OLLA Project Report

Final Activity Report

March 2009

This public report is part of the **OLLA** project:
High brightness OLEDs for ICT & Next Generation Lighting Applications
funded under the IST priority (contract nr 4607)
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For more information about the project, please visit: http://www.olla-project.org

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1 Executive Final Summary of the OLLA project

Solid State Lighting can be seen as direct and efficient conversion of energy into visible light. While inorganic LEDs are the best solid-state solution for directed light, such as spotlight, Organic LEDs (OLEDs) are a very promising technology for large area surface lighting. OLEDs are the first thin and flat light sources, which gently and evenly glow over the whole surface without much heat generation. Such illuminating area elements have been imagined for long by architects and designers.

It was the objective of the OLLA project to demonstrate high brightness and efficient OLED technology for use in real lighting and ICT applications. The project's major challenge was to advance the combination of size, lifetime and efficiency of OLEDs, without compromising on the white colour experience. With its combined targets of 50 lm/W efficiency, 10,000 hours lifetime and larger surfaces, OLLA wanted to extend the technology towards what's generally seen as the market entrance value for initial OLED lighting products.

In the first project period, a lot of effort was spent on developing a common understanding at different levels: person relations, the way of working together, current OLED technology and its issues and roadblocks, general technology vision, and the specific OLLA priorities. Project internal workshops and a dedicated lecture event by the experts of the consortium have been instrumental in this process. This exchange of ideas and knowledge was accompanied by an equally intensive exchange of OLED basis materials. They were tested and compared in the various partners' labs, thereby checking not only the materials but proving also the available measurement set-ups. In later phases the project has benefited greatly from this initial investment.

Based on the early investigations and past experience of the partners, a wish list of novel OLED material characteristics was formulated. Based on the list, novel material were designed, synthesised and developed, followed by intense material characterisation. Once interesting materials with the right properties were found, these material layers were tested inside real OLED-devices and compared to standard devices. Over the 3 years, several hundreds of OLLA materials and compounds were made, characterised, tested and finally discussed. As this turned out to be an intense workload, a new way of material screening was developed to speed up screening and to get a better view on their specific performances.

All these materials and other technical issues were discussed at OLLA wide workshops, which were organised every half year. In total, 9 of such OLLA wide workshops were conducted across Europe, covering also several partner sites for lab visits.

In the second year OLLA released a white paper on luminous efficacy measurement. This was developed to set a minimal laboratory evaluation standard. This standard allows cross comparison between different research groups around the world. The draft document was well received in the international OLED community and received some recommendations and remarks. On basis of these inputs, we published an updated whitepaper version on the OLLA website.

In the final year of the project, most effort was put into the development and delivery of the OLLA lighting demonstrators and the finalization of the project tasks. A number of materials developed within the timeframe of OLLA were selected and used inside the final demonstrators.

The polymer materials within OLLA have been on par with the state-of-art. Two systems, one interlayer and one single layer system were extensively investigated and compared. As final result in polymer OLEDs, the OLLA partners showed an external quantum efficiency of 5%, in combination with a lifetime of over 1000 hours (without additional light out coupling structures).

Much higher efficacy values are achieved with phosphorescent blue "small-molecule" emitter systems. Although no remarkable progress in the development of a complete novel and stable phosphorescent blue material was reached, progress and deeper understanding was reached with mixed phosphorescent and fluorescent emitter sources. This way of making white light proved to be the best trade-off between colour point, lifetime and efficacy.

Right at the end of the project, the predefined efficacy level of 50 lumens per Watt in white OLED light was reached, in combination with a lifetime of over 10.000 hours at standard brightness level. This combination of results was not shown elsewhere before. Tests with extreme lab scale light out coupling methods showed even larger lumens per Watt. This indicated that a lot more light is generated, but still is trapped inside the substrate and OLED device structure itself.

The OLLA Milestone 3 demonstrator (source M.Klop)

During the whole 45 months period, the project got very much attention from the outside world. Many articles in popular magazines and newspapers were published, and even 5 TV items were made with OLLA demonstrators. OLLA got several invited talks and scientific papers at all international OLED conferences.

OLLA and especially its partner IPC also conducted specific OLED summer schools as open trainings. For four years in a row, this training event has been a great success, with over 200 visitors trained on OLED technology and related fields. Attempts are made to continue the OLED summer school activity even after the project.

