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Microscopic Investigation of Mono-layer/Multi-layer self-assembled InAs QDs on $GaAs_{1-x}Sb_x$/GaAs Composite Substrates for Photovoltaic Solar Cells

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The maximum energy conversion efficiency of a photovoltaic (PV) solar cell consisting of single-junction semiconductor layer is limited by the Shockley-Queisser (SQ) effect, which is ~ 31% under one sun illumination according to theoretical calculation [1]. In order to increase the efficiency, multi-junction and multi-transition approaches have been proposed. These schemes aim to allow subband gap absorption by introducing intermediate states within the band gap of the barrier material in order to increase photocurrent [2]. Quantum dots (QDs) are considered as a promising candidate material for multiple transition solar cells because of their discrete density of states, which would favor the formation of a quasi-Fermi level discontinuity between the bulk and the confined materials [3]. Formation of self-assembled InAs QDs embedded in $GaAs_{1-x}Sb_x$ layer has been shown to follow the Stranski-Krastanov (SK) growth mode with a lattice-mismatch of ~7% between InAs and GaAs(Sb) matrix. A set of mono-layer InAs QDs on $GaAs_{1-x}Sbx$/GaAs and a set of multi-layered InAs QDs on $GaAs_{1-x}Sbx$/GaAs with different Sb concentration and layer periods were grown on semi-insulated GaAs (001) substrates using molecular beam epitaxy (MBE). It is interesting to investigate the structure-growth-performance properties of this material system using electron microscopy before further utilizing them in actual photovoltaic applications. Cross-sectional TEM samples were prepared using mechanical polishing and dimpling followed by argon ion-milling. Most images were recorded using high-angle annular-dark-field (HAADF) imaging in a JEOL-2010F field-emission STEM operated at 200 keV, which provided a nominal probe size of ~2 Â. Preliminary STEM observations of InAs/$GaAs_{1-x}Sb_x$/GaAs QDs system are reported here.

Figure 1(a) is a schematic showing the structure of these MBE-grown self-assembled InAs QDs on $GaAs_{1-x}Sb_x$/GaAs. The Sb concentration is ~7% and ~10%, respectively, in order to tune the energy band alignment. Figure 1(b) is a high-resolution HAADF-STEM image revealing the cross-sectional morphology of InAs QDs on $GaAs_{0.9}Sb_{0.1}$/GaAs. The δ-doping line is shown clearly, and the InAs QDs embedded into the $GaAs_{0.9}Sb_{0.1}$ epilayer are marked by the red arrows. Multi-layered InAs QDs (10×) were grown on $GaAs_{1-x}Sb_x$/GaAs composite layer with the nominal Sb concentration of 8%, 15% and 20%, respectively, by varying Sb to As flux ratio. The actual Sb composition was determined to be 7.25%, 9.8% and 10.2% from XRD analysis. The stress relaxation in GaAsSb layers was found to be 0, 18% and 23%, respectively. Figures 2 (a) and (b) are typical HAADF-STEM images showing 10 periods of InAs QDs on $GaAs_{0.93}Sb_{0.07}$ and $GaAs_{0.902}Sb_{0.098}$, respectively. Detailed correlation between structural morphology and optical properties will be described.

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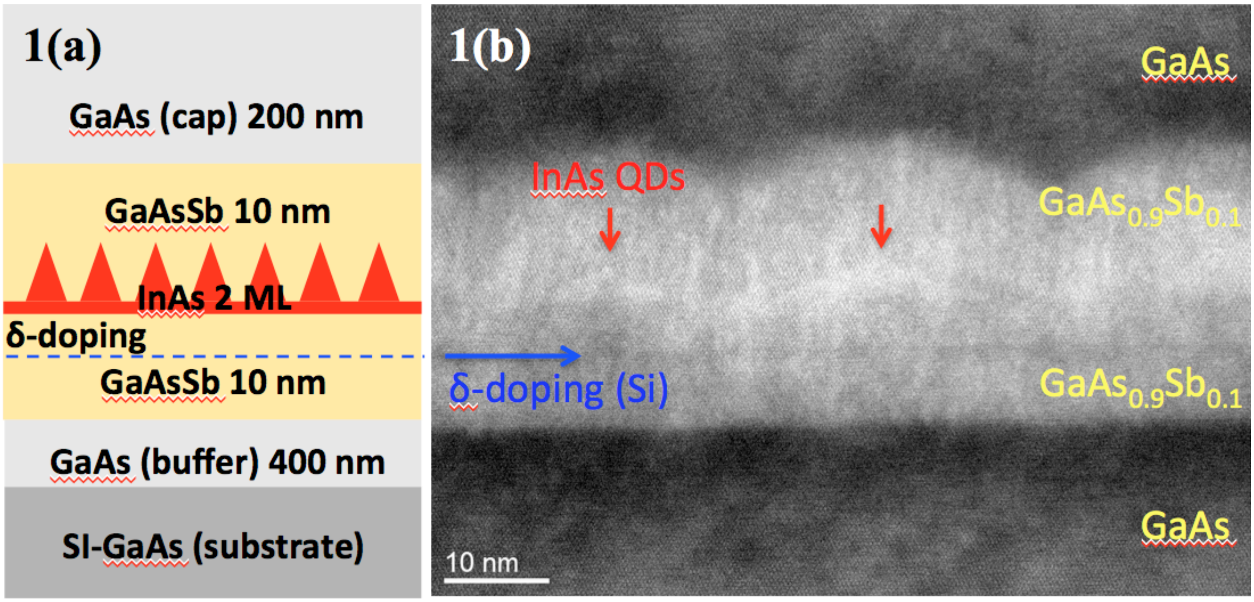

