PROJECT FINAL REPORT

Grant Agreement number: **247928**

Project acronym: **LAMP**

Project title: LASER INDUCED SYNTHESIS OF POLYMERIC NANOCOMPOSITE MATERIALS AND DEVELOPMENT OF MICRO-PATTERNED HYBRID LIGHT EMITTING DIODES (LED) AND TRANSISTORS (LET)

Funding Scheme:

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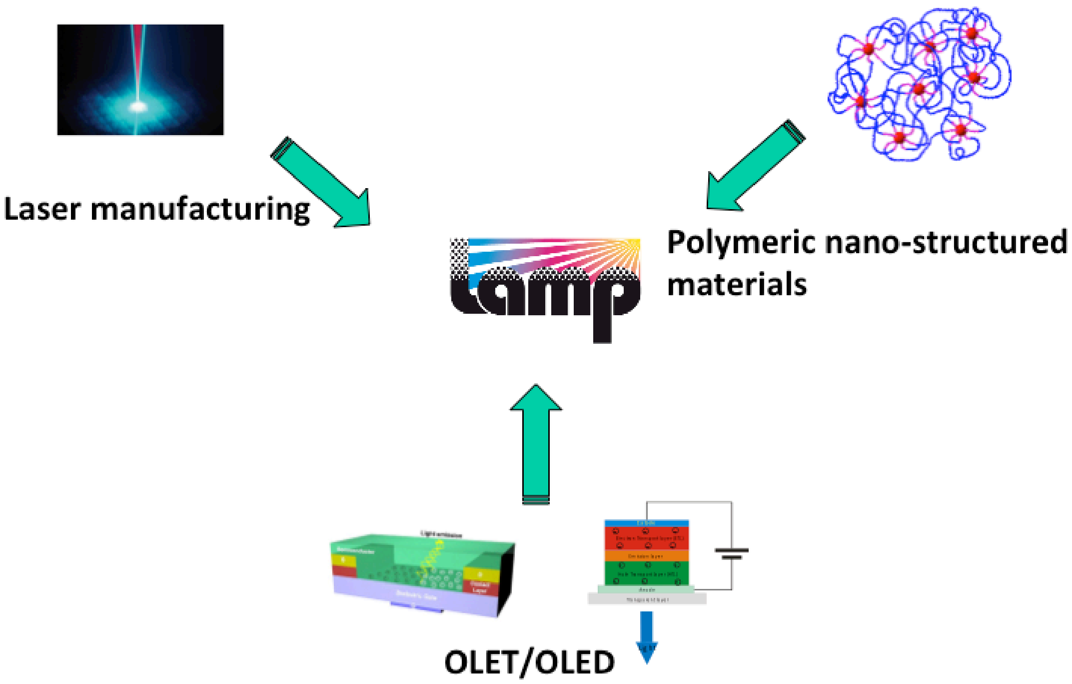
1.1 Executive summary

Nanostructured composites of inorganic and organic materials are promising materials for electronic and optoelectronic device applications. This project addresses the development of a simple methodology to fabricate light-emitting devices from such materials. In particular, it explores depositing the materials from solution, and patterning them by laser to make Organic Light Emitting Diodes (OLEDs) and Transistors (OLETs).

A B C

The localised synthesis of the nanocomposite is obtained by using a laser source (A) that leads to a desired pattern of generated nanomaterial in the polymer matrix (B). The laser patterning used on the light-emitting device defines the pattern of light emission from it, enabling information to be displayed or warning lights to be made (C).

This type of direct laser micro-patterning, that is one of the key ideas of the project needs at least two other basic concepts to be exploited in a real device. In particular OLED/T realisation using laser technology implementation needs three main steps to be accomplished: *i*) the development of suitable materials, *ii*) optimisation of the laser patterning and *iii*) the OLED/T manufacturing with the materials and laser technologies set up.



If the laser technology is the core idea of the project, the formation of an in situ formed nanocomposite as light emitter is another factor of innovation of LAMP. The huge potential of the polymeric nanocomposites originates from the combined properties of the polymers and the inorganic nano-sized filler material. The direct growth of the nanomaterial inside a specifically designed polymer is aimed to enhance the properties of electron transfer from the conductive polymer to the nanomaterial that in term of real device fabrication means the production of light sources with improved performances as light emission and lifetime.

Excellent results have been obtained in terms of synthesis of highly thermally stable and luminescent polymers needed to work as host materials in nanocomposites. Synthesis of organometallic complexes having high solubility in common organic solvents and having low decomposition temperatures has been achieved. Photophysical properties of polymer/precursor nanocomposites have provided important input to the selection of optimised blends for laser patterning. The first ever patterning of emissive quantum dots inside conjugates polymers using picosecond and nanosecond lasers has been achieved.

The fabrication of an OLED/T by means of the laser technology and the new materials developed within the first part of the project, is the step forward of LAMP and initial encouraging results on the development of a prototype device were obtained using direct laser patterning.

The interest of this project lies in the advantages of the methodology and materials explored here which opens a new approach to patterning of solid state lighting (SSL) and displays. In addition the use of inorganic nanoparticles as light emitters is expected to improve the lifetime of the organic SSL devices.

The use of polymers and their combination with nanomaterials through the laser activation can be applied in the fabrication of logos and information panels such as cockpit-LED which warn the driver about the status of the car. The simplicity of the technique and its spatial resolution can improve the visualisation of symbols coupled with a simpler electronic and minor energy consumption.

Another advantage is the methodology itself, which uses laser irradiation as way of patterning instead of lithography – a process that needs cumbersome steps and cost consuming processes from industrialisation point of view. The OLED as expected and developed in LAMP, is cheaper than a standard one in overall production costs having a **production cost reduced of approximately 12%** mainly due to a reduction of the manufacturing steps proposed with LAMP methodology.

1.2 Project context and objectives

Context

Optoelectronic devices are among the most attractive candidates for the next generation of light sources owing to the potential of reduced energy consumption and high quality lighting properties. In particular organic light emitting diodes (OLED) or organic light emitting transistor (OLET) are attractive candidates as they can be fabricated using solution processable techniques on large area and flexible substrates at low cost.

In OLED a film of organic material sandwiched between two electrodes and under applied voltage bias the organic material emits light. OLED can be based on films of polymers or organic small molecules. Multi-structured OLED consists of hole transporting, emissive and electron transporting layers which can be either deposited by vacuum sublimation or by solution processed methods. In OFET devices the active organic semiconducting material works as a *channel* in which the current flows between two electrodes (source and drain contacts). The flow of charges in the polymeric layer is modulated by the gate electrode (the field-effect in the channel). In such devices when a gate potential is applied, charges are accumulated in the organic semiconducting materials, and can move between the source and drain electrodes (field-effect conduction). In electroluminescent materials, this leads to light generation within the channel. In this sense the OFET can be considered as an Organic Light Emitting Transistor (OLET).

Both OLED and OLET use organic materials as emitters, however the light production/harvesting of “all organic” devices are affected by several drawbacks that are crucial for their commercial application. The purity of colour emission is affected by different ageing rates of active compounds and its components may often be subject to water damage. A completely new technology platform able to overcome the aforementioned problems affecting “all organic” devices is the use of semiconductor nanocrystals or quantum dots (QDs) as active elements for light production. The use of QDs for LED production (QD-LED) was proposed, because the incorporation of QDs as light emitting centres improves the device performance in terms of colour ageing, device lifetime. In addition their electro-optical properties can be modulated by adjusting the size without changing the chemistry of the synthesis with respect to the organic molecules used as light chromophore in “all organic” light emitting devices.

A key issue of display manufacturing, including OLED/T, is how to pattern the pixels to make a colour display. Patterning is also useful for lighting, for example to create symbols and logos. . Currently patterns are drawn on such devices by several techniques, namely photolithography, shadow masks and ink jet printing and it is one of the major barriers for commercialization of patterned OLED as it increased the manufacturing costs. The microlithography technology used for the patterning of layers impacts on the overall costs of the device by greater than 30% when considering the complexity of actual devices and the high cost of facility investments. This figure increases exponentially when considering large area devices.

The evolution proposed by this project consists of bring together the combination of organic/inorganic materials and laser technology to improve and reduce the costs of device manufacturing. The formation of QDs in polymers through laser action is demonstrated and a QD-OLED/T can be obtained without the use of complex patterning technologies.

LAMP methodology for the direct patterning of active materials with a laser is expected to contribute in the reduction of manufacturing costs enabling potential penetration in several demanding markets as such as the automotive industry.

