

 CHEOPS	Title Second Industry Workshop	Deliverable Number D5.5
Project Number 653296		Version 1

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CHEOPS – Production technology to achieve low Cost and Highly Efficient phOtovoltaic Perovskite Solar cells

Deliverable D5.5

Second Industry Workshop

WP5 – Dissemination and Exploitation

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Revision History

Author Name, Partner short name	Description	Date
Isabel Heller Sørensen (ACCEL) Johannes Ripperger (ACCEL)	Draft deliverable	18.03.2017
Thorsten Rissom (OXPV) Sylvain Nicolay (CSEM)	Revision 1	20.03.2017
Isabel Heller Sørensen (ACCEL) Johannes Ripperger (ACCEL)	Final version	26.03.2017

Acronyms and abbreviations

ACCEL	accelopment AG (<i>CHEOPS Beneficiary No. 12</i>)
CSEM	Centre Suisse d'Electronique et de Microtechnique (<i>CHEOPS Beneficiary No. 1</i>)
CTL	Charge transport layer
EPFL	École polytechnique fédérale de Lausanne (<i>CHEOPS Beneficiary No. 7</i>)
EU	European Union
Fraunhofer	Fraunhofer Institute for Applied Polymer Research (<i>CHEOPS Beneficiary No. 6</i>)
H2020	Horizon 2020
INERIS	Institut National de l'Environnement et des Risques (<i>CHEOPS Beneficiary No. 5</i>)
OXPV	Oxford Photovoltaics Ltd. (<i>CHEOPS Beneficiary No. 10</i>)
PK	Perovskite
SHJ	Silicon Heterojunction
WP	Work Package

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1 Introduction

This deliverable outlines the content presented at the Second Industry Workshop of the CHEOPS project. The workshop was held in the form of a webinar on 12th March 2018 11:00-12:00 CET as part of WP5 dedicated to dissemination and exploitation. Its primary purpose was to inform members of the CHEOPS Industrial Advisory Board (IAB) about the accomplishments and challenges at the current stage in the project and discuss potential exploitation of research results. The webinar featured presentations by the WP leader of all scientific WPs (WP1-WP4). The IAB members attending the workshop were Heiko Plagwitz (Evatec AG), David Martineau (Solaronix SA) and Luca Sorbello (Dyesol Italia). Jörg Müller (Q-Cells GmbH) had signed up for the webinar but ultimately was not able to participate.

2 Objectives

The objectives of the Second Industry Workshop were to:

1. Provide an overview at about two thirds of the project duration.
2. Inform the IAB members about the latest advancements in the four research and development work packages (WP1 - WP4).
3. Receive constructive feedback and inputs from the IAB members on potential exploitation of results in WP1-WP4.

3 Target audience and participants

The target audience for the Second Industry Workshop were the members of the CHEOPS IAB. The role of the IAB is to advice the consortium on technological and commercial requirements, exploitation opportunities and other industry-relevant matters. The board is composed of experts from European equipment manufacturers and other companies in the PV perovskite sector.

Table 1: Participants of the Second Industry Workshop

Name	Presentation	Organisation
Host		
Isabel Heller Sørensen		ACCEL
Presenters		
Sylvain Nicolay	Production technology to achieve low Cost and Highly Efficient phOtovoltaic Perovskite Solar cells	CSEM
Arnaud Walter	WP1: Perovskite single-junction development	CSEM
Armin Wedel	WP2: Upscaling and stability	Fraunhofer
Pierre Bouchard	WP3: Risk assessment and roadmap development	INERIS
Matthias Bräuninger	WP4: PK/c-Si SHJ tandem device development	EPFL
IAB members		
Heiko Plagwitz		Evatec AG
Luca Sorbello		Dyesol Italia
David Martineau		Solaronix SA
Further participants		
Johannes Ripperger		ACCEL
Thorsten Rissom		XPV

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4 Organisation and format

In December 2017, the project coordinator Sylvain Nicolay (CSEM) invited all the members of the IAB to the Second Industry Workshop. In this email, members were asked to indicate their preferred date through a doodle poll to ensure as many participants as possible. Based on the result of the doodle poll the 12th March 2018 at 11:00-12:00 CET was fixed and communicated to all participants.

