D4.5
WP4

COLAE
Commercialising Organic and Large Area Electronics

September 2014

COLAE: Commercialization Clusters of OLAE

Work package 4: Towards a virtual foundry

Public Final Report

Project name: Commercialization Clusters of OLAE
Acronym: COLAE
Project type: Coordination and support action
Starting date: 1 September 2011
Duration: 36 months
Call: FP7-ICT-2011-7
Grant agreement number: 288881
Website: www.colae.eu

Responsible partner

iL INNOVATION LAB thinking works

Compiled by
Ralf Mauer and Michael Potstada (iL)

Executive Summary

The main objective of COLAE's work package 4 (WP4) was to support the alignment process of the OLAE centres towards becoming a joint service provider in the form of a virtual foundry. In order to reach this goal, the project partners have joined forces in WP4 to work on advancing the foundry concept for OLAE

- by systematically exchanging information about technological capabilities,
- by customizing a common design tool kit that connects these technological capabilities,
- by progressing the standardization of OLAE, and
- by identifying and disseminating the unique selling propositions of OLAE.

Several key results of these endeavours were achieved during the project. A deep understanding among the project partners about their problem solving capabilities for OLAE was developed through a threefold approach: (1) a competence matrix was assembled reflecting the capabilities of the consortium,. (2) this matrix was applied in WP3 to find suitable experts contributing to feasibility studies, and (3) project meetings were held at the facilities of project partners granting the consortium partners insight into the way of working of the host centre. The foundry concept was advanced by developing a customization procedure that enables the adaption of a design tool kit to a new manufacturing technology within three months through a very close cooperation with the FP7 project TDK4PE. This procedure was validated by CSEM, CPI and CEA with three different manufacturing technologies: gravure printing, screen printing and photolithography. As a result for the first time ever a design tool kit connects four manufacturing technologies for OLAE (including inkjet by TDK4PE). This is an important step towards a virtual foundry for OLAE and an unprecedented cooperation between technology centres for OLAE. Additionally, standardisation of printed electronics has been advanced by the consortium: four partners participate in IEC TC 119 Printed Electronics, the mirror group to IEC TC 119 was founded in Switzerland by COLAE members, two proposals for standardization projects have been started in IEC tracing back to WP4 activities. Finally, a white paper about the status of standardization in OLAE and a macroeconomic analysis of OLAE disseminating the USPs in the form of a SWOT and PESTEL analysis were published on the project website www.colae.eu.

Content

Objectives of WP4: Towards a virtual OLAE Foundry

The main objective of COLAE's work package 4 (WP4) was to support the alignment process of the OLAE centres towards becoming a joint service provider in the form of a virtual foundry. By establishing such a supportive structure between the European OLAE centres, it will be possible to have an improved way to accept enquiries from SMEs and LSEs seeking business opportunities in OLAE in the future.

In order to reach this goal, the project partners have joined forces in work package 4 to work on advancing the foundry concept for OLAE by exchanging information about R&D and manufacturing capabilities, by customizing a common design tool kit that connects these R&D and manufacturing capabilities across Europe, by progressing the standardization of OLAE, and by jointly identifying and disseminating the unique selling propositions of OLAE through a macroeconomic analysis in the form of a SWOT and PESTEL analysis.

Progress made towards the objectives

The foundry concept originates from the microelectronics industry. There, a foundry is a company that is specialized in contract manufacturing of electronic circuits for multiple customers. These customers are so-called fabless companies that are specialised in the design of circuits for specific applications without internal manufacturing capabilities. This symbiosis of fabless design companies and "design-less" fabrication companies evolved from the need to efficiently utilize the expensive equipment required to manufacture microelectronic circuits and was enabled by a high degree of technology standardization allowing the development of computer assisted design tool kits. These tool kits facilitate the development of application specific circuits without the need to know about the limitations of the manufacturing technologies, as these are included in the tool kits and automatically checked by the software during the design process.

When COLAE, specifically WP4 "Towards a virtual OLAE foundry", started out in 2011 with the aim of taking first steps towards transferring the foundry concept to Organic and Large Area Electronics, standardization of the technology was very sparse and design tool kits were not available. Initially, WP4 focused on enhancing the cooperation between the European OLAE centres involved in COLAE by identifying their R&D and manufacturing capabilities. The resulting competence matrix was later fused with the expertise database of WP3 "Feasibility Network" and utilized to identify suitable experts for feasibility studies. The subsequent attempt to match these capabilities to industry requirements for service packages was complicated by the fact that foundry services can, by definition, not be developed without standardization and design tool kits. Thus, the services identified were not closely related to the foundry concept, but rather focused on connecting the different offerings under the term "The

COLAE approach", i.e. user-centric innovation workshops, product requirement interviews, feasibility studies and trainings.

