Realization of the Three-Dimensional Network of Nanostructures and Their Optical Scattering Properties

by

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ABSTRACT

To enhance our capability of controlling light, there is a need to discover and invent materials with a new set of optical properties that are not easily attainable in naturally occurring materials. By engineering the materials to create complex network structures, randomly or periodically, the light-matter interaction is modified as well as their optical properties, such as index of refraction, transmission, reflection, diffraction, absorption and emission, and finally, light guiding and trapping. This thesis is to study the optical scattering from the complex network structures and to implement methods for realizing such kinds of nanostructures. Two extreme cases of network structures will be investigated. One is vertically aligned carbon nanotubes (VA-CNTs) array – a three-dimensional random network system. The other is the periodic, three-dimensional photonic crystal. The optical properties of both network systems are investigated by means of reflectance, diffuse reflectance, transmittance, and emission measurement.

We found that the VA-CNTs array is the darkest man-made material with total reflectance of 0.03-0.05% from visible to mid-infrared. Moreover, the results of diffuse reflectance measurement suggest that VA-CNTs array is a strong light diffuser. These observations are attributed to the high porosity in the bulk and the random network of entangled nanotubes on the surfaces. The results suggest that VA-CNTs array can be used as a broadband sunlight absorber integrated with a solar conversion system, such as thermophotovoltaic and thermal conversion system, to enhance the conversion efficiency of the system. In additional, we demonstrated that VA-CNTs array is a nearly perfect blackbody by performing thermal emission measurement.

For the periodic, three-dimensional photonic crystal, we realized a visible 3D photonic crystal with photonic band edge at 0.65 μm. Moreover, we demonstrated that the Fabry-Perot resonant modes deep inside the photonic band gap with different polarizations can be tuned over brand spectral range in a monolithic fashion. Finally, we realized an active photonic structure by incorporating colloidal quantum dots into this photonic crystal. The results show that this photonic structure can control the spectral shape, peaks position, spectral shape, polarization, and directionality of quantum dots emission. Moreover, the quantum dots emission may be enhanced by this photonic

structure. This suggests that this kind of photonic structure may be used for smart lighting.

Realization of both networks of nanostructures enhances our capability of controlling light. Both nanostructures can be used for many applications, including energy applications, such as solar conversion system and smart light.