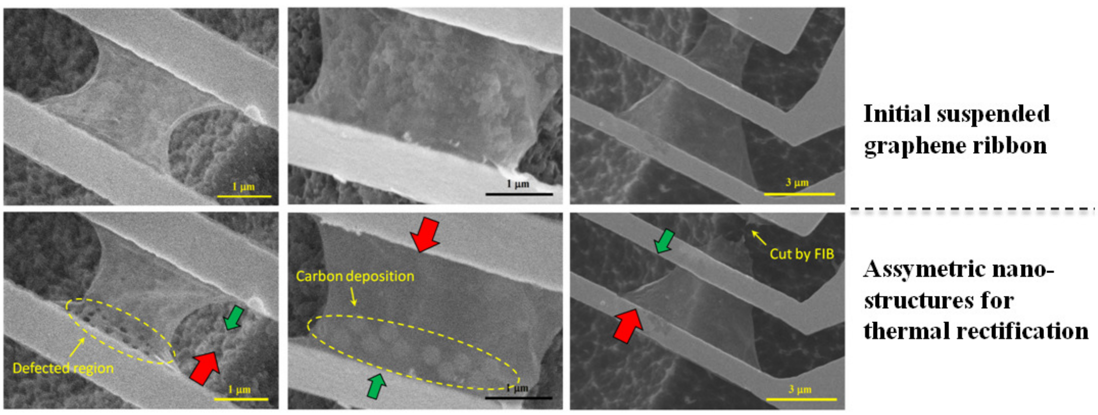

Fig. 1: SEM images of three different types of graphene thermal rectifiers