The EMRP project Metrology for III-V materials based high efficiency multi-junction solar cells

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***Abstract* — End of 2013 EURAMET, the European metrology organization opened a call to advance measurement science and technology in the field of Energy by providing funding for Joint Research Projects (JRP) to be funded jointly by the European Commission and the participating countries in the frame of the European Metrology Research Programme (EMRP).**

This paper describes a planned project; no technical results will be available at the time of the conference. We feel, however, that CPEM is a suitable platform to discuss our plans.

***Index Terms* — Nanoscale electrical measurement, Multi-junction solar cells standards, high conversion efficiency, III-V materials characterization.**

I. Introduction

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 sources depending of the country and the market conditions. In the energy offer, 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 lowering cost of silicon based solar cells. This is however not sustainable, both financially and in terms of power requirement. This project supports an emerging offer in the solar energy sector that requires far less area per kilo-watt-hour produced and has the potential to be sustainable without government subsidies.

Concentrated photovoltaics (CPV) uses relatively cheap optical elements to concentrate the sun light onto highly efficient multi-junction solar cells (MJSC) [1]. III-V materials based MJSC structures are designed so that each junction absorbs a separate portion of the solar energy spectrum, allowing for solar energy conversion with efficiencies as high as 44% [2]. The technology is rapidly advancing from a proven space technology to ter restrial application. A key element for the technology to compete with existing traditional energy sources is to further increase the cell efficiency to 50% or higher. According to the industry roadmap [3], an increase in MJSC efficiency from 44% to 50% will leverage a 60% cost reduction in energy produced from 2011 to 2020.

This project addresses the main metrological challenges faced by the present developments of high-efficient III-V MJSC where material engineering play a great role:

III–V MJSC structur es are made of a high number of layers, which makes a pure experimental optimization difficult and expensive; this also limits the uncertainty of cell calibration due to the complexity of their spectral response. Beside the complexity of the structure, the re is a dramatic lack of reliable material properties data for the compound semiconductors used in these cells: discrepancies about 30% are currently observed between measured and modeled efficiencies. The industrial sector and academic research require ac curate and spatially resolved metrology to determine traceable and complete III-V material data sets: structural, optical, electrical, optoelectronic and thermionic properties are required. There is also a need to develop metrological tools to quantify the transport mechanisms, the influence of quantum confinement and interfacial effects in these structures to accelerate their market adoption.

Rating the performance of PV modules is critical for determining the cost per watt, and efficiency is useful to assess the relative progress among PV concepts. To date, only MJSC with a maximum of three active layers can be calibrated in NMIs across Europe. For these systems, lower calibration reproducibility and higher uncertainties are obtained in comparison with primary silicon reference solar cells investigated for instance by differential spectral responsivity (DSR). With the next generation of multi-junction solar cells already in production it is urgent to work towards new standards and lower the uncertainty in measurement of MJSC efficiency.

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 as high as 80%. The metrological tools needed to develop this next generation of solar cells and migrating from the expensive Ge substrate to cheaper Si one also need to be investigated.

II. Scientific and Technical Objectives

The objective 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 work program is aiming at developing techniques and methodologies to enable traceable and accurate characterization of structural, optical, electrical, optoelectronic and thermionic properties of III-V material based MJSC, from the macro to nanoscale, in order to enhance efficiency of present devices and enable the production of next generation solar cells.

The JRP addresses in detail the following scientific and technical objectives:

- 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 of particular importance to deeply understand the electrical transport phenomena in these heterostructures;
- To characterize 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 characterize 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 material 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.

III. Project Impact

There are two strategies to reduce the levelized 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 reduction in land area required, while the second one tends to decrease the modules cost with economies of scale in manufacturing or by using less 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 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 particularly 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 standard documents dealing with best practices in connection with several important topics, which are already under standardization process of ISO/IEC committees.

The proposed research 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 amplifier) or optical data storage (lasers for DVD, Blu-ray).

References

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