# Organic Light Emitting Diodes, OLEDs. Activities in the ENEA Laboratory of Nanomaterials and Devices

Lighting has a central role in human activities and is being recognized its importance for the health and wellbeing of human beings. Therefore, efficient light sources are mandatory for their effective use in everyday life and to reduce the electrical energy that lighting uses nowadays. The OLEDs can be one of the key responses to this demand because of their peculiar properties. ENEA NANO Laboratory is actively working on this technology, collaborating with companies to bring it to the market

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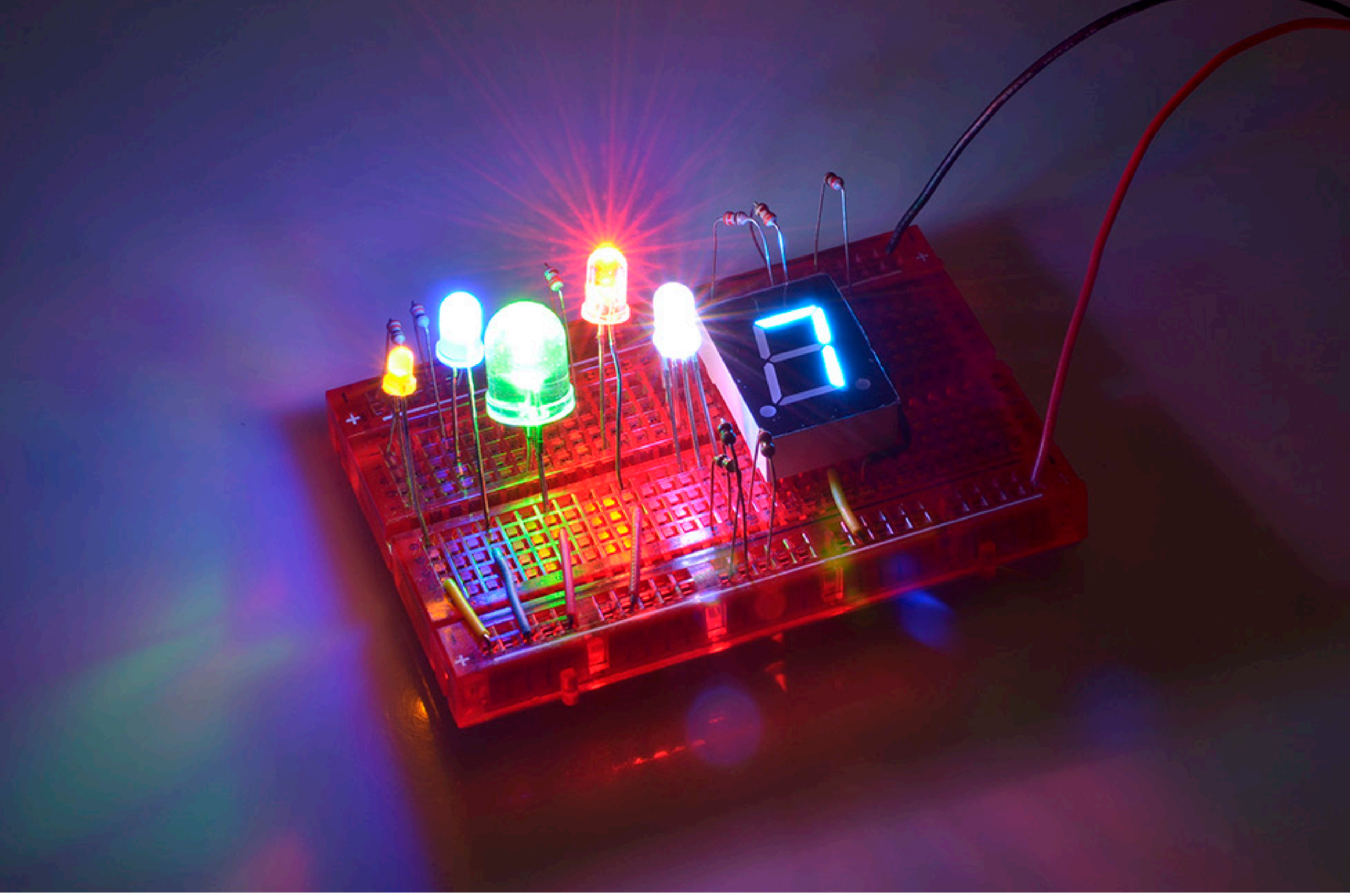
*by* **Maria Grazia Maglione**, **Paolo Tassini**, **Claudia Diletto** *and* **Carla Minarini**, *ENEA*

