Light trapping in arrays composed of subwavelength non-imaging light concentrators

Light trapping and the broadband absorption of the solar radiation has various important applications in the field of solar energy conversion. For example, light trapping supports the realization of ultrathin PV cells with absorption comparable to bulk solar cells; this directly leads to lower recombination currents, higher open circuit voltages and overall photovoltaic efficiency enhancement. The Yablonovitch limit is based on statistical ray optics that provides the maximum light trapping possible in a homogeneous semiconducting film of a given thickness. The limit assumes maximal occupation of the absorber optical modes by randomizing the textures of the top and bottom interfaces of a given film; the randomization produces interface-photon scattering events that impart additional momentum components to the impinging radiation and in this manner allows the occupation of the absorber guided and radiation modes, for example. Surface arrays of subwavelength features can impart these momentum additions to the impinging radiation by scattering and/or diffraction. Moreover, surface arrays of semiconducting subwavelength features introduce additional optical modes that can be populated by the incoming radiation, namely, localized trapped modes also referred to as Mie modes. The presence of Mie modes and hybridization of these with guided modes and/or radiation modes, for example, permits light trapping beyond the Yablonovitch limit. Surface decoration with ordered or disordered arrays of subwavelength semiconducting features such as nanocones, nanospheres, nanopillars (NPs), rods, nanoholes, etc., was shown experimentally and numerically to provide broadband absorption enhancement of the solar radiation due to efficient light trapping.

Recently, we introduced the light funnel (LF) array, which is a new light trapping scheme bio-inspired by the *fovea centralis*. With LFs we refer to subwavelength cones with the large base facing the impinging radiation. We presented a numerical study of free-floating silicon LF arrays. The absorption spectra of LF arrays is characterized by strong spectral absorption peaks, and we demonstrated superior broadband absorption of the solar spectrum compared with other recent advancements in the field. We showed that deformation of the NP geometry into a LF geometry results in the formation of 3D complex Mie modes that enhance the optical coupling between the LF array and the incoming radiation. We also showed that the coupling of the LF array with an underlying substrate provides an additional absorption enhancement. Finally, the realization of silicon LF arrays was also demonstrated.

The work on LF arrays was recently expanded to arrays composed of subwavelength non-imaging light concentrators (NLCs). Nonimaging optics was developed by Winston and colleagues during the late 1960s and early 1970s, in which they realized that the performance of light collection systems (in terms of collecting aperture and the angular field of view) could be maximize if one is to leap beyond the physics of geometrical image-forming optics. There are various designs of NLCs such as light cone (LC) NLC, paraboloid NLC, hyperboloid NLC (=trumpet NLC), compound parabolic concentrators (CPC) and its derivatives, etc.

We numerically show that silicon NLC arrays provide >75% broadband absorption enhancement of the solar radiation compared with that of optimized nanopillar arrays. We show that CPC arrays function as anti-transmission layers as only few photons transverse the CPC arrays which is in contrast to nanopillar arrays that function as anti-reflection layers. We show that the absorption enhancement in NLC arrays is due to efficient occupation of Mie modes which is motivated by the unique CPC geometry, and we demonstrate light trapping at the Yablonovitch limit. Finally, we showed that the enhanced absorption is directly translated into enhanced short-circuit currents.

Currently our research focuses on basic questions involving light trapping and broadband absorption of the solar radiation in NLC arrays. Our research methodology involves fabrication of various NLC arrays, far-field spectroscopy, near-field microscopy, electromagnetic and device calculations, and the realization of PV cells based on NLC arrays.

Bioelectronics and biosensors based on novel silicon multi-gate field-effect devices

The interface between biomolecules and solid surfaces has been the subject of the interdisciplinary research of bioelectronics for the last three decades. Still, to date, the commercialization of bioelectronic devices is very limited; for example, biosensors based on field-effect devices is a research topic highly pursued for more than 40 years, and still, to the best of our knowledge, no products are available today in the market. Moreover, very few successes were reported to date. The reason for this reflects the main challenge in bioelectronics, namely, adequate control over the biomolecule-solid interface. For example, biomolecules are known to play different roles in nature, when found in aqueous media and free to change conformation as part of carrying out their original function. Attaching these molecules to solid surfaces clearly introduces new working conditions, which might affect the conformation, optical properties, electrical properties and the functionality in general. Currently, the biomolecule-solid interface is mainly controlled using chemical and biological modifications, as well as surface texturing, of the solid surface. Still, there is a significant gap in understanding the processes underlying the integration and functionality of biomolecules in solid state devices.

Our research focuses on electrostatically controlling the biomolecule-solid interface. For this purpose, we use novel field-effect silicon devices that locally introduce electric fields into the interface vicinity. Our research methodology involves device fabrication, electrical sensing measurements and device numerical calculations.