Conclusion

The OLLA consortium concluded its cooperation with a large public demonstration event on June 12th 2008, in Eindhoven, the Netherlands. Goal of this event was to show the project outcome to a larger audience. Here the final demonstrators (Final milestone demonstrator and ICT demonstrators) were exhibited and the successful conclusion was celebrated in a mini symposium on OLED lighting.

Within the timeframe of the OLLA project, many materials, OLED stacks and processes were developed and large sized lighting tiles were successfully demonstrated. OLLA has clearly proven that OLED technology is applicable and fit for initial lighting application purposes.

The OLLA project officially closed on July 1st, 2008. OLLA delivered all its contractual obligations and it succeeded its own goals as set in the proposal written 5 years before. This success could only be accomplished with a large group of hard working and cooperating research professionals. This was recognised by the Organic Semiconductor Industry Association with the delivery of the OSIA R&D award 2008.

Although OLLA has ended, its research spirit and experiences is being continued in several FP7 follow-up projects, such as Fast2Light, Aeviom, CombOLED and OLED100.eu, and hopefully many more OLED lighting projects in the future.

Peter Visser

Aachen, December 2008

2 Work performed and results at work package level

The work performed through the OLLA project was divided in several tasks, which were grouped around 5 technical work packages (WP's). Dedicated WP's were formatted on OLED material synthesis, small molecule devices, polymer devices, light management and modelling, and application research. A management and dissemination work package completed the program. The objectives and major public end results from each technical WP are shortly described below.

2.1 WP 1: Material Synthesis & Characterization

The by far largest amount of man months of the project was spent on the development of novel OLED emitter materials and OLED compounds. Both small molecule and polymer OLED materials systems were investigated into great depths in the search for more efficient and more stable materials for high brightness OLEDs.

Starting point for the material investigation was the partners existing knowledge and known shortcomings of standard OLED materials. Strategies and routes for novel materials and material classes were drawn and evaluated in several rounds. Besides complete novel materials, also failure mechanisms of existing OLED materials were intensively studied in order to learn to overcome these failures. This was especially the case for blue phosphorescent materials, as these are well known for their short lifetimes.

In the course of the project many hundreds of materials were synthesized. Once compounds were created and purified, these were characterized on several predefined parameters. Based on the results of these characterization tests, decisions were made to upscale some of the novel materials into larger amounts, so that tests on OLED device level could be done. Then materials were moved from WP 1 to WP2 in case of small molecules or WP3 in case of polymers for further testing.

For small molecule OLED systems, several types of matrix materials and also other layer materials as hole blocking materials with better material properties were developed.

In the search for new matrix materials with higher energy levels, matrix materials with different cores showed promising initial results. However, they proved to be very difficult to synthesize, and were already claimed in third party patents. Therefore an alternative approach was found and worked out. In the search for long living phosphorescent materials, novel blue metal complexes were tested, but all attempts turned out to be instable or comparable to standard materials.

The screening and characterization of the many novel compounds and materials, as well as the OLED level devices appeared to be a very time consuming activity. Therefore OLLA developed and implemented an alternative screening approach. This new technique gave a rather quick overview on the weak spots of certain new materials, without compromising to the total screening results. It also was a good method to give a quick feedback to the synthetic groups. Once promising materials were identified, these were fully characterized via the regular methods and are tested against the OLLA reference devices.

On of the OLED device characterisation set-ups (source: Philips)

Part of the WP1 effort was spent into enhancement of the efficiency of white OLEDs over the red chronopher. Many know red phosphorescent OLED compounds loose part of their energy via radiation in the non visible infrared region, the so called ‘red tail’. A requisite for efficient white OLEDs is therefore access to red emitters with narrow red spectra.

A task was formed around a special class of small molecule materials comprising rare earth materials. Different classes comprising rare earth emitters were identified from literature and several compounds were made. Special emphasis was put to Europium (Eu-III) compounds, as these compounds show a strong red peak value in the visible range. Several new reds were synthesized and successfully characterized, and studied into devices.

