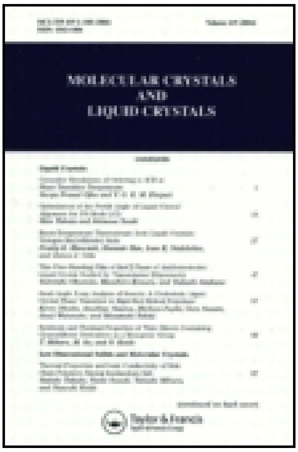


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Organic Electroluminescent Materials

Sofia Torgova [a c] & Alfredo Strigazzi [b c]

[a] FSUE SSC "NIOPIK", Organic Intermediates & Dyes Institute, B. Sadovaya 1/4, Moscow, 103787, Russia

[b] Dipartimento di Fisica, and Istituto Nazionale di Fisica della Materia (INFM), Politecnico di Torino, C. Duca degli Abruzzi 24, Torino, I-10129, Italy

[c] Joint Laboratory of Orientationally Ordered Media (OOM-Lab), C. Duca degli Abruzzi 24, Torino, I-10129, Italy

Version of record first published: 18 Oct 2010

To cite this article: Sofia Torgova & Alfredo Strigazzi (2002): Organic Electroluminescent Materials, Molecular Crystals and Liquid Crystals, 375:1, 61-72

To link to this article: http://dx.doi.org/10.1080/10587250210559

Mol. Cryst. Liq. Cryst., Vol. 375, pp. 61-72

1058-725X/02 $12.00 + .00

Organic Electroluminescent Materials

SOFIA TORGOVA[a,c] and ALFREDO STRIGAZZI[b,c]

[a]*FSUE SSC "NIOPIK" (Organic Intermediates & Dyes Institute) B. Sadovaya 1/4, Moscow 103787, Russia,*
[b]*Dipartimento di Fisica, and Istituto Nazionale di Fisica della Materia (INFM), Politecnico di Torino, C. Duca degli Abruzzi 24, I-10129 Torino, Italy and*
[c]*Joint Laboratory of Orientationally Ordered Media (OOM-Lab), C. Duca degli Abruzzi 24, I-10129 Torino, Italy*

ABSTRACT
The present paper mainly consists of a brief review about organic electroluminescent materials. Different types of organic light emitting substances belonging to conjugated polymers and low molecular mass compounds are described: the advantages of light emitting liquid crystals are shown.

Keywords: organic light-emitting materials; OLEDs, liquid crystals, discotics, calamitics

INTRODUCTION

Electroluminescent (EL) displays technology, comprising organic light-emitting diodes (OLEDs), is a rapidly growing field with widespread applications [1]. Scientific and engineering interest in OLEDs has been high because of their potential to offer a lower-cost alternative tool to current light display technologies ranging from simple backlight- to large-scale flat-panel displays.

A wide range of materials has been reported to be used in EL devices, these vary from low-molar-mass molecules (such as metalquinolinates) to processable polymers. Light–emitting polymers (LEPs) belong to a class of materials known as conjugated polymers, which have unique optical and electrical properties. Wafer-thin and flexible, LEPs can be made to emit the full spectrum of visible light when an electric current is passed trough. The ability to produce white light from OLEDs by combining red, green, and blue emissions will open a wealth of applications for LEPs.

We have discovered that some low-molecular-mass aromatic polycycles have a very bright electroluminescence with different wavelength emission.

Highly conjugated low-molar-mass liquid crystalline molecules are desirable as self-organising properties of the material can be exploited to improve device performance and to achieve linearly polarized electroluminescence [2,3].

In this paper a brief review about electroluminescent technology and organic light emitting substances will be done.

CONSTRUCTION OF OLEDs

The simplest display consists of a single organic layer sandwiched between a transparent electrode layer (usually indium-tin-oxide, ITO, which exhibits a high work-function and may serve as positive contact) and a metal electrode (usually metals with low work function, such as Ca, Al or their alloys are employed as negative contact).(Fig. 1)

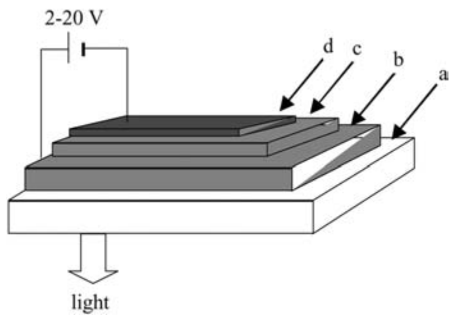


FIGURE 1 Fundamental setup of a single-layer electroluminescence device:
a) optically transparent substrate (e.g. glass);
b) optically transparent electrode (e.g. ITO);
c) organic luminescent layer (100 nm thickness);
d) metallic electrode (e.g. Al, Mg/Ag, Ca, Al/Ca);

More efficient electroluminescent devices can be obtained from organic multi-layer systems, where are present two additional layers: hole- or electron- transporting layers. (Fig. 2).

