Effective Medium Calculation of the Radiative Properties of Doped Silicon Nanowire Arrays

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One-dimensional structures with nanometer diameters and high aspect ratios, such as nanotubes, nanorods, and nanowires, have become the focus of intensive research. This is because of their promising applications including biosensors, solar cells, piezoelectric resistors, photodetectors, and thermophotovoltaic devices. A large number of studies have been carried out both experimentally and theoretically on the fabrication and characterization of such one-dimensional nanostructures. Common fabrication methods include chemical vapor deposition and laser ablation. The effective medium theory, the transfer matrix method, and molecular dynamics simulation are often used to model their optical and thermal properties. Nanowire arrays can modify the spectral radiative properties of the surface to achieve high absorption or high reflection, depending on the geometric parameters and the inherent dielectric functions of the composite materials. The radiative properties are strong function of wavelength and polarization. While much has been done for metallic and dielectric nanowire arrays, the effect of doping in silicon on the visible and infrared radiative properties has not been extensively studied. Doped silicon nanowire arrays may have important applications in solar and thermal photovoltaic devices as well as for radiation detectors. In the present study, we use the recently tested Drude model for the free-carrier absorption and the band-gap absorption model for the indirect transitions of heavily doped silicon with doping concentrations greater than 10^{18} cm^{-3}. The effects of volume filling ratio, doping concentration, wire length or thickness of the nanowire carpet, and temperature are investigated with the effective medium theory based on the general Maxwell-Garnett approach.The effective optical constants are evaluated in the wavelength regions from the visible to the mid-infrared. The study reveals that the absorptance of heavily doped silicon nanowires can be greatly enhanced at both shorter and longer spectral regions owning to the low effective refractive index along with the increased free carrier absorption. However, within the intermediate spectral range, the absorption of doped silicon nanowires is smaller than that of the doped silicon films due to the significant decrease of the effective extinction coefficient near the band gap wavelength.The results may impact the design of solar cells and radiative filters and absorbers in thermophotovoltaic devices.