As for the First Industry Workshop, the second edition was held in the form of a webinar. The reasons for this was, on one hand the positive feedback which had been received from IAB members and WP leaders in the aftermath of the First Industry Workshop and on the other hand the additional benefits of saving time and costs for travelling. In early 2018, WP leaders and the coordinating team from CSEM and ACCEL prepared a number of power point slides to support the oral presentations during the workshop. Two weeks prior to the meeting, all participants were sent a link to access the online meeting platform along with the agenda for the workshop.

The webinar itself took place on the online meeting platform [Adobe Connect](#) which was put at the disposal of CHEOPS by ACCEL. The software is a tool which provides easy access to conduct online conferences, with the additional functionality to share presentations on a screen visible to all participants. The combination of these multiple functionalities of Adobe Connect makes it a very good alternative to a physical meeting. One day after the workshop, ACCEL sent an appreciative email to all members of the IAB with the slides and key points presented the day before. The slides were shared with all members of the CHEOPS consortium through the [Document Management System](#). In the following week, follow-up questions were submitted by IAB members to the WP leaders as basis for continuous dialogue between parties.

In summary, the organisation and chosen format for the Second Industry Workshop were perceived to be a success by all participants.

5 Workshop Presentations Summaries

The workshop slides presented to IAB members include - in large parts - information on key results which are currently under peer review for scientific publication or are intended to be submitted for peer-reviewed publication. The slides are therefore not included in this report in their original form, but have rather been summarised in the following to provide an overview of the key points and achievements presented.

5.0 Welcome and introduction round

Project coordinator Sylvain Nicolay (CSEM) welcomed IAB members and WP leaders to the Second Industry Workshop with a short introductory statement on the current state of play of CHEOPS. He highlighted that the project is at the forefront of PV perovskite research in Europe. With the project entering its final year, he gave an optimistic prognosis for CHEOPS to achieve its targeted goals saying that the deliverables are challenging to reach but that in any case, CHEOPS is at the forefront of competition both in the case of single- and tandem junction developments. He also further mentioned that the project management will now increase its efforts to work with industry actors on the theme of stability and upscaling of PV perovskite solar cells. Finally, he announced that CHEOPS will be organising and hosting the European PV perovskite days at the University of Oxford in summer 2018. This event will bring all major EU-funded research projects in the field of PV perovskite research together for two days of intensive workshops and exchange to strengthen synergies with other academic actors. The hope is that this event will resemble the added value of the exchange already existing between CHEOPS and IAB members.

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5.1 Presentation of WP1: Perovskite single-junction development

The achievements of WP1 were presented by WP leader Arnaud Walter from CSEM on behalf of his working group. The presentation included an overview of the defined tasks for WP1 with current results and achievements.

Task 1.1 *Development of low cost production oriented processes for charge transport and charge blocking layers* (lead: CSEM, participants: CHOSE, TYNDALL-UCC, M1-18) has been completed. The results for this task concluded that sputtering is an industry relevant method for the deposition of CTLs since it allows for higher efficiencies.

Task 1.2 *Optimisation of active PK material formation and interfaces* (lead: CHOSE participants: CSEM, USAL, M1-18) has also been completed. Results emphasise impact for measured efficiency and better results on NiO HTL developed in WP4. Lastly, the addition of Cs and FA as well as a mix of Br and I, leads to increased bandgap and also to better stability of devices.

Task 1.3 *Improvement of morpho-electro-optical properties of FTO by APCVD and comparison of APCVD FTO/TiO₂ layers with APCVD FTO/wet coated TiO₂* (USAL, M1-24) has been completed. For this task, a broad range of FTO deposition parameters were explored and a number of conditions applied led to cell performances comparable to or higher than the commercial TEC7 reference. This can thus be seen as a further encouraging result from WP1.

Task 1.4 *Developing efficient minimodule architecture and laser patterning* (lead: CSEM, participant: CHOSE M10-36) has not yet been completed and it is still too early stage to conclude on results. However the 2-step deposition process to increase efficiency of devices, while ensuring reproducible results, was presented in an overview to IAB members. Furthermore a special 10x10cm² substrate developed by CHOSE was shown accompanied by figures of measurement showing good progress.

Task 1.5 *Development of lead free stable perovskite material* (UOXF, M1-36) has not yet been concluded and research is still ongoing. However, three aspects of lead-free perovskites were highlighted including three examined lead-free or reduced alternatives.

The summary and outlook for WP1 show that most tasks have been successfully completed and that results obtained in modules are ready to be transferred to WP4. Overall results are encouraging on “reduced-lead” perovskite efforts and efforts henceforth will therefore be focused on upscaling to 1 cm².

5.2 Presentation of WP2: Degradation and stability testing

The achievements of WP2 were presented by WP leader Armin Wedel from Fraunhofer on behalf of his working group incl. researchers from IAP, CHOSE and OXPV. The presentation included an overview of the defined tasks for WP2 and the current results and achievements.

Task 2.1 *Degradation mechanisms and measurement and stability testing protocols* has been finalised with the conclusion on encapsulation processes and resins highlighting that the degradation mechanisms are determined by different interface between the PV cell and the encapsulation material.

Task 2.2 *Development of encapsulation material/process for long lifetime device* has also been finalised. In the presentation a glass/glass encapsulation scheme with a butyl rubber edge sealant, developed by CSEM, was presented in a three dimensional visualisation to IAB members. The first results of DH degradation tests on such PK devices show very encouraging results which hold great promises for future upscaling.

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Task 2.3 *Developing PK single junction module* has been completed to 40%. The presentation of results for this task included an overview of the printing process with detailed information on the printing of PEDOT:PSS and printing of perovskite. For the latter, both the double step process developed by CHOSE and a single step disposition was presented. In a concluding summary of printing strategies the advantages and draw-backs of various methods were provided to IAB members.

Task 2.4 *Developing PK large modules for specific BIPV applications* was mentioned but not included in the presentation, since it is too early stage to show any conclusive results.

Task 2.5 *Semi-transparent mini module progress* has been partly completed. Researchers working on this task currently focus on the lamination process development and transfer. A short outline for the second half of 2018 included the targets to improve full size tandem cell efficiency beyond 25%, improve second process run of mini modules, evaluate improved mini modules and finally to deliver the D2.5 mini module.

5.3 Presentation of WP3: Risk assessment and roadmap development

The achievements of WP3 were presented by WP leader Pierre Boucard from INERIS on behalf of his working group. The general aim of WP3 is to tackle societal issues raised by the development of PK technologies along the entire life cycle. The presentation included an overview of the defined tasks for WP3 and the current results and achievements.

Task 3.1 *Management and framework of the risk assessment* has been completed. The task is based on a questionnaire which was sent out to all partners. The main conclusions show that participants share general definition of the devices, that crystalline Si is used as a benchmark by the vast majority and that the regulatory context as well as the end-of-life for devices are seen as one of the main uncertain issues for PV technologies. It was highlighted that these points are important to acknowledge in research as well as for industry actors. This was confirmed by IAB members.

Task 3.2 *Environmental impact and resource efficiency calculations* aims at assessing the life-cycle environmental impact via LCA. An overview of this method – a recognised and standardised methodology to evaluate and assess the environmental impact of a technology from cradle to grave - was provided to IAB members along with a number of key findings of preliminary results. It was also mentioned that work is in progress to conduct further data collection, to compare with benchmarks and to conduct a sensitivity analysis. Final results will be available by summer 2018.

Task 3.3 *Cost of Ownership (CoO) calculation and business related risk analysis* is scheduled to be concluded within six months and only preliminary results were therefore presented at the workshop. For the aspect of cost of ownership, researchers are currently modelling different power plant sizes incl. 2kW, 20mW and 1GW power plants. For the aspect of risk assessment, researchers are currently working on a list of possible risks sorted by severity. The preliminary results of this analysis show that materials availability is not going to be of any major concern for industrial production.

Task 3.4 *Socio-economic analysis: EHS and regulatory considerations* has partly been completed. The assessment of opportunities and threats included an overview of results of the first tests of combustion with Fire Propagation Apparatus (FPA) and results of three leaching tests. The latter showed that lead in PV perovskite solar cells as currently produced are not surpassing the values for hazardous waste. This is a positive indication for the future of PV technologies and for the later upscaling of the technology.

Task 3.5 *Refinement of quantified future development roadmap* was only briefly mentioned as it is still too early in the process to provide conclusive results.

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5.4 WP4: PK/c-Si SHJ tandem device development

The achievements of WP4 were presented by WP leader Matthias Bräuninger from EPFL on behalf of his working group. The presentation included an overview of the defined tasks for WP3 and the current results and achievements.

Task 4.1 *Development of contacting layers compatible with monolithic tandem integration* has been partly completed. Preliminary results show that the current materials of choice for TCOs are MoOx, IYO and ITO. For CTLs they are C60 with SnO₂, SpiroTTB and NiO. For perovskite these are CsI or CsBr based-compounds.

Task 4.2 *Development of PK solar cell compatible with monolithic tandem integration* has also been partly completed. Results show that CsBr in co-deposition with Pbl₂ could be a potentially very promising new reference for tandem cells, since it has slightly higher energy gaps than with CsI and therefore makes a perfect candidate for tandem cells. In the presentation it was also mentioned that CsBr show more conformal perovskite growth and lower annealing temperatures, resulting in a lower risk of forming unreacted Pbl₂.

Task 4.3 *Tandem device integration on 2 cm² with efficiency >29%* is still to be achieved, but earlier experiments of upscaling are showing an optimistic prognosis. The deposition of perovskite onto textured wafer, which is required to achieve the final deliverable, has been proven to be challenging. Still the consortium has been able to demonstrate world record efficiencies on such device structures and we are still aiming at achieving the 29% efficient device.

6 Conclusion and next steps

The Second Industry Workshop was concluded with an open discussion between WP leaders and the IAB members. The discussion reflected the added value of the shown project results for IAB members and clearly indicated the appreciation on the side of IAB members to be kept up to date on the progress. Summarising it is to be concluded that the Second Industry Workshop was perceived as a success by all participants. On basis of the exchange, the CHEOPS consortium will now take steps to develop a document with best practice recommendations and contributions to standards foreseen to be published as Deliverable 5.8 scheduled for January 2019. In the process of developing this report, IAB members will be consulted to ensure that results are in line with industry requirements, and therefore will provide an added value not only for the academic community working on PK technologies but also for the growing industry in this field.

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Appendix 1 - Agenda for the 2nd CHEOPS IAB Webinar

Date Monday 12th March 2018

Schedule 10AM-11AM UK Time / 11AM-12PM CET

Location Teleconference
<https://accelopment.adobeconnect.com/cheops-meeting/>

List of invited participants

No.	Organisation	Name(s)	Role
1	CSEM	Sylvain Nicolay	CHEOPS Project Coordinator (MP6)
2		Arnaud Walter	CHEOPS WP Leader WP1
3	Fraunhofer	Armin Wedel	CHEOPS WP Leader WP2
4	INERIS	Pierre Boucard	CHEOPS WP Leader WP3
5	EPFL	Matthias Bräuninger	CHEOPS WP Leader WP4
6	ACCEL	Isabel Sørensen	CHEOPS Dissemination Manager (WP5)
7		Johannes Ripperger	CHEOPS Project Manager (WP6)
8	XPV	Thorsten Rissom	CHEOPS Industry Partner
9	Q-Cells	Jörg Müller	IAB Member
10	Evatec AG	Heiko Plagwitz	IAB Member
11	Solaronix	David Martineau	IAB Member
12	Dyesol UK	Luca Sorbello	IAB Member

Agenda		
Time (CET)	Activity	Lead
11:00-11:10	Welcome & State of Play	Sylvain Nicolay CSEM, CH
11:10-11:20	WP1 review: Achievements, Challenges, Next steps	Arnaud Walter CSEM, CH
11:20-11:30	WP2 review: Achievements, Challenges, Next steps	Armin Wedel Fraunhofer, DE
11:30-11:40	WP3 review: Achievements, Challenges, Next steps	Pierre Boucard INERIS, FR
11:40-11:50	WP4 review: Achievements, Challenges, Next steps	Matthias Bräuninger EPFL, CH
11:50-12:00	Discussion	All