Semiconducting silicon-tin quantum dots as environmentally friendly material for carrier multiplication solar cell at low cost

[1]Research Center for Photovoltaic Technologies, National Institute of Advanced Industrial Science and Technology (AIST), Central 2, Umezono 1-1-1, Tsukuba, 305-8568, JAPAN, [2]Nanotechnology and Advanced Materials Research Institute (NAMRI), University of Ulster, BT37 0QB, Northern Ireland, UK, [3]Graduate School of Engineering, Tohoku University, Sendai, Japan

○Vladimir Švrček[1], Mickaël Lozac'h[1], Davide Mariotti[2], Noboru Ohashi[3], Tetsuhiko Miyadera[1], Koji Matsubara[1],

E-mail: vladimir.svrcek@aist.go.jp

Quantum dot (QD) solar cells with carrier multiplication (CM) offer great potential for conversion efficiency improvements. CM refers to the scattering of a hot electron (hole) with a valence band electron, whereby the excess energy of the hot electron (hole) is used to create additional excitons that can considerably enhance photocurrent generation in solar cells. In principle CM can be enhanced by quantum confinement effects in QDs. Ideally, nanostructures with CM effects should be integrated easily and at low cost with current silicon-based photovoltaic (PV) technologies; this justifies our research in silicon-based QDs, which could potentially overcome the shortcomings of silicon indirect bandgap and offer quasi-direct transitions. However, research showed that the relatively wide energy bandgap of nano-silicon does not offer optimal conditions for solar energy absorption.

The focus of this contribution is to report on the opportunities offered by Si-alloying in QDs to overcome the limitations of elemental nano-silicon, preserving quantum confinement effects and achieving the CM threshold at the maximum of the solar spectrum. Theoretical calculations of the electronic structure in binary SiSn compounds predict the energy bandgap to be below that of Si, which becomes direct at 0.85 eV with a minimum of 0.46 eV. However, the Si-Sn system presents some synthetic challenges due to the large difference in size between Si and Sn atoms and due to thermodynamic instability as $Si_{1-x}Sn_x$ alloys are inherently metastable. We have demonstrated that the synthesis of semiconducting SiSn QDs can be achieved via a highly non-equilibrium spatially confined short-pulsed (ns or fs) laser process. These SiSn QDs have quantum confinement size (< 10 nm) and are well dispersed with a relatively narrow size-distribution. A shift in the absorption peak down to 0.85 eV and at 0.64 eV is clearly observed. SiSn QDs have been therefore studied in details including the analysis with synchrotron radiation. In order to accurately determine the energy band structure (e.g. valence band) of the QDs, hard x-ray photoelectron spectroscopy using excited synchrotron radiation ($h\nu$ = 7939 eV) in SPring-8 was used.