Publishable Summary

The APPOLO project is seeking to establish and coordinate connections between the end-users, which have demand on laser technologies for (micro)fabrication, knowledge accumulated in the laser application laboratories of research institutes and universities and the laser equipment manufacturers (preferable SMEs: for integration, lasers, beam control and guiding, software, etc.) in order to facilitate faster validation of the process feasibility and adaptation or customization of the technology (equipment) for manufacturing conditions. Core of the consortium consist of laser application laboratories around Europe which are connected to a virtual APPOLO HUB to accumulate knowledge and infrastructure and promote the easy-to-access environment for development and validation of laser-based technologies. The APPOLO project cover activities on technical, technological and economical assessment of new equipment supplied by project partners in 8 complex assessment value chains and preparation of standardised procedures for the assessment service with can be provided for new project partners and customers beyond,

All activities of the APPOLO project during the second year of implementation were performed close to the workplan.

During the second year, the APPOLO project established clear outlines for assessment templates. Using these templates, partners validate new equipment by assessing them according to APPOLO HUB specified parameters. These assessments allowed partners to present their finding to customers and, therefore, gained feedback how to successfully implement assessment procedures for the desired application. The Open call for new partners and experiments was successfully implemented with 12 application received, and 7 of these experiment proposals were selected. The APPOLO HUB will organize information exchange between new and existing partners and HUB members. The activities will include training on assessment procedures, exchange of knowledge of successful assessment experiments.

WP2 is going with some delay according to its plan. EKSPLA has developed the new concept and manufactured the laser emitting picosecond pulses at 1342 nm. The performance of the modified ps-laser @ 1.342 µm is close to, and its assessment was started at FTMC in laser scribing of CIGS thin film solar cells. Onefive GmbH has delivered an optimized laser based on GENKI platform to BUAS for validation. The high pulse energy available supports successful BUAS approach to high-throughput CIGS scribing. NST has assembled and tested first LSE300 scanner using non-coated optics. Delivery of the coated parts has been delayed by 3 months. ELAS has finished upgrading its DuoMaster laser processing for installation of the EKSPLA 1342 nm ps-laser. Their validation started at FTMC. The new method of on-line electrical characterisation of thin film solar cells during laser scribing process was developed by FTMC. BUAS worked on optimizing P1-3 scribing processes. In Y2, the focus was set on optimizing scribing velocity with electrical validation of the achieved scribe quality. More than 1.5 m/s scribing velocity was demonstrated for P2 process using two different scribing approaches.

Within the second year of the project in **WP3**, substantial advances were achieved within all active tasks. The main activity in the initially proposed tasks was focused on equipment assessment for laser processing of CIGS-based PV devices using metallic substrates. Therefore, the development of a suitable P1 process in a stack of metallic substrate/dielectric barrier/Molybdenum contact was the main challenge within the CIGS activities of APPOLO at UPM and IOM. The activities/tasks of the WP3 are finalized with deliverables and milestones. In addition to the planned activities within the work package, additional work was carried out for the development of the best practice laser scribing processes for CIGS scribing and assessment of the laser and the equipment.

The PV market is changing very fast due to the still very fast development of the scientific and technical achievements, declining prices for PV modules and the change of the fabrication sites for the modules to East Asia. These changes of the PV market within the last two years enforced decision of the partners on the further development of PV-modules for being competitive in the production of modules in the future. The new developed Perovskite solar cells hold the potential of

easy, low-cost fabrication of solar modules that can be competitive to the currently domination silicon modules. This material system is now within the focus of the proposed modifications of WP3.

Progress was made by each partner in all tasks of **WP4** addressed in year two. However, delays in delivery of JDSU laser system and NST polygon line scanner made it impossible to follow the work plan exactly at BUAS. Therefore, some deliverables and milestones have to be postponed. After real progress in Y1 on the development of a new ps or fs laser source with 100W power and high repetition rate, an average power significantly higher than 100W was achieved with a system on the optical table. The transfer into an industrially suited prototype has led to unforeseen problems. An average power of 65 W was achieved with the system in the final housing, and some improvements have still to be done. The new version of the LSE-170 lines scanner with the new firmware was tested. NST has developed the new high numerical aperture version (HNA) but its delivery postpone due problems with optical coatings.

