Modeling and Analysis of Double Layer Motheye Anti Reflective Coatings on Organic Light Emitting Diode

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Abstract: In this work modeling of double layer motheye anti-reflective coating (DLAR) on organic light emitting diode (OLED) is presented. Finite difference time domain method (FDTD) and Fresnel reflection theory is used to study the reflection and transmission of light of Organic Light Emitting Diode (OLED) using Anti-reflective coatings (ARC). The double layer motheye anti-reflective coatings are incorporated on the surface of glass substrate of an OLED. This is done to reduce the losses existing in OLEDs substrate-air interface. The refractive index (RI) of the top and bottom layer of ARC is engineered and the thickness of the top and bottom layer anti-reflective coatings is modelled using Fresnel's reflection theory. The effect of double layer motheye ARC on OLED for enhanced far field intensity is analysed. It is found that the far field electric intensity of DLAR based OLED has a significant enhancement compared to OLED with Single layer Antireflective coatings on the glass substrate.

1 INTRODUCTION

The OLED is formed by the arrangement of metal-organic emissive layer in a specific order. Light is emitted when DC voltage source is applied across the anode and cathode of the OLED (Tang and Vanslyke, 1987 and Tang, 1989). Due to the applied voltage, the population of the excitons are increased to produce light by radiative decay. (Macleod, 2010 and Lee, 2003). The emission wavelength of the OLED device can be chosen by using appropriate organic dopants for the fluorescent-based device (Wasey et.al, 2000). When the voltage is applied, a singlet excitons are produced to emit Fluorescent light with internal quantum efficiency (IQE) is 25 %. The external quantum efficiency is limited to 20% for the conventional OLED device (Wasey et.al, 2000). The formation of light takes place in the emissive layer of the device. When the device is excited with the source, it undergoes radiative decay to emit the maximum number of excitons. The emitting of the light from the device can be either top emitting or bottom emitting depending on the design structure (Kim.et.al, 2016). The application of OLEDs based on the Anti-reflective coatings is emerging in in display technology, photo detectors etc., (Sharma et.al, 2017). The Anti-reflective coating are made of nanostructures. These are placed on the devices such as OLEDs, solar cells etc. to reduce the reflection losses that exist at the glass substrate interfaces.

These tapered Nanostructures are placed in the coating layer above glass substrate. The sub wavelength Nanostructures are created using various materials to reduce the reflection losses. The DLAR concept was used on solar cells to improve the efficiency as in (Dhungel et.al, 2006).

Many experiments have been carried out in the literature using photonic crystals, micro lenses, patterned substrates, dielectric nanoparticles in display and other applications to improve the light out coupling efficiencies (tan et.al, 2017).

In the recent years, a technique to reduce losses is done by adopting periodic nanostructures such as bio mimicking motheye. This is an efficient technique to incorporate on the surface of the glass substrate of the OLED. There are various types of anti-reflection coatings such as single layer Anti-reflective coatings, double layer anti-reflective coatings etc. The effects

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of SLAR are studied in (Keshavarz Hedayati et.al, 2016) showing a significant improvement in the light coupling efficacy when compared to Photonic crystals. In this work the effects of double layer anti-reflective coatings on OLED are investigated. The thickness, height and pitch are parameters that define the response of the system and can be designed to tailor this response.

2 DESIGN OF DLAR BASED OLED

This section describes the modelling of parabolic shaped Double layer Anti-reflective coating (DLAR) and modelling of DLAR on OLED.

2.1 Modeling of Double Layer Motheye Anti Reflective Coating

The Double layer motheye Anti-reflective coating (DLAR) was investigated on solar cells, which showed a significant enhancement due to coverage of broad band solar spectrum. In this work, the DLAR is placed on OLED as there is a limited number of adjustable parameters in single layer motheye Anti-reflective coatings (SLAR).

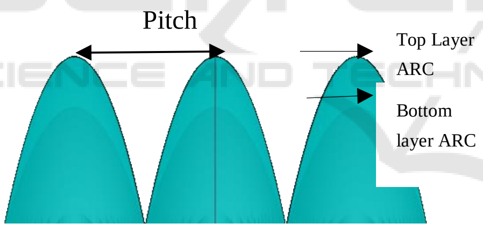

Figure 1: Parabolic shaped Double layer ARC.