Large area, non-glare and relaxing light sources for our houses and working places. Thin, light and efficient photovoltaics cells for the building facades. Pervasive but non-invasive sensors for health, wellbeing and the environment. Flexible, long-lasting batteries. Cheap and sustainable fabrication processes with high yield and large throughput.
All of this is now possible thanks to a totally new technology, which uses organic materials and new approaches for the devices fabrication: it is the Organic and Printed Electronics (OE).

## Organic and Printed Electronic

We can think it all started just 30 years ago, in 1987, when Tang and VanSlyke of KODAK company published their seminal work about a new efficient type of electroluminescent devices made by using organic materials, the OLEDs, organic light emitting diodes [1]: they demonstrated how it was possible to exploit “plastics” as active materials for electronic devices. From then, several hundreds of thousands of scientific papers have been published and continue to be published[1] by many research groups all over the world, and lots of companies are born to bring to the market new materials, new devices, new processes, new systems and new products that will be used



in every aspect of society and industry into few years [2]. Lighting, ICT, automotive and means of transportation, white goods and domotics, agri-food, biomedicine, environmental monitoring, logistics, Internet of Things, etc. are a few examples of the applications of the OE.

### OLEDs, the human friendly new light source

OLEDs are made of extremely thin films of organic materials sandwiched between two contacts, named anode and cathode, respectively. Excluding the substrate on which an OLED is fabricated, the total thickness of a device is far less than one micrometre. When an electrical current flows through a device, electrons are injected into the device from the cathode and holes from the anode. These charges drift through the organic films until they arrive at a specific interface or in a specific layer, the emitting layer (EML), where they recombine generating light. The electronic properties of the EML determine the colour of the light. Apart the substrate, at least one of the two contacts, usually the anode, is transparent, so the generated light can exit the device (Figure 1). To improve the performances, research has developed devices architectures of several layers and added structures to perform different functions and generate more light and colours, increase efficacy, and extend lifetime.

The first application of OLEDs has been in flat displays: with respect to the liquid crystal displays (LCDs), OLED displays don't need backlighting, neither polarizers nor colour filters and liquid crystal cells, because an OLED pixel is a light source that can be directly driven to form the desired images. So, OLED displays can be made thinner, lighter, more efficient, faster, and have more vibrant colours and a wider angle of vision than LCDs[2]. Moreover, OLED displays fabrication processes can be simple and cheap, using low environmental impact materials, and can be prepared on flexible substrates like plastic and metal foils. In these days, OLED displays are used in many models of mobile phones, and large TV sets are presented by various companies [3].

The second application of OLEDs is for lighting: large area light sources, mainly for interiors. The