During the second half of the project, a reorientation towards the main objective of the work package namely advancing the foundry concept for OLAE technologies became possible due to two developments: (1) the uptake of standardization activities by the International Electrotechnical Commission and (2) the completion of a technology design kit by the FP7 project TDK4PE, that was available for customization using COLAE manufacturing techniques. The partners of WP4 reacted to these developments by taking both active and supporting roles in the standardisation process and by customizing the TDK4PE technology design kit in order to be able to jointly offer foundry-type design access, based on a shared design tool kit in the future.

Supporting the alignment process of the European OLAE centres involved in COLAE

A first step towards the alignment of these centres was to set up a database containing the capabilities and service offerings by all project partners. For this purpose a survey was conducted at the beginning of the project that contained two parts. The first part aimed at collecting general contextual information about a centre such as its strategic strengths and weaknesses or the membership structure of associated regional clusters in terms of size and industry to academia ratio. The second part focused on specific R&D competences and capabilities that are present in a respective centre. Based on these data points, WP4 was able to develop a competence matrix that illustrates COLAE partners' knowhow along the OLAE value chain. In order to test this matrix for its practicability, the project partners in WP4 decided to execute a virtual use case. After a system analysis for an OLAE enabled fire-fighters' jacket, subtasks were distributed to partners in accordance to the competence matrix. The results of this case proved that the new transparency increased efficiency and effectiveness of decision making among the COLAE partners. In the second half of the project, semi-structured interviews were conducted with representatives of each centre in order to update the database and account for changing capabilities over time. These interviews also complemented the survey data with qualitative information. At this point in time, the COLAE consortium decided to bridge efforts between WP4 and WP3 to benefit from synergies: the competence database was merged with the expertise database developed in WP3 to improve the selection process for experts to contribute advice to feasibility studies.

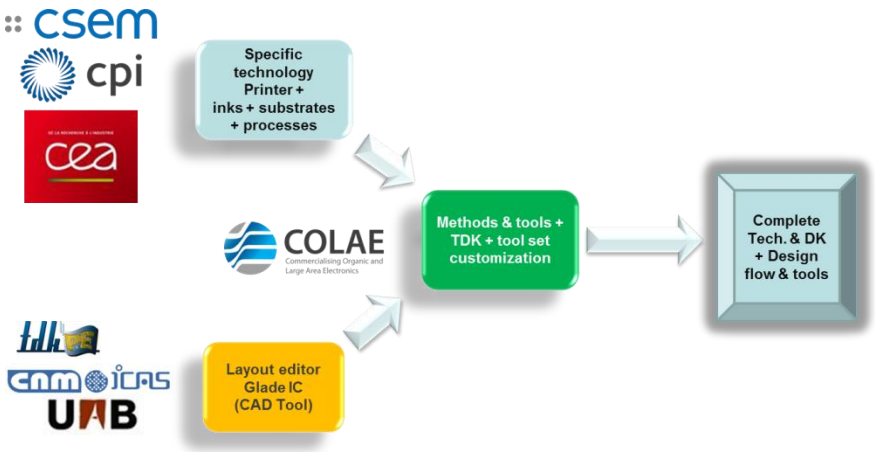
The result of this approach was an increased transparency among the project partners concerning the distribution of problem solving capabilities for OLAE in Europe. This transparency enables an effective alignment of resources in future activities aiming to support companies seeking business opportunities throughout Europe.

Advancing the foundry concept for OLAE

Standardization is a fundamental prerequisite for the evolvement of a foundry-type industry model. Therefore, the COLAE partners took on an active role in the development of standards and supported the International Electro-technical Commission (IEC) by raising the awareness for the ongoing standardisation process. The following contributions have been made:

- Four partners of COLAE joined IEC Technical Committee 119 "Printed Electronics",
- a mirror group to IEC TC 119 has been founded in Switzerland by CSEM with support from iL (Electrosuisse TK 119 Gedruckte Elektronik),
- two standardisation projects have been proposed in IEC TC 119 that can be traced back to WP4 activities: one on semiconductor inks for printed circuits by CPI and one on data formats for technology design kits by PEC4 (UAB),
- a white paper on the status of standardization including a guide on how to participate was published on the COLAE website and
- a workshop was organized jointly with the German Electrotechnical Commission (DKE) to evaluate the interest of the OLAE community in standardization.