In Figure 1, the parabolic shaped double layer motheye anti-reflectors are shown. The pitch of both the layers are carefully tailored in order to reduce the reflection losses. The dimension of double layer motheye Antireflective coatings such as thickness, pitch and height are tailored from the Fresnel's reflection theory.
Figure 2 and Figure 3 shows the modelling of Double layer ARC placed on the glass substrate which is periodic in nature and are tapered at the sides of the structure. This simulation is carried out to get the insight of absorption and transmission in the DLAR. The following boundary conditions are used to model the DLAR: x (maximum) = anti symmetric and y (maximum) = symmetric. Also two monitors are placed to get the reflection analysis behind the source and other monitors amount of transmission. The plane wave is chosen to get the effects of ARCs with Bloch/periodic wave type. The transmission, reflection and absorption plots are extracted from the above simulation set up. The modeling is done using a commercially available Lumerical FDTD software.

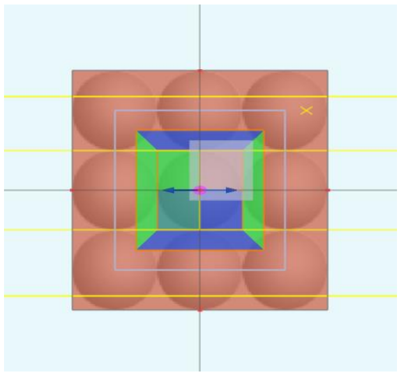

Figure 2: Modelled Double layer Anti-Reflective coatings (XY view).

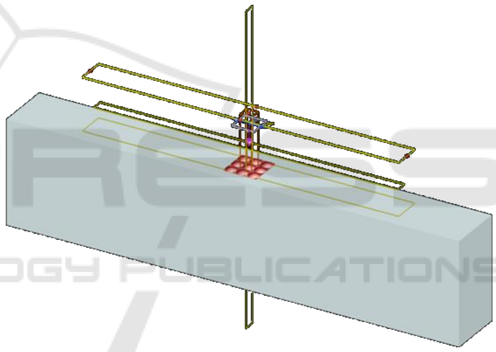

Figure 3: Perspective View of DLAR.

In DLAR, two reflectance's are considered so that maximum reflection is supressed by undergoing destructive interferences at two interfaces. One at top layer and bottom layer ARC interface and another at bottom layer and glass substrate interface.
Figure 3, shows following layers: Glass substrate, Bottom layer ARC, Top layer ARC and air medium. The multilayer stack layers are chosen at different refractive indices that satisfies following condition.

$$n_0 < n_{top} < n_{bottom} < n_{substrate}$$

where, n_0 = Refractive index of the air , n_{top} = Refractive index of top layer Anti-reflective coating n_{bottom} = Refractive index of Bottom layer Anti-reflective coating, $n_{substrate}$= Refractive index of the substrate.
The anti-reflection stack is designed for a particular wave length of 540nm to emit green fluorescent light.

In this simulation, the reflection and transmission spectra are obtained. The reflection is almost supressed compared to SLAR. The DLAR coatings are also called as V-coatings, since the spectral patterns are obtained is V-shaped, due to quarter – quarter coatings or thickness relationship. These V-shaped coatings are perfectly suitable for the point of care applications as discussed in (Lee et.al. 2016) and in OLED based bio sensors as in (Krujatz et.al. 2016).

2.2 Design of DLAR based OLED

This section describes the design and modelling of Double layer Anti-reflective coating (DLAR) based OLED.

2.2.1 Design of Fluorescent OLED

The DLAR based Fluorescent OLED shown in the Figure 4. It contains multi-layer stack with Alq3-Tris (8-hydroxyquinoline) aluminum as an Organic layer placed in between anode and cathode. The Alq3 is chosen in order to emit green light at an operating wavelength of 540nm. The work function of the various layers used in the proposed OLED structure is chosen from (Novotny et al., 2006).

