Enhanced energy accommodation of gas molecules by surface modification with vertically aligned single-walled carbon nanotubes

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Abstract

Since rarefied gas flows in micro/nano devices are dominated by the interaction of gas molecules and solid surfaces, surface modification technique is one of the critical issues for optimizing the thermal performance of these devices. In this paper, we demonstrate the successful application of vertically aligned single-walled carbon nanotubes (VA-SWNTs) as surface modification material to enhance the energy accommodation of gas molecules on surfaces. The scattering of gas molecules on quartz surfaces covered with VA-SWNTs was investigated by the molecular beam technique. VA-SWNTs were grown by alcohol catalytic CVD method and their thicknesses range from 0.1 to 20 μm. These films have well aligned structure except in the topmost part of the films, where SWNT bundles are randomly oriented. The high porosity more than 95% allows gas molecules to penetrate into the films and to have number of collisions with SWNT bundles before leaving the films. For this reason, the surface modification efficiently enhances the energy accommodation of incident molecules in spite of poor accommodation during each single scattering event on SWNT. The energy accommodation coefficients of helium, which tend to be small even for rough surfaces because of the large mass mismatch between helium and surface atoms, were close to unity for the modified surfaces. The measurements were performed also for the free-standing samples, which enable us to evaluate the scattering of gas molecules on VA-SWNT films in detail without the presence of substrates. The scattered molecules are divided into three components; reflected molecules, diffusively transmitted molecules, and directly transmitted molecules without interaction with SWNTs. Even for the film as thin as 0.1 μm, the incident molecules are found to be well accommodated to the surface temperature. This result suggests that, regardless of the film thickness, most molecules have enough number of collisions with SWNTs for efficient energy transfer in the randomly oriented layer at the topmost of the films.