Advertisement displays manufactured by hybrid in-mould integration
“OptIntegral”

D4.5: KEY FINDINGS FROM THE DEMONSTRATORS AND NEEDS FOR FURTHER RESEARCH.

Project No. 643956

Start date of project: 01-02-2015

Duration: 3 years

Revision: 01

Date: 05.03.2018

Document Information

Document Name: D4.5. Key findings from the demonstrators and needs for further research.

WP and task: WP4 T4.4

Revision: 01

Revision Date: 05.03.2018

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Dissemination Level

Project co-funded by the EC within the H2020 Programme		
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Approvals

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Document history

Revision	Date	Modification
Version 1	31.01.2018	V1 draft version
Version 2	05.03.2018	Contributions from Partners + final review
Version 3		
Version 4		

Table of Contents

1.- INTRODUCTION

In this document, the main findings of Optintegral project are summarized. After all work carried out during the project, there are some important points to take into account when similar products are going to be developed. Each demonstrator encountered different difficulties which finally were solved after some iterations. Besides, future research topics have been mentioned for each manufacturing step.

2.- LIGHT-PIPE AND RGB-DISPLAYS (NEO).

2.1.- Demonstration results

Key findings:

- UBATH student evaluation of circular canvas display with RGB backlighting against traditional light box canvas display showed that the tested display is significantly more effective than standard display on both communication and metacommunication. The test display is also perceived to be more attention-getting mainly due to its shape. The result indicates that customizable, curved and slim shape can be significant factor increasing the communication and metacommunication value of a display.
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Topics identified for future research:

- As a result of demonstration at Amsterdam ISE 2018 Neonelektro received several inquiries about LED-foil products. One common question of potential customers is how to control the content of dynamic RGB-foil installations. This is the topic of research and development Neonelektro has already identified also in other potential customer cases. In the future Neonelektro is strongly focusing on developing scalable and user-friendly control system for customers.

2.2.- Manufacturing process of light-pipe (BIM) display.

Key findings:

- Innovative method of manufacturing light guide element for advertisement backlighting and general lighting was developed.
- The optical features integrated on the display surface in the in-mould process made the illuminating (top) surface more even. The optics turns the light along the structure causing more absorption in the moulding material due to longer travelling distance. Still, goniometer measurements indicate that if no optical features are used more light escapes from the backside of the panel. Compared to reference sample (with no optical features) the inmold integrated optical features on display surface increased light output on useful directions (front surfaces and sides) by 17%.
- Thermal measurements show that on average embedding reduced LED temperatures 20% compared to bare foil simples.

Topics identified for future research:

- Testing of light-guide display (BIM) showed that only 40% of the light leaves from the lightguide from the primary (top) surface. The efficiency could be improved by integrating (printed) optical elements on LED foil or using 2K moulding to provide optical features also on the back side.
- Connection between display modules is essential in order to build large area displays. A new connector was developed for electrical connections of LP-display during the OptIntegral project, but experience from that in real use conditions is still low. Connectors have been identified as a key issue for implementing this technology so far, and research on this topic needs to be continued.
- In-mould integration of the light-pipe display required a laser cutting on the LED foil, and the pilot manufacturing revealed issues in the alignment accuracy. Web tension could be used to improve the accuracy in future. Also, deformities in the print could be checked prior cutting and in volume production, the cutting could be done by a laser operating on a roll form substrate or by using mechanical cutting (converting) also in roll format.
- For industrial manufacturing the supporting adhesive dispensing should be processed automatically. Here, the LED bonding during the pilot manufacturing was done automatically, but the supporting adhesive was dispensed by hand.
- Yield in pilot manufacturing was lower that expected. For volume manufacturing, the whole tolerance chain considering alignment accuracy, thermal expansion of the substrate during molding process and dimensional variation within the roll, should be considered to make a design that will provide acceptable yield. Also, inspection system during the moulding could be used to verify correct positioning to the mould before overmoulding.
- Goniometer and local luminance measurements show around 50% deviation in light uniformity between opposite edges of the module. This non-uniformity is caused by accumulation of light intensity towards the edge where LEDs are pointing to. Optical coupling between adjacent modules needs to be studied and developed to correct the bias in light uniformity of single module.

2.3.- Manufacturing process of RGB Display

Key findings:

- R2R over-moulding processes instead of the standard sheet insert process was successfully used in the RGB display manufacturing. As such, a significant increase in the throughput and cost efficiency can be concluded as the separate sheet cutting step is avoided. R2R over-moulding process has also less complex foil inserting in the moulding tool and there are better possibilities to fully automate the process.
- Optical measurements show that the RGB display performs with higher efficiency and surface illumination than the bare LED foil although some light absorption must occur in the slightly diffusing optical element overmoulded on the LEDs. The benefit is 2 - 4 % depending on the color and is assumed to be caused by improved thermal performance of the overmoulded sample. The measurements show 30% decrease in LED temperature due to overmoulding.

- Visual inspection indicates that overmoulding spreads the light to wider area that helps to create more evenly illuminated surfaces. In final application this would mean that thinner structures could be used as the printed advertising canvas could locate closer to the illuminating foil.

Topics identified for future research:
- The overmouding covers the LEDs and it is assumed to protect the LEDs against environmental stress. However, reliability of the developed structures was not investigated in OptIntegral-project and should be addressed with future research.
- Copper conductors would have better electrical conductivity and they are more environmentally friendly compared to silver tracks. So, especially in large, printed displays with long wirings copper conductors are interesting topic for future research.
- Similar to light-pipe display, connectors compatible with flexible electronics are a key issue for implementing this technology, and research on this topic needs to be continued to find optimal solutions.
- Similar to light-pipe display, the supporting adhesive was dispensed over the LEDs by hand. For industrial manufacturing, automatic process should be developed.