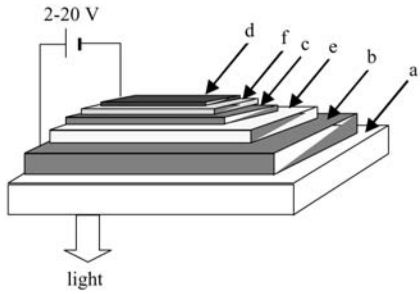


FIGURE 2 Fundamental setup of a multi-layers electroluminescence device:

a) optically transparent substrate (e.g. glass);
b) optically transparent electrode (e.g. ITO);
c) organic luminescent layer (100 nm thickness)
d) metallic electrode (e.g. Al, Mg/Ag, Ca; Al/Ca);
e) holes transporting layer;
f) electrons transporting layer

ADVANTAGES OF OLEDs AND MECHANISM OF ELECTRO-LUMINESCENCE

The advantages of electroluminescent displays based on OLEDs with respect to liquid crystal (LC) displays are evident:

- their construction is very simple;
- they do not require polarizers;
- they do not require backlight;
- they have high visibility under any brightness level and from any viewing angle;
- they are very thin;
- they require very low voltage, often below 10 V;

- the emitting layer is a single organic substance instead of mixture of 12 LC, as it is in LC-material suitable for displays applications;
- as a result – the cost is rather low.

OLEDs have also some disadvantages: the most unpleasant among them are:
- they do not have enough long life time (in a lot of cases it is less than 10000 hours);
- they need complicate packaging in order to prevent the oxidation of the cathode (often made of calcium) through contact with air and humidity.

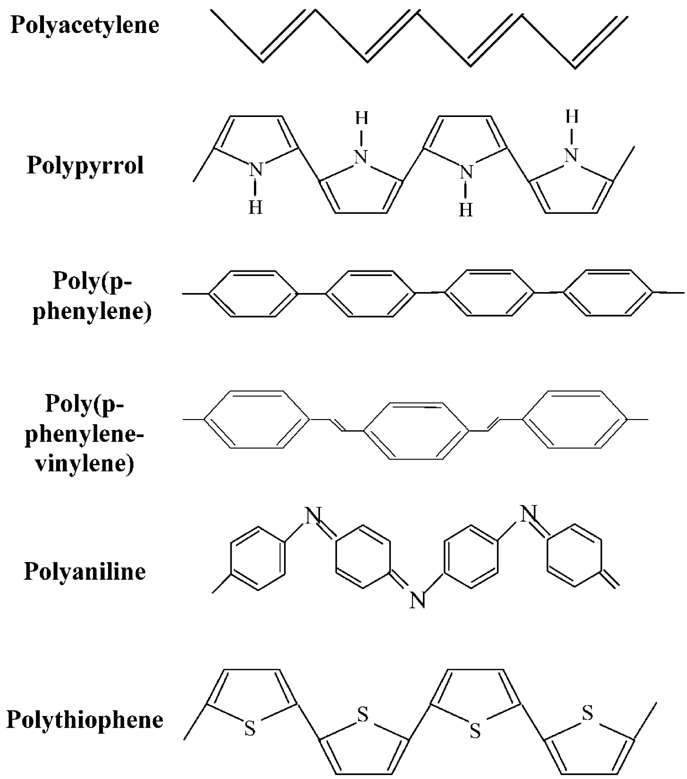
The electroluminescence of polyconjugated polymers has the following mechanism: a de-localized ð-electron system runs along the polymer chain, which has alternation of single and double bonds, and in turn provides the semiconducting properties to the polymer and gives it the ability to support positive and negative charge carriers with high mobilities along the polymer chain.

In the case of low-molecular-mass materials charge transfer occurs between molecules.