Objectives

The general objective of the project can be divided into three main goals:

a) **development of suitable materials.** The material synthesis comprises both QD precursor and polymer matrix development. The synthesis of the two materials alone is not sufficient to accomplish the task because these two components have to be mixed and thermally treated in order to attain the desired nanocomposite;

b) **formation of a polymer nanocomposite through laser irradiation.** The development of direct laser patterning (DLP**)** technology on polymeric matrices needs the set up of different laser sources and conditions to stimulate the formation of QDs, preserving the polymer functionality;

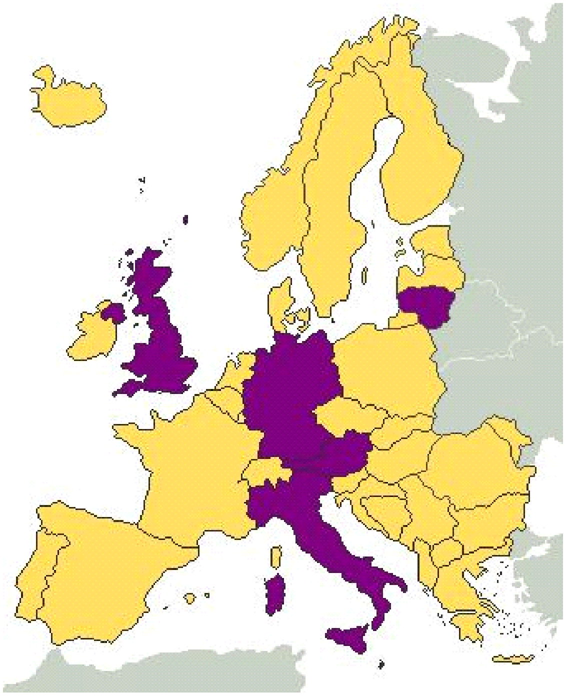
c) **manufacturing of a QD-LED/LET** based on a) and b). In relation to device development, the main goal consists in the realisation of a light emitting device formed by QDs by means of DLP instead of the current methods that makes use of shadow masks, photolithography or inkjet printing. In this case the main challenge is to set up laser conditions forming the nanocomposite but allowing also the device functionality.

Consortium

The LAMP consortium gathers 7 groups belonging to five different countries, and it has been built with the scope to cover not only the expertise needed for the project, namely materials synthesis, materials laser processing and device manufacturing, but also to recruit research groups actively working in the field of LED research and manufacturing.

Partners list

Organisation name	Short name	Country
Italian National Agency for New Technologies, Energy and Sustainable Economic Development	**ENEA**	**Italy**
University of Wuppertal (Institute for Polymer Technology)	**BUW**	**Germany**
Centro Ricerche Fiat	**CRF**	**Italy**
Ekspla UAB (SME)	**Ek**	**Lithuania**
National Research Council	**CNR**	**Italy**
Organic Semiconductor Centre (School of Physics and Astronomy University of St. Andrews)	**USTAN**	**United Kingdom**
Joanneum Research Forschungsgesellschaft GmbH	**JR**	**Austria**



For any additional information it is possible to look at the project web site at the following link: www.lamp-project.eu

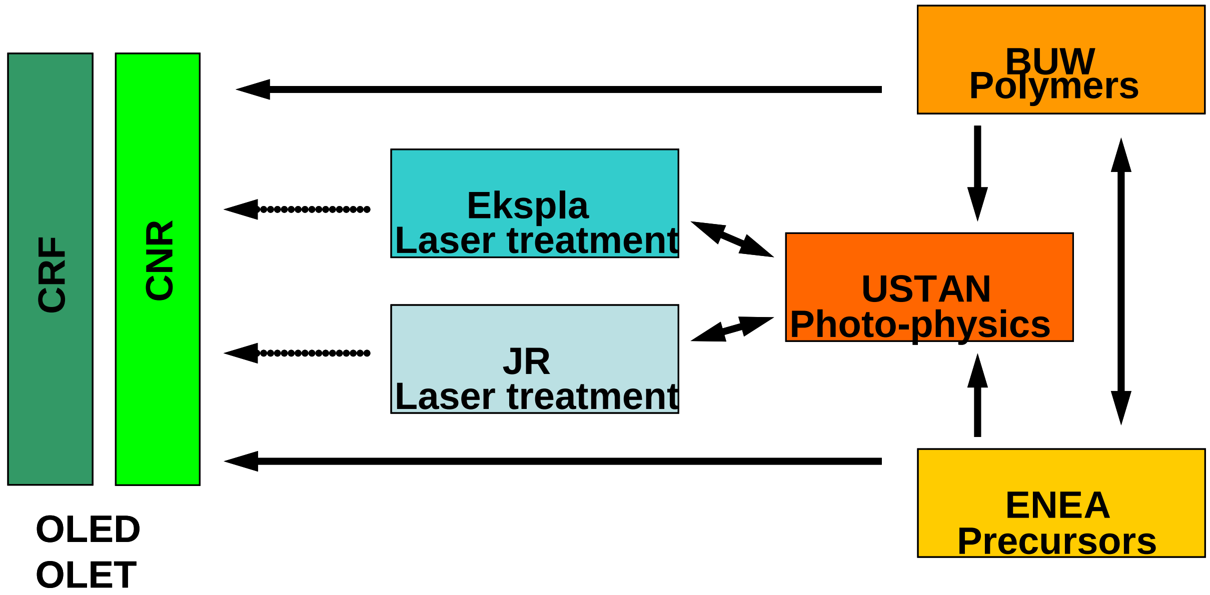
1.3 Description of the main S&T results

In the following section the main results achieved during the three years of the project are described. This section is divided into two main parts: i) the working team - illustrating the role of the team in the development of the project and ii) the summary of the main results obtained by the consortium.

1.3.1 Working team

The results obtained during the project were achieved by organising the team as shown below in scheme 1.3.1. The scheme illustrates the workflow of the activity lead by the different teams.

- ENEA leads the synthesis of the precursors and project management
- BUW synthesised the polymers and supported ENEA in the synthesis of some precursors;
- USTAN studied the photo-physical properties of the materials prepared by BUW and ENEA and polymer/nanoparticle composites. After defining conditions for thermal conversion of nanoparticle composites, USTAN prepared samples for laser processing by JR and EKSPLA
- Ekspla and JR made the laser treatment of the samples received by USTAN and characterised them on the basis of fluorescence microscopy and TEM.
- CRF and CNR fabricate and characterise the OLED/Ts with the laser treated samples received by Ekspla and JR.



Scheme 1.3.1

During the project this scheme was flexible, and when needed the working strategy has been revised following the needs of the project. This was especially true in the third year, where the teams showed strong flexibility to alter task if required, indeed JR were able to start production of the OLED with laser patterning directly in their labs.

1.3.2. Main results of the LAMP project

The key result after the three year project term is the realisation of a laser patterned OLED/T using the materials set up within the Consortium.

The result has been obtained through three sequential steps:

i. selection of the suitable materials both polymers and precursors;

ii. selection of the laser patterning conditions for the formation of the nanocomposite with the prepared materials;

iii. the fabrication of the OLED/Ts by means of the selected materials and laser conditions.

To achieve this result, several polymers and precursors were synthesised. All the combinations polymer/precursor tested within project passed a careful selection of their chemical and photo-physical properties before and after baking/laser treatment. Only the blends showing good chemical and photo-physical properties were then applied and checked for their use on devices.

Out of several interesting polymer/precursor nanocomposite combinations three blends (P14/PR04, PPy/PR06 and F8BT/PR06) are summarised here.

An OLED has been manufactured by lasers using precursors of CdS while an OLET has been realised with a CdSe precursor. Both results are a proof of principle that the laser patterning can be used for OLED/Ts manufacturing.

Polymers and precursors selection

The selection of the materials started with the synthesis of precursors and polymers that are studied separately, then in combination (blend formation).

The study of precursors includes the evaluation of the QDs formation conditions, i.e. temperature, times and solvents, then the study of their optical and structural properties.

The precursor was decomposed by heating it at a specific temperature and the formation of quantum dots (QDs) was investigated by Transmission Electron Microscopy (TEM), X-ray diffraction (XRD), ultraviolet-visible absorption (UV/Vis) and photoluminescence (PL) spectroscopy, respectively.

In figure 1.3.2.1 is shown an example of TEM study of CdS QDs in order to simplify the growth conditions of the QDs.

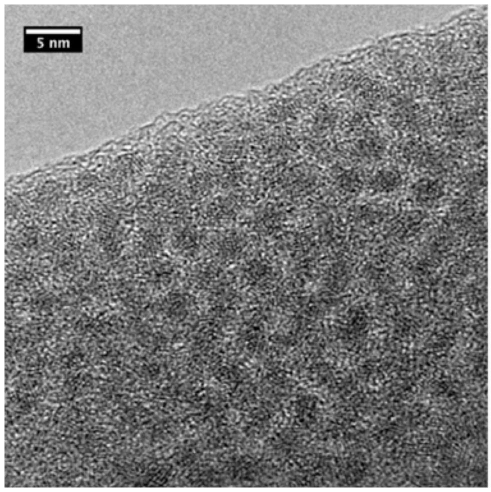


***Figure 1.3.2.1** TEM images of the QDs generated by the PR03 precursor in solution at 260 C° 30 min. The analysis indicates the presence of CdS nanocrystals of an average size of 3.4* nm

A series of single source precursors for the QDs synthesis has been considered and the selection of the best precursor has been made before their optical properties are measured as shown in figure 1.3.2.2 for the QDs generated by the decomposition of the precursor PR05.