Due to the delay in its delivery, the scale–up process was investigated with numerical and analytical models respectively calculations. The results help to be prepared for the scale – up experiments and already know which strategies have to be used if problems with heat accumulation can occur. Four different methods do deal with the intersection region of the two parts of a stitched image were developed and investigated. It is possible to generate an almost but not totally invisible intersection.

In **WP5**, a 3D mould texturing method is assessed and optimized for applications on automotive interior components, with the goal to obtain soft-touch effects by the micro/ nano-textured surfaces. This work is based on a technology previously developed by Lightmotif that enables laser ablation of micro- and nanoscale features on 3D curved moulds by ultra-short pulsed lasers. Lightmotif and CRF cooperate with the goal to obtain a method that enables the production of polymer parts for car interiors with added functionality due to a micro- and nano-textured surface, obtained by a textured mould. The surfaces show a soft-touch effect which results from a largely reduced contact area of skin and polymer part. Besides the haptic properties of the surface other relevant aspects like aesthetic properties of the textures are optimized.

Two tasks in **WP6** were focused on optimization and development of suitable laser head for the surface treatment. FTMC, ELAS and EKSPLA have worked on design and assembly of the 3D laser processing head ADILAW with the support of AMSYS measuring head. Work on laser structuring of polymers and metal plating was performed by CRF and FTMC, defining suitable regimes of laser structuring. Excellent results were achieved with polypropylene based material. BIOA has worked on the electrical design of touch sensors that will be used to validate the equipment and technology.

The main objective of **WP7** is to adapt the Laser Induced Forward Techniques (LIFT), a well-known laser direct writing technique for material transfer, to define metallic contacts onto flex optoelectronics devices. UPM was assessing laser sources from partners-suppliers (EK, ONE5) using setup developed by Mondragon for the potential use of their equipment for the metallization by LIFT. An end-user (ASNT) was making the final assessment of the metallization process through a detailed characterization (morphological, electrical and performance in the final device) of the deposited metallic lines. As a proof of concept, an important milestone is included in this activity targeting the full metallization of a CIGS solar cell on steel flex substrate with fingers and busses deposited by the proposed LIFT technology.

During the second year in **WP8**, LUT developed the real-time monitoring system based on outputs of a high-speed camera and spectrometer. In addition, an adaptive control system developed for control of a pulsed laser in real-time based on the output of a spectrometer. The system with high-speed camera passed the first tests at FTMC in real laser microfabrication experiments.

During the second year, AMSYS has working on implementation two approached in on-lime monitoring which could work with polygon scanner. Linear fiber coupler was investigated at FTMC. Notwithstanding, it provide useful information of the laser processing, further development needed to get reliable results. Another, coaxial approach of on-line monitoring was implemented at AMSYS as laboratory setup and will be transferred to FTMC for testing with LSE300 polygon scanner. Focus-

Tilt system for integration with ADILAW laser processing head was delivered to ELAS and installed in DuoMaster laser system of ELAS for f real conditions validation.

Dissemination and exploitation activities in **WP9** are on track with the original plan. In the second year, the general exploitation and dissemination strategy was set-up, and work was performed accordingly. Internal RTD activities are ongoing and the opportunities for exploitation becoming more clear. In general, APPOLO partners have had a high presence at international events to promote project results and the APPOLO HUB idea. Press releases were made about this and can be viewed on the website. In addition, two issues of the APPOLO newsletter were prepared and disseminated. Workshops were dedicated to specialist while other science related events attracted students and general public. Possible business model and processual work of APPOLO was discussed within the consortium as well as technical and processual documents exchanged. In Exploitation, further steps were taken to strategically collect all IP and exploit it accordingly. Work was conducted on the improvement of the exploitation plan and a general market overview.

