Solid-State Thermal Regulation and Rectification Based on Polyethylene Nanofibers

Xiao Luo [S] and Sheng Shen [C]
Department of Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA, U.S.A.
shengshe@andrew.cmu.edu

Ultrahigh-draw-ratio mechanical stretching is used to fabricate polyethylene (PE) nanofibers with high chain alignment and high degree of crystallinity. The nanofibers show an orthorhombic crystal structure with a high thermal conductivity (~70 $Wm^{-1}K^{-1}$) at room temperature. However, rotational disorder occurs at a temperature close to melting temperature, in which the nanofibers switch to the hexagonal phase with a sharp drop of thermal conductivity. Such a solid-state phase transition makes the PE nanofibers an intrinsic thermal regulator. Measurements show a thermal switching ratio in average ~8x with maximum ~10x. Consistent thermal regulation is realized within 50 cycles without degradation. Furthermore, electron-beam irradiation is employed to modify the phase transition. Phase transition is retained for lightly-irradiated (LI) PE nanofibers but occurs at a lower temperature. In contrast, phase transition disappears in heavily-irradiated (HI) PE nanofibers. Here, the heterogeneous irradiated-pristine PE nanofiber junction is fabricated by e-beam irradiation on a part of a nanofiber, and the asymmetry of the junction shows a strong thermal rectification behavior. The HI-P junction shows ~50% thermal rectification within only 10K temperature bias. Besides, the LI-P junction shows a dual-mode thermal rectification in which heat flow can be rectified in both directions under different working temperatures. The remarkable thermal regulation and rectification performance of PE nanofibers shows great potential of using polymers in advanced thermal management.