Coupling of light into nanowire arrays and subsequent absorption

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Keywords: Light, absorption, scattering, subwavelength, semiconductor, nanowire, periodic array, photovoltaics, solar cells

In this work we report on a theoretical study of the coupling of light into an array of III-V semiconductor nanowires and subsequent absorption in the array. The response to incident light was modeled with the Maxwell equations that were solved with our novel scattering matrix method[1]. We found the absorption in the array to depend on the material, diameter and length of the nanowires, as well as the period of the array. Nanowires of a length of just 2 μm were able, after an appropriate choice for the other parameters, to absorb above 90% of the incident energy of both TE and TM polarized incident light, with photon energy more than 5% above the band gap, for incidence angles up to 60 degrees. This high total absorption arises from a good single interface coupling of light into the nanowire array at the interface between air and the array and absorption inside the array before the light reaches the interface between the nanowires and the substrate. We found that for a given photon energy there exists a critical nanowire diameter above which a dramatic increase in the absorption occurs. The critical diameter decreases for increasing photon energies. Simple models based on an effective refractive index for the array, calculated from the filling factor of the nanowires, could not reproduce this diameter dependence, highlighting the importance of using full electromagnetic simulations. The critical diameter can be explained in terms of the dispersion of waveguiding modes in single, isolated, nanowires, and their connection to the eigenmodes of the nanowire array. Finally, by combining semiconductors of decreasing band gap from the top to the bottom of the nanowires we found very good absorption profiles for next-generation solar cells where high energy photons are absorbed close to the top of the array and lower energy photons are absorbed closer to the bottom. This study is of importance for photovoltaics and general subwavelength optics in periodic structures.

References:

[1]N. Anttu and H. Q. Xu: To be published