All partner significantly contributed to RTD activities in WP1-WP8. The chart below presents

Two websites for the project are running with permanent update of information: www.appolo-fp7.eu for all project related activities and dissemination and http://appolohub.appolo-fp7.eu/ for APPOLO HUB as a single access point to consolidated infrastructure and expertise of the laser application laboratories, involved in the project. Increased traffic of visitor was observed during Open call process and after each world-wide conference, where APPOLO activities were intensively presented.

Project Objectives for the Period

The APPOLO project cover activities on technical, technological and economical assessment of new equipment supplied by project partners in 8 complex assessment value chains and preparation of standardised procedures for the assessment service with can be provided for new project partners and customers beyond:

- Four different routes (FTMC, BUAS, IOM, UPM) in thin-film scribing for monolithic interconnections in CIGS solar cells are running in parallel based on lasers with different pulse duration and wavelength for optimising processes based on various substrates: glass, polymer and metal foil.
- Surface texturing by lasers is in validation process for printing and polymer moulds. Three groups (BUAS, IOM, LM) are involved in the assessment experiments. The high scanning speed and high pulse repetition rate are required for cost-effective surface texturing on printing rolls. Precision of fabrication is not less important. Therefore, the activities during Y1 included new equipment development and validation as well as development strategies for efficient and precise material removal.
- Validation of laser structuring processes for metallisation are running at FTMC and UPM. Modification of polymer surface followed by electro-less metallisation is a way in simplification of fabrication procedures on complex 3D parts used in car production.

An additional objectives are for monitoring and on-line control:

- Verification of the existing monitoring techniques, including spectrometers, high-speed an infra-red cameras, should be done at LUT concentrating on applicability the techniques for laser microfabrication process monitoring.
- New on-line methods are planned for high-speed and precise in-line monitoring of laser scribing processes by utilizing polygon scanners and for 3D processing.

In the second year, RTD activities moved from preparation work on assessment procedures and modification of the equipment to validation the equipment itself and assessment their applicability in technological processes, selected by end-users in the Consortium.

Work Progress and Achievements during the Period

1.1. Overview of the progress of the work

The APPOLO project cover activities on technical, technological and economical assessment of new equipment supplied by project partners in 8 complex assessment value chains. The standardised procedures for the assessment service were in preparation in the first year, however, final version of the assessment templates (D1.6) were finalised in M24 only.

All activities of the APPOLO project during the first year of implementation were performed close to the workplan. Dissemination and exploitation plans were updated.

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As soon as the laser system of TBWP is installed in the lab, the system will be combined with the polygon scanner. The goal is to scale up the ablation process for copper up to 100 W. After receiving the new polygon version with the additional mirrors the achievable accuracy is investigated together with the new laser system, and scale up experiments will be performed. The last step is the integration of both, the new laser system and the new polygon scanner version into the setup designed by DG. With this setup, cylinders will be machined.

Due to the delay in the equipment to assess delivery, the scale–up process was investigated with numerical and analytical models respectively calculations. The results help to be prepared for the scale – up experiments and already know which strategies have to be used if problems with heat accumulation can occur. Four different methods do deal with the intersection region of the two parts of a stitched image were developed and investigated. It is possible to generate an almost but not totally invisible intersection.

