

DESCRIPTION

ORGANIC EL DISPLAY

5 Technical Field

The present invention relates to an organic electroluminescent (EL) display.

Background Art

Since organic EL displays are of self-emission
10 type, they have a wide viewing angle and a high repose
speed. In addition, they do not require a backlight,
and therefore, low-profile and lightweight are
possible. For these reasons, the organic EL displays
are attracting attention as a display which substitutes
15 the liquid crystal display.

An organic EL element, which is the main part of the organic EL displays, includes a light-transmitting front electrode, a light-reflecting or light-transmitting back electrode facing the front electrode, and an organic layer interposed between the electrodes and containing a light-emitting layer. The organic EL element is a charge-injection type light-emitting element which emits light when an electric current flows through the organic layer.

25 In the meantime, the luminance of the organic EL
element increases with the magnitude of current flowing
through the EL element. However, if the current

density is increased, power consumption increases and the lifetime of the organic EL element is significantly reduced. Therefore, in order to achieve high luminance, low power consumption, and long lifetime, it is important to more efficiently extract the light emitted by the organic element from the organic EL display, i.e., to improve an outcoupling efficiency.

Disclosure of Invention

An object of the present invention is to improve an outcoupling efficiency of an organic EL display.

According to an aspect of the present invention, there is provided an organic EL display comprising an organic EL element which comprises a first electrode, a second electrode facing the first electrode, and an active layer interposed between the first and second electrodes and including an emitting layer, and an outcoupling layer facing the first electrode, wherein the organic EL element forms a waveguide layer which includes the first electrode and the active layer and in which light components from the emitting layer propagate in an in-plane direction parallel to a main surface of the waveguide layer while causing multiple-beam interference, wherein a distance between the outcoupling layer and the waveguide layer is shorter than a wavelength of light from the organic EL element, and wherein a guide length x in μm calculated by using a following equation (1), a number of reflection m

calculated by using a following equation (2), an
 absorption coefficient α in μm^{-1} of the waveguide
 layer, and an outcoupling efficiency β of the
 outcoupling layer satisfy a relationship represented by
 5 a following inequality (3), where L is a thickness in
 μm of the waveguide layer, θ_i is an incident angle at
 which a light component with the highest intensity
 emitted by the emitting layer and propagating in the
 in-plane direction in the waveguide layer while causing
 10 multiple-beam interference is incident on a main
 surface of the waveguide layer facing the outcoupling
 layer, and the outcoupling efficiency β is a luminous
 energy ratio of a light component extracted from the
 waveguide layer with respect to an incident light for a
 15 single reflection of the light component with the
 highest intensity on the main surface of the waveguide
 layer facing the outcoupling layer.

$$x = \frac{L}{\cos \theta_i} \quad \cdots (1)$$

$$m = \frac{1}{2} \left(\frac{\ln 100}{\alpha x} + 1 \right) \quad \cdots (2)$$

$$\beta \sum_{M=1}^m \frac{(1-\beta)^{M-1}}{\exp\{\alpha(2M-1)x\}} > 0.1 \quad \cdots (3)$$

Brief Description of Drawings

25 FIG. 1 is a sectional view schematically showing
 an organic EL display according to a first embodiment
 of the present invention;

FIG. 2 is a view schematically showing how an outcoupling layer extracts light from a waveguide layer, in which the light propagates in an in-plane direction while causing multi-beam interference, to the atmosphere;

FIG. 3 is a view schematically showing how the light propagates in the waveguide layer in the in-plane direction while causing multi-beam interference;

FIG. 4 is a graph showing an example of a relationship between an absorption coefficient of the waveguide layer and a number of reflection;

FIG. 5 is a graph showing examples of a relationship between a number of reflection and an outcoupling efficiency;

FIG. 6 is a sectional view schematically showing an example of a structure which can be employed for an organic EL element of the organic EL display shown in FIG. 1; and

FIG. 7 is a sectional view schematically showing another example of a structure which can be employed for an organic EL element of the organic EL display shown in FIG. 1.

