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Analyses of Interfaces in Wafer-Bonded Tandem Solar Cells by Aberration-Corrected STEM and EELS

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Crystalline silicon based tandem solar cells are a promising way to circumvent the conversion efficiency limits of conventional single-junction photovoltaic cells. In such devices, the visible wavelength range of the solar spectrum is converted more efficiently by adding additional pn-junctions on top of a Si cell (Figure 1).

High-quality III-V multi junction solar cells on Si can be fabricated by surface-activated wafer bonding at room temperature. In this way the formation of lattice-mismatch induced defects in the active solar cell layers can be reduced or completely avoided. In this approach, a 10 μm thin GaInP/GaAs dual junction solar cell is grown lattice-matched on GaAs and transferred to Si by direct wafer bonding (Figure 2).

An essential stage of our treatment is the in-situ particle bombardment of the surfaces before bonding aiming at cleaning and surface activation for the subsequent wafer bonding process. In an effort to optimize the process, two alternative concepts of pre-treatment for bonding have been investigated: ion beam bombardment (IB) and fast atom beam bombardment (FAB), both at various experimental parameters. The FAB method has been successfully used as well for the bonding of other semiconductor systems [1, 2].

HR-TEM and STEM-HAADF investigations on cross-sections of the bonding interfaces between the GaAs and the Si cell reveal the presence of amorphous layers (< 4nm thick) at the bonding interfaces (Figure 3). Figure 4 shows examples of element distributions extracted from STEM-EDXS (TECNAI F30 G2, left) and STEM-EELS (ER-C Titan 80-300 FEG with a CEOS double hexapole corrector, middle and right) analyses of the identical wafer-bonded GaAs - Si interface of a multijunction solar cell bonded after a non-optimal pre-treatment. The comparison clearly demonstrates that STEM-EELS analyses in aberration-corrected STEM are able to reveal fluctuations of element concentrations within the amorphous interface layer of nanometer extension, including those of light elements, and thus extend by far the analytical capabilities with respect to an EDXS analysis using a non-corrected TEM. Such measurements support assessing the influence of the interface on the measured current-voltage characteristics of a multi-junction solar cell.

References:
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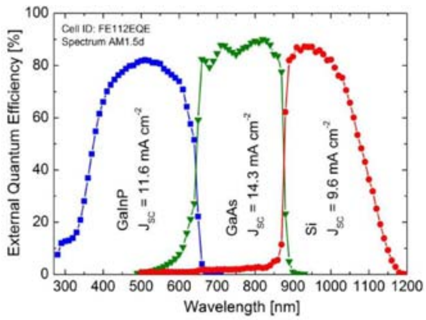

Figure 1. External quantum efficiency as measured for a GaInP/GaAs//Si multi-junction solar cell. Bonding performed after atom beam bombardment treatment.

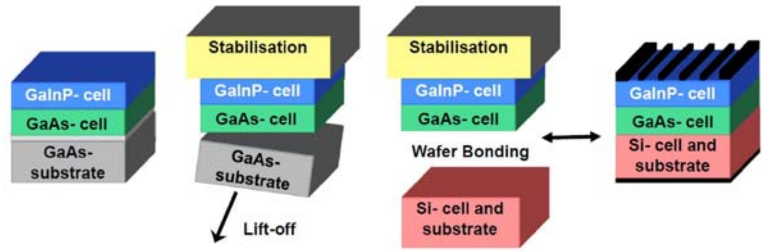

Figure 2. Process steps of wafer bonding.

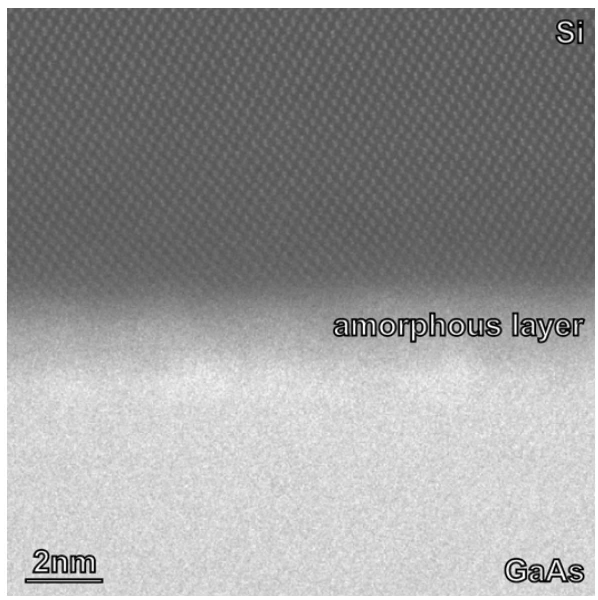

Figure 3. Cross-section HAADF-STEM image of the amorphous interlayer at the bonding interface between the GaAs middle-cell and the Si bottom-cell. III-V multi junction solar cell wafer-bonded on Si after ion beam bombardment treatment.

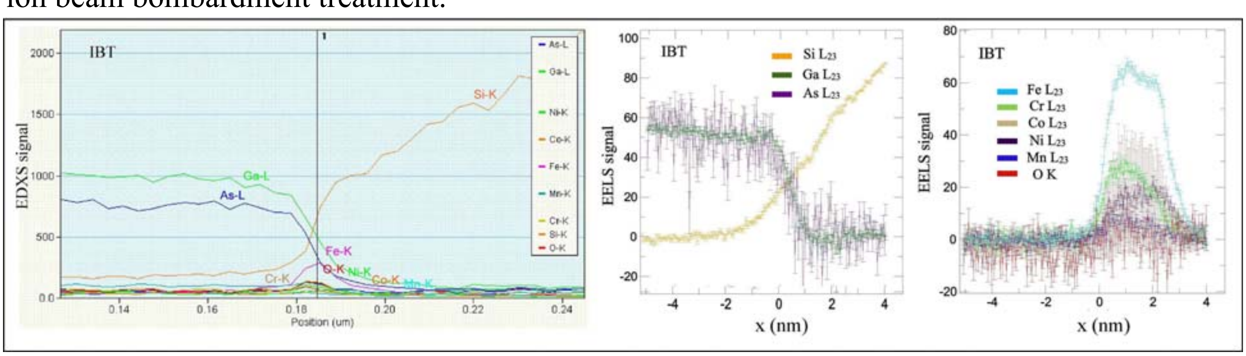

Figure 4. STEM-EDXS (left) and STEM-EELS profiles (right) for a III-V multi junction solar cell wafer-bonded on Si after ion bombardment treatment taken across the bonding interface. Si, O, C, Ga and As signal intensities after background subtraction and normalization to the inelastic scattering cross-section are shown. The resulting normalized EELS signal is proportional to the area density of the elements. Error bars reflect the 68% confidence interval for the signal calculated as the combined effect of signal noise, background noise, and background extrapolation error. The elemental profiles reveal the presence of a gallium and silicon oxide amorphous double layer with a minor carbon contamination. Adopted from [4].

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