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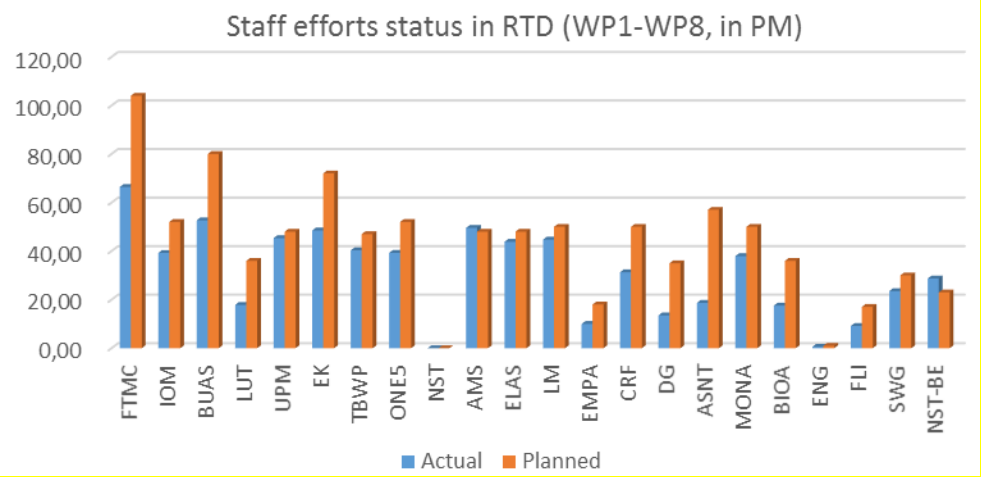
All partner significantly contributed to RTD activities in WP1-WP8. The chart below presents personnel efforts of every APPOLO consortium partner: actually used versus planned for full project duration in WP1-WP8.



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consolidated infrastructure and expertise of the laser application laboratories, involved in the project.

Significant delay in deliverables and achieving milestones on time remains a serious problem in the whole project.

Overall, 22 deliverables were planned for the reporting period of M13-M24.

- 18 deliverables were accepted by the consortium and submitted to EC on time or with delay up to 60 days;
- 1 deliverable (D1.8) is still in preparation;
- 3 deliverables (D2.4, D4.3, D4.6) are postponed to later time due to delays in delivery equipment (ONE%, JDSU lasers, NST polygon scanner) to access. Achievement of final gaol of related assessment value chains is still feasible until M36;
- 6 deliverables were left not submitted from the first year, 5 of them are submitted to the date.

The public deliverable D1.7 due to M12 was not finalised but success stories from project achievement were presented in various forms for specialist and general public. In the first year, mainly the preparation job for assessment experiments took place, interesting for general public information will be incorporated into deliverable D1.8 which is ongoing.

There were 10 milestones planned during period M13-M24 in the APPOLO project, 5 were remaining from the first year.

- 5 of milestones were successfully achieved during reporting period of M13-M24.
- Additional 5 were achieved until this Report preparation.
- 5 will be reached with expected delay of 4 months.

Modification of lasers for APPOLO assessment took much longer than expected, especially at ONE5 (MS43) and JDSU (D4.2, MS51). Problems with durable optical coatings postpones delivery of modified versions of polygon scanner s by NST-BE (MS62, MS71). Those accumulated delays postponed planned assessment experiments. As the risk mitigation, verifications the (speed, efficiency, etc.) limits in laser application important for the APPOLO partners end-users were performed using complementary equipment available in APPOLO equipment pool (demo lasers and polygon scanner from the Consortium) or provided by third parties (lasers).

Continuous verification of the on-line monitoring tools available at LUT led to setups which finally were tested at FTMC laboratory on ability to work in real laser microfabrication conditions with promising results (MS45). Monitoring tool developed by AMSYS are under validation at ELAS and FTMC (MS64). The new version of on-line monitoring to polygon scanner in awaiting in the Laser application laboratory of FTMC/ELAS (MS71).

Reaction to Reviewer recommendation be implemented in Year 2 of the project.

Recommendation 1.1

In preparing the competitive call, the consortium must ensure that it is clear to prospective applicants what is acceptable and what is not (in particular regarding the call topics and the duration of the proposed assessment experiments). The consortium is encouraged to critically review the call timetable to ensure that adequate time is allocated for proposal writing and evaluation. In particular the consortium should be aware of the EC requirements regarding the schedule and information to be provided for approval. The revised call documents should be submitted for commission approval prior to publication.