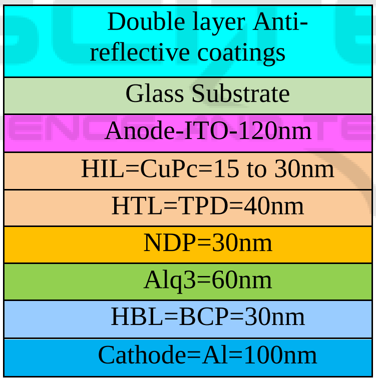

Figure 4: DLAR based Fluorescent OLED.

The refractive index of the materials and the structure of the OLED used in the present work is referred from the literature (Chaya et al., 2018). The DLAR is placed on the surface of the substrate to avoid the light trapped inside the layer. The maximum light is coupled out to supress the losses due to reflections. The simulation of the DLAR based OLED is carried out using Lumerical FDTD.
Figure 5, shows the modeled double layer motheye Anti-reflective coatings based OLED for the structure shown in Figure 4. To obtain Fluorescent based OLED device, the Alq3 organic material is used that operates at 540nm. This layer is placed in emissive layer.

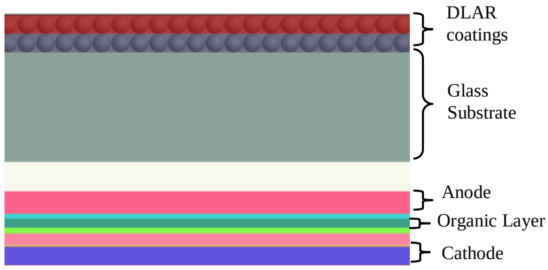

Figure 5: Modelling of OLED using DLAR (XY View).

The double layer moth-eye Anti-reflective coatings are made of top layer and bottom layer. The Magnesium Fluoride and Mesoporous silica are used as top and bottom layers of DLAR respectively. These layers are placed on surface of the glass substrate of the OLED to suppress reflections that exist on the substrate-air interface. The materials used in DLAR based OLED device are detailed as follows, Indium Tin oxide as anode, Aluminum as Cathode, BCP-(2, 9 Dimethyl-4, 7-diphenyl-1 as Hole Blocking Layer (HBL), CuPC- (Copper (II) phthalocyanine) as Hole Injection layer(HIL), (N, N'-Bis (3-methylphenyl)-N,N'-diphenyl benzidine) as Hole Transport layer(HTL)-TPD, Tris(8-hydroxyquinoline) aluminum (Alq3) as emissive layer, Double layer Motheye Anti-Reflective Coatings (pitch=300nm, radius=100nm), Glass Substrate with 1.52 refractive index is chosen in the present work.

3 METHODOLOGY

The Fresnel's Reflection theory is used in this work to model the double layer motheye Anti-reflective coatings. The reduction in reflectance from the glass-air interface is achieved by optimising the thickness of the double layer Anti reflection coatings. By tailoring the thickness of the Anti-reflective coatings destructive interferences is achieved to supress reflection. As discussed in (Lee et.al, 2000), the two quarter wavelength coatings, the Optimum refractive index is determined by the equation (1) and (2),

$$n_{top}^3 = n_{air}^2 n_{glass} \quad (1)$$

$$n_{bottom}^3 = n_{air} n_{glass}^2 \quad (2)$$

Where, n_{top}= Refractive index of top layer Anti-reflective coating, n_{bottom}= Refractive index of bottom

layer ARC, n_{air}=Refractive index of air, n_{glass}= Refractive index of glass substrate.
Where, n_{top}= Refractive index of top layer Anti-reflective coating, n_{bottom}= Refractive index of bottom layer ARC, n_{air}=Refractive index of air, n_{glass}= Refractive index of glass substrate.

4 RESULTS AND DISCUSSION

4.1 Transmission and Reflectance Patterns of DLAR

Figure 6 and 7, shows the transmission and reflectance patterns of the double layer Anti-reflective coatings with respect to viewing angle. The transmission and reflectance patterns are obtained at an operating wavelength of 540nm. Theta in the graphs represent the angle at which the light transmits and reflects normal to the surface.
It is observed from the Figure 6, that the transmission of DLAR is greatly enhanced.