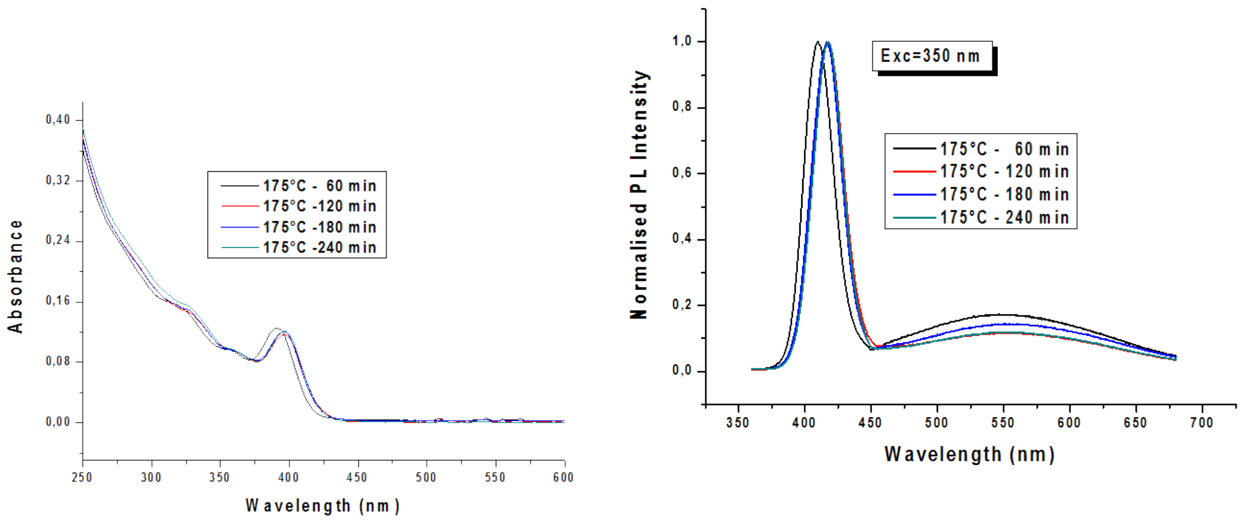


***Figure 1.3.2.2:** UV-Vis and PL spectra of CdS QDs generated by PR05.*

The generation of the QDs from the precursors was also studied in a film because all the prepared materials will have to be used in this state. In this case the best technique to asses the presence of the QDs and their distribution in the film has been the HR-TEM as shown in figure 1.3.2.3.

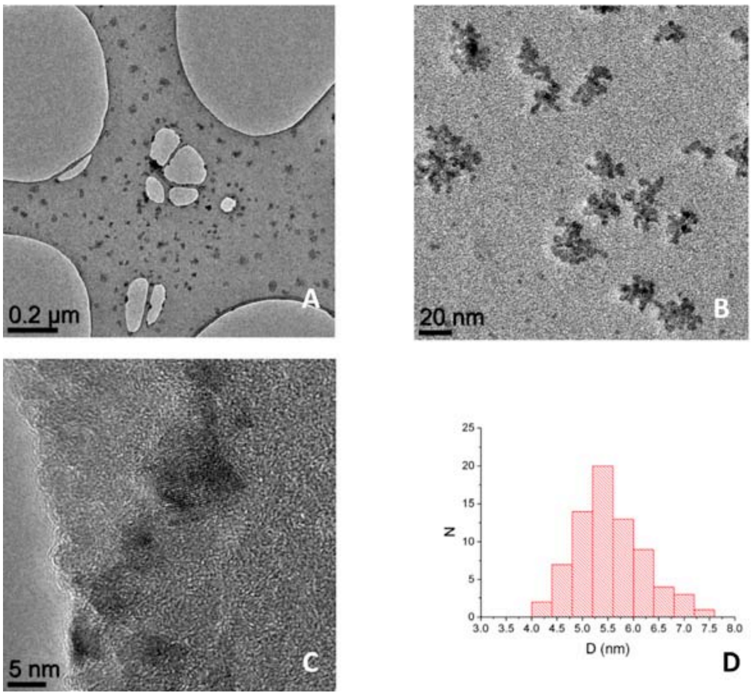


Figure 1.3.2.3: *Low (A), medium-high (B) and high (C) magnification images of QDs generated by thermal annealing; the histogram (D) used to evaluate the average diameter of the QDs. In this case the PR05 alone generates clusters of 5-10 QDs of 5.5 nm average size.*

In parallel several classes of matrix polymers were examined. Below are depicted chemical structure and synthesis of an initial series of polyfluorenes with varying length of the alkyl side chains. The polyfluorenes PF6, PF8 and PF12 have been synthesized in aryl-aryl polycondensation reactions after Yamamoto (figure 1.3.2.4).

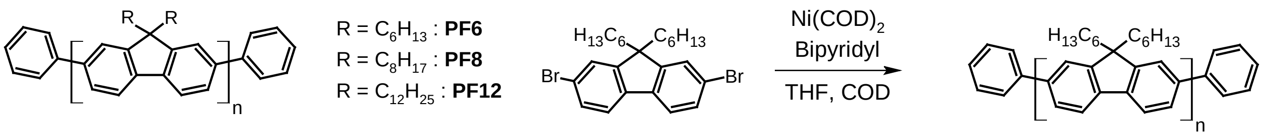


Figure 1.3.2.4 *Fluorene homopolymers and their general scheme of synthesis*

Following this, several classes of polymers were synthesized taking into account that their physico-chemical properties have to be compatible with the ones of the precursors in order to obtain suitable polymer/precursor blends. The polymers were optimised towards this goal, especially concerning their solubility and thermal/chemical stability. Several types of polymers with good stability in a wide temperature range and sufficient solubility have been developed, including PF8 and PF10 as well as the new polymers BocPF12 and PME124, enabling an optimal combination with the prepared nanoparticle precursors (figure 1.3.2.5).

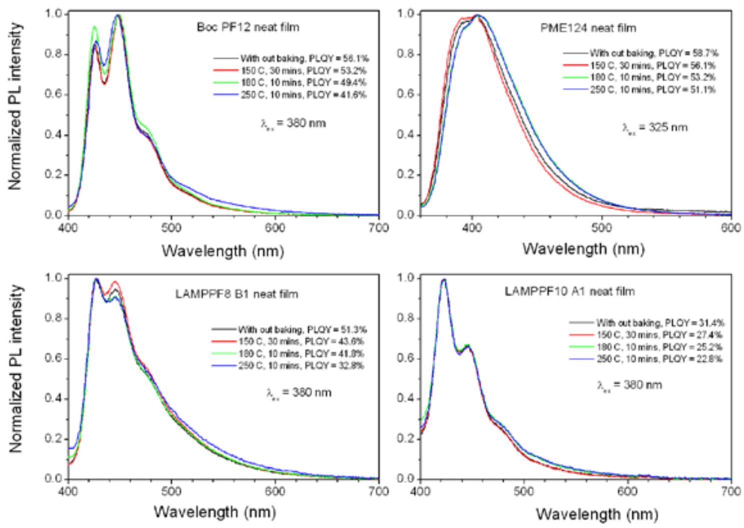


Figure 1.3.2.5: *Fluorescence emission spectra of four LAMP polymers showing a good thermal stability.*

Precursor polymer blend

The second stage of the materials selection included the optical and structural study of the precursor/polymer blend in film state under thermal treatment to observe the formation of the nanocomposite. In figure 1.2.3.6 is reported a typical structural study of the blend film to investigate the presence and distribution of the QDs inside the film.

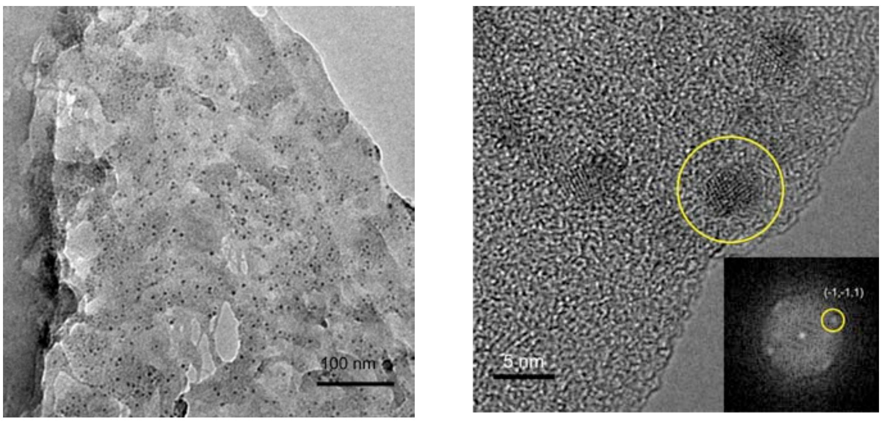


Figure 1.3.2.6: *At low resolution (left) the P6/PR01 film presents CdS QDs included in a polymeric matrix. At higher resolution (right), the presence of CdS QDs with an average size of 5 nm is reported.*