3.- 3D-DISPLAY (HOL)

3.1.- Demonstration results

Key findings:
- A novel glasses-free 3D light field LED wall technology, applying novel lens design and optimized for chip size in high-density arrangements, has been developed. Fundamentally, this is a new product category, offering a visual platform for large-scale digital signage showing real 3D content and applications.
- Optical measurements showed that the performance of 3D LED wall prototype is matching the design values, and features 70 degrees field of view and 1200 cd/m² brightness. The display is freely scalable in size by seamlessly tiling cabinets.
- The technology was demonstrated with the help of the prototype panel to selected industrial partners at Holografika showroom and to potential customers at ISE 2018 during the public workshop. A lot of industrial interest was raised during the public workshop with the participation of potential users, invited technology companies, integrators from all over the world. Visitors claimed that the product concept was of great novelty value and very promising in creating effective advertisements through eye-catching 3D impressions without the need for accessories, offering the practical advantages of modular LED wall displays.

3.2.- Manufacturing process of HOL display

Key findings:
- Extreme high-density LED board design has been developed to maximize the number of viewing directions per pixel. It was difficult to find reliable manufacturing technology and partner. The prototype board has been successfully manufactured by normal

technology, however the yield has to be increased, but the upgraded demonstrator board design is only feasible by ELIC technology.

- Due to the technological complexity of the 3D LED board design the prototype was built on rigid FR4 PCB. Unfortunately FR4 cannot be over moulded. The matter was studied and concluding that the reliability of the over-moulded product was not sufficient. The main difficulty is the difference of CTEs that causes high internal stress rupturing the structure and detaching LEDs. Consequently, both lenses were manufactured in a separate moulding process and the first lens is attached with index matched optical adhesive to a rigid PCB board.

Topics identified for future research:

- The optics for 3D LED wall display is manufactured in separate moulding process. The optics is then attached with index matched optical adhesive to a rigid PCB board imitating the over-moulded structure allowing the design to benefit from the fully integrated nature of in-mould hybrid integration. The flexible over-moulded and the demonstrated rigid structure are both based on the same display design and only differ in manufacturing steps. Consequently, the developed 3D LED wall display design can be straight-forwardly upgraded to full in-mould hybrid integration whenever the flexible substrates meeting the 3D LED wall display density requirements are available. With this approach the demonstrators are closer to the marketable product at the end of the project, while can be changed to hybrid integration in the future when injection over mouldable substrates are available.

4.- BACK-LIGHT DISPLAY (MEGA)

4.1.- Manufacturing process of back-light display

5.- LSR DISPLAY (EURECAT)

Key findings:

- A light-pipe display using Liquid Silicone Rubber has been developed.
- Optical features with LSR over foils with LEDs results in a new range of products. Some optical properties of LSR like refractive index or luminous transmittance are better than other thermoplastic materials with the same hardness.
- Due to the rheological properties of LSR, high accuracy geometry can be achieved and then new optical features moreover, parts with undercuts can be molded using this materials.
- LSR allows to create parts for outdoor applications due to have a good aging and weather resistant (ozone and UV-rays resistant).

Topics identified for future research:

- Adhesion between foil and LSR was poor. A compatibility study of two materials was not carried out due schedule constraints. A further research in foil material is needed in order to assure chemical adhesion.

- LSR process should be optimized in order to reduce the amount of time which the foil is in contact with the high temperature from the mold.
- As mentioned above, connections between overmoulded parts and overmoulded parts and power supply unit are key issues that needs a further research.
- Regarding to the foil feeding system, in order to industrialize the process, some developments are needed. Roll-to-roll process should be optimized taking into account the mould temperature. Another option could be to use a robot with a special hand to manipulate the foil in sheet format.
- No recyclable.

6.- MULTI-LAYER FOIL DEMONSTRATOR (VTT)

Many applications, such as HOL and MEGA displays, require a multilayer board to be able to provide required electrical contacts to complex electronic systems. However, only rigid boards can currently provide such capability, but are not compatible with overmoulding. With overmoulding additional features such as protection, mechanical structures, thermal structures and optics could be integrated to the devices in one process step. In Optintegral, manufacturing process for multilayer flexible substrate compatible with overmoulding was developed and demonstrated with 4-layers.

Key findings:

- The flexible substrates can be laminated together to form optically clear structure with printed wiring in multiple layers.
- Vias without separate via filling step can be produced with high yield.
- The transparency is significantly improved with the developed multilayer method. The multilayer wiring covers only half of the surface area that the single-layer wiring of the same design takes.

Topics identified for future research:

- In addition to multiple layers, many advanced applications require very dense component spacing. This aspect was not investigated here, and should be addressed with future research.

The manufacturing process was demonstrated on sheets (contrary to R2R) and manufacturing included manual phases. Development towards R2R and full automation is needed to make the process more viable to industrial use.

7.- CONCLUSIONS

Several new prototypes and product concepts have been developed and demonstrated successfully to both the industry and the public.

Despite a lot of work has been carried out, there are some general points to improve. The automation of some steps within all the demonstrators is a key issue to assure a cost effective products. Take advantage of injection molding process creating more 3D complex features in order to obtain new range of displays.

General accuracy should be improved in all demonstrators especially in the alignment of LEDs and optic features. Accuracy over all the manufacturing steps should be high in order to not accumulate errors through the process steps.