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IN-DEPTH ANALYSIS OF MOCVD-GROWN GaInP/Ga(In)As/Ge TRIPLE JUNCTION SOLAR CELLS BY SECONDARY ION MASS SPECTROMETRY

INTRODUCTION

Concentration photovoltaic (PV) based on III-V solar cells is one of the most promising technologies for dramatically reducing the cost of PV electricity. In order to reduce costs, a high efficiency is usually pursued. This is the main reason for the huge development of multijunction cells (MJCs) which are able to achieve very high efficiencies thanks to their more efficient use of the solar spectrum.

In particular, GaInP/Ga(In)As/Ge triple junction solar cells represents the alternative with higher efficiency and lower cost. GaAs and other III-V semiconductors present high quality properties: a direct bandgap with high absorption, relatively insensitivity to temperature, and radiation resistance. These properties make them suitable for three major applications: thermophotovoltaics (TPV), concentrator systems, and space applications. Within the arsenal of techniques required to characterize such devices, secondary ion mass spectrometry represents the most powerful one due to the complete atomic/molecular information provided; the excellent sensitivity and the reproducibility. Examples of quadrupole SIMS obtained during the MOCVD preparation of the structures will be provided, evidencing the excellent reproducibility and usefulness of the technique.

Figure 1. Concentrator solar cel array.

EXPERIMENTAL CONDITIONS

The analyses were performed using a 5 keV Ar^+ primary ion beam with a current of 500 nA. Despite its lower ion yield, Ar^+ has been used as primary ion keeping unaltered the oxidation state of the surface, in order to monitor possible oxidation processes along the sample thickness. The sample was sputtered at a 45° incidence angle and the emitted secondary ions were analyzed by means of a triple stage quadrupole analyzer, situated at the surface normal.

A 45° electrostatic energy analyzer (EEA) placed prior to the mass filter allows energy-resolved selection of the secondary ions coming into the quadrupole. The primary ion was digitally rastered over an area of 650x790 μm^2, collecting the signal from the 60% central region in order to prevent crater edge effects.

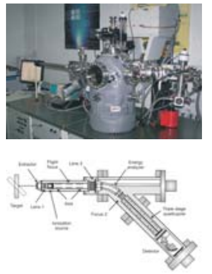

Figure 4. The Hiden SIMS Workstation

SURFACE CHARACTERIZATION

SIMS spectra of the constituent layers in the stacked structure revealed that some trace impurities might appear during the layer deposition in the MOCVD reactor.

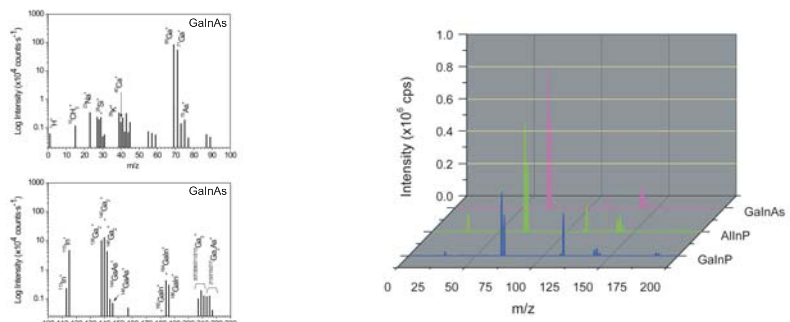

Figure 9. Positive ion mass spectra of the different layers in the TJ solar cell.

SAMPLE DESCRIPTION

New developments in III-V solar cell technology for concentrator photovoltaic systems are based on triple junction solar cells and bandgap engineering. The main components for III-V solar cells are GaAs and InP, which can be alloyed with other materials to give rise to ternary or compounds like $Al_xGa_{1-x}As$ or $In_xGa_{1-x}As_yP_{1-y}$. By selecting the relative proportions of the elements in the compounds, the bandgap value can be modified to optimize the conversion efficiency by collecting a broad range of solar spectrum. Nowadays, conversion efficiencies up to 39% have been reported for the new generation of triple junction solar cells.

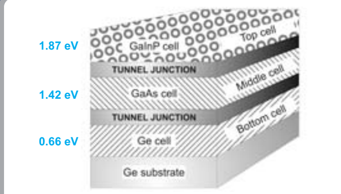

Figure 2. Schematic baseline triple junction cells

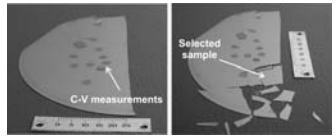

Figure 3. MOCVD grown sample wafers.

One of the main advantages of the Ge-based TJ solar cells is the low-cost substrate. Furthermore, the germanium active subcell increases the voltage of the tandem subcell, since it is connected in serial with the top two subcells. The absorption of the solar spectrum is divided between the three subcells. Even after the GaInP and GaAs subcells have absorbed the photons with energy greater than 1.42 eV bandgap of GaAs, there is still ample photogenerated current in the 0.66 eV bandgap Ge cell.

SIMS DEPTH PROFILING

SIMS depth profiling allows monitoring the presence of impurities or the diffusion of dopants within the multilayered structure which must be reduced to improve the cell efficiency.

COMPOSITION DEPTH PROFILE

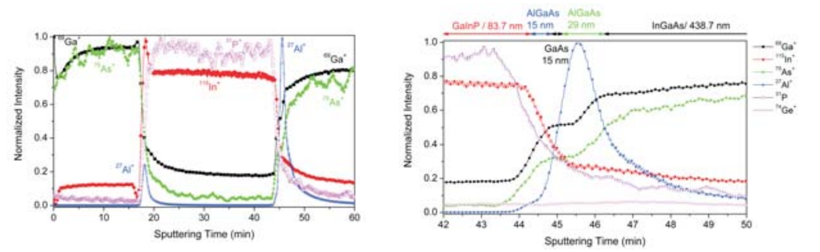

Figure 6. Positive ion depth profiling of different sub-layers in a Ge-based triple junction solar cell.

IMPURITY DEPTH PROFILE

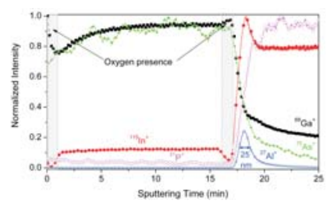

Figure 7. Positive ion depth profile of a TJ Ge-based solar cell. The presence of oxygen impurities was identified at the topmost layers and the Al interface.

DOPANT DEPTH PROFILE

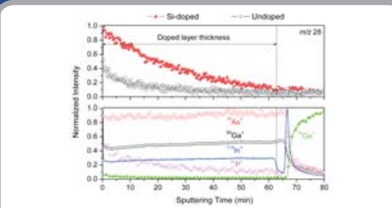

Figure 8. Positive ion depth profile of a TJ Ge-based solar cell, illustrating the dopant diffusion dopant within the structure and the contamination of the topmost

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