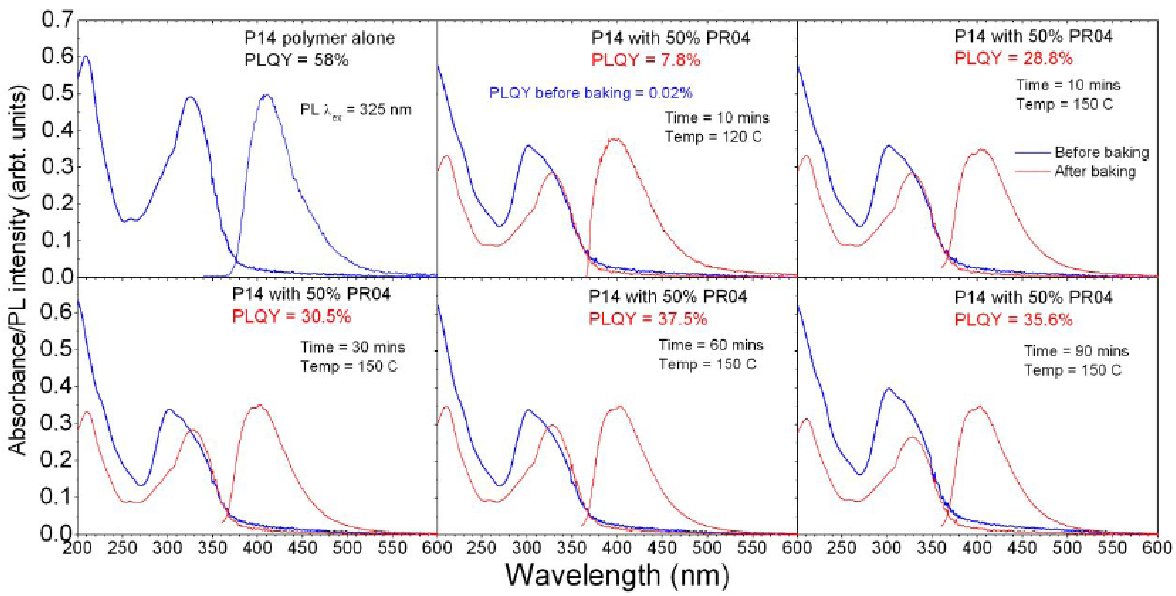
During the three years of the project several polymers and precursors were synthesised and a large number of blend combinations were studied. The photophysical analysis of all the blends that can be generated by the combinations of both polymers and precursors indicated two interesting blends for initial laser treatment: P14/PR04 and a PPy/PR06. A brief description of their optical properties is reported in the next section.

P14/PR04 blend

The P14/PR04 blend shows interesting behaviour. In neat films the polymer P14 alone has PLQY 58% with absorbance peak at 325 nm and PL peak 405 nm. When the polymer is blended with precursor PR04, before baking the film absorbance has peak at 305 nm corresponding to the absorbance peak of the precursor PR04 with shoulder at 325 nm so there is signature of both precursor and polymer. The PLQY of the blended films before baking is less than 0.2%, the precursor completely quenches the polymer emission. After baking the films at different temperatures at different times the PLQY starts increasing with PLQY maximum 37.5%, the PLQY values are indicated in the figures 1.3.2.7 a and b.

This is an important result: the heating leads to PL and so these samples should be suitable for laser patterning even if the PL is not due to QDs.

A



B

Figure 1.3.2.7: *a) Absorption and PL spectra before (blue) and after (red) the annealing.*

b) histogram of the PLQY as a function of annealing conditions.

Laser treatment

Laser treatment of P14/PR04

When the P14/PR04 blend was studied, the film was not fluorescent in the regions not irradiated by the laser source as predicted by the photophysical study reported above. Only for some combinations of the laser power and pulse numbers, it was possible to observe the fluorescence without the film disruption. Three large-area samples were analysed in more detail by means of PL microscopy and other optical techniques. The visual image of the laser treated samples (figure 1.2.3.8) shows clearly the formation of the yellow coloured areas typical of CdS material. Intensity of the yellow colouring increased with the used laser power.

The laser treated samples under the fluorescence microscope (figure 1.2.3.8 1-2-3) display the fluorescence that was further examined by means of absorption and PL spectroscopy. The three samples show different level of fluorescence. The high intensity in the central part of the Gaussian beam destroyed the film fluorescence as linear structures of the scanned area become more evident (inset # 3 in figure 1.2.3.8).

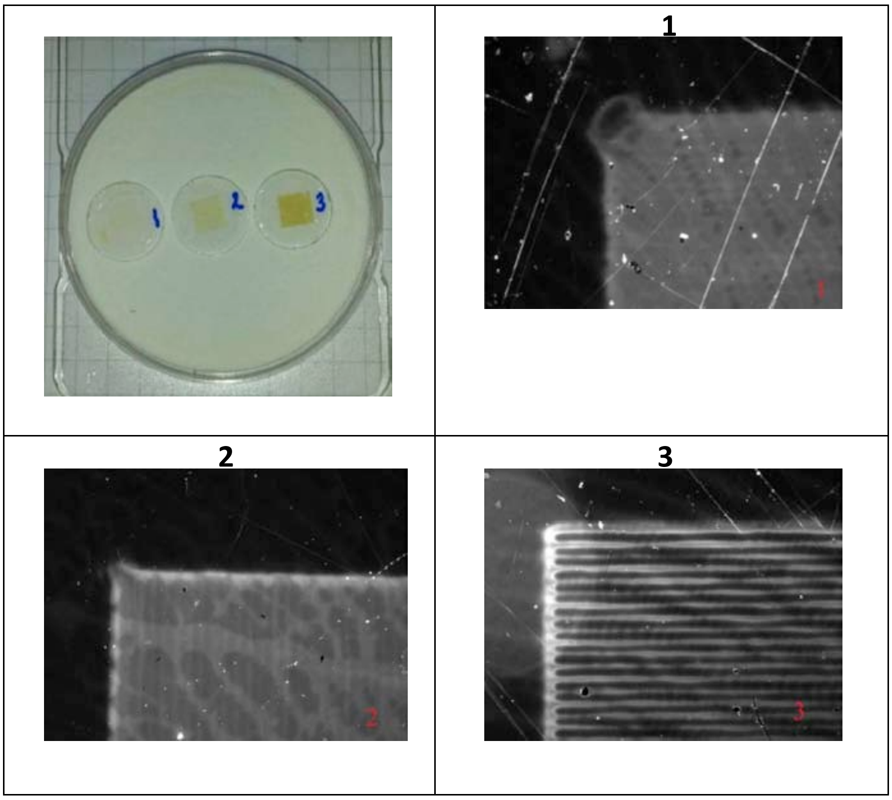


Figure 1.2.3.8: *Optical and PL images of the laser treated blend P14/PR04. The three samples (1, 2 and 3) are treated with different mean laser powers.*

The same blend has been treated with a different laser system using the Nd:YAG laser at 355 nm (Avia laser system).

Film laser treatment at LP = 1 mW shows that when the neat polymer P14 is treated its fluorescence is quenched at both, faster and slower scan speed (the bold black lines are marks on the films) (figure 1.2.3.9).

DLP of the precursor alone does not reveal any fluorescence at all.

As forecasted from photo-physical analysis the combination of polymer and precursor, P14/PR04, reveals that only in the regions irradiated by the laser the PL signal is restored. Moreover, one can see a difference between the two images at different laser scan speeds. When the speed is high the PL seems more intense while when the speed is low it appears in a rather yellow color.

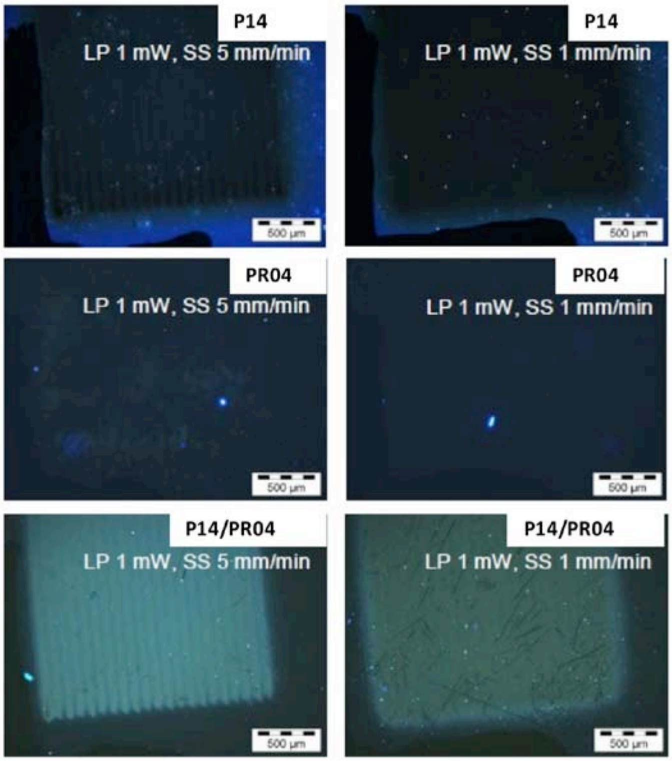


Figure 1.2.3.9: *fluorescence images of the P14 and PR04 both alone and mixed when treated with the Avia laser system.*

OLED/Ts Fabrication

The work done in material synthesis and laser patterning enable their application on direct laser writing on OLEDs and OLETs platforms.

