Engineering of 3D-barriers by charged quantum dots for effective broadband photovoltaic conversion

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Quantum dot (QD) solar cells attract much attention due to their ability to enhance efficiency of solar cells by utilizing energy of the below-bandgap photons via absorption by multiple energy levels introduced by QDs. However, so far the intensive efforts to improve real devices have shown very limited success*:* an increase in photovoltaic efficiency due to QDs has not exceeded a few percent compared to the reference solar cell based solely on the matrix material. Limitations of the current technology are well understood. Not only absorption, but relaxation and recombination are also drastically enhanced due to the QD energy levels. Can we force QDs to work for absorption without enhancement of the recombination processes?

The technology proposed here is based on quantum dots with built-in charge (Q-BIC) embedded in the i-region of a p-i-n junction. The built-in-dot charge is managed by band engineering accompanied with corresponding intra-dot doping. The charged dots may be used to create unique combinations of 3D potential barriers that will direct the motion of photocarriers. For example, such barriers may separate electrons from holes or some carriers from QDs.

In very recent publications [1, 2], we have experimentally demonstrated that Q-BIC technology provides strong harvesting and conversion of IR radiation. Moreover, the IR conversion is significantly enhanced by tshort wavelength radiation (optical pumping). The first pass optimization of Q-BIC broadband photovoltaic devices has already demonstrated that conversion of infrared energy adds 5% to the cell efficiency. The short circuit current density increases to 24.30 mA/cm^2 compared with 15.07 mA/cm^2 in undoped QD solar cells (i.e. 50% increase) without deterioration of the open circuit voltage. We are now working with samples that lead to the additional 10% increase in efficiency compared to identical devices without QDs or devices with weakly charged dots (and the short circuit current density increases up to 30 mA/cm^2). There are two basic effects behind these radical improvement: (i) the built-in QD charge enhances the photoinduced intraband transitions in QDs and transitions from QD localized states to conducting states in the matrix; (ii) the built-in QD charge creates potential barriers around the dots and exponentially suppress the capture processes for photocarriers of the same sign (Fig. 1). The reported data are limited by the value of built-in-dot charge of six electrons per dot. However, the obtained results show that we are still far from saturation of positive effects due to interdot doping. Further doping-related improvements and their limitations are under investigation. The proposed Q-BIC technology has a potential to improve the conversion efficiency of a broadband solar cell by adding up to ~20% to the total efficiency of a reference solar cell.

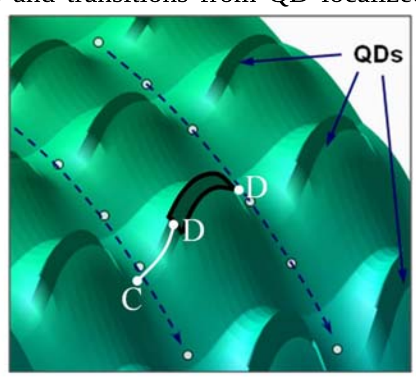

Fig. 1. 3D potential profile in QD structures.

1. K. A. Sablon, A. Sergeev, N. Vagidov, *et al.*, *Nanoscale Res. Lett.* **6**, 584 (2011).
2. K. A. Sablon, J. W. Little, V. Mitin, *et al.*, *Nano Lett.* **11**, 2311 (2011).