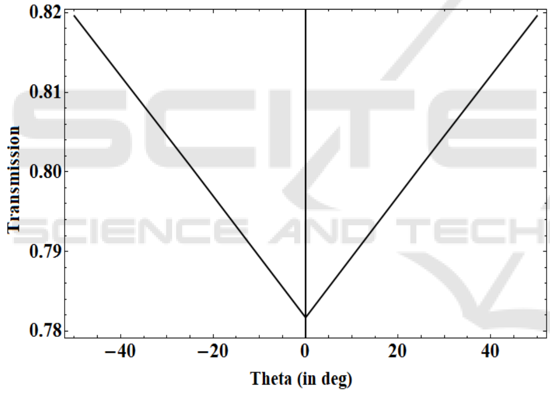

Figure 6: Transmission Spectra of DLAR.

Also in Figure 7, the reflection is almost suppressed to zero, helps to reduce the glass substrate-air interface losses, when this DLAR is placed on OLED.

4.2 Refractive Indices of Top and Bottom Layer ARC

Figure 8, shows the Refractive index (RI) of Top layer versus RI of bottom layer of ARC curve. For different top layer RI values the RI of the bottom layer ARC varies. Based on this analysis the coating materials are chosen which is to be placed on the OLED glass substrate.

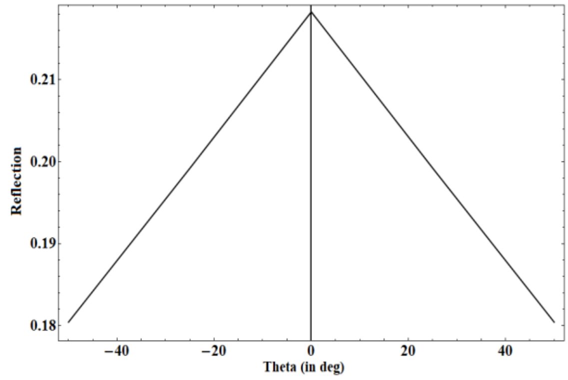

Figure 7: Reflection Spectra of DLAR.

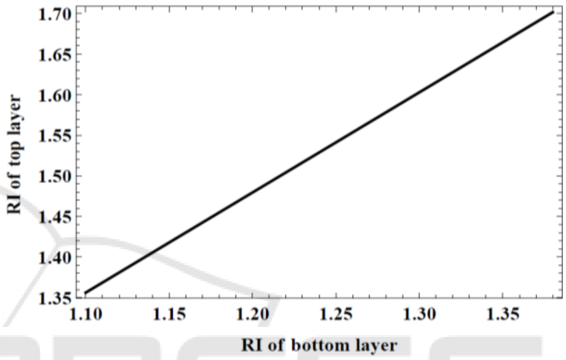

Figure 8: RI of Top and bottom coating layers.

4.3 Thickness of Top and Bottom Layer ARC

Figure 9 shows the thickness of the top layer ARC calculated for coating materials of different RI of Top ARC layer.
The curve shows that the thickness varies from 95 to 125 nm for coating materials of RI values ranging from 1.10 to 1.42. Therefore, this curve ensures that the ARC thickness is chosen appropriately for a particular coating material.
Figure 10 shows the thickness of the bottom layer ARC calculated for coating material for different bottom layer ARC. The curve shows that the thickness varies from 80nm to 100 nm for coating materials of RI values ranging from 1.35 to 1.70.

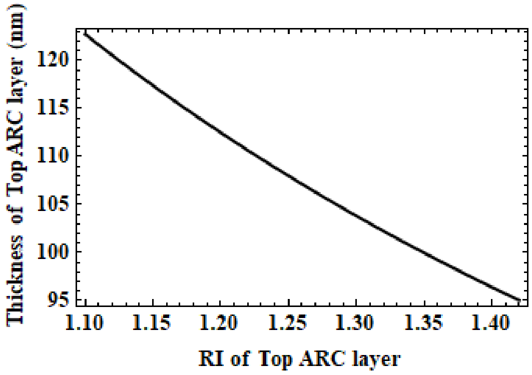

Figure 9: Thickness of Top ARC layer.