Within the polymer material development tasks, many modifications and variations of materials were tested. Charge transport was studied intensively for the performance and colour balance improvement of white polymers. Issues around thermal stabilities were solved. Measurements of hole and electron mobility’s in the polymers gave valuable hints to adjust charge balance in the copolymer.

At the end of the OLLA project results of WP1 were made visible in demonstrators. Several materials and material compounds developed within WP1 were finally used into the OLLA demonstrators.

2.2 WP 2: Small Molecule OLED Devices & Technology

The goal of this WP was to make most efficient devices with the use of novel materials from WP1 and to develop adequate prototyping techniques towards manufacturing of large area OLED lighting modules. The main innovation required here was the optimization of the device architecture to increase device efficiency and lifetime. In close cooperation with the materials synthesis tasks, device investigations and device designs were tested. Results on light management and modelling from WP 4 were also incorporated to further optimize the performance of white OLEDs.

During the course of OLLA it became clear that OLED material developments only make sense in combination with work on device structure: the deep understanding of the interactions between different materials in devices is a prerequisite for knowledge creation. Several thousands of test samples were produced (most handmade) and measured. Technical insights (sometimes even on molecular level) were captured and documented in reports, scientific articles, PhD theses.

Part of the work was devoted to investigate new and promising deposition technologies. Dry physical methods relying on vacuum thermal evaporation (VTE) were investigated as well as organic gas-phase deposition (OVPD). Whereas the first one has already achieved an advanced status, for novel materials the process compatibility had to be assessed. The novel and very promising OVPD process has intrinsic differences, which could help to overcome the limitations of standard VTE. Gas phase deposition also opens possibilities for new sophisticated and thereby more efficient device architectures. A study was performed on the possibility for larger sized OVPD deposition, as well as higher deposition rates. Further studies were done in the pre-qualification of organic material for OVPD deposition.

Small Molecule OLED deposition under high vacuum (source Philips)

Within WP 2 the final large and efficient OLED stacks were made. OVPD technique was demonstrated in smaller handheld devices.

2.3 WP 3: Polymer OLED Devices and Technology

Aim of the work here was efficiency and lifetime optimization of white light emitting polymer OLED systems. Extensive research was carried out on polymer degradation mechanisms, which differ from small molecule systems.

Examination of charge transport behaviour helped to understand of the energy loss patterns of the dyes used. Several new dyes and polymers were made, and homogeneity of brightness of large area polymer OLEDs was tested.

Polymer OLEDs are deposited from solution basis by means of spin coating. This technique has limitations in size. One possible alternative route which also offers options for lower production costs is foreseen by the usage of large area printing techniques. However, OLED printing sets own challenges in terms of layer uniformity. The layer uniformity is governed by the properties of the polymer ink and substrate, printing cylinder design and printing parameters.

Within OLLA, the method of gravure printing, as used for printing of newspapers, was studied at VTT. Within this study polymers and special smoothing layers were modified. Gravure printing proved to be comparable to standard spin-coating. Additionally, an initial cost analysis of gravure printed OLEDs for future production was prepared.

A white gravure printed OLED device (source VTT)

A large area printed white OLED comprising a printed organic and PEDOT injection layer was successfully demonstrated at the final event in the format of an airplane exit sign.

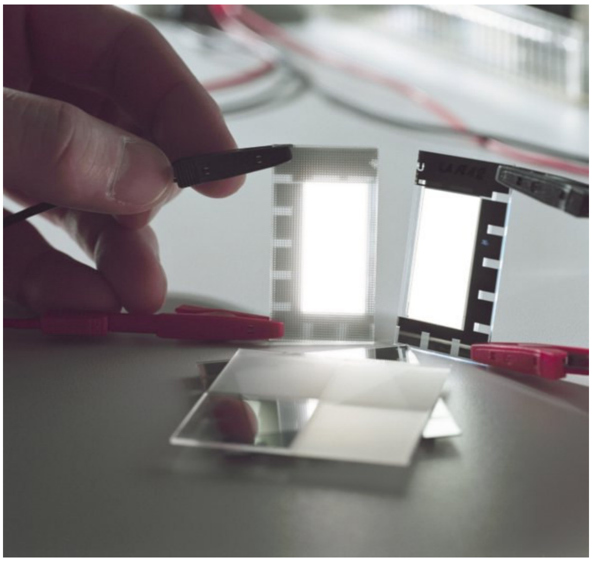
Although Polymeric OLEDs are running behind small molecule OLEDs in terms of lifetime and efficiency, significant progress and basic knowledge was being made. Lifetimes and efficiency for white polymeric OLEDs were more than doubled. In terms of production costs, roll-to-roll production of wet coated devices is seen as cost effective.