Best Mode for Carrying Out the Invention

An embodiment of the present invention will be described below in detail with reference to the accompanying drawings. The same reference numerals denote the same or similar constituent elements

throughout the drawings, and a repetitive description thereof will be omitted.

FIG. 1 is a cross sectional view schematically showing an organic EL display according to an embodiment of the present invention. In FIG. 1, the organic EL display 1 is illustrated such that its display surface, that is, the front surface, faces downwardly and the back surface faces upwardly.

The organic EL display 1 is a top emission type organic EL display which employs an active matrix drive method. The organic EL display 1 includes an insulating substrate 10 such as a glass substrate.

On the transparent substrate 10, pixels are arranged in a matrix form. Each pixel includes a pixel circuit and an organic EL element 40.

The pixel circuit include, for example, a drive control element (not shown) and an output control switch 20 connected in series with the organic EL element 40 between a pair of power supply terminals, and pixel switch (not shown). The drive control element has a control terminal connected to a video signal line (not shown) via the pixel switch and outputs a current, whose magnitude corresponds to a video signal supplied from the video signal line, to the organic EL element 40 via the output control switch 20. A control switch of the pixel switch is connected to a scan signal line (not shown), and a switching

operation of the control switch is controlled by a scan signal supplied from the scan signal line. Note that other structures can be employed for the pixels.

On the substrate 10, as an undercoat layer 12, for example, an SiN_x layer and an SiO_x layer are arranged in this order. A semiconductor layer 13 such as a polysilicon layer in which a channel, source and drain are formed, a gate insulator 14 which can be formed with use of, for example, TEOS (tetraethyl orthosilicate), and a gate electrode 15 made of, for example, MoW, are arranged in this order on the undercoat layer 12, and these layers form a top gate-type thin film transistor (referred to as a TFT hereinafter). In this example, the TFTs are used as TFTs of the pixel switch ST, output control switch and drive control element. Further, on the gate insulator 14, scan signal lines (not shown) which can be formed in the same step as that for the gate electrode 15 are arranged.

An interlayer insulating film 17 made of, for example, SiO_x which is deposited by a plasma CVD method, covers the gate insulator 14 and gate electrode 15. Source and drain electrodes 21 are arranged on the interlayer insulating film 17, and they are buried in a passivation film 18 made of, for example, SiN_x . The source and drain electrodes 21 have, for example, a three-layer structure of Mo/Al/Mo, and electrically

connected to the source and drain of the TFT via contact holes formed in the interlayer insulating film 17. Further, on the interlayer insulating film 17, video signal lines (not shown) which can be formed in the same step as that for the source and drain electrodes 21 are arranged.

A flattening layer 19 is formed on the passivation film 18. Reflection layers 70 are arranged on the flattening layer 19. A hard resin can be used as a material of the flattening layer 19, for example. A metal material such as Al, for example, can be used as a material of the reflection layer 70.

The flattening layer 19 and the reflection layer 70 are covered with an outcoupling layer 30. Here, as an example, the outcoupling layer 30 includes a first portion 31 with light-transmission property, and second portions 32 dispersed therein. For example, the second portions 32 have light-transmission property, and are different in refractive index from the first portion.

If an arrangement of the second portions 32 substantially forms a lattice when the outcoupling layer 30 is observed in a direction perpendicular to its film surface, the outcoupling layer 30 serves as a diffraction grating. Alternatively, if the second portions 32 are randomly arranged when the outcoupling layer 30 is observed in a direction perpendicular to that its film surface, the outcoupling layer 30 serves

as a light-scattering layer.

The outcoupling layer 30 may not have a structure shown in FIG. 1. For example, the outcoupling layer 30 may be a film with light-transmission property which is provided with a number of recesses or protrusions on a main surface thereof.

On the outcoupling layer 30, first electrodes 41 with light-transmission property are arranged spaced apart from one another. Each first electrode 41 faces the reflection layer 70. In addition, each first electrode 41 is connected to a drain electrode 21 via through-holes formed in the passivation film 18, the flattening layer 19, and the outcoupling layer 30.

