Off-Axis Electron Holography of In-Situ-Biased Highly-Doped p-AlGaAs/n-GaInP Junctions for Solar Cell Applications

Vita Mergner[1,2], Malte Klitzke[2], Dr. Patrick Schygulla[2], Dr. David Lackner[2], Dr. András Kovács[1], Prof. Dr. Wolfgang Jäger[3], Prof. Dr. Rafal E. Dunin-Borkowski[1], Dr. David Cooper[4]
[1]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, 52425 Jülich, Germany, [2]Fraunhofer Institute for Solar Energy Systems ISE, 79110 Freiburg, Germany, [3]Materials Science, Christian-Albrechts-University, 24143 Kiel, Germany, [4]Univ. Grenoble Alpes, CEA, LETI, F-38000 Grenoble, France

Introduction and motivation

Multi-junction solar cells that are based on MOVPE-grown III-V compound semiconductor layers achieve the highest solar cell efficiencies, as they absorb light from a large part of the solar spectrum. Tunnel junctions provide electrical interconnections to the device sub cells, while yielding high current capabilities and high optical transparency. As the tunnelling probability decreases exponentially with increasing depletion width, high dopant concentrations are required to achieve the narrowest junctions. Structural and electrical analysis with high spatial resolution is essential to provide feedback to optimize the growth process. Electrostatic potentials at p-n junctions can be measured quantitatively with nm spatial resolution using off-axis electron holography (EH).

Methods

Here, we combine EH with in situ electrical biasing and optimized TEM sample preparation to study electrically-contacted p-AlGaAs/n-GaInP tunnel hetero-junctions grown in upright and inverted configuration. First electron-transparent specimens of different thicknesses were studied to assess the influence on the measured electrostatic potentials of the presence of electrically-inactive specimen surface layers introduced during focused ion beam (FIB) milling. The crystalline thickness of each specimen was measured using convergent beam electron diffraction (CBED) in a scanning TEM (STEM) (Fig. 1B). The TEM specimens were prepared using dedicated chips for an electrical biasing TEM holder (Protochips Aduro 500). Reliable contacting was achieved by developing two different FIB milling procedures. First, conventional FIB milling was used to extract a region of interest, while preserving a pre-deposited Ohmic top contact (Fig. 1A). Tungsten was then deposited in the FIB workstation onto the bottom of the sample to provide a second electrical contact. The second approach involved the use of plasma FIB milling to extract slices of the wafer that contained the original top and bottom metal contacts. Electron hologram stacks were recorded from both junction configurations to improve the sensitivity and spatial resolution of the results. Measurements of depletion width were recorded as a function of both specimen thickness and applied external bias.

Results

Phase images (proportional to projected electrostatic potential) were reconstructed from the holograms as a function of applied electrical bias. Figure 1C shows a phase image recorded at zero bias and a corresponding line profile of the phase across the junction.

The inverted and upright junction configuration exhibit similar depletion widths measured at zero bias. Analysis under external bias is necessary to reveal differences in tunnelling performances occurring in the current regimes of operation under light. Our results demonstrate the importance of optimizing specimen preparation when performing in situ electrical biasing experiments. In particular, to create Ohmic electrical contacts, as opposed to the Schottky contacts that are normally formed using FIB metal deposition. By using an optimized specimen preparation approach, we could compare the electrostatic potential distribution across upright and inverted p-AlGaAs/n-GaInP junctions reliably.

Conclusions

This study demonstrates the progress that has been achieved in realizing successful in situ characterization of dopant potential distributions in III-V tunnel hetero-junctions in real solar cell devices.

Graphic:

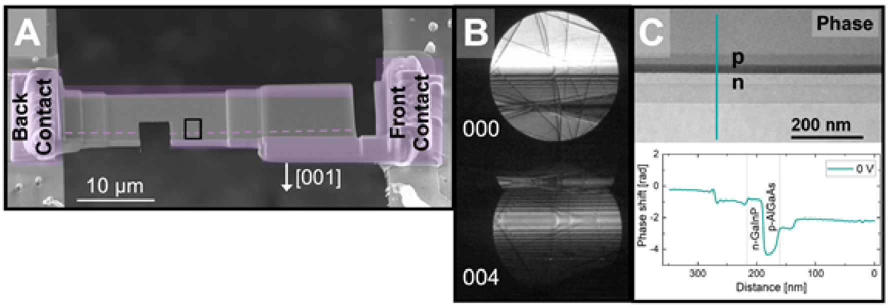

Fig. 1: A) Scanning electron micrograph of a TEM lamella of a multi-junction solar cell device that contains an upright-grown p-AlGaAs/n-GaInP tunnel hetero-junction (pink dashed line) prepared using a Ga-ion FIB backside-milling procedure. The lamella is mounted on a chip for *in situ* electrical biasing. B) STEM-CBED pattern recorded from the region marked in A to measure the crystalline specimen thickness. C) Electron optical phase image reconstructed from an off-axis electron hologram stack recorded at zero applied bias from the tunnel junction. A corresponding line profile of the phase shift (proportional to the projected electrostatic potential) is extracted from the phase image across the junction.

Keywords:

Electron Holography, III-V Multijunction PV