In summary, standardisation of OLAE is a young field that is rapidly growing in importance. It is currently strongly driven from Asia with limited interest in participation by European companies. Further efforts should be taken to raise the awareness for this process and to demonstrate the benefits of participating in standardization - such as early access to information, facilitated market access or reduced risk in R&D efforts.



A technology **design tool kit** (TDK) that was developed by the FP7 project TDK4PE was adapted to manufacturing technologies provided by CPI (photolithography) and CSEM (gravure printing). CEA is providing screen-printed CMOS technologies developed in the frame of FP7 project COSMIC.

For this purpose a customization routine based on extracting technical parameters and implementing rules in design tools was developed, which now allows customization in approximately 3 months. The resulting design tool kit was validated by designing a circuit controlling a tic-tac-toe game, that had already been manufactured by inkjet printing in the framework of TDK4PE. Due to time constraints, the manufacturing of this controller could not be finished before the end of COLAE. However, the simulations of the circuit, which were experimentally validate with simpler functional circuits like inverters, yielded comparable results as those in TDK4PE. Therefore it can be indirectly derived, that the design and simulation output of the design kit is valid. The partners involved in the design of this controller will continue their work and manufacture it after the completion of COLAE.

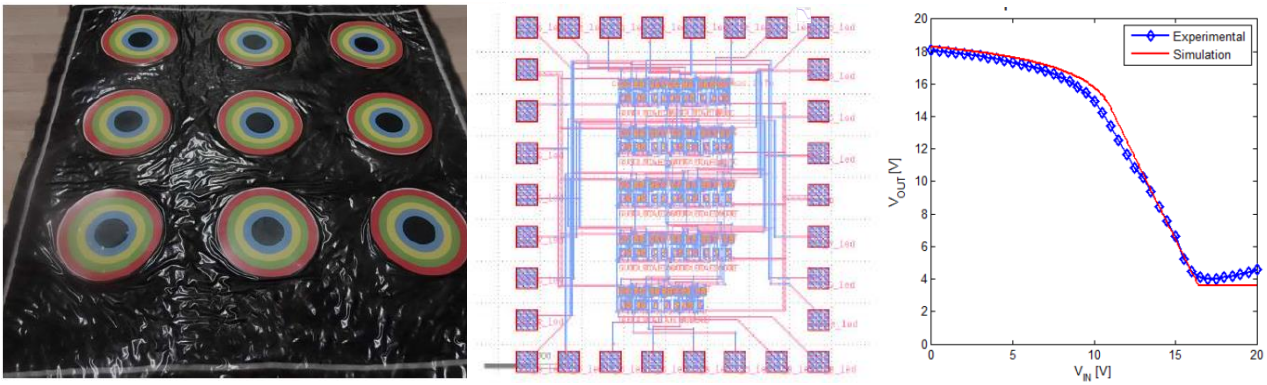


Figure 1. Left: Gameboard of Tic-Tac-Toe Game by TDK4PE. Middle: Design of circuit for controller. Right: Experimental validation of design and simulation of an inverter circuit.

In future work further improvement of the manufacturing processes and iterations of the design tool kit are required to enhance the functionality that can be realized with this technology. The design kit is now available for four different OLAE manufacturing technologies (including inkjet by TDK4PE) by four different research institutes throughout Europe, which represents a large step towards a virtual foundry for OLAE in Europe. The customization of the design tool kit has enabled CSEM, CPI, and CEA to offer low volume contract manufacturing services for circuits designed using the tool kit. CSEM and PEC4 offer assistance for using the design kit and also design services based on the tool kit. The following table displays a comparison of technical specifications of the different manufacturing technologies.

	CSEM	CPI	CEA
Process	5 step gravure printing	5 step photolithography	CMOS by screen printing
Substrates	Flexible	Flexible	Flexible (10x10 cm^2)
Charge carrier mobility	~ 5 $x10^{-2}$ cm^2/Vs	>3 cm^2/Vs	~ 1 cm^2/Vs (both n- and p-type)
Typical transistor channel length	60 µm	<10 µm	>10 µm
Time from design to foil	0.5-3 months	0.5 months	1 month
Throughput	High	Low	Medium

In future work, the design tool kit could be customized for a larger number of European OLAE centres and the resulting range of services offered could be connected to a platform like Europractice, which would create an efficient way to make the services accessible to companies throughout Europe.