A benchmark study on polymer OLED emitters was made and the work performed within OLLA turned out to be on par with the global state-of-art. A large final white polymer demonstrator module of $15x15cm^2$ was fabricated and shown as signage demonstrator the final event. A large final white polymer demonstrator module of $15x15cm^2$ was shown as signage demonstrator the final event.

2.4 WP 4: Electro-Optical properties of OLEDs & OLED Modelling

A major problem of thin film emissive devices is the out coupling of the generated light into the air. In a conventional OLED, only 20% of the generated light is out-coupled into the forward direction. The rest is lost via wave guiding into the layered OLED emitter structure, and thus lowering the efficiency of the device.

To improve out-coupling, internal reflections, reflections at the OLED-glass and the glass-air interfaces have to be reduced. OLLA studied different external structures and other implementation measures, which enhanced light out coupling.



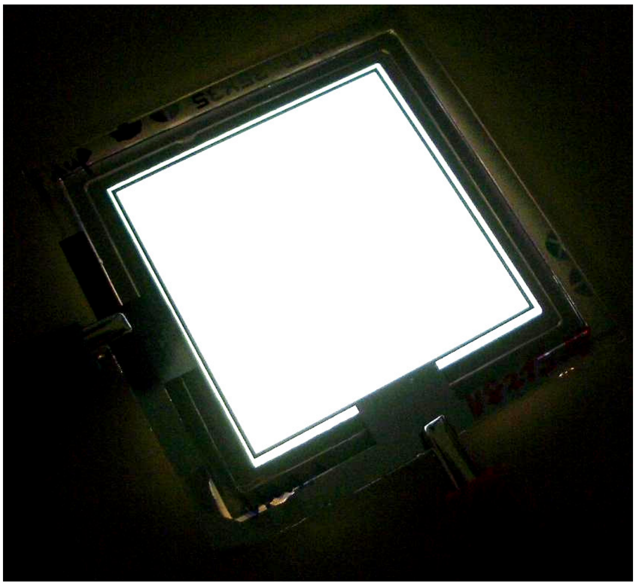
An OLED with and without external out coupling structures (source: Philips)

Precise computer modelling of layered OLED structure was performed. Various periodic and non-periodic micro- and nanostructures were simulated and compared with practical experiments. Good agreement was achieved between calculations and experiments. Various fabrication techniques of periodic diffraction structures were tested, including micro imprint lithography.

Progress in understanding the major loss mechanisms in OLEDs has lead to rapid improvements in efficiency. As final result, OLLA demonstrated that light extraction from glass substrates into air by micro-lens arrays can be improved by 50% to 80% (i.e. by factor 1.6) by using micro-refractive structures. A dominant brightness enhancement factor is the reflectivity of the OLED layers themselves.

Indium tin oxide (ITO) is the most commonly used as transparent OLED electrode material due to its high transparency and good electrical properties. However, Indium is a relatively rare material on the earth. The high demand for use displays and the relative high production cost make ITO less desirable for mass production of OLEDs for lighting applications.

As alternative transparent electrode, OLLA studied the polymeric material PEDOT/PSS. In May 2006 OLLA showed in a press release the first ITO-free green OLEDs with a polymeric anode made on basis of H.C. Starcks Baytron. Later on in the project, a white P-i-n type OLED panel with more than 10 lm/W was successfully demonstrated.



An ITO free white OLED with polymeric anode

Another part of the work was devoted on the electrical simulation of organic semiconductor devices. This can be a powerful tool for future device optimalisation. Through modelling, the number of devices for optimalisation runs could be reduced. However, many basic physical processes in OLEDs were not yet fully understood.

Within OLLA two device modelling tools, i.e. a tool for multilayer polymeric devices and a tool for multilayer small-molecule devices are were developed and parameters were measured. These tools may support OLED device development in future.

2.5 WP 5: System Design & Application research

Within WP 5 the interaction of the various system design aspects of OLED lighting were studied, with special focus on the packaging and driving of larger OLED tiles.

