E-004

Applications of XPS and SIMS for the development of Si quantum dot solar cell

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Precise control of the position and density of doping elements at the nanoscale is becoming a central issue for realizing state-of-the-art silicon-based optoelectronic devices. As dimensions are scaled down to take benefits from the quantum confinement effect, however, the presence of interfaces and the nature of materials adjacent to silicon turn out to be important and govern the physical properties.

Utilization of visible light is a promising method to overcome the efficiency limit of the crystalline Si solar cells. Si quantum dots (QDs) have been proposed as an emission source of visible light, which is based on the quantum confinement effect. Light emission in the visible wavelength has been reported by controlling the size and density of Si QDs embedded within various types of insulating matrix. For the realization of all-Si QD solar cells with homojunctions, it is prerequisite not only to optimize the impurity doping for both p- and n-type Si QDs, but also to construct p-n homojunctions between them.

In this study, XPS and SIMS were used for the development of p-type and n-type Si quantum dot solar cells. The stoichiometry of SiOx layers were controlled by in-situ XPS analysis and the concentration of B and P by SIMS for the activated doping in Si nano structures. Especially, it has been experimentally evidenced that boron atoms in silicon nanostructures confined in SiO2 matrix can segregate into the Si/SiO_2 interfaces and the Si bulk forming a distinct bimodal spatial distribution. By performing quantitative analysis and theoretical modelling, it has been found that boron incorporated into the four-fold Si crystal lattice can have electrical activity. Based on these findings, p-type Si quantum dot solar cell with the energy-conversion efficiency of 10.2% was realized from a [B-doped $SiO_{1.2}$(2 nm)/SiO_2(2 nm)]^{25} superlattice film with a B doping level of 4.0 x 10^{20} atoms/cm^2