As part of the Workshopon the results of WP4, nine presentations were given on the **dissemination of the work on design tool kits** and to highlight the current state of the art in general. Several speakers and attendees highlighted the need for a broad range of development requirements in the reduction in cost of materials, better understanding of parameters of materials and processes as well as in the use of design tools to enable designers to work more effectively with Organic Large Area Electronics. There is a need for more applications where OLAE demonstrates clear advantages over microelectronics. There is also a need for design tools and process limitations to be understood by designers, as well as the opportunities that OLAE characteristics such as short / bespoke run capability and design flexibility can bring when developing systems. Overall the feeling was very positive about the progress the COLAE project had achieved in setting rules and parameters for designers of circuits and devices. In the interactive session following the dissemination section, the attendees of the workshop identified current challenges for the development of design tool kits such as batch-to-batch variations in material properties, lack of file format compatibility between design software and software used for manufacturing (e.g. of gravure cylinders, silk screens or photolithography masks), lack of component libraries, and lack of standardization for system integration. Suggestions made by the workshop participants on how to overcome these challenges included, for example, dedicated material purchasing strategies, facilitation of cooperation between design software vendors and printing

master manufacturers, financial support for developing open access component libraries and stronger European involvement in standardization in general. The result of the workshop was a schematic proposal for a large scale technology demonstration project centered around inkjet-customizable gate arrays with special focus on topics such as the development of libraries of frozen processes, setting up a marketplace for components and standardization. Such a project should have an obligation to publish the results widely for the benefit of the entire community. The results of this session were also **reported to WP6** "New Wave Research" for further consideration.

Analysing and Disseminating the Unique Selling Propositions of OLAE

In order to contribute to the identification of the path towards commercialization of OLAE, the partners involved in WP4 have performed a **PESTEL and SWOT** analysis of OLAE with a specific focus on the four vertical markets Lighting and Signage, Energy Harvesting and Storage, Medical/Wellness, and Packaging. From this analysis the most important **unique selling propositions** (USPs) of OLAE were extracted: innovative form factors, weight reduction, environmental friendliness, low energy consumption, and enhanced freedom of design. A PESTEL analysis is a tool that was used to analyse external drivers that can have an impact on the development of OLAE. These drivers include Political, Economic, Social, Technological, Environmental, and Legal factors. A SWOT analysis was used to investigate strengths, weaknesses, opportunities and threats for OLAE in the respective markets.

In order to compare these USPs to the current market need, product requirement interviews with more than 40 European companies in the respective markets have been conducted in WP1 and analysed quantitatively in the context of the SWOT and PESTEL analysis. It was found that the most important requirements from a market perspective for OLAE match well with most of the USPs: Innovative form factors, compliance with standards, lifetime of more than five years (less for packaging), energy usage, and appearance. The requirement for compliance with standards is a particularly interesting point that has not been identified as a USP. In a large number of the product ideas discussed during the product requirement interviews, the compliance with standards was a necessary requirement for the applicability of any new technology. Consequently, a comprehensive study of such standards could be used to systematically identify application cases for which OLAE can improve on incumbent technologies, or at least set target specifications for the further improvement of OLAE. The requirement of a lifetime of more than five years for most applications is still challenging today for many applications. It is a major technological driver as discussed in the PESTEL analysis.

The full report about this macroeconomic analysis was **published on the COLAE website** and is available for open access.

Lessons learnt

There were a number of experiences made in this work package that may be of general interest for the further development of Organic and Large Area Electronics at large. The most important of these lessons learnt will be reviewed in this chapter.

Supporting the alignement process of the European OLAE centres. In COLAE a threefold approach was taken to develop a deeper understanding for the technological capabilities and organizational settings among the European OLAE centres. First a survey and interview based exchange of information was initiated that resulted in a database that was easily accessible for all centres. This database acted as a basic source of information about the capabilities of the different centres. The second approach was to use this database in a practical task, i.e. in order to identify suitable expertise for feasibility studies in WP3. This proved to be a very important step, as databases that do not have a particular application scenario tend to become obsolete and unusable, which was effectively prevented by integrating WP4's database into WP3. The final approach was not originally forseen in the work plan of the project but turned out to be extremely effective: all steering group meetings of the project were held on the premises of project partners in the form of a general assembly, i.e. with all partners present. This way the involved partners got a practical first-hand impression of the hosting centres which complemented the pen-and-paper approach of the database.