The OLEDs

The procedure followed for the laser patterned OLED has been: first, the realisation of the OLED with the polymers and precursors produced by the consortium then the implementation of the laser patterning on this platform.

The OLED structure proposed by CRF is reported in figure 1.2.3.10 and showed the formation of two couples of pixels (larger and smaller).

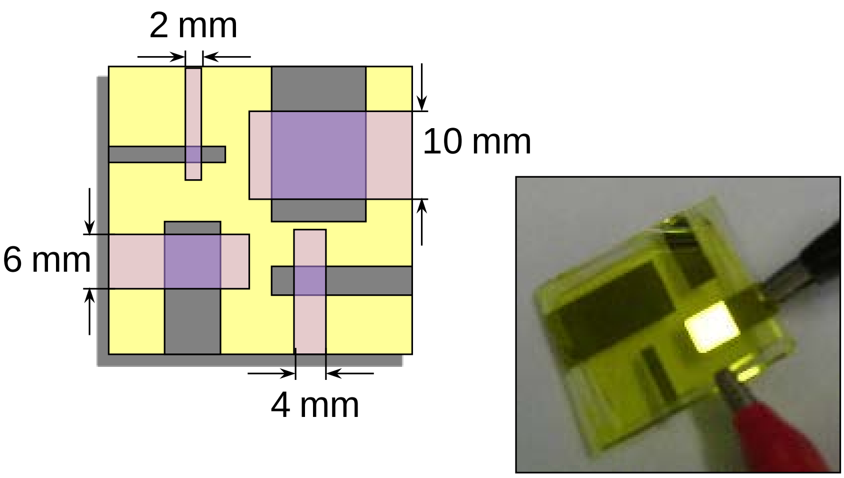


Figure 1.2.3.10: Structure of the OLED realsied by CRF. CRF processed manufacture four pixels of different size. It is possible to switch on/off separately each device.

The initial signal identified for the laser patterning is the emergency light signal in a car cockpit as reported in figure 1.2.3.11.

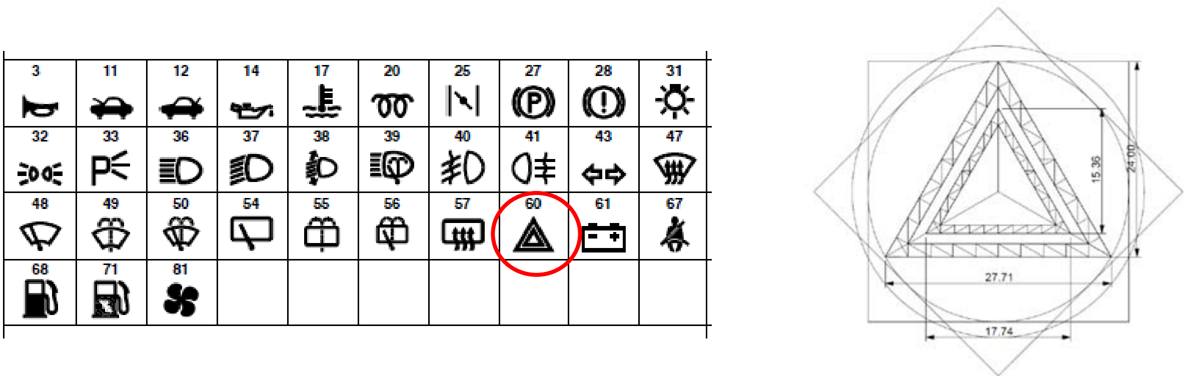


Figure 1.2.3.11: *The polymer is deposited onto ITO patterned substrates. Finally a metal film is deposited as cathode on top of the structure by thermal evaporation in ultra-high vacuum*

The figure 1.2.3.12 displays the first OLED realised with a polyfluorene polymer produced by BUW.

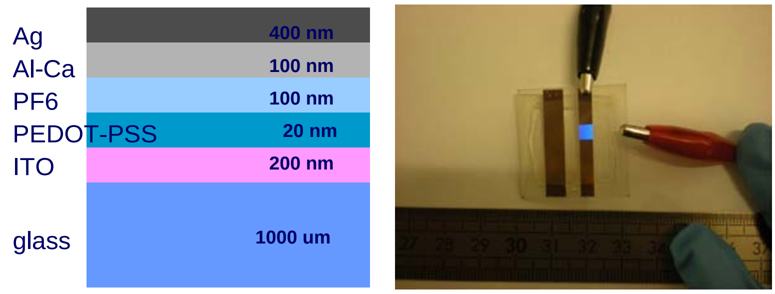


Figure 1.2.3.12: *On the left is reported the layer structure of the OLED. On the right the first OLED realised with one of the LAMP polymers.*

The next step has been the manufacturing of the OLED with the blend P14/PR04. The photophysical behaviour of this blend has shown that in combination with PR04 the polymer is quenched, but after the formation of the QDs the PL of the polymer is restored. This effect is clearly shown in figure 1.2.3.13 A and B. The three dark quartz plates become luminescent only after their thermal annealing. The OLED manufactured with the blend is working only after the thermal annealing (figure 1.2.3.13 C).

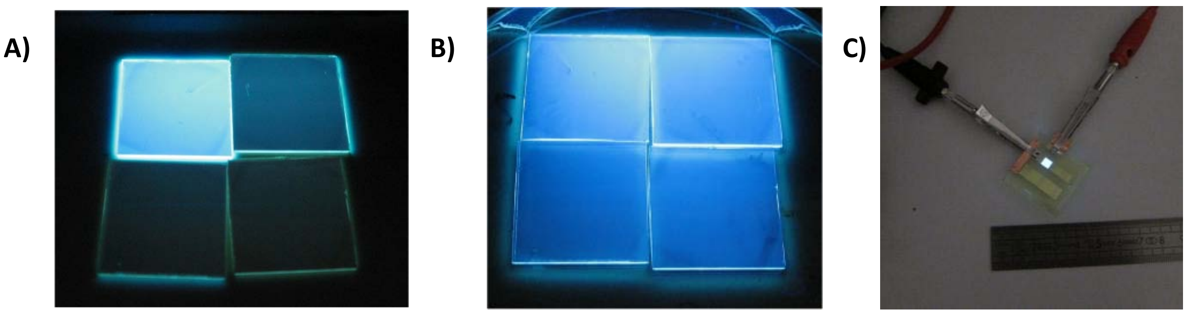


Figure 1.2.3.13: *The blend is deposited on a quartz glass with different PR04 concentration. The film containing PR04 before the annealing are dark (A); after thermal annealing the PL of the polymer is restored (B); In C is reported the working OLED realised with this blend after*

The next laser treatment has been carried out on an OLED realised by Joanneum Research and characterised by CRF. The laser patterned OLED was realised combining a standard polymer with PR04. The standard polymer showed a similar effect displayed by the P14/PR04 blend. In the first laser prototype reported in figure 1.2.3.14 the laser action is indicated by the sharp definition of the patterned and un-patterned area (sharp line in the inset of figure 1.2.3.14).

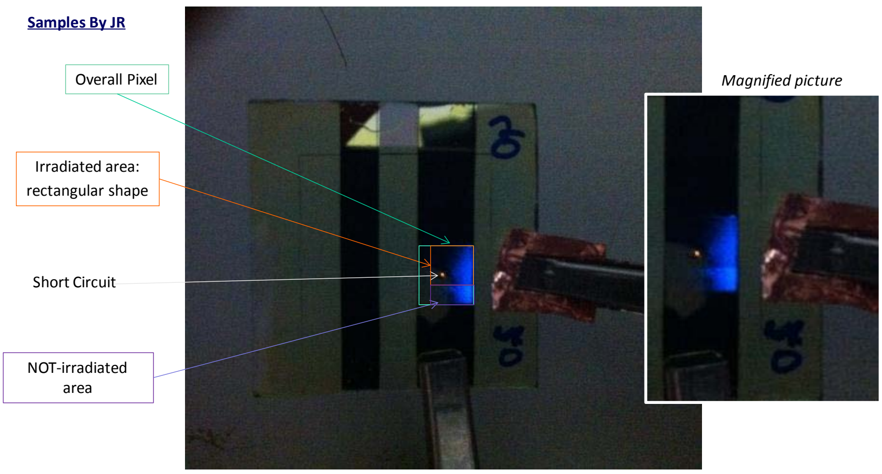


Figure 1.2.3.14: *The laser action is highlighted by the sharp line visible in the inset. Some short circuit is also observable in the first prototype.*

OLET Manufacturing

The implementation of OLET device has been carried out in two main stages: i) optimisation of the OLET architecture (position of the contacts and dielectric material) and ii) implementation of the laser patterning technique to the new system.