The first electrode 41 is an anode in this example. As a material of the first electrode 41, for example, a transparent conductive oxide such as an ITO (indium tin oxide) can be used.

A partition insulating layer 50 is placed on the outcoupling layer 30. In the partition insulating layer 50, through-holes are formed at positions corresponding to the first electrodes 41. The partition insulating layer 50 is an organic insulating layer, for example, and can be formed by using a photolithography technique.

An active layer 42 including a light-emitting layer 42a is placed on each first electrode 41 which is exposed to a space in the through-hole of the partition

insulating layer 50. The light-emitting layer 42a is a thin film containing a luminescent organic compound which can generate a color of, for example, red, green or blue. The active layer 42 can further include a layer other than the light-emitting layer 42a. For example, the active layer 42 can further include a buffer layer 42b which serves to mediate the injection of holes from the front electrode 41 into the emitting layer 42a. The active layer 42 can further contain a hole transporting layer, a hole blocking layer, an electron transporting layer, an electron injection layer, etc.

The partition insulating layer 50 and the active layer 42 are covered with a second electrode 43 with light-transmission property. The second electrode 43 is a cathode which is continuously formed and common to all pixels. The second electrode 43 is electrically connected to an electrode wiring, the electrode wiring being formed on the layer on which video signal lines are formed, via contact holes (not shown) formed in the passivation film 18, the flattening layer 19, the outcoupling layer 30, and the partition insulating layer 50. Each organic EL element 40 includes the first electrode 41, active layer 42 and second electrode 43.

In general, the organic EL display 1 shown in FIG. 1 are sealed by glass sealing or protective film

sealing in order to prevent the organic EL elements 40
from being deteriorated due to contact with moisture or
oxygen and the like. In addition, in general, a
polarizing plate is placed on the front side of the
5 organic EL elements 40.

Although the organic EL display 1 shown in FIG. 1
is of top emission type, the organic EL display 1 may
be of bottom emission type. For example, the
reflection layer 70 may be omitted, and the second
10 electrode 43 may have light-reflection property.

As described above, in the organic EL display 1,
the outcoupling layer 30 is placed so as to be adjacent
to the organic EL element 40. When such a structure is
employed, as described below, the light emitted by the
15 light emitting layer 42a of the organic EL element 40
can be extracted from the organic EL display 1 with
higher efficiency.

A portion of the light components emitted by the
light emitting layer 42a propagates in an in-plane
20 direction while repeating reflection (reflection or
total reflection) in a region including the first
electrode 41 and the active layer 42 of the organic EL
element 40, in this example, in a layered structure of
the first electrode 41 and the active layer 42. That
25 is, a portion of the light components emitted by the
light emitting layer 42a propagates in the in-plane
direction while repeating reflection in a waveguide

layer which includes the first electrode 41 and the active layer 42. The light components propagating in the in-plane direction cannot be extracted from the waveguide layer if an incident angle on a main surface of the waveguide layer is great.

When the outcoupling layer 30 is placed adjacent to the organic EL element 40, a direction of the light emitted by the light emitting layer 42a can be changed. Thus, it becomes possible to extract the light components emitted by the light emitting layer 42a from the organic EL display 1 with higher efficiency.

As described above, when the outcoupling layer 30 is used, luminous efficiency of the organic EL display 1 can be improved. However, a portion of the light components propagating in the waveguide layer in the in-plane direction is absorbed by the waveguide layer itself.

Therefore, in the present embodiment, the organic EL display 1 is designed as follows. That is, firstly, a guide length x (μm) is calculated in accordance with the following equation (1), in which L is a thickness (μm) of the waveguide layer, and θ_i is an incident angle at which a light component with the highest intensity emitted by the emitting layer 42a and propagating in the in-plane direction in the waveguide layer while causing multiple-beam interference is incident on a main surface of the waveguide layer

facing the outcoupling layer 30. Secondary, a number of reflection m is calculated in accordance with the following equation (2) using the guide length x (μm) and an absorption coefficient α (μm^{-1}) of the waveguide layer. Thirdly, the organic EL display is designed such that the number of reflection m , the absorption coefficient α (μm^{-1}), the guide length x (μm), and an outcoupling efficiency β of the outcoupling layer satisfy a relationship represented by the following inequality (3), where the outcoupling efficiency β is a luminous energy ratio of a light component extracted from the waveguide layer with respect to an incident light for a single reflection of the light component with the highest intensity on the main surface of the waveguide layer facing the outcoupling layer 30.

