Publishable JRP Summary Report for ENG51 SolCell
Metrology for III-V materials based high efficiency multi-junction solar cells

Background

Today's energy policies are based on three requirements: the energy should be secure, affordable and sustainable. The solution is likely to be a mix of energy production sources depending of the country and the market conditions. As an energy source, photovoltaics (PV) has grown at a phenomenal rate of over 40% per year for the last decade. This was mostly driven by government subsidies and the reducing cost of silicon based solar cells. This is however not sustainable, both financially and in terms of power requirement. This project supports emerging developments in the solar energy sector that require far less area per kilowatt-hour produced and have the potential to be sustainable without government subsidies.

Concentrated photovoltaics (CPV) use relatively cheap optical elements to concentrate the sunlight onto highly efficient multi-junction solar cells (MJSC). III-V materials based MJSC structures are designed so that each junction absorbs a separate portion of the solar energy spectrum, enabling solar energy conversion with efficiencies as high as 44%. The technology is rapidly advancing from a proven space technology to terrestrial applications. A key element for the technology to be able to compete with existing traditional energy sources is to further increase the cell efficiency to 50% or higher.

Need for the project

The large number of layers in III–V MJSC structures makes a purely experimental optimisation difficult and expensive; this also limits the uncertainty in the calibration of the cells due to the complexity of their spectral response. In addition to the complexity of the structure, there is a lack of reliable data on material properties for the compound semiconductors used in these cells and discrepancies around 30% are currently observed between the measured and modelled efficiencies. The industrial sector and academic research require accurate and spatially resolved metrology to determine reliable and complete III-V material data sets (structural, optical, electrical, optoelectronic and thermionic properties), particularly for all materials used in sophisticated state of the art MJSC and emerging devices. Metrological tools need to be developed to understand the transport mechanisms, the influence of quantum confinement and interfaces effects in these structures in order to accelerate their market adoption.

Rating the performance of PV modules is critical for determining the cost per watt, and the efficiency is a useful parameter to assess the relative performance of different PV concepts. So far only MJSC with a maximum of three active layers can be calibrated in NMIs across Europe and lower calibration reproducibility and higher uncertainties are obtained in comparison with primary silicon reference solar cells investigated for instance by differential spectral responsivity (DSR). Hence with the next generation of multi-junction solar cells already in production, the urge for corresponding new standards and lower uncertainties are becoming more and more urgent.

Increasing the number of junctions, using innovative nanostructures or coupling PV with other harvesting technology such as thermoelectric could in theory increase the conversion efficiency to as high as 80%. The metrological tools needed to develop this next generation of solar cells and to migrate from the expensive Germanium substrate to the cheaper Silicon one also need to be investigated.

Scientific and technical objectives

The overall aim of this JRP is to develop traceable metrological infrastructure in support of the rapid advances made on multi-junction solar cells that are based on III-V materials. The JRP will develop techniques and methodologies to enable the traceable and accurate characterisation of structural, optical, electrical, optoelectronic and thermionic properties of III-V material based MJSC, from the macro to

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nanoscale, in order to enhance the efficiency of the current devices and enable the production of the next generation solar cells.

The scientific and technical objectives are:

- To develop methods to accurately measure electrical transport properties of III-V complex heterostructures: band-gap, work function, dopant distribution, photocurrent, carrier density, diffusion length, doping dependent minority carrier lifetime, absorption coefficients and series-resistances. Accurate measurements of these physical parameters are particularly important to understand the electrical transport phenomena in these heterostructures;
- To characterise composition, thickness, structural and optical properties of III-V material in order to highlight the effect of defects concentration, microstructure and interfaces on the recombination mechanisms of charge carriers;
- To measure carrier transport between interfaces in MJSC and to characterise narrow tunnel-junction properties;
- To develop reliable tools and workflows to measure size dependent electronic structures of nanostructured semiconductor quantum dots;
- To measure thermoelectric properties of III-V materials and thermal transport across interfaces;
- To develop traceable and reliable calibration methods and standards for determining device efficiency, linearity, temperature dependence and spectral responsivity of MJSC devices ;

Expected results and potential impact

There are two strategies to reduce the levelised costs of electricity from photovoltaics: the first one tends to reduce the system cost by increasing the module efficiency, which also provides the advantage of smaller systems and a reduction in the land area required, while the second one tends to decrease the cost of the modules with economies of scale in manufacturing or by using fewer or cheaper materials.

This JRP will focus on the first strategy by developing the metrological tools required to improve the efficiency of existing triple-junction solar cells to 50%. The project will also explore potential new cell structures to further improve efficiency and will investigate the second strategy with the possibility to manufacture the cells on silicon; a substrate that is both cheaper and available in larger wafers. The project will develop and provide primary standard calibration of MJSC, a metrological infrastructure lacking at present in Europe and required by all end-users for CPV. Specific deliverables of the JRP will be technical pre-standard documents dealing with best practices in connection with several important topics that are already part of the standardization process within ISO/IEC committees.

The research in the JRP will help to create impact by developing reliable and traceable measurement techniques and standards for III-V MJSC devices. The development of standard materials and procedures will help the transfer of metrology solutions between R&D laboratories and fabrication centres, thereby increasing the extent of cooperation, and adding metrological traceability to established research techniques. Moreover, success in this area will support the further development of nano-engineering and other advanced techniques, creating new opportunities to improve materials used for widespread applications and particularly renewable energies.

Improved materials metrology for III-V materials combination will also impact on a variety of other sectors. III-V technologies have been key to many major lifestyle-influencing technologies such as displays and lightning (light emitting diodes), communication (diode lasers, power amplifiers) or optical data storage (lasers for DVD, Blu-ray).

JRP start date and duration:	1 July 2014, 36 months
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