Figure 1. (a) Structural schematic of monolayer self-assembled InAs QDs on $GaAs_{1-x}Sb_x$/GaAs. (b) HAADF-STEM image of monolayer self-assembled InAs QDs on $GaAs_{0.9}Sb_{0.1}$/GaAs.

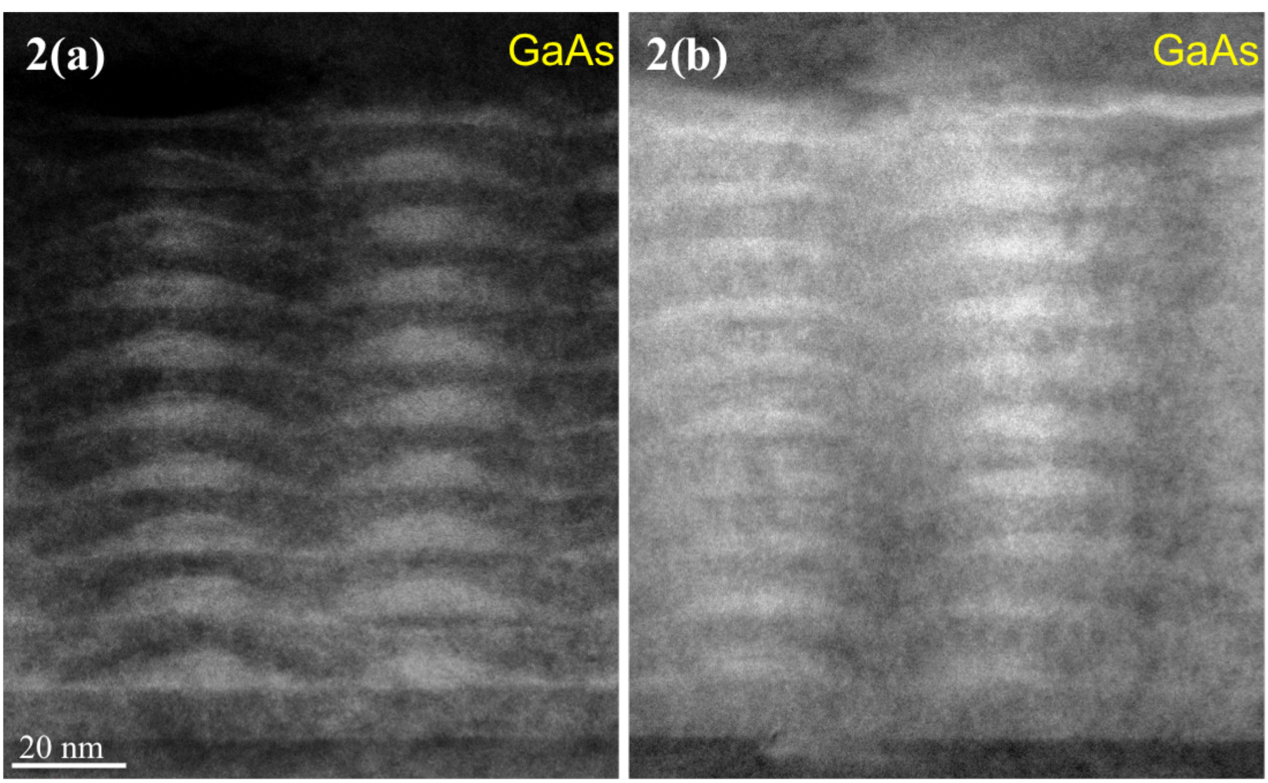

Figure 2. (a) HAADF-STEM image showing 10 periods of self-assembled InAs QDs on $GaAs_{0.93}Sb_{0.07}$/GaAs. (b) HAADF-STEM image showing 10 periods of self-assembled InAs QDs on GaAs0.902Sb0.098/GaAs.

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