Optical interferometric characterization of organic light emitting diodes

Kanchan Saxena[1*], Dalip Singh Mehta[2], Ritu Srivastava[1], and M. N. Kamalasanan[1]
[1]Polymeric and Soft Materials Section, National Physical Laboratory,
Dr. K. S. Krishnan Road, New Delhi - 110012, India.
[2]Laser Applications and Holography Lab., Instrument Design Development Centre (IDDC), Indian Institute of Technology Delhi, Hauz Khas, New Delhi – 110016, India
[*]kanchan@mail.nplindia.ernet.in

Abstract: *It is generally assumed that the electro-luminescence emission pattern from OLEDs is approximately Lambertian, spatially incoherent and diffuse. Recently, we measured the spatial coherence properties of light emitted by organic electro-luminescent devices based on most widely used organic light emitting material tris - (8-hydroxyquinoline) aluminum (Alq_3) using Young's double slit experiment. Fourier transform technique was used for the measurement of visibility of the interference fringes and from which the modulus of the degree of spatial coherence was determined. It has been confirmed that the coherence properties of the light emitted by a simple organic light emitting device (OLED) matches with that of practical Lambertian sources.*

Keywords: Organic light emitting diodes; spatial coherence; optical interferometric technique.

Introduction

Organic light emitting devices are of considerable interest and have gained a great deal of attention because of their high luminance, low driving voltage and high efficiency [1-2]. It is well known that the light generation mechanism in OLEDs is due to the radiative recombination of excitons on electrically excited organic molecules. Light is generated from thin organic emitting layer spontaneously in all directions and propagates via various modes, that is, external modes (escape from the substrate surface), substrate-, and indium tin oxide (ITO)/organic-wave-guided modes due to total internal reflection (TIR) [3-4]. Optical characterization of OLEDs is generally done by measuring the photoluminescence (PL) and electro-luminescence (EL) spectra which gives information about radiative life-time, spectral-peak, spectral-width, and color of the emitted light. Apart from these, one of the important characteristics of practical light sources to be determined is the intensity distribution and coherence properties for the complete optical characterization of light emitted by them.

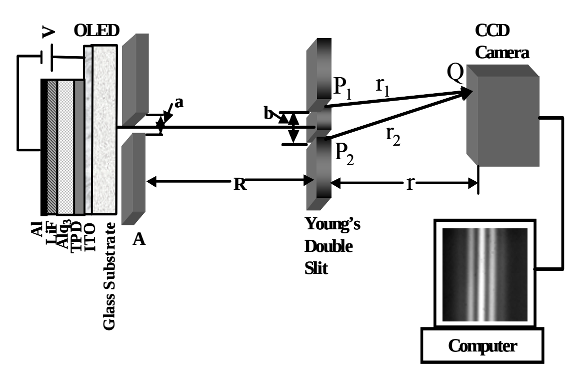
There has been enormous amount of research and development in the measurement of coherence properties of Lambertian and non-Lambertian sources[5-6]. So far spatial coherence properties of practical Lambertian sources, such as, diffuse reflectors, thermal light sources (gas discharge lamps or incandescent matter) and sources of blackbody radiation has been widely studied [5-6]. As mentioned above that the future practical lighting sources would be OLEDs because of their low power consumption, high efficiency, low cost, flexibility and long life-time. In many industrial applications of OLEDs, such as, for flat panel displays and general lighting spatially incoherent, wide angle, and diffuse light pattern is required. It is generally assumed that the EL emission pattern from OLEDs is approximately Lambertian [1-2]. Measurement of coherence properties, in particular spatial coherence of the EL emission gives information about the distribution and propagation of light generated by the source. In this letter we report the measurement of spatial coherence properties of light emitted by organic electro-luminescent devices based on tris - (8-hydroxyquinoline) aluminum (Alq_3).

Experimental Details

Bilayer OLEDs were fabricated on indium tin oxide (ITO) coated glass substrate using a shadow mask to obtain 4mm X 10mm active device area. The hole transport layer in these devices was 25 nm thick triphenyl diamine (TPD) deposited by vacuum evaporation technique after the ITO surface was treated by O_3 plasma. The electron transport and emitting layer in all devices were 35 nm Alq_3 deposited by vacuum sublimation. The cathode consisted of ~1 nm thick LiF layer and a 100 nm thick aluminum layer.

Determination of degree of coherence:
Coherence measurements were performed using the Young's double slit experiment by varying the size of the source and double slit separation. The schematic experimental set-up for measuring the spatial coherence of the light emitted by OLED is shown in Figure 1.

