Enhancement of organic solar cells by silver nanoantennas

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Photon management with nanostructures represents one of the most promising ways to further advances in performance of thin-film photovoltaic (PV) cells. Previously we have developed a light trapping structure (LTS) based on patented silver nanoantennas (NAs) [1] supporting the collective modes for the efficient light confinement in the bulk of the absorbing substrate [2, 3]. Lower losses and advantageous energy distribution resulting from these modes called leaky domino-modes made the use of phenomenon attractive for the practical study with realistic solar cells [4, 5]. Their impact looked most promising for organic solar cells (OSCs) applied on a window glass and converting the infrared light into electricity so that the visible light transmits through the window [5]. OSCs are not very efficient solar cells but promising due to their very low weight, very low cost, stability of parameters and flexibility. 10 years ago, 0.5% of power conversion efficiency (PCE) was a standard value for OCSs. Nowadays, the best OCSs manifest 11% PCE in their single-junction variant and 13% in tandem devices. However, the main drawback of these thin-film solar cells keeps the same – insufficient absorption of light in the PV layer. The reason is strongly sub-wavelength thickness of this layer at frequencies of solar radiation. If the rear electrode of the OSC is transparent, the most of power transmits throughout. If it is of metal, no any antireflective coating may prevent a strong reflection because it occurs inside the structure. The increase of thickness of the PV layer leads to high recombination losses rapidly growing when the thickness exceeds the exciton size. That is why the thickness does not exceed 100-150 nm and special mechanisms of the PV absorption enhancement called light trapping are of vital importance for the commercialization of OSCs.

In this talk, we present theoretical and experimental results of the enhancement granted to the PV absorption by our NAs for a particular OSC [1]. We have chosen a classical bulk-heterojunction molecular OSC with phthalocyanine as a donor nanolayer and fullerene as an acceptor one. Unfortunately, we did not manage to fabricate a transparent conductive cathode on the surface of the OSC patterned by NAs. We decided to replace the transparent material of the top electrode [5] with a metal simultaneously replacing a transparent OSC integrated with window glass and operating in the infrared [4, 5] by a classical 10 years old version of such OSC mainly targeted to conversion of the visible range. A typical PCE for this cheapest and easily fabricated OCS is 0.5%., whereas its optical loss even in presence of an anti-reflective coating is close to 80% [5]. In the visible range, our NAs with properly chosen dimensions theoretically offer to such an OSC a double enhancement of the PV absorption. This double enhancement should result, in accordance to the theory of such OSCs, in the 25% increase of the overall PCE. Comparing the results obtained for several samples comprising our NAs with the results obtained for the same samples without NAs we have experimentally observed a noticeable improvement of the short circuit current and the fill-factor (though accompanied by a slight decrease of the open-circuit voltage). Finally, we observed the enhancement of PCE from 0.389% to 0.486% i.e. 24% increase. We have proved the duplication of the optical absorption granted by our NAs measuring the plane-wave reflection coefficient over the solar spectrum for all samples of OSCs. In our experiments, the samples without NAs comprised an optimal anti-reflective coating. The present study finalizes the experimental confirmation of the claims of [1] originally based only on numerical simulations and theory of leaky domino-modes.

References

1. C. Simovski, US Patent No 9252303: February 2, 2016
2. P.M. Voroshilov and C.R. Simovski, *Phot. Nanostr.: Fund. Applic.*, Vol. 20, 18-30, 2016
3. I.S. Sinev, et al., *Nanoscale,* Vol. 7, 765-771, 2015
4. C.R. Simovski, at al. *Opt. Express*, Vol. 21, A714-A725, 2013
5. P.M. Voroshilov, C.R. Simovski, and P.A. Belov, *J. Mod. Optics*, Vol. 61, 1743-1748, 2014