$$x = \frac{L}{\cos \theta_i} \quad \dots (1)$$

$$m = \frac{1}{2} \left(\frac{\ln 100}{\alpha x} + 1 \right) \quad \dots (2)$$

$$\beta \sum_{M=1}^m \frac{(1-\beta)^{M-1}}{\exp\{\alpha(2M-1)x\}} > 0.1 \quad \dots (3)$$

The outcoupling efficiency β and the number of reflection m will be described with reference to FIGS. 2 and 3.

FIG. 2 is a view schematically showing how an outcoupling layer extracts light from a waveguide layer, in which the light propagates in an in-plane

direction while causing multi-beam interference, to the atmosphere.

In FIG. 2, a layered structure of the first electrode 41 and the active layer 42 is defined as a waveguide layer 140. In addition, in FIG. 2, $L1_i$ and $L1_r$ indicate light with the highest intensity propagating in the in-plane direction in the waveguide layer 140 while causing multiple-beam interference, and $L2$ indicates the light extracted from the waveguide layer 140 through the outcoupling layer 30 to the atmosphere when the light $L1_i$ is incident on an interface between the waveguide layer and the outcoupling layer.

When the light $L1_i$ is incident on the interface between the waveguide layer 140 and the outcoupling layer 30, a portion of the light is extracted from the waveguide layer 140 to the atmosphere as light $L2$, and another portion is reflected as $L1_r$. The outcoupling efficiency β is a value calculated from the following equation (4) concerning the light $L1_i$ and the light $L2$.

$$\beta = \frac{\int_0^{2\pi} \int_0^{\pi/2} i(\theta, \phi) d\theta d\phi}{I_0} \quad \dots (4)$$

In equation (4) above, I_0 indicates a luminous energy of incident light $L1_i$. In addition, $i(\theta, \phi)$ indicates a luminous energy of light components of the light $L2$ which travel in a direction defined by a polar angle θ and a cone angle ϕ when the polar axis is

parallel to the film surface.

FIG. 3 is a view schematically showing how the light propagates in the waveguide layer in the in-plane direction while causing multi-beam interference. In FIG. 3, L1 indicates a light component with the highest intensity of the light propagating in the in-plane direction while causing multiple-beam interference in the waveguide layer 140.

As shown in FIG. 3, the guide distance x (μm) is a length of a line segment which is parallel to the traveling direction of the light L1 and extends from one main surface to the other main surface of the waveguide layer 140. In the case of ignoring decrease in luminous energy of the light L1 due to reflection, a luminous energy I_{1M} of the light L1 reflected M times on the interface between the waveguide layer 140 and the outcoupling layer 30 can be calculated from the following equation (5), in which M is a number of reflection of the light L1 on the interface between the waveguide layer 140 and the outcoupling layer 30, α (μm^{-1}) is an absorption coefficient of the waveguide layer 140 concerning the light L1, and I_0 is an initial luminous energy of the light L1.

$$I_{1M} = \frac{I_0}{\exp\{\alpha(2M-1)x\}} \quad \dots (5)$$

A number of reflection m corresponds to the number M in the equation (5) when the luminous energy I_{1M} is one hundredth of the luminous energy I_0 . That is, the

number of reflection m is a total number of reflection on the interface between the waveguide layer 140 and the outcoupling layer 30 until the luminous energy of the light $L1$ is decreased to one hundredth of the initial luminous energy.

FIG. 4 is a graph showing an example of a relationship between the absorption coefficient α of the waveguide layer and the number of reflection m . In the figure, the abscissa indicates the absorption coefficient α , and the ordinate indicates the number of reflection m .