OLED materials are very sensitive for intrusion of water and air. Therefore OLED materials are packaged. A current standard but expansive method is to use a glass-glass structure incorporating getter material. This method is not very well suited for large area OLEDs. A cheaper and thinner low temperature encapsulation concept for larger OLED devices was developed. It was tested on leakages through accelerated lifetime tests.

Another part of the work was dedicated to the electrical driving of larger OLEDs. A versatile programmable power supply for testing and identifying optimal OLED addressing schemes for OLEDs versus current-voltage diode characteristics was developed. The power supply exhibits a high degree of freedom, enabling correcting non-ideal OLED performance by adjustment of proper driving conditions. Through controlled feedback over the driver, the lifetime of OLEDs could be 50% increased.

A programmable OLED driver (Source IPMS)

Voltage decay over large area electrodes is a serious problem for lighting applications. It is visible as brightness drop over the area. Different ITO contact positions and additional integrated conducting elements, such as metal grids on ITO, were found to be possible solutions considerably reducing variation of brightness over the electrode area. It was shown that a very low brightness variation can be achieved with integrated metal grids.

Total OLED lighting system approaches were studied and a number of possible applications were generically identified. For that reason, a workshop on signage applications for external parties was organized in November 2005. The main instrument for gathering lighting requirements for OLED lighting was through questionnaires and end-user interviews. The results were put into an internal report and roadmap.

3 Impact on industry

The OLLA project was set up to show the feasibility of OLED technology into the ICT and Lighting domain. For that aim, many novel materials, OLED stacks and processes were developed and larger sized efficient lighting tiles were successfully demonstrated.

With its final demonstrations on June 12^{th}, 2008, the project clearly showed the technical feasibility for many lighting applications. Furthermore through all information requests, conference invitations, market consultant interview and other media attention from Europe and the rest of the world, OLLA also showed the market interest for novel thin lighting applications.

But the OLLA outcome is only a starting point to build a European OLED lighting industry. More research and development effort has to be performed. As OLED technology is a multi disciplinary technology, good and close collaboration is a prerequisite. With OLLA the European lighting industry proved that it's capable conducting such cooperation's.

To come to OLEDs suited for mass general illumination, next technical milestones have to be met: 100 lumen/Watt, lifetimes of 100.000 hours or more and much lower production costs. At this level OLEDs could compete with existing, but mercury containing fluorescent lighting sources.

By October 2008, the follow up project on OLED production technology called OLED100.eu will start. It has the sharp targets to developing OLED tiles with 100 lumen/Watt efficacies, 100.000 hours of lifetime, 100 x 100 cm^2 size, at a cost level of 100 Euro. With this and other important technology projects like Fast2light , Aeviom, CombOLED project, Europe will continue to lead the research frontier on OLED lighting, and secures the future of its own lighting industry.

Appendix A: Overview of OLLA partnership entities

University partners:
- Ecole Polytechnique Fédérale de Lausanne (EPFL), CH
- Katholieke Universiteit Leuven (KUL), B
- Rijksuniversiteit Groningen (RUG), NL
- Technische Universität Dresden (IAPP), D
- Universität Kassel, D
- Université Louis Pasteur (ULP), F
- Universiteit Gent, B

Research Institutes:
- Centre Nat. la Recherche Scientifique, Institute des Materiaux Jean Rouxel (CNRS-IMN), F
- Consiglio Nazionale delle Ricerche (CNR-ISOF), I
- Fraunhofer Inst. for Photonic Microsystems (IPMS), D
- Institute of Physical Chemistry of the PASc,PL
- Interuniversitair Micro-Electronica Centrum (IMEC), B
- National Nanotechnology Lab (NNL), Lecce, I
- VTT Technical Research Centre, Fin

Industrial Partners:
- Aixtron AG, D
- Merch OLED Materials GmbH, D
- H.C. Starck GmbH, D
- Novaled GmbH, D
- Osram Opto Semiconductors GmbH, D
- Philips Electronics Nederland BV, NL
- Philips Lighting GmbH, D
- Philips Technologie GmbH Forschungslaboratorien, D
- Sensient Imaging Technologies GmbH, D
- Siemens AG, D