Two different OLET architectures have been used in device realization: bottom-gate and bottom-contact (BG-BC, Figure 1.2.3.15a) and bottom-gate and top-contact (BG-TC, Figure 1.2.3.15b). In particular, complex fabrication processes as beam-lithography and chemical etching processes are optimized at CNR for realizing substrates with devices presenting different channel lengths and widths.

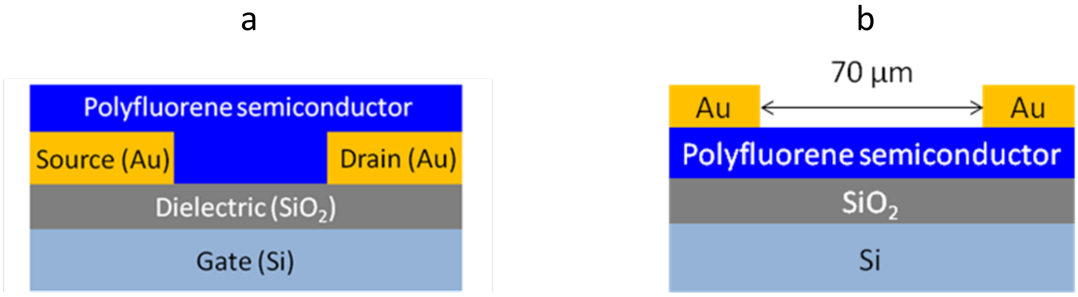


Figure 1.2.3.15: *Sketches of different OLET architectures implemented (a) bottom-gate/bottom-contact (BG-BC) and (b) bottom-gate/top-contact.*

Moreover, we implemented Si/SiO_2 as an inorganic substrate/dielectric platform in order to avoid possible fabrication issues related to the incomplete solvent orthogonality between dielectric and polymeric layers. The experimental activity revealed that the most performing device architecture with polyfluorene semiconductors is bottom-gate and top-contact. Moreover, the F8BT polymer was revealed to be much more effective in field-effect charge transport with respect to other polymers suitable for OLEDs. So F8BT coupled with PR06 has been the preferred combination. The photophysical and structural properties of the blend F8BT/PR06 LAMP precursor has been studied to discriminate the formation of the emissive quantum dots. This study demonstrates that CdSe quantum dots are formed in the blend after proper annealing process.

The laser patterning has then been carried out on the top contact bottom gate architecture and in figure 1.2.3.16 is illustrated the patterning process. Every chip is composed by four different devices so that different patterning geometry and conditions can be implemented on different devices using the same active layer.

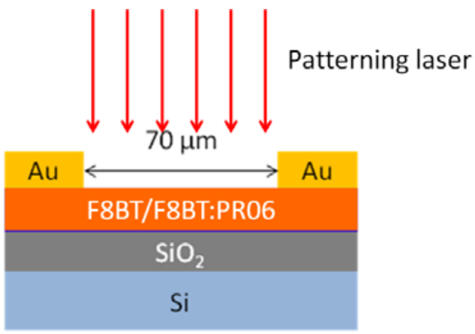
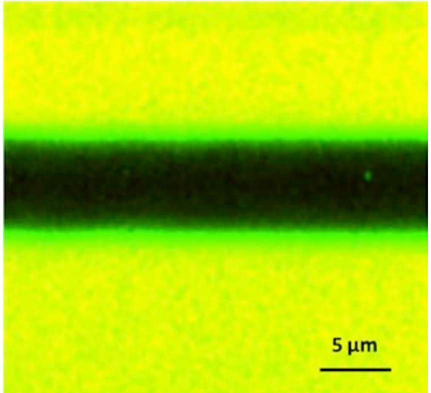


Figure 1.2.3.16. *Sketch of the pattering geometry used for fabricating patterned QD-LETs. Indeed the Ekspla impinging laser is scanned in the device channel area across the source and drain electrodes.*

In Figure 1.2.3.17 the confocal laser scanning microscope (CLSM) characterization of the active channel is shown of an F8BT-based OLET where laser patterning is performed.

Figure 1.2.3.17 *CLSM image of zoomed area within the device channel where direct laser patterning is performed. The color scale is modified in order to enhance the emission from the patterned region. Excitation wavelength 488 nm, objective 60x oil, dichroic mirror 497 lp*



At higher magnification (Figure 1.2.3.17) it is possible to observe that the fluorescent material is present in the laser-scanned area. Indeed, the morphology of the film is connected and homogeneous as in the device channel region where no laser action was performed. Though, a clear determination of the color of the emission quantum dots enriched area is not straightforward with CLSM.

The photophysical analysis of the patterned region reported in figure 1.2.3.18 revealed that the PL spectrum of the blend in the laser patterned region is instead shifted towards higher wavelengths and broadened in the profile with respect to the corresponding sample without laser pattering. Moreover, the difference in intensity between the two spectra is less pronounced with respect to the F8BT-alone.

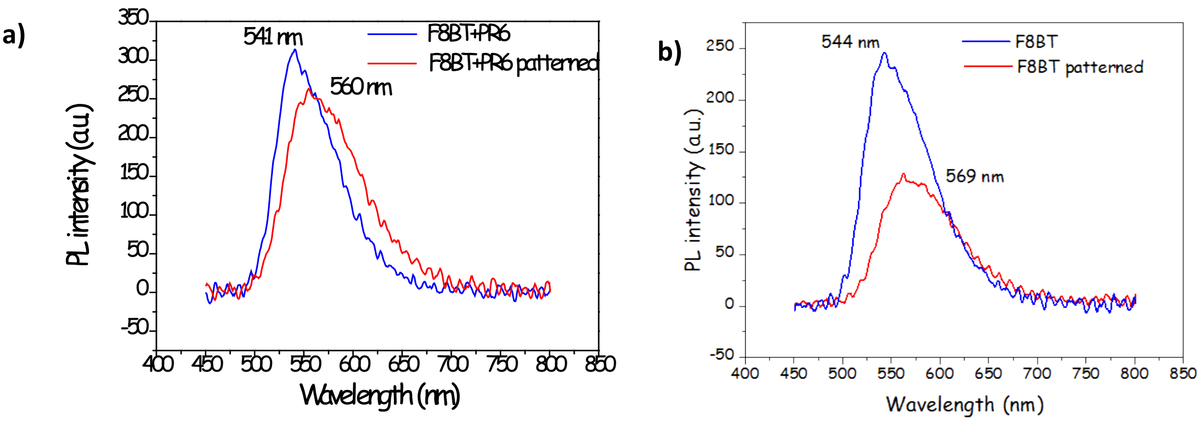


Figure 1.2.3.18 *Fluorescence spectra of the active layers within the channel region in OLETs. The measurements are performed in as-deposited (blue line) and in the patterned (red line) regions. A comparison between F8BT-alone (a) and the F8BT-PR06 (b) blend is reported.*

The characterization highlights that the laser action has enhanced the QDs formation in the polymeric matrix because a broad and red-shifted emission is expected when the emissive QDs are present in the blend given that CdSe QDs emits around 650 nm.

Thus, we have fully demonstrated the feasibility of the LAMP protocol in realizing QD-LET by implementing direct laser patterning.

Conclusions

In conclusion we have successfully developed a methodology for direct laser patterning of nanocomposite films of polymer/semiconductors and OLED/T devices which was the key goal of this project. To achieve this milestone we have synthesised several thermally stable luminescent polymers and highly soluble organometallic precursors. Furthermore we have developed methods to prepare organometallic precursors to mix with polymers in common organic solvents to achieve high quality solid-state films of nanocomposites. Photophysical properties have played key role in selecting the appropriate materials having the correct energy levels of polymer and precursors.

We have shown that two blends (P14/PR04 and PPy/PR06) were most suitable for laser patterning and OLED manufacturing, along with one blend of (F8BT/PR06) suitable for laser patterning and OLET manufacturing.

Laser patterned OLED devices were realised with two main strategies using Blue Merck/PR04 blend while laser patterned OLETs were realised with the F8BT/PR06 blend.

The project development, considered from the point of view of the OLED manufacturing, is illustrated in figure 1.2.3.19.

A similar evolution has been done for materials, photophysical characterisation and laser patterning.

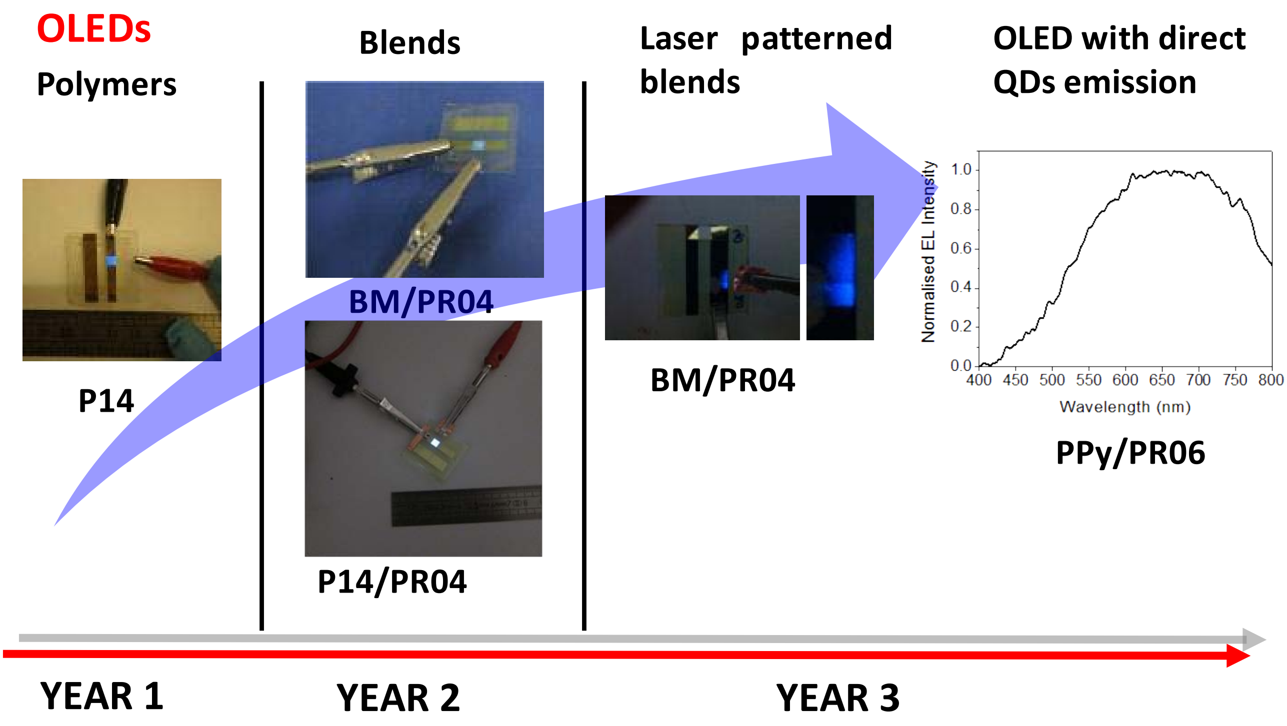


Figure 1.2.3.19: *Temporal evolution of the device realisation by using LAMP technology*

1.4 Potential impact

The LAMP project produced an OLED/T device realised with laser processing (no photo-lithographic and evaporation methods).

The significant output of the project helped in:

a) controlled materials manipulation. In particular polymer and QDs can be used for OLED/T manufacturing only if their chemical-physical properties are correctly arranged;

b) localised laser structuring of a nanocomposite starting from a polymer/precursor mixture is possible with different laser systems. A demonstrator of laser machine has been prepared by Ekspla to manufacture OLED;

These exploitation items have an impact on different areas: impact on the topic of the project (car and general lighting), impact on industry and societal implication on EU citizens.

1.4.1 Impact on car and general lighting

The strategic impact of the proposed device operating at a low DC voltage and characterised by a simple method of production and with the performances of the nanocomposite materials is of huge proportion in the automotive context. In fact the number of cars equipped with high information displays is growing fast and moreover the information content is booming (telecommunication and navigation, entertainment and infotainment, etc.). The increase of information to be displayed calls for displays with higher resolution/better performances of display, convergence of information into multi-functional displays. LAMP project introducing the combination of organic/inorganic materials grown directly within the polymeric matrix, moves toward the improvement of lifetime stability and higher efficiency. In addition the introduction of a new strategy of patterning contributes to decreases in the price of the info-panel with respect to the use of photolithography (see next paragraph).

1.4.2 Impact on Industry (manufacturing of OLED/Ts)

The laser processing technologies production, followed within LAMP is expected to be one of the most promising techniques for novel nanomaterials manufacture. Micro-manufacturing is now a key value-adding element for many sectors of industry – and the predicted nanotechnology future will also be largely delivered by micro-technologies. LAMP is focused on the development of novel method of synthesis of polymer nanocomposites addressing large consumer-markets: automotive, lighting and information displays. The development of this new synthetic strategy joined the use of laser technology and the performances of polymer nanocomposites to realise optically active devices. This method of production is a real step ahead for industry because it applies laser technology, a well established technological platform in industry, and nanocomposite new materials, considered one of the most promising solutions for an optimal incorporation into new products of the light emitting devices (LED/LETs).

The flexibility of the laser direct writing techniques opens easy control and variability in product design. Laser producers, laser system integrators and industries involved in R&D will gain advantages from laser patterning for electronics, but also in information-technology, biomedicine, energy, catalysis, biomedicine, pharmaceuticals and speciality-chemicals materials applications.

The existing laser institutes, the application centres and the industries providing solutions for material processing. For example in Eastern Europe, there are only a few institutes which are capable of transferring knowledge of laser material processing to local companies.

Potential applications are logos and information as equipment condition of passenger seat belt reminders (PSBR, Figure 1.4.2.1) which warn the driver when any of passenger does not wear the seat belt is confirmed as well as working requirements for such equipment (reminding timing, reminding duration, reminding type, display position, etc.). The simplicity of the message allows application of cockpit-LEDs today and OLED within 3-5 years.

***Figure 1.4.2.1**: Potential application of LAMP manufactured technologies*

Thanks to the developed laser beam technology and novel LED/LET construction European display end-user industries could differentiate their products more and more. The project will then:

1. Assures employment in the high-tech contexts of info panel and novel solid state light sources actually dominated by ASIA and USA with very minor European production;
2. Contributes to the technological and basic know-how in Nanotechnology addressed by the European Union as a key problem to originate a knowledge-based society;
3. Contributes to simplify and to improve, in term of costs, the OLED/T manufacturing.

1.4.3. Impact on EU citizens education

The LAMP project contributes in terms of education to science and new lighting systems of young people and citizens. During several LAMP presentations young people and citizens in general become involved in the comprehension of the new OLED technology and the benefits of the solid state lighting for energy saving.

The people met during public conferences or road shows asked more information about nanotechnology and often for the first time they learnt how this new branch of technology can have novel benefits and improve the world.

1.5 Project Exploitation

OLED/Ts manufacturing

LAMP produced at least two main "tools" to open the way for OLED/Ts manufactured by lasers:

i) the correct material manipulation (interaction between the organic and inorganic) and

ii) the laser patterning of the devices.

The exploitation on materials has been suggested by the photo-physical study of the film blend of the polymer and the precursors (QDs). Toward this direction a strong effort in polymer and precursors synthesis has been carried out. As a consequence of this effort a particular synthesis of QDs in the film has been exploited and patented. This correct material combination paved the way to realise OLED/Ts prototype with promising performances.

The realised OLED/Ts devices, even if both of them are not ready for the commercialisation, CRF and CNR evaluated the costs of the device production comparing the laser patterning technology with photolithography. A flowchart describing the existing and expected manufacturing chain is showed below (figure 1.5.1). Considering this layout, LAMP proposes to include the laser treatment for the QD formation in the few production chain points depending on used materials and final device structure. The flow intends to get a clear overview of the main manufacturing steps in order to develop the targeted devices.

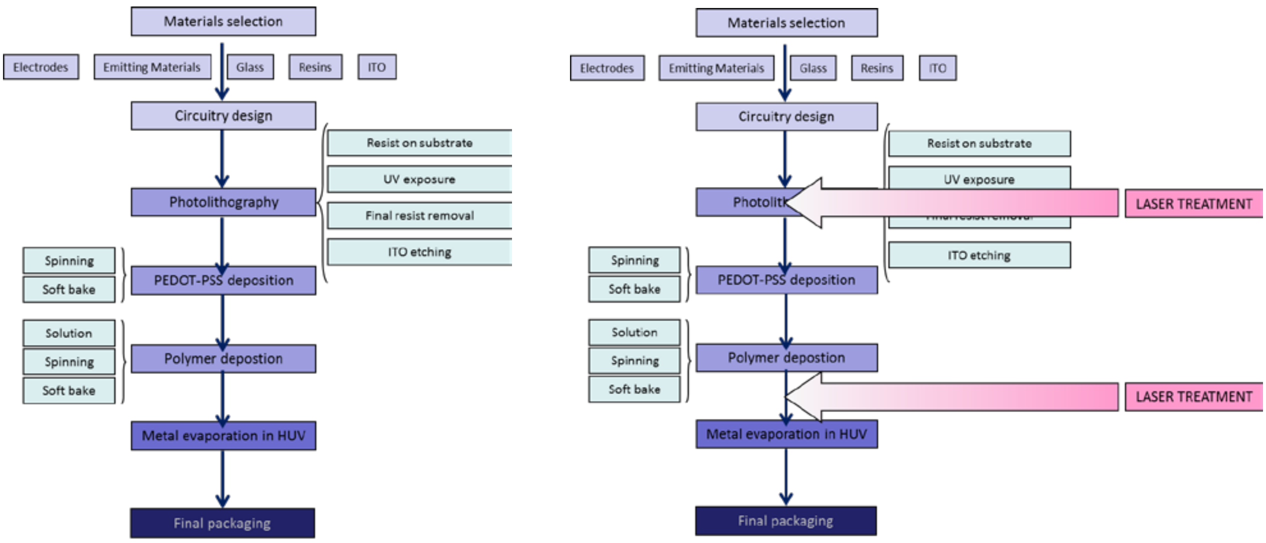


***Figure 1.5.1**: i)left: current OLED manufacturing chain; ii)right: new production process chart*

The introduction of the laser treatment is expected in two phases.