DIFFERENT TYPES OF ORGANIC LIGHT EMITTING MATERIALS

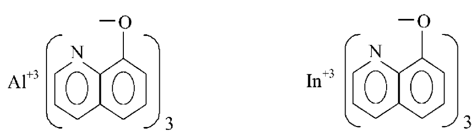
It has been reported a huge amount of materials to be used in EL devices: these vary from light –emitting conjugated polymers (LEPs) to low-molar-mass molecules (such as metalquinolinates). On figure 3 the first and well known LEPs are presented.

FIGURE 3: Light emitting polymers



Among low-molar-mass molecules, the metal complexes such as Al-quinolinate and In-quinolinate are playing the most important role (fig.4).

FIGURE 4: Low-molar-mass molecules



Aluminum-8-oxaquinolinate Indium-8-oxaquinolinate

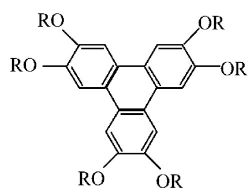
We have synthesized and investigated low-molecular-mass polyaromatic molecules, which are exhibiting red, green, light blue and blue emission and are suitable for display application.

It is necessary to underline, that one of the most important advantages of low molecular weight organic compounds is the possibility to be deposited by thermal evaporation in high vacuum, instead by spin-coating deposition used for LEP. This allows to make the complete device in one vacuum cycle.

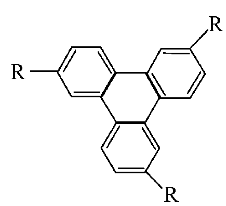
LIQUID CRYSTALLINE ORGANIC LIGHT EMITTING MATERIALS

Liquid crystals are of particular interest for organic light emitting diodes. They have some advantages with respect to the compounds mentioned above. Columnar LC with a suitable molecular structure can exhibit an unusually high charge carrier mobility of the order $0.1 cm^2V^{-1}s^{-1}$. Moreover, liquid crystals show the ability to self-organize, i.e. defects are healed by annealing such compounds in the temperature range of the mesophase. In addition to this self-healing process, some columnar LC spontaneously show a uniform homeotropic orientation, even on untreated substrates. Thus, LC are particularly useful for generating uniformly oriented defect-free layers. Some discotic LC, which have very good light emitting properties, as reported by authors [4-7], are presented on the figure 5.

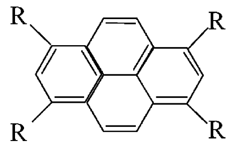
FIGURE 5: Light emitting discotic liquid crystals



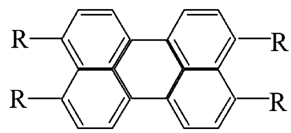
Hexapentyloxytriphenylene ($R=C_5H_{11}$)



Triphenylene ($R=CO_2Alk$)



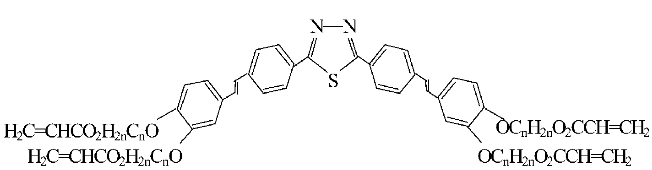
Pyrene (R= CO_2Alk)



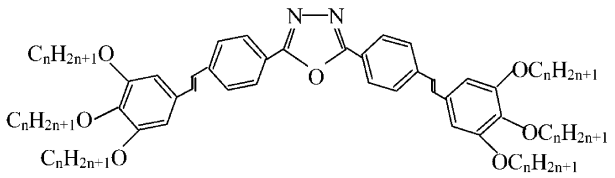
Perylene (R= CO_2Alk)

Another interesting feature is shown by calamitic, and in particular smectic liquid crystals. Uniform homogeneously oriented nematic or smectic LC exhibit a linearly polarized luminescence with intensity of linear dichroism I /I up to 25:1 and a luminance of up to 250 cd m^{-2}. The main structures of calamitic LC, reported by authors [8-10], are shown on the figure 6.