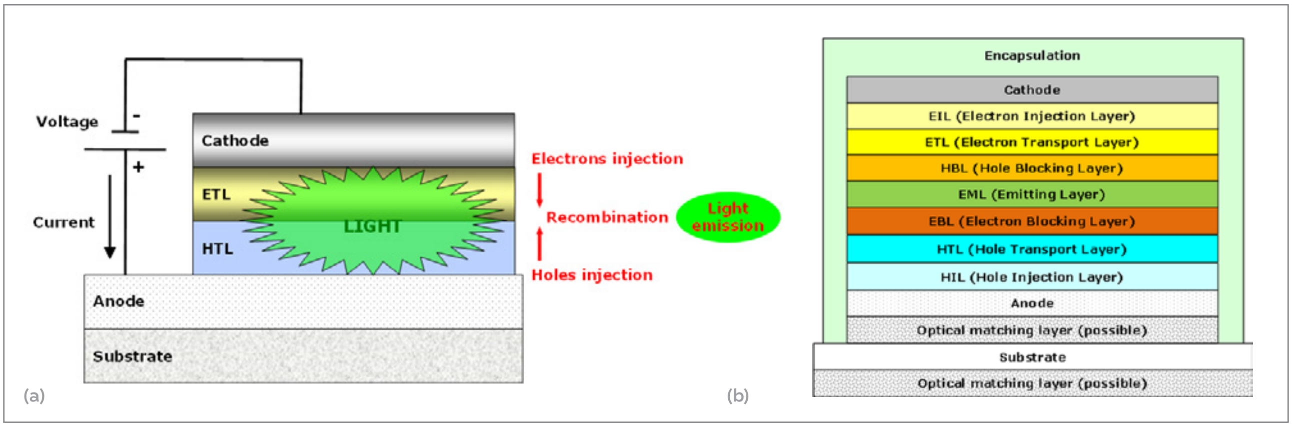



**Fig. 1** (a) Basic OLED structure and working mechanism: usually the electron transport layer is also the emitting layer. (b) Example of OLED structure aimed at increasing the performances

devices of these lamps have the same advantages listed for the OLED displays, with the addiction of the potentiality to obtain emitting surfaces in the range of the square metres, and not using poisonous materials like mercury. OLED sources can be prepared of every shapes and geometries, and this possibility is further increased using flexible and foldable substrates (Figure 2). Then, the light emitted by the OLED sources can be of every colour and hues, the intensity easily adjusted, and the large area of the devices generates a non-glare light, so they can be tailored and fitted to be best used in architectural outfitting and interior design, with brightness and colour ideal for the human well-being, making OLEDs an important element for the diffusion of the so called Human Centric Lighting [3]. For the fabrication, the printing processes on continuous stripes are actively studied, similar to the ones of the publishing industry, to succeed in preparing large active surfaces at high pace on flexible substrates.

## ENEA SSPT-PROMAS-NANO Laboratory

It's now well over ten years that ENEA Laboratory of Nanomaterials and Devices (SSPT-PROMAS-NANO), in the ENEA Research Centre Portici, has studied organic devices, their processing and applications. NANO is organized as a full lab-scale processing line for simulation, design, fabrication and test of materials, devices and systems for organic and printed electronics. Research themes cover OLEDs (organic light emitting diodes), OPV (organic photovoltaics), transistors and RFIDs (radio frequency identification devices), sensors, materials, processes for layers deposition and patterning, as well as the recovery and reuse of valuable materials at the end-of-life of the devices, and the applications of this technology.
In particular, activities on OLEDs are focused on: the improvement of the devices performances and efficiency, using strongly emitting materials, and applying innovative devices architectures; the increase in the active area with good uniformity of the generated light; the study of materials with a reduced use of critical raw