FIG. 4 shows data in the case where the thickness L of the waveguide layer is $0.21 \mu\text{m}$, and an incident angle θ_i is 60° . As shown in FIG. 4, in the case where the absorption coefficient α is $0.5 \mu\text{m}^{-1}$, the number of reflection m is 12.

Based on the foregoing, the luminous energy $I2_M$ of the light $L2$ extracted from the waveguide layer 140 to the atmosphere at the time of an M -th reflection of the light $L1$ on the interface between the waveguide layer 140 and the outcoupling layer 30 can be calculated from the following equation (6).

$$I2_M = \frac{I_0 \beta (1 - \beta)^{M-1}}{\exp\{\alpha(2M-1)x\}} \quad \dots (6)$$

Therefore, a total luminous energy $\Sigma I2_M$ of the light $L2$ extracted from the waveguide layer 140 to the atmosphere when the light $L1$ is reflected n -times on

the interface between the waveguide layer 140 and the outcoupling layer 30 can be calculated from the following equation (7).

$$\sum_{M=1}^n I_{2M} = I_0 \beta \sum_{M=1}^n \frac{(1-\beta)^{M-1}}{\exp\{\alpha(2M-1)x\}} \quad \dots (7)$$

Therefore, a ratio of the total luminous energy ΣI_{2M} of the light L2 when the light L1 is reflected n -times on the interface between the waveguide layer 140 and the outcoupling layer 30 with respect to the initial luminous energy I_0 , i.e., the outcoupling efficiency, $\Sigma I_{2M}/I_0$ can be calculated from the following equation (8).

$$\sum_{M=1}^n I_{2M}/I_0 = \beta \sum_{M=1}^n \frac{(1-\beta)^{M-1}}{\exp\{\alpha(2M-1)x\}} \quad \dots (8)$$

FIG. 5 is a graph showing examples of a relationship between the number of reflection n and the outcoupling efficiency $\Sigma I_{2M}/I_0$. In the figure, the abscissa indicates the number of reflection n , and the ordinate indicates the outcoupling efficiency $\Sigma I_{2M}/I_0$. In addition, FIG. 5 shows data in the case where the thickness L of the waveguide layer is $0.21 \mu\text{m}$, an incident angle θ_i is 60° , an absorption coefficient α is $0.5 \mu\text{m}^{-1}$, and outcoupling efficiency β is 0.01 , 0.05 , 0.1 , 0.2 , or 0.3 .

As shown in FIG. 5, a change in the outcoupling ratio $\Sigma I_{2M}/I_0$ in accordance with an increase of the number of reflection n is slowed down when the number

of reflection n is 5 or more, and substantially saturates when the number of reflection n is about 12.

In addition, as the outcoupling efficiency β increases, the outcoupling ratio $\Sigma I_{2M}/I_0$ also increases. In particular, in the case where the outcoupling efficiency β is 0.05 or more, if the number of reflection n is 5 or more, an outcoupling ratio $\Sigma I_{2M}/I_0$ of 10% or more can be achieved.

As is evident from the foregoing, when the organic EL display 1 is designed so as to meet the relationship represented by the inequality (3), it becomes possible to more efficiently extract the light propagating in the in-plane direction from the waveguide layer 140. That is, the light outcoupling efficiency of the organic EL display 1 can be improved.

Although the foregoing description considers only attenuation of light $L1$ due to absorption of the waveguide layer 140, in actuality, the light $L1$ is attenuated by being reflected on the interface between the waveguide layer 140 and the second electrode 43. When attenuation of the light $L1$ caused by reflection on this interface is restricted, the outcoupling efficiency of the organic EL display 1 can be further improved.

FIG. 6 is a sectional view schematically showing an example of a structure which can be employed for the organic EL element of the organic EL display shown in

FIG. 1. FIG. 7 is a sectional view schematically showing another example of a structure which can be employed for the organic EL element of the organic EL display shown in FIG. 1. The organic EL element 40 shown in FIG. 6 and the organic EL element 40 shown in FIG. 7 have the same structure except for the second electrode 43 as a cathode.

