ATOMIC RESOLUTION (S)TEM AND XEDS CHARACTERIZATION OF GaSb/GaInAs AND GaSb/GaInP BOND INTERFACES FOR HIGH-EFFICIENCY SOLAR CELLS

Andras Kovács¹, Felix Predan², Jens Ohlmann², David Lackner², Frank Dimroth², Rafal E. Dunin-Borkowski¹ and Wolfgang Jäger³

¹Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, 52425 Jülich, Germany
²Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany
³Materials Science, Christian-Albrechts-University of Kiel, 24143 Kiel, Germany

Abstract

Multi-junction solar cells based on III-V semiconductors reach the highest conversion efficiencies and are currently used primarily in concentrator photovoltaic systems and for power generation on satellites or spacecraft. Fabrication by wafer bonding is of interest since efficiencies of up to 46% have been obtained [1], and efficiencies of up to 50% are within reach. Fast atom beam activation is generally used as a pre-treatment to remove oxides and contamination before bonding [2]. Activation treatment and bond processing often result in amorphous interface layers with inadvertent impurities [3]. We investigate cross-section samples of as-bonded and thermally annealed (≤ 500 °C) GaSb/GaInAs and GaSb/GaInP layer systems by combining aberration-corrected high-resolution transmission electron microscopy (TEM), high-angle annular dark-field scanning (S)TEM, and in-situ TEM. Energy-dispersive X-ray spectroscopy (XEDS) using an aberration-corrected probe allows to monitor element distributions with high precision and with sub-nanometer resolution.

For GaSb/GaInAs, the crystal lattices are interconnected, and the bond interfaces show terraces, misfit dislocations, and nanometer-size pores and cavities. XEDS profile measurements reveal element fluctuations in near-interface regions. For as-bonded GaSb/GaInP, the crystal lattices are in a nearly perfect epitaxial orientation relationship with each other while the interfaces are characterized by an amorphous interlayer about 1.5 nm thick. XEDS mappings reveal minor enrichments of Ga in the interface region. These phenomena are related with the wafer pre-treatment before bonding. During thermal annealing, the interfaces change their atomic structure and their element composition. The amorphous interlayers reduce their thickness by recrystallization, resulting in a largely epitaxial interface at 500° C. XEDS mappings reveal detectable amounts of In and P (≥ 225 °C) as well as small pores and In-rich crystalline precipitates (≥ 400 °C) in the GaSb near-interface regions. These results allow to understand the electrical properties of interfaces [4] and confirm the essential role of such studies in the monitoring, control, and optimization of concepts for the fabrication of high-efficiency solar cells.