1. Before the emitting polymer/precursor deposition intending to substitute the photolithography process. In this case a great economic saving occur due to the removal of several manufacturing phases (resins deposition, UV exposure, chemical etching, curing).
2. After the emitting polymer/precursor deposition, to allow the establishment of emitting QDs within the layered structure.

Consequently significant advantages in time reduction, costs and materials safety are expected with the success of the LAMP project.

The OLED as expected and developed in LAMP, is cheaper than a standard one in overall production costs. Considering a simple ration between standard (considered as 100%) and LAMP device, **production cost is reduced of approximately 12%** especially due to the safety of the photolithography process. Additionally, a reduction in the manufacturing time could occur in LAMP devices.

Finally, it is expected that further development of OLET technology in next 5 years will further reduced the cost of the entire LAMP device fabrication given that the OLET platform is intrinsically more efficient in light-emission and structurally less complicated that OLED platform.

Cost Table

	Traditional OLED	LAMP OLED	LAMP OLET
Costs	100 %	87.5 %	90.7 %

Laser patterning machine

Within the LAMP project several materials were acquired/synthesised and used for laser patterning. In particular different commercial organic molecules, metal-organic precursors and their blends with very different chemical-physical characteristics where irradiated by the laser. Each one of these materials and their blends needs of a specific laser regime in order to form QDS without destroying the polymer and the device. The machine is therefore built to be very flexible depending of the material characteristics. On the basis of the results obtained in the project Ekspla built a laser machine prototype including the laser, the positioning system, optics and chamber for patterning under controlled atmosphere.

This demonstrator is intended to combine experience in polymer-precursor modification by laser irradiation with requirements for QD-LED to produce display devices and QD-LET structures with laser generated localized clusters of semiconducting quantum dots. The system includes a specialized laser source, beam positioning and a controllable environment for the samples during the patterning process. Some limitations remain due to the variability of the material combinations for OLED and OLET applications. However, the system parameters can be easily adopted in the LAMP laser demonstrator. One of the characteristics of the machine is its flexibility because new materials can stem from the research and the equipment has to be easy to modify to take into account the new working conditions.

In particular the compatibility with the roll to-roll technology and, in general, with the flexible substrates is taken into consideration;

Reference market for the demonstrator

The market for laser systems using LAMP technology or similar approaches in laser modification of organic-inorganic composite materials is first of all in the electronics industry with application in automotive and consumer markets.

First of all, as CRF is a partner, the LAMP technology will be pushed to the supplier chain of Fiat group to be used in light emitting signs for cars, as was foreseen in the project.

In addition, EKSPLA and its affiliate the laser system manufacturing company ELAS have global network of distributors, which will be used to spread information on the LAMP technology on QD formation and complementary application of laser technologies for modification composite materials.

2 Use and dissemination of foreground

2.1 Dissemination actions (section A public)

The use and dissemination of the foreground followed the initial plan established at the beginning of the project. Three main specifications where identified by the partners for the use and dissemination of the foreground:

1. definition of **dissemination standards** (project logo, document templates, general structure of the website);
2. definition of the content to be disseminated (**Quality assurance**). In this case the disseminated information are shared before between the partners. The Managing Board decided the type of action to be pursued and the content to be published;
3. in case of foreground with potential industrial application (**management of intellectual properties**) the Managing Board prepared a Consortium Agreement on the basis of the non-binding guidelines published by the Commission (DESCA simplified FP7 model).

The dissemination work is presented in the following tables divided in three main actions:

i) dissemination to scientific world;

ii) dissemination to industry;

iii) dissemination to general public.

Each one of these dissemination actions has its specific media. In general the scientific communication has been done through the publication on scientific journals and/or attending at scientific meetings (oral presentation or posters at conferences).

The communication toward industry has been done preferentially thorough focused meeting either public or restricted.

The general public activities were mainly carried out through press release, movies, open meetings in the labs or “road shows”. For specific and important events (LAMP workshop or presentation of the LAMP team) two movies were realised by the staff of ENEA-Web TV.

The project web site summarised all the activities in specific pages as illustrated in the next section.

2.2 Project web site

The LAMP web site was directly updated by the project coordinator and its structure has been realized by means of Plone platform. The Plone structure is essential from the point of view of graphics, however the less impact of graphics is balanced by the "easy to handle" procedures to up to date the site with new contents. This makes it possible a constant and rapid access by the project coordinator to make the desired changes.

The classical website menu including Home, Consortium, News, Events, Contact and Links was enriched with a new section called "educational" reporting an accessible explanation of the meaning of the terms and technologies used within the project (figure 2.2.1). This section should help a general interested reader on the main techniques and concepts used in the LAMP project.

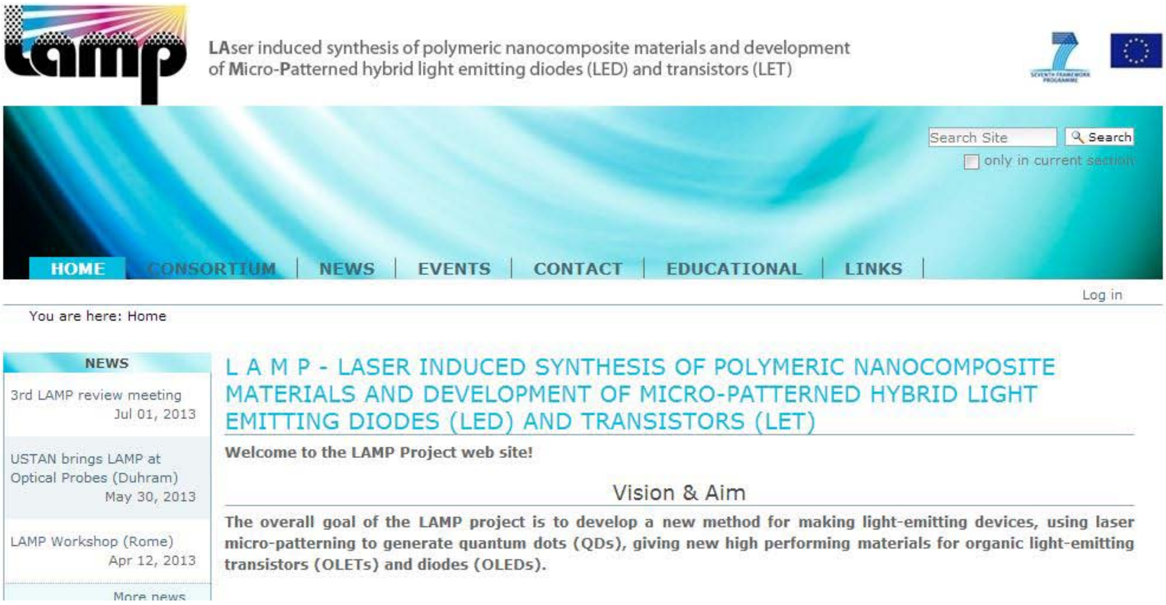


Figure 2.2.1. Main structure of the LAMP web site.

Year by year the web site was monitored with Google statistics to observe the traffic on the web site. This survey illustrated that the number of visit in increased year by year even if the page visited and the average time is decreased (table 2.2.1).

Table 2.2.1 Site usage (total)

Time	Visits	Pages/Visit	Avg. Time on Site	% New Visits	Bounce rate (%)
1st year	930	4.96	00:03:01	45.91	50.97
2nd year	1776	5.04	00:02:58	67.23	58.00
3rd year	2307	2.91	00:01:38	80.67	67.58

The analysis of the most actives countries in visiting the web site, reported in the table 2.2.2, showed that the, except Italy, are India US and Germany. A deeper investigation on the most visited pages revealed that the educational and the consortium pages are the more interesting for the visitors. The events and news sections are also found interesting by the visitors.

Table 2.2.2 Site usage: the first ten results

Country	Visits	Pages/Visit	Avg. Time on Site	New Visits (%)	Bounce Rate (%)
Italy	748	4,14	00:02:25	63,37%	54,95%
India	236	1,48	00:00:37	93,64%	77,97%
United States	228	1,25	00:00:10	86,40%	89,91%
Germany	107	2,48	00:01:30	88,79%	67,29%
Austria	99	11,62	00:07:58	75,76%	27,27%
UK	95	2,72	00:01:15	91,58%	67,37%
South Korea	64	1,28	00:00:19	89,06%	89,06%
China	52	1,79	00:01:05	88,46%	63,46%
Lithuania	52	2,00	00:01:53	75,00%	63,46%
Spain	40	2,15	00:00:50	87,50%	70,00%