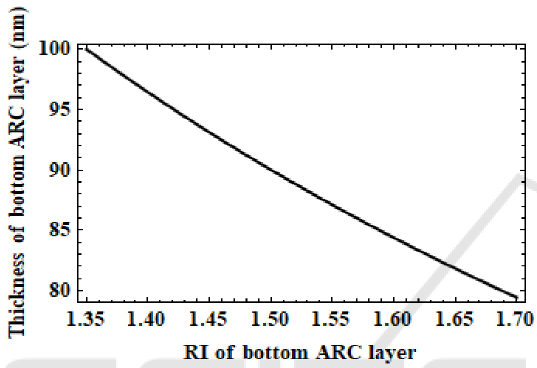

Figure 10: Thickness of Bottom ARC layer.

4.4 Optical Admittance and Far Field Profile of OLED

Figure 11 shows the optical admittance of the double layer motheye anti-reflective coatings. The curve shows the optical admittance of the substrate coated with a quarter wave optical thickness of the DLAR.

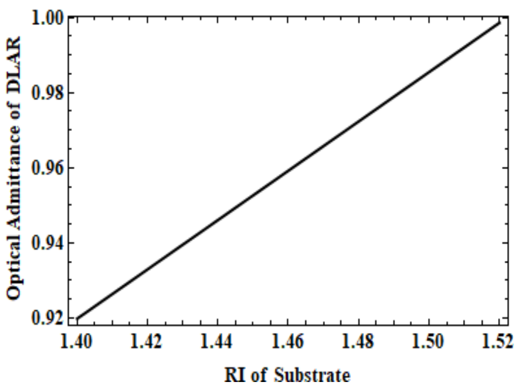

Figure 11: Optical Admittance of DLAR.

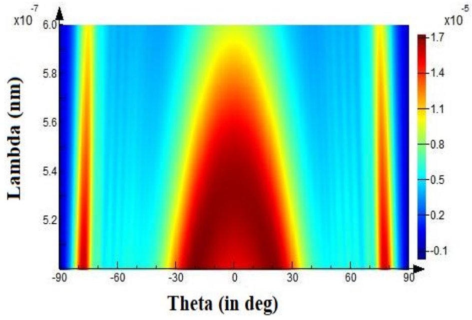

Figure 12 (a): Far field intensity of Single layer ARC.

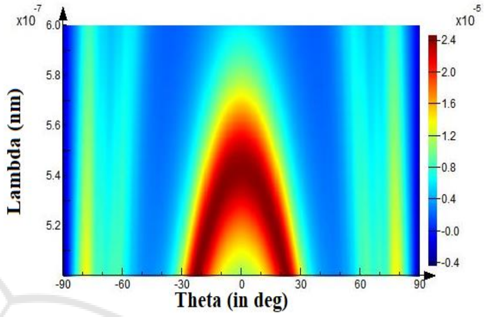

Figure 12 (b): Far field intensity of Double layer ARC.

The Far field intensity of the Single layer Anti-Reflective coating on the surface of the substrate of the OLED is shown. The materials chosen for the coatings is Mesoporous silica with refractive index of 1.1.

The far field intensity achieved is about 1.7×10^{-5}V/m as shown in Figure 12 (a). When double layer coatings of Magnesium Fluoride (MgF_2) (top layer ARC) / Mesoporous silica (bottom layer ARC) is coated on the surface of the glass substrate of the OLED.

The maximum reflection is supressed and far field electric intensity is achieved of about 2.4×10^{-5} V/m compared to single layer ARC placed on OLED as shown in Figure 12(b). It is observed that, the DLAR based OLED performance enhances the far field electric intensity compared to conventional OLED devices.

5 CONCLUSIONS

In this work, the effects of reflectance and transmittance of double layer motheye Anti-reflective coatings are investigated. The thickness of the two layer ARC are modelled using Fresnel's theory. This is done to reduce maximum reflections that imposes losses on the substrate-air interface. Comparative study is carried out for both DLAR and SLAR placed on OLED. The enhancement in the far field intensity is achieved with DLAR based OLED is 2.4 x 10^{-5} V/m in greater in comparison with single layer ARC placed on OLED of about 1.7x10^{-5} V/m. Based on these simulations the reflection losses are reduced at the glass-air interface of an OLED. Such DLAR based OLED can be prepared to effectively use in display and lab-on a chip applications.

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