Towards realizing a virtual foundry. COLAE has shown that the virtual foundry concept is now ready to be applied to OLAE by constructing first design tool kits and opening these to the electronics designers community. In this workpackage a procedure was developed to extract process technology information to build such design kits. This procedure can be applied to any "frozen" process that can be maintained without modifications for an extended period of time. The development of this procedure was only possible due to an extensive cooperation between COLAE and the FP7 project TDK4PE, leveraging more value out of both projects. The cooperation was facilitated by UAB who acted as the project coordinator of TDK4PE and has very close ties to COLAE by being a founding member of project partner PEC4. The results of this activity are highly relevant to the OLAE community, as they enable separated design and fabrication of circuits by contractors for the first time. This experience should encourage other EU funded projects to seek cooperation with complementary research projects wherever possible.

Standardization. In the field of standardization a discrepancy was found to exist between policy makers and researchers in companies or academia. Policy makers generally consider standardization to be an important topic that should be closely tied into any innovation process for many reasons, like e.g. a facilitation of market uptake of innovations. However, researchers in the field of OLAE both in companies as well is in academia were found to have generally limited knowledge and willingness for contributing to the standardization process. This lack of knowledge

accompanied by a wide variety of negative preconceptions about standardization like high level of burocracy, slow and time consuming progress, or limits for technical plurality, constrain the interest of researchers to engage in standardization. A combination of raising awareness, educating scientists and encouraging through financial support (especially for recovering travel costs) might increase the number of European researchers contributing to standardization. In this context, one of the major findings regarding standardization is that the burocratic barriers for joining the standardization process are very low. For a participation in the IEC standardization process it is sufficient to contact a national standards developing organization (SDO) and to join the respective national mirror group to the corresponding IEC technical committee. In case such a mirror group does not exist (which is common in Europe for printed electronics), it is sufficient to gather five technical experts that want to participate in standardization and to (jointly) request the formation of a mirror group by the national SDO. The SDO is then obliged to follow the request.

Summary

In late 2011, 18 European OLAE centres set out on a path towards aligning their efforts for supporting companies seeking business opportunities in Organic and Large Area Electronics in the project COLAE. As a result of the activities in COLAE's work package 4, the project partners have developed a deep understanding of the problem solving capabilities for OLAE among the European OLAE centres. This was achieved by setting up a competence database containing detailed information about all project partners' competences complemented by qualitative contextual information, e.g. about strengths, weaknesses or associated regional clusters. This understanding enabled the partners to answer industrial requests efficiently as proven by the application of this database for feasibility studies in WP3.

Additionally, the project partners have achieved significant progress towards transferring the foundry concept from the microelectronics industry to Organic and Large Area Electronics in WP4: The technology design kit that was developed in the European project TDK4PE for inkjet printing of organic circuits was customized for three additional manufacturing technologies: Gravure printing, screen printing and photolithography. As a result, four European OLAE centres have connected their manufacturing technologies through a common design tool kit, an important first step towards a virtual OLAE foundry. The partners involved now offer design and (low volume) manufacturing services based on these developments. The functionality of the design kit was demonstrated by designing a controller circuit for a tic-tac-toe game. It needs to be noted however, that further development work is required to enhance the functionality and applicability of organic circuits designed and manufactured through the process flow enabled by the design tool kit. These results were disseminated in a workshop on OLAE design rules on May 13th 2014 at CPI, UK. As a supporting action for transferring the foundry concept, the partners of COLAE have been actively engaged in standardization of OLAE: four partners of COLAE joined IEC Technical Committee 119 "Printed Electronics"; a mirror group to IEC TC 119 has been founded with COLAE support in Switzerland; two standardisation

projects have been proposed in IEC TC 119 that can be traced back to WP4 activities and a white paper on the status of standardization including a guide on how to participate was published on the COLAE website.

Another aim of COLAE was to disseminate information on the status of OLAE to the European business community. This was done in WP4 by jointly performing and publishing a macroeconomic analysis in the form of a SWOT and PESTEL analysis. From this analysis unique selling propositions were derived and compared to end-user expectations about the technology extracted from interviews performed in WP1. Selling propositions such as innovative form factors, low energy consumption or increased freedom of design are meeting expectations of end users and are consequently expected to be strong drivers for market acceptance of OLAE.

With these activities WP4 successfully started the alignment process of the OLAE centres towards becoming a joint service provider in the form of a virtual foundry in the near future.

Grant agreement No. 288881

D4.5

WP4

FP7-ICT-2011-7

info@colae.eu

www.colae.eu