Figure 1. Experimental set-up for measuring the



spatial coherence of the light emitted by OLED.

A variable rectangular aperture *A* was illuminated by light emitted by OLED uniformly and incoherently. In the far zone of *A*, at a distance of R = 55 cm, a double slit with each slit opening of 150 μm was placed. The separation between the double slit b was also varied between 400 μm to 760 μm. In the far-zone of the double slit at a distance of r = 60 cm two-dimensional interferograms were recorded by a cooled charge-coupled device (CCD) camera for various slit separations and were stored in the computer for signal processing. In a two-beam interference based on Young's double slit experiment the intensity of light at a point Q in the detector plane is written as[5-6].

$$I(Q) = I_1(Q) + I_2(Q) + 2\sqrt{I_1(Q)}\sqrt{I_2(Q)}\left|\gamma_{12}(\tau)\right|\cos(\beta_{12}(\tau)), \quad (1)$$

where $I_1(Q)$ and $I_2(Q)$ are the intensities of the two beams, $\gamma_{12}(\tau) = \gamma(R_1, R_2, \tau)$ is the complex degree of spatial coherence of the light at points P_1 and P_2 which are at distances R_1 and R_2, respectively from the source, $\tau = r_2 - r_1/c$ is the time delay between the two beams reaching at point Q (with r_1, and r_2 being the distances of the path traveled by two beams reaching at point Q as shown in Fig. 1 and c the speed of light) and $\beta_{12}(\tau)$ is the phase of $\gamma_{12}(\tau)$ varying between 0, and π. Traditionally, the fringe visibility $V(Q)$, which is the measure of the sharpness of interference fringes at point Q, is determined by measuring the maximum (I_{max}) and the minimum (I_{min}) of the interference fringe intensity using the following expression [5-6].

$$V(Q) = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{2\sqrt{I_1(Q)}\sqrt{I_2(Q)}}{I_1(Q) + I_2(Q)}\left|\gamma_{12}(\tau)\right|. \quad (2)$$

Assuming $I_1(Q) = I_2(Q) = I(Q)$ Eq. (2) reduces to $V(Q) = \left|\gamma_{12}(\tau)\right|$, from which the modulus of the degree of coherence can be determined.

In the present study we used Fourier-transform fringe analysis technique to determine the visibility of the interference fringes [7]. According to this technique the first-order spectrum of the Fourier transform gives information about the depth of modulation and phase of the interference fringes. The degree of spatial coherence can be determined by computing the ratio of the first order peak with that of zero-order peak [7].

Theoretically it has been shown that the degree of spatial coherence of the light field generated by a spatially incoherent source is given by the following expression

$$\gamma_{12}(\tau) = \left|\frac{\sin(ab\omega/2cR)}{(ab\omega/2cR)}\right|. \quad (3)$$

where a is size of the aperture A, b is the separation between the two slits, and R is the distance between the aperture plane and the double slit plane.

Results and Discussions

Figure 2 shows the electroluminescence EL spectrum of a typical Alq_3 based OLED. The EL spectrum peaks at 520 nm

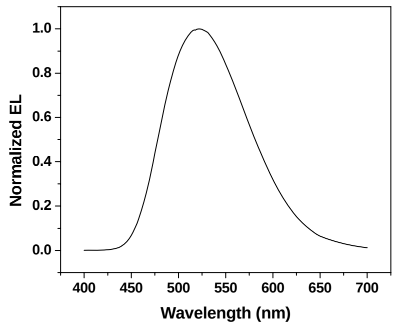


Figure 2. EL spectrum of Alq_3 based device

Figure 3 shows the interferograms recorded by varying the double-slit separations from 400 μm - 760 μm for rectangular aperture opening fixed at a = 450 μm. interferograms were also recorded for similar double-slit separations for a = 500 μm. During the recording of the interferograms exposure time of the CCD camera was maintained 1 second and utmost care was taken to avoid the stray light. Two-dimensional fast Fourier-transform (2D-FFT) of each interferogram was then computed. Fig. 4 shows an example of 2D-FFT corresponding to the interferograms recorded for b = 400 μm and a = 450 μm. The visibility of the interference fringes was determined from the ratio of the first order spectral peak height of the spatial carrier fringes to that of the zero-order spectral peak [7]. In Figure 5 solid circles with error bars represents the experimentally determined values of the degree of spatial coherence of the light emitted by OLED for the rectangular aperture opening of a = 450 μm.

