Solar hydrogen production with epitaxial III-V tandem absorber structures


1National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401, USA
2University of Nevada, Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154, USA
3TU Ilmenau, Ehrenbergstr. 29, 98693 Ilmenau, Germany
4Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany
5University of Würzburg, Am Hubland, 97074 Würzburg, Germany
6Advanced Light Source, Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720, USA
7Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, D-14109 Berlin, Germany
8Brandenburgische Technische Universität Cottbus, Konrad-Wachmann-Allee 1, D-03046 Cottbus, Germany
9Konrad-Wachsmann-Allee 1, D-03046 Cottbus, Germany
10Advanced Light Source, Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720, USA
11Hahn-Meitner-Platz 1, D-14109 Berlin, Germany

Solar fuel generation by direct photoelectrolysis of water provides a possible solution for the energy storage and transportation needs of a sustainable energy economy. The initial observation of photoelectrochemical (PEC) water splitting [1] triggered the search for appropriate semiconductor materials sufficient for large-scale economic solar hydrogen production. In contrast to photovoltaic (PV) applications, where highest device power is a sufficient efficiency criterion, PEC devices must provide the threshold voltage to drive the water splitting reactions, while the solar-to-hydrogen conversion efficiency is directly proportional to the generated current. Wide band gap materials may drive the water splitting reaction, but do not make use of a substantial portion of the solar spectrum. In contrast, most standard PV materials like silicon do not provide the thermodynamic threshold to split water [2]. Tandem absorber structures overcome this undesirable trade-off, featuring promising efficiency potentials. Subsequent absorption of different portions of the sunlight by two semiconductor materials with appropriate band gaps enables better utilization of the solar spectrum [Fig. 1], providing a sufficient combined voltage. InGaP/GaAs tandem photoelectrodes have enabled world record solar to hydrogen conversion efficiencies of up to 12.4% [3], but are still susceptible to destruction by the device. We explore the potential to improve both efficiency and durability of III-V tandem absorber structures by introducing nitrogen into the top absorber layer in order to achieve inherently better stability than pure phosphides [5]. Hence, we have evaluated post-growth nitridation of the top absorber layer in order to resolve its role in the effective protection on InGaP surfaces.

Post-growth modifications of the epitaxial InGaP surfaces are essential to achieve the desired device performance and durability in contact to the electrolyte. Metal co-catalyst deposition significantly reduces the overvoltage requirements for the hydrogen evolution reaction. Enhanced performance was achieved with sputtered metal nanoparticles in comparison to electrochemical Pt deposition. In contact with an aqueous electrolyte, both pure III-N materials as well as classical III-V semiconductors with only dilute bulk nitrogen concentrations demonstrate inherently better stability than pure phosphides [5]. Hence, we have evaluated post-growth nitridation of the InGaP surface to form the interface with the electrolyte. As will be presented, low-energy N+ ion bombardment actually has led to greatly improved durability without significant impact on PEC performance. Both X-ray photoelectron spectroscopy (XPS) and synchrotron-based soft X-ray emission spectroscopy (XES) were applied to characterize the quantity and chemical configuration of implanted nitrogen in order to resolve its role in the effective protection on InGaP surfaces against photocorrosion reactions.

References cited: