1 Publishable Summary

QCOALA is a FP7 European funded project within Theme 3 'Information and Communication Technologies' (FP7-ICT-2009-6). This project is a collaboration between EU companies and research organisations, with the objective of developing a new dual-wavelength laser processing system for welding thin-gauge aluminium and copper, 0.1mm to 1.0mm in thickness, with integrated process monitoring and in-line non-destructive inspection, and establishing its capability to provide a reliable, high-speed, low-cost and high-quality joining solution for electric car battery and thin-film photovoltaic (PV) cell interconnections.

Through fully integrated process ICT and Statistical Process Control (SPC), the new system will facilitate in-line quality control, as well as a higher level of automation in manufacturing, and thereby achieve higher yield and throughput, for both these high-in-demand applications. This project will help the Beneficiaries, with expertise in the constituent components of the new system, to increase their annual turnover between 15 and 25%, their productivity between 50% and 100% and their yield between 2 and 10%.

1.1 Objectives

- Develop a new laser processing system for the welding of thin-gauge aluminium and copper, 0.1mm to 1.0mm in thickness, with integrated process monitoring and in-line non-destructive inspection.
- Establish its capability to provide a reliable, high-speed, low-cost and high-quality joining solution for electric car battery and thin-film photovoltaic (PV) cell interconnections.

The consortium is composed of companies and research institutions with expertise in different domains, including laser system development, laser materials processing, quality monitoring control and non-destructive weld inspection.

The concept of QCOALA is to develop a laser source with a dual-wavelength beam delivery system tailored to the welding of electric car battery and thin-film PV cell interconnections. Welding strategies will be developed to suit these applications and materials, and are integrated with process monitoring and non-destructive inspection sensors.

The market for Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) is growing rapidly, and, with this, the need for batteries. Lithium-ion batteries require several stages of construction, with one particular stage requiring the joining of highly-conductive aluminium (or copper) tabs to the electrode cell ends of the battery (Figure 1). Laser welding is being considered for replacing the current joining technique, which is considered too slow and produces too many weld imperfections.

Figure 1 Image of super-capacitor battery type (Image courtesy of Volkswagen).

Super-capacitor batteries comprise a 'bank' or 'stack' of batteries, which are interconnected using aluminium (and sometimes copper) tabs. The cumulative aluminium weld area determines the electrical conductivity of the connection, and as such, the performance of the device. Laser welding offers the advantage of high-speed, low heat input and low-distortion compared with more the conventional resistance spot or TIG welding process.
The second application addressed in the QCOALA project represents a key technology in the future PV industry. Flexible organic and inorganic solar cells are increasingly becoming important as an

alternative source of energy (Figure 2). An outstanding question is how to interconnect the individual cells? Flexible metal tabs or foils, generally made of aluminium or copper, are welded to the cells to form modules. An accurate, low heat input process is required, since PV cells on <100µm thick foils are extremely fragile and sensitive to mechanical, chemical and thermal stress. Laser welding offers the advantage of a low chemical, thermal and mechanical impact.

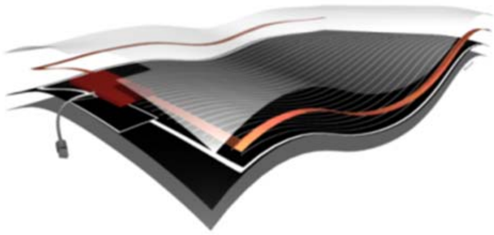

Figure 2 Image of flexible solar cell (Image courtesy of Flisom).

1.2 Results achieved during the first 24 months of the project include:

An industry ready 1.5kW peak power GreenMix laser prototype and a 3kW peak power lab prototype (Figure 3).

Figure 3 Dual wavelength test platform (Images courtesy of LASAG).

- An on-line temporal pulse control.
- A weld Monitoring System prototype for dual-wavelengths (532nm and 1064nm) to be used for quality assurance of laser welds in thin-gauge aluminium and copper interconnections.
- A dual-wavelength beam scanner integrated into the GreenMix laser, with dual-wavelength in coupling unit capability (Figure 4).

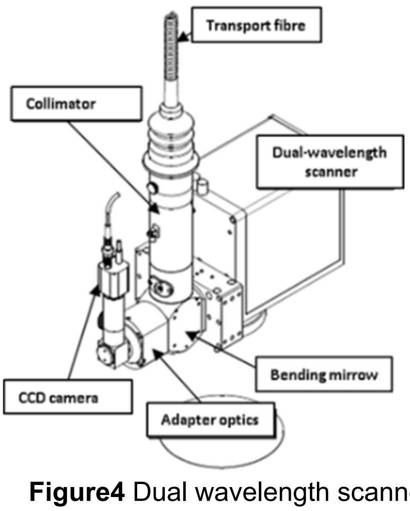

Figure4 Dual wavelength scanner (Image courtesy of LASAG).

- Imperfection-recognition algorithms for analysis of monitoring data and detection of weld imperfections.
- Eddy Current and Digital Radiography inspection systems.
- Assessment of processing parameters at 1064nm and 532nm wavelength, for joining aluminium to aluminium, copper to copper and aluminium to copper (Figures 5 and 6).

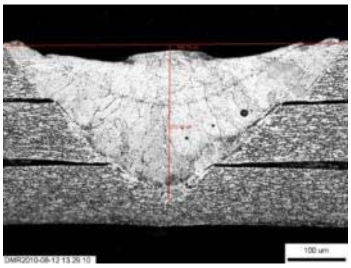

Figure 5 Spot weld of 3x0.1mm thickness copper foils with a 532nm source. (Photo: TWI)

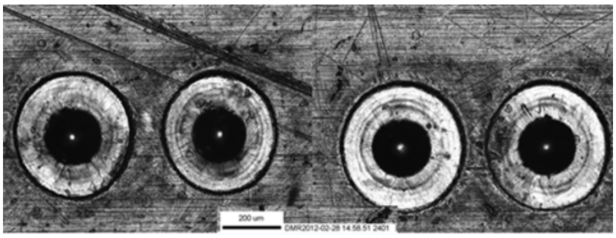

Figure 6 Reproducible spot welds in 532nm laser source. (Photo: TWI)

1.3 Expected final results and their potential impact and use

It is expected that the following will result from the QCOALA project:

- A GreenMix laser processing system will be developed and tested for the welding of aluminium and copper interconnections in electric car battery and thin-film PV panel applications.
- Development and testing of a dual-wavelength scanner integrated to the GreenMix laser.
- Real-time temporal pulse control allowing thermal management and closed-loop control of the process.
- Weld quality improvement strategies based on processing parameters, including wavelength, spot size, beam quality, pulse length, average and peak power, and repetition rate, for aluminium and copper.
- A weld monitoring system for dual-wavelength (532nm and 1064nm), comprising fast-rate image acquisition and processing algorithms for imperfection recognition in laser-welded aluminium and copper interconnections.
- A digital radiography and eddy current weld inspection system with Automatic Defect Recognition (ADR) for aluminium and copper interconnections.

If the above results are achieved, they will facilitate the introduction of advanced automation into mainstream manufacturing, and promotion of the development of an early European market for advanced technologies such as electronic and photonic devices, control and new assistive automation and robot systems. This will result in the growth in European equipment and product manufacture and the resultant increase in jobs.

The impact of QCOALA in its concept is fully embedded into the manufacturing part of the European Economic Recovery Plan (EERP), i.e. Factories of the Future, and the Information and Communication Technology research theme of the Cooperation Work Programme. Moreover, through the applications the work is centred on, its impacts also extend to both the Energy-Efficient Buildings (through the PV application) and the Green Car (through the electric battery) initiatives. Its impacts will be felt not only in the ICT arena, but in a number of other Research themes, in particular, NMP, Energy, Environment and Transport.

1.4 Project website

More information about the QCOALA project can be found in its website: www.qcoala.eu.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 260153

1.5 The Project Objectives

The QCOALA project is focusing on achieving three key objectives:

Quality – A reliable in-line quality assurance system for the QCOALA applications will be achieved by monitoring the processing input parameters; by monitoring processing conditions taken directly from the process; by measurement of directly quantifiable parameters, such as physical and geometrical information; and by correlation between the direct measured parameters and the processing results to provide feedback information into the production line and process control. Fully integrated process ICT and Statistical Process Control (SPC) will facilitate in-line quality control and achieve higher throughput and yield, through reduction of scrap rates below 1% and reducing pseudo-errors below 1%. Beneficiaries expect the approach to increase yield by between 2 and 10%.

Productivity – By using the new laser system, with its dual wavelength capability, and tailored welding strategies developed for both thin-gauge aluminium and copper, the energy needed per weld will be much less compared with currently used manufacturing processes. In addition to the high weld quality achieved through in-line monitoring and inspection, the reliability and durability of the new approach will be superior to existing technologies. The qualities of samples of >100 pieces (existing technologies vs QCOALA technology) will be evaluated and compared to each other. Additionally, the energy consumption will be analysed. It is expected that the energy consumption will decrease by >20% per weld, with Beneficiaries estimating an increase in productivity of between 50 and 100% and a yield increase between 2 and 10%.

Autonomous operation – All system components will be integrated through robust ICT protocols to ensure that product quality can be assured and maintained (QA/QM), and full autonomy of the processing system. The introduction of 100% inspection through integrated process monitoring and in-line weld inspection will reduce scrap rate and repair costs of the high-volume automotive and alternative energy applications under investigation. However, this will only be economically acceptable, when this is carried out in-line, allowing remedial action to be taken immediately, through process-based ICT.

1.6 Technical approach

Technological developments in a variety of areas will be carried out around the battery and PV applications and their aluminium and copper interconnections, in order to achieve the QCOALA key objectives. Within the work programme each of the technology developments made in QCOALA will be tested and demonstrated, both individually and collectively, for related technologies. Towards the end of the project, all developed technologies will be assessed and integrated as appropriate to evaluate the performance of the fully integrated QCOALA system in a simulated production environment for the high-quality welding of electric car battery and thin-film PV cell interconnections.

The work is divided into eight Work Packages (WP). The project started with a detailed specification of the products which the QCOALA end users wish to produce with the developed QCOALA technologies (WP1). These industrial requirements have to be translated into technological development on four distinct levels, i.e. laser system development, process laser welding activity, process monitoring and quality assurance and in-line weld inspection (WP2, WP3, WP4 and WP5). In the final stage of the work, all developed technologies will be integrated to demonstrate the capability of the three main objectives quality, productivity and autonomous operation (WP6). The final two work packages comprise project management (WP7) and exploitation and dissemination of the created Foreground (WP8). Figure 7 shows a flowchart showing the interaction between work packages. Each of the eight Work Packages has its own objectives (listed below), milestones and deliverables:

WP 1 **– QCOALA system specification**

- Finalise the specification of the QCOALA system to be developed.
- Finalise the methodology to be followed for the development of the QCOALA technologies

WP 2 – Laser system development

- Carry out a laser system technology assessment
- Design and manufacture a QCOALA laser demonstration platform with dual-wavelength (Green and IR), on-line temporal pulse capability and dual-wavelength scanner for welding thin-gauge Al and Cu interconnections.

WP 3 – Intelligent laser welding

- Assess the effect of spot size, beam quality, laser wavelength (in particular ~1064nm and ~532nm), pulse duration, pulse repetition rate, average and peak power, on the welding performance of Al and Cu interconnections in terms of absorption efficiency, welding speed and weld quality (process stability).
- Develop a tailored energy strategy to allow the development of on-line temporal pulse capability of the QCOALA laser demonstration platform (WP2).
- To develop the optimum process parameter window and establish welding strategy for high-quality welding of thin-film PV cell interconnections and electric battery Al and Cu interconnections.

WP 4 – Process monitoring and quality assurance

- Develop and evaluate a Weld (process) Monitoring System with imperfection-recognition software to assure high quality laser welding of thin-gauge aluminium and copper interconnections.
- Develop an operator-friendly user interface for the WMS.

WP 5 – In-line weld inspection

- Develop a Digital Radiography (DR) weld inspection system for high-quality laser welding of aluminium and copper interconnections.
- Develop an Eddy Current (EC) weld inspection system for high-quality laser welding of aluminium and copper interconnections.

WP 6 – System integration and demonstration

- Integrate the WMS, the DR and the EC inspection systems into the QCOALA laser demonstration platform
- Evaluate the performance of the fully integrated QCOALA system in a real production environment for the high-quality welding of electric car battery and thin-film PV cell interconnections, and compare with current conventional joining technology.

WP 7 – Project Management

- Ensure that the QCOALA project is well managed, the objectives met in the agreed timescales, the results are effectively exploited, the deliverables and milestones are achieved, and the financial and contractual aspects adhered to.

WP 8 – Exploitation and dissemination

- Generate information and technology from the results of the project and disseminate these by means of conferences, publications, and other means and to develop and implement exploitation plans (including training) for each project Beneficiary. Special attention will be taken on IPR issues.

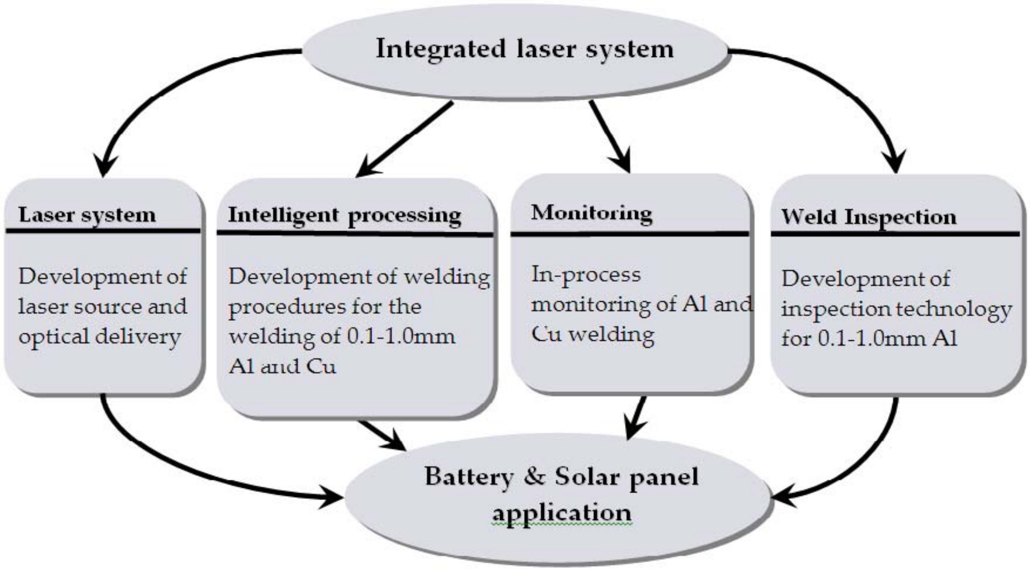

Figure 7 Interaction of technologies to be developed in QCOALA.