All those recommendations were implemented in revised version of the Open call documents which were approved by EC (D10.3). Selection of new partners and experiments was performed

and their accession to Grant and Consortium Agreements in ongoing, main delay no is validation of legal status f new partners by REA EC,

Recommendation 1.2

Greater emphasis should be placed on the creation of a vision and a business model for the proposed hub. Wider engagement with end users and suppliers via the hub should be demonstrated in Year 2.

This issue was common for all Management Board and General Assembly meeting with discussion on APPOLO HUB vison and sustainability beyond the project. Intensive work was done by Engage analyzing former and existing virtual hub and clusters in Europe. Result of this research is included in to two-volume deliverable D9.9-1 and D9.9-2.

Recommendation 1.3

The consortium should clarify how and when the technology outputs of WP8 will be integrated in the other technology work packages.

Following up APPOLO partners to LUT in September 2014, monitoring techniques further developed at LUT were initially tested in FTMC labs and results from high-speed camera provided promising results to be implemented for laser microfabrication. Coordinated activities with tasks in WP2 and WP3 are under planning now for Y3.

One on-line monitoring approach from AMSYS was investigated at FTMC. In principal, it provide useful information of the laser processing, but further development needed to get reliable results. As the tool hardly could be integrated into new versions of polygon scanners, the approach was rejected for implementation. Another, in-line (coaxial) approach of on-line monitoring was implemented at AMSYS as laboratory setup and will be transferred to FTMC. Its testing at FTMC will be started just after delivery LSE300 polygon scanner.

FTS (Autofocus-autotilt device) was delivered for integration with ADILAW laser processing head to ELAS in July 2015 and it is on validation in real conditions be installed in DuoMaster laser system of ELAS at FTMC.

Recommendation 1.4

The risk assessment and mitigation plans should be up-dated and reported at future review meetings.

The issues related with risk mitigation is permanently monitored and discussed in MB meetings. As main risk is related to delivery of equipment to assess and its specifications, flexible plan of use equipment from APPOLO pool is prepared. The main goal is to reach specifications set by the end-user requirements.

Recommendation 1.5

Unnecessary duplication in reporting should be avoided. The Project Periodic Report should provide a concise top-level view of progress, issues and remedial actions only, and refer to the deliverable reports for more detailed technical information.

We tried to implement this recommendation as much as possible.

Recommendation 1.6

Future costs to be presented in the “Use of Resources” should be streamlined and aggregated in reasonable packages.

Chart on use of resources added in this report to each WP.

Recommendation 1.7

The updates of the Dissemination / Exploitation Plans to be prepared at the end of each reporting period should include training aspects, in particular relating to the hub.

Efforts in this aspect were increase during Y2, involving

Recommendation 1.8

The public reports on assessment experiments (Deliverables D1.7 to D1.10) should include meaningful details of exploitation, impact and benefits.

As D1.7 was not finalized and other are ongoing, this issue was reflected in brochure prepared for I4MS event in Brussels in May 2015.

Recommendation 1.9

All future deliverables and reports shall include a confirmation that any work or result described therein is genuinely a result of the APPOLO project and that any other source has been properly referenced.

Included into revised template of WP reports.

Recommendation 1.10

All public project reports, deliverables and published papers should be put on the project website.

To be done with public deliverables due to M24. Placement of scientific papers in public domain should consider limitations coming from publisher.

Recommendation 1.11

The consortium should be aware of the format of the Final Report of APPOLO, in particular with respect to dissemination and exploitation and the questionnaire to be then provided.

To be done for Final Report

Recommendation 1.12

The legibility of the slides would be improved by using larger fonts.

Kept in mind in preparation

Recommendation 1.13

At future review meetings, every partner should be represented by key personnel.

Consortium management press partners to be presented on high enough level. Based on real availability of particular responsible persons.

Recommendation 1.14

The follow-up of all recommendations shall be addressed in the next Periodic Report and at the next review meeting.

The text above.