In each organic EL element 40 of FIGS. 6 and 7, the first electrode 41 which is an anode includes an ITO layer 41a and an amorphous carbon layer 41b. The thickness of the ITO layer 41 is 50 nm, for example, and the thickness of the amorphous carbon layer 41b is 3 nm, for example.

In the organic EL element 40 of FIGS. 6 and 7, the active layer 42 includes the light emitting layer 42a, a TPT layer 42b, a BALq layer 42c, and an Alq₃ layer 42d. Note that the "TPT" is tetraphenylthiophene, Alq₃ is an aluminum complex in which three oxines coordinate with an aluminum atom, and BALq is obtained by substituting one of quinolate ligands of Alq₃ by phenolate. For example, the thickness of the light emitting layer 42a is 30 nm, and the thickness of the TPT layer 42b is 90 nm. In addition, for example, the thickness of the BALq layer is 10 nm, and the thickness of the Alq₃ layer is 40 nm.

In the organic EL element 40 of FIG. 6, the second electrode 42 which is a cathode includes an ITO layer

43a, an MgAg layer 43b, and an LiF layer 43c. For example, the thickness of the ITO layer 43a is 50 nm, the thickness of the MgAg layer 43b is 10 nm, and the thickness of the LiF layer is 1 nm.

5 On the other hand, in the organic EL element 40 of FIG. 7, the second electrode 42 which is a cathode includes an ITO layer 43a, an Ag layer 43d, an MgAg layer 43b, and an LiF layer 43c. In the organic element 40 of FIG. 7, for example, the thickness of the
10 ITO layer 43a is 50 nm, the thickness of the Ag layer 43d is 5 nm, the thickness of the MgAg layer 43b is 5 nm, and the thickness of the LiF layer is 1 nm. In this way, the organic EL element 40 of FIG. 7 is different from the organic element 40 of FIG. 6 in that
15 the Ag layer 43d is added to the second electrode 42 and the MgAg layer 43b is thinner.

An MgAg alloy is excellent as an electron injection layer. However, the MgAg alloy is comparatively large in light absorption.

20 In the organic EL element 40 of FIG. 6, if the MgAg layer 43b is thinner, light absorption by the second electrode 43 can be reduced. However, if the MgAg layer 43b is thin, an underlayer below the MgAg layer 43b is damaged when the ITO layer 43a is formed
25 on the MgAg layer.

In the organic EL element 40 of FIG. 7, the Ag layer 43d is placed between the MgAg layer 43b and the

ITO layer 43a. Ag is smaller in light absorption as compared with the MgAg alloy. In addition, the Ag layer 43d prevents the undercoat from being damaged when the ITO layer 43a is deposited. That is, when the structure of FIG. 7 is employed, light absorption by the second electrode 43 can be reduced as compared with a case in which the structure of FIG. 6 is employed. Moreover, it becomes possible to prevent the undercoat from being damaged when the ITO layer 43a is deposited.

Such effects can be attained by another method. For example, in the organic EL element 40 of FIG. 6, an Ag content in the MgAg layer 43b may be increased. For example, the Ag content may be increased from 7% to 50%. By doing this, light absorption by the second electrode 43 can be reduced.

Note that an amorphous carbon is a material whose light absorption is comparatively large. Therefore, it is desirable that an amorphous carbon layer 41b be thinly formed.

In addition, instead of the MgAg layer, for example, there may be used an organic substance layer doped with an alkaline metal element and/or an alkaline earth metal element, for example. For example, a layer of Alq₃ doped with Cs may be used. In this manner, it becomes possible to ensure transparency of a light-transmission electrode.

While the above embodiment has described a case of

placing the outcoupling layer on the back side of the organic EL element by way of example, the outcoupling layer may be placed on the front side of the organic EL element.

5 The outcoupling layer may employ another construction. For example, the outcoupling layer may employ a diffraction grating structure. The display may further include a flattening film for flattening irregularities on a surface of the outcoupling layer.

10 While the above embodiment has described a top emission structure, a bottom emission structure can be employed. When a bottom emission structure is employed, by using Ag as a material of a light-reflection upper electrode, absorption of light by a layer adjacent to a waveguide layer can be decreased as
15 compared with the case where Al is used as the material.