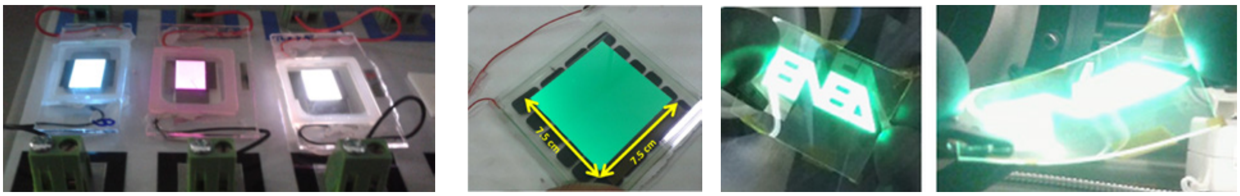



**Fig. 2** ENEA NANO OLEDs: (a) on glass, area 1 cm$^2$ and about 55 cm$^2$; (b) on plastic

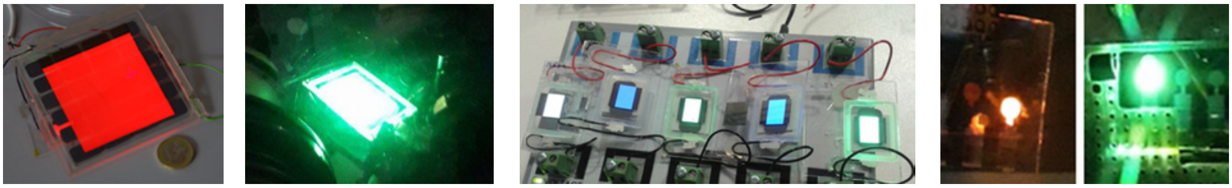


Fig. 3 Other ENEA NANO OLEDs of various shapes, dimensions and colours

materials, mainly for the anode; the use of effective and sustainable processes, like ultra-high vacuum deposition techniques, deposition from solution and printing; the increase of the devices lifetime, studying the degradation mechanisms of their materials to prevent them, applying an ENEA NANO patented encapsulation layout, and studying new barrier materials to seal the devices prepared on both rigid and flexible substrates; the study of innovative bio-based and bio-compatible materials; and to obtain useful devices characteristics for energy efficient applications in human centric lighting, in the biomedical sector, etc..

ENEA NANO can fabricate and characterize OLED light sources emitting at any wavelengths of the visible spectrum, with various geometries and dimensions (ranging from a few square millimetres up to tens of square centimetres), both on flexible and rigid substrates. Moreover, OLEDs are studied having a broad emission spectrum to achieve an overall white emission of different colour temperatures (warm or cold white). These sources have a lifetime of several thousands of hours, a low turn on voltage and reach a luminance above 50000 cd/m$^2$ at 10 V (Figure 2, Figure 3).

The ENEA NANO competence covers a wide range of topics:

- thin-film deposition of organic and inorganic materials through high vacuum techniques and from solution (thermal evaporation,

sputtering, spin-coating, printing);
- development of innovative organic and hybrid conductive transparent materials;
- structural, morphological, optical and electrical materials characterizations;
- design of devices architectures and layouts, and in-house preparation of photolithographic masks;
- devices fabrication and encapsulation;
- electrical and electro-optical characterizations of devices;
- devices lifetime improvement and ageing studies.

ENEA NANO leads or participates in several funded research projects studying OLEDs:

- Public Private Laboratory TRIPODE, for large area OLEDs and development of encapsulation methods;
- ALADIN Project, dealing with OLEDs for lighting systems and small smart signage systems;
- RELIGHT (Research For Light) Project for the improvement of OLEDs performances and lifetime, and their application in a diagnostic medical system.

ENEA NANO is member of international organizations like the Organic and Printed Electronics Association (OE-A) and of the Emerging Lighting, Electronics and Displays working group of the Photonics21 European technological platform. NANO also collaborates with different Italian companies working on lighting and encapsulation (Beghelli, Vimar, Electrolux, BTicino, Saes Getters, etc.), and universities.

*For further information,*
*please contact:*
*mariagrazia.maglione@enea.it*

[1] Over 3 million of matches can be found in Google Scholar, searching for "organic electronics"

[2] LCDs began to be produced several years before than OLED displays, so many improvements have been applied in their fabrication, increasing their performances and decreasing the market prices, that's why LCDs displays are now cheaper than OLED ones

[3] OLED displays are often indicated as AMOLED, for active matrix organic light emitting display, as they are made of specific electronic circuits (the active matrix), fabricated side-by-side each pixel, that generate the required levels of current to power on the OLED pixels at the desired light intensity and colour


**REFERENCES**

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