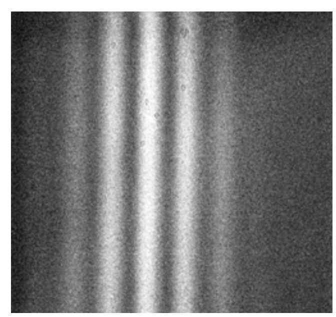


Figure 3. Interferogram for double slit opening, b = 400 μm and aperture size, a = 450 μm

The experimental results of the spatial coherence were compared with the theoretical values by inserting the values of the experimental parameters a, b, and R in Eq. (3). In Figure 5 solid curve shows theoretically calculated values of the modulus of the degree of spatial coherence. The experimental results of spatial coherence agree well with their theoretical counterparts within the experimental errors. These results show that the distribution of light emitted by the OLED device is quasi-homogeneous Lambertian and for such sources the spatial coherence of light across the source plane is of the order of $\lambda/2$ [5-6].

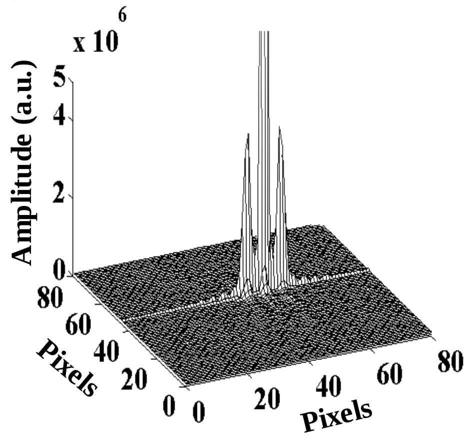
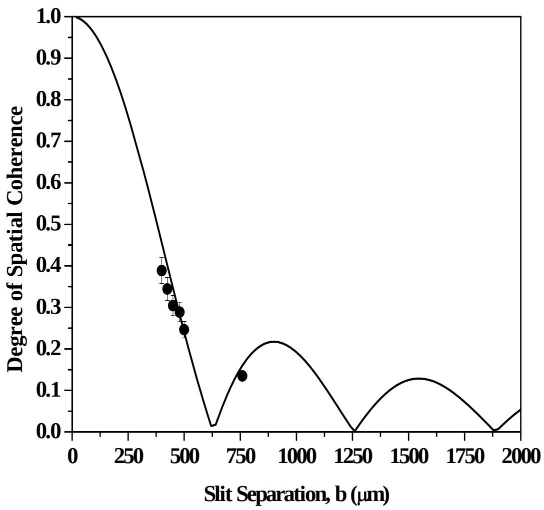


Figure 4. 2D-FFT corresponding to the interferograms recorded for *b* = 400μm and *a* = 450 μm



Figures 5. Solid circles are experimentally determined values of the degree of spatial coherence of the light emitted by OLED for the rectangular aperture opening of a = 450 μm and solid curve is theoretically calculated values of the modulus of the degree of spatial coherence.

Acknowledgements

The authors are thankful to the Director, National Physical Laboratory, for continuous encouragements. One of the authors (K.S.) is grateful to Department of Science and Technology, New Delhi for funding this project (SR/WOS-A/PS-08/2003).

References

1. C. W. Tang and S. A. VanSlyke, "Organic electroluminescent diodes", *Appl. Phys. Lett.*, vol. 51, pp 913 – 915, 1987.
2. *Handbook of Luminescence, Display Materials and Devices,* edited by H. S.Nalwa, and L. S. Rohwer, (ASP Press California, USA 2003), Vol. 1.
3. Gu, D.Z. Garbuzov, P.E. Burrows, S. Vankatsh, S. R. Forrest and M. E. Thompson, *Opt. Lett*. "High-external-quantum-efficiency organic light emitting devices", vol. 22, pp. 396 – 398, 1997.
4. C. F. Madigan, M. H. Lu and J. C. Sturm, "Improvement of outcoupling efficiency of organic light emitting diodes by backside substrate modification", *Appl. Phys. Lett*., vol. 76, pp. 1650 – 1652, 2000.
5. M. Born and E. Wolf, *Principles of Optics* (Cambridge Univ. Press, New York, 1999).
6. L. Mandel and E. Wolf, *Optical Coherence and Quantum Optics*, (Cambridge Univ. Press, New York, 1995).
7. D. S. Mehta, H. Hinosugi, S. Saito, M. Takeda, T. Kurokawa, H. Takahashi, M. Ando, M. Shishido, and T. Yoshizawa," A spectral interferometric microscope using tandem liquid-crystal Fabry-Perot interferometers for the extension of the dynamic range in three-dimensional step-height measurement", *Appl. Opt*., vol. 42, no. 4, pp. 682 – 688, 2003.