 As has been described above, when the layer adjacent to the waveguide layer is made of a material
20 having low light absorption, attenuation of light in the waveguide layer can be suppressed.

 In addition, in a display utilizing a reflection layer, by placing a material whose refractive index is lower than that of an organic layer or a transparent
25 electrode and whose absorption is low between the reflection layer and the transparent electrode, attenuation of light in the waveguide layer can be

suppressed.

In addition, by decreasing a thickness of a layer with large absorption coefficient included in the organic layer or by replacing the layer with large
5 absorption coefficient by a transparent layer attenuation of light in the waveguide layer can be suppressed.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore,
10 the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as
15 defined by the appended claims and their equivalents.

C L A I M S

1. An organic EL display comprising:

an organic EL element which comprises a first electrode, a second electrode facing the first electrode, and an active layer interposed between the first and second electrodes and including an emitting layer; and

an outcoupling layer facing the first electrode, wherein the organic EL element forms a waveguide layer which includes the first electrode and the active layer and in which light components from the emitting layer propagate in an in-plane direction parallel to a main surface of the waveguide layer while causing multiple-beam interference,

wherein a distance between the outcoupling layer and the waveguide layer is shorter than a wavelength of light from the organic EL element, and

wherein a guide length x in μm calculated by using a following equation (1), a number of reflection m calculated by using a following equation (2), an absorption coefficient α in μm^{-1} of the waveguide layer, and an outcoupling efficiency β of the outcoupling layer satisfy a relationship represented by a following inequality (3), where L is a thickness in μm of the waveguide layer, θ_i is an incident angle at which a light component with the highest intensity emitted by the emitting layer and propagating in the

in-plane direction in the waveguide layer while causing multiple-beam interference is incident on a main surface of the waveguide layer facing the outcoupling layer, and the outcoupling efficiency β is a luminous energy ratio of a light component extracted from the waveguide layer with respect to an incident light for a single reflection of the light component with the highest intensity on the main surface of the waveguide layer facing the outcoupling layer.

$$x = \frac{L}{\cos \theta_i} \quad \dots \quad (1)$$

$$m = \frac{1}{2} \left(\frac{\ln 100}{\alpha x} + 1 \right) \quad \dots \quad (2)$$

$$\beta \sum_{M=1}^m \frac{(1-\beta)^{M-1}}{\exp\{\alpha(2M-1)x\}} > 0.1 \quad \dots \quad (3)$$

2. The display according to claim 1, wherein the outcoupling efficiency β is 0.05 or more.

3. The display according to claim 1, wherein the number of reflection m is 5 or more.

4. The display according to claim 1, wherein the number of reflection m is 12 or less.

5. The display according to claim 1, wherein the display is a top emission display, and wherein the outcoupling layer is disposed on a back side of the organic EL element.

6. The display according to claim 1, wherein the display is a top emission display, and wherein the

outcoupling layer is disposed on a front side of the organic EL element.

7. The display according to claim 5, wherein the second electrode comprises a conductive oxide layer, an alloy layer which is interposed between the conductive oxide layer and the active layer, and a metal layer which is interposed between the conductive oxide layer and the alloy layer and is smaller in absorptance than the alloy layer.

8. The display according to claim 6, wherein the second electrode comprises a conductive oxide layer, an alloy layer which is interposed between the conductive oxide layer and the active layer, and a metal layer which is interposed between the conductive oxide layer and the alloy layer and is smaller in absorptance than the alloy layer.

9. The display according to claim 5, wherein the second electrode comprises a conductive oxide layer, and wherein the active layer further includes an organic layer which is interposed between the emitting layer and the conductive oxide layer and is doped with alkali metal element and/or alkaline-earth metal element.

10. The display according to claim 6, wherein the second electrode comprises a conductive oxide layer, and wherein the active layer further includes an organic layer which is interposed between the emitting

layer and the conductive oxide layer and is doped with alkali metal element and/or alkaline-earth metal element.