Dependence of carbon nanotube forest density on nucleation temperature in dynamic chemical vapor deposition recipes

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Synthesis of vertically aligned carbon nanotubes (CNTs), commonly referred to as CNT forests, is required for many applications that take advantage of anisotropic mass/energy transport properties, such as high electrical or thermal conductivities in electrical interconnects and thermal interfaces, respectively. However, important questions remain: (1) how catalyst formation can be controlled, and (2) what determines CNT nucleation density. In growing CNT forests via catalytic chemical vapor deposition, thin metal films deposited on a substrate are first converted into nanoparticles by dewetting at high temperature in a reducing atmosphere. Upon introducing a hydrocarbon gas, some of these nanoparticles nucleate CNTs that continue to grow until self-termination. Usually, the conditions for the dewetting and nucleation steps are coupled. Here, we developed a dynamic recipe, in which we decoupled the catalyst preparation step from CNT nucleation step by using rapid thermal processing. We found that nucleation density of CNTs in a forest has a negative correlation with the nucleation and growth temperature regardless of the dewetting temperature. For the same nucleation temperature of 720 °C, density of CNT forests remained nearly constant

with varying dewetting temperature from 500 to 900 °C. Atomic force microscopy analysis revealed that particle number density does not correlate to CNT density. Hence, nucleation density in CNT forest growth can be controlled by tuning the CNT nucleation condition, independently from the catalyst preparation conditions as long as sufficient particles are formed by dewetting. This insight enables decoupling density and diameter of CNTs in forests for tailoring their collective properties.