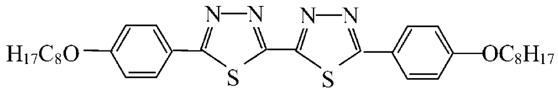
FIGURE 6: Light emitting calamitic liquid crystals



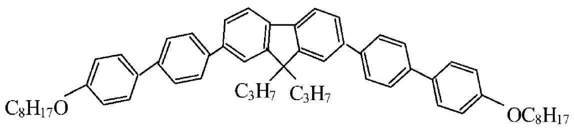
2,5-bis(4-[(E)-2-(3,4,-dialkenoilalkyloxyphenyl)-ethenyl]phenyl)thiadiazole



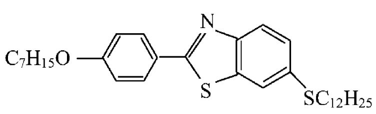
2,5-bis(4-[(E)-2-(3,4,5-trialkoxyphenyl)ethenyl]phenyl)oxadiazole



5,5’-bis(4-octyloxyphenil)-2,2’-bi-1,3,4-thiadiazole



4,4’-bis(4-octyloxybiphenil)fluorene



2-(4’-Heptyloxyphenyl)-6-dodecylthiobenzothiazole

In summary, there is high interest in developing new electroluminescent LC in order to make use of their high charge carrier mobility, self-assembling properties and\or dichroism of the luminescence. It was also shown, that LC are very good transporting layers.

It is necessary to notice, that the efficiency of electroluminescent devices strictly depends on the presence of charge transporting layers and also on the thickness of emitting layer.

With indium-8-oxaquinalinate we succeeded to have the brightness 650 cd m^2 with threshold voltage 9 V only using as a hole transporting layer specially synthesized amine, whereas with well known commercial hole transporting material "PEDT" almost no electroluminescence was observed even at 15 V.

For what is concerning the thickness: the best one of emitting layer for polymers is near 100-120nm, for metallo-complex compounds 80 – 100 nm, for liquid crystals 50 –70 nm. The optimization of the thickness allows us to reduce the threshold voltage, sometimes to 5-6 V.

CONCLUSIONS

A brief review about electroluminescent technology and materials has been done, and some new results have been announced. It is possible to conclude, that:

1. Light emitting organic compounds provide the direct conversion of electrical energy into light.
2. During the last decade different types of light emitting materials were synthesized: polymers, low-molecular weight compounds and liquid crystals. We have found that low-molecular weight compounds are very promising.

3. Liquid crystals (both discotic and calamitic) are particularly useful for construction of OLEDs, due to their high charge carrier mobility and their ability of developing defect-free superstructures.

Acknowledgements

The authors are very grateful to: Eugenii Shebanin, Victor Nefedov, Vladimir Bochenkov for the synthesis of light emitting materials and to Anatoly Yastrebov for the measurements of physical parameters and creation of prototypes. One of the authors (S.I.T.) acknowledges the support of INCO Copernicus Concerted Action "Photocom", under Contract No. IC15-CT98-0806.

References

1. L.J. Rothberg and A.J. Lovinger, *J.Matter.Res.* **11**, 3174 (1996).
2. M. Grell and D.D.C. Bradley, *Adv.Mater.,* **11**, 895 (1999).
3. A.E.A. Contoret, S.R. Farrar et al, *Adv.Mater.,* **12**, 971 (2000).
4. K.S. Whitehead, M. Grell, D.D.C. Bradley, M. Jandke and P. Strohriegl, *Appl.Phys.Lett.,* **76**, 2946 (2000)
5. S.B. Benning, T. Hassheider, S. Keuker-Baumann, H. Bock, F.D. Sala, T. Frauenheim and H.-S. Kitzerow, *Liq.Cryst.* **28,** N 7, 1105 (2001)
6. D. Adam, F.Closs, T.Frey, D. Funhoff, D. Haarer, H. Ringdorf, P. Schumacher and K. Siemensmeyer, *Phys.Rev.Lett,* **70,** N4, 457 (1993)
7. M. Sato, R. Ishii, S. Nakashima, K. Yonetake and J. Kido, *Liq.Cryst.* **28,** N 8, 1211 (2001)
8. M. Funahashi and Jun-ichi Hanna, *Phys.Rev.Lett,* **78**, N11, 2184, (1997);
9. A.E.A. Contoret, S.R. Farrar, S.M. Kelly, J.E. Nichols, M. O'Neill and G.J. Richards, *Synth.Metals* (in print)
10. A.E.A. Contoret, A. Eastwood, S.R. Farrar, S.M. Kelly, J.E. Nichols, M. O'Neill, G.J. Richards and C. Wu, *Mol.Cryst.Liq.Cryst.* (in print)