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(71) Applicants: **CAMBRIDGE DISPLAY TECHNOLOGY LIMITED** [GB/GB]; Building 2020, Cambourne Business Park, Cambridgeshire CB23 6DW (GB). **SUMITOMO CHEMICAL COMPANY LIMITED** [JP/JP]; Floor 18, Sumitomo Twin Buildings, 27-1, Shinkawa 2-chome, Chuo-ku, Tokyo 104-8260 (JP).

(72) Inventors: **DOUST, Alexander**; c/o Cambridge Display Technology Ltd, Building 2020 Cambourne Business Park, Cambridgeshire CB23 6DW (GB). **OWOARE, Richard**; 300A Mill Road, Cambridge CB1 3NL (GB). **JAKOBSSON, Fredrik**; 37B Pakenham Close, Cambridge CB4 1PW (GB).

(74) Agent: **SHARP, Alan**; c/o IP Department, Cambridge Display Technology Ltd, Building 2020, Cambourne Business Park, Cambridgeshire CB23 6DW (GB).

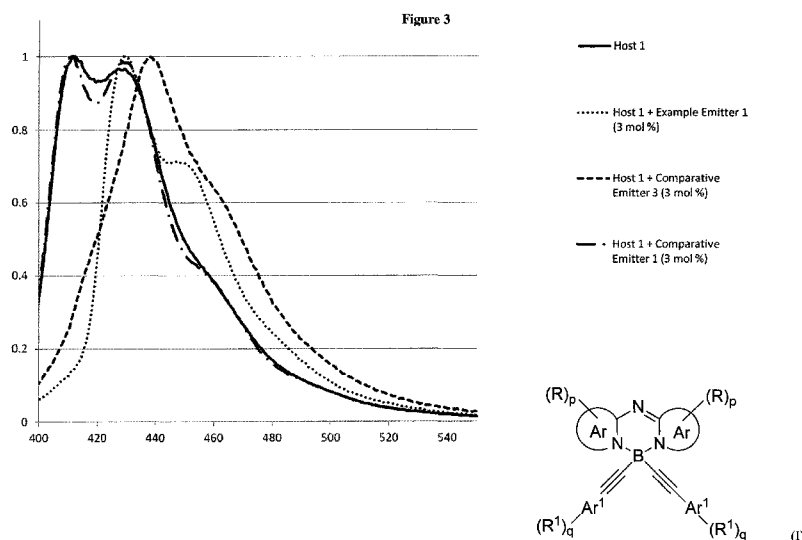
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(54) Title: LIGHT-EMITTING MATERIAL



LIGHT-EMITTING MATERIAL

Field of the invention

The present invention relates to light-emitting materials, in particular fluorescent light-emitting materials, compositions, formulations and light-emitting devices comprising said light-emitting materials and methods of making said light-emitting devices.

Background

Electronic devices containing active organic materials are attracting increasing attention for use in devices such as organic light emitting diodes (OLEDs), organic photoresponsive devices (in particular organic photovoltaic devices and organic photosensors), organic transistors and memory array devices. Devices containing active organic materials offer benefits such as low weight, low power consumption and flexibility. Moreover, use of soluble organic materials allows use of solution processing in device manufacture, for example inkjet printing or spin-coating.

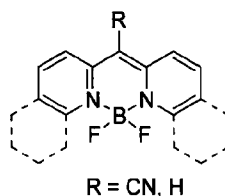
An OLED device may comprise a substrate carrying an anode, a cathode and one or more organic light-emitting layers between the anode and cathode.

Holes are injected into the OLED device through the anode and electrons are injected through the cathode during operation of the device. Holes in the highest occupied molecular orbital (HOMO) and electrons in the lowest unoccupied molecular orbital (LUMO) of a light-emitting material present within the OLED device combine to form an exciton that releases its energy as light.

Within an OLED device, the light-emitting material may be used as a dopant within a light emitting layer. The light-emitting layer may comprise a semiconducting host material and the light-emitting dopant, and energy will be transferred from the host material to the light-emitting dopant. For example, J. Appl. Phys. 65, 3610, 1989 discloses a host material doped with a fluorescent light-emitting dopant (that is, a light-emitting material in which light is emitted via decay of singlet excitons).

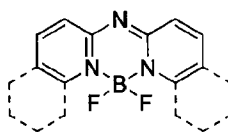
Suitable light-emitting materials developed to date include small molecule, polymeric and dendrimeric materials. Suitable light-emitting polymers include poly(arylene vinylenes) such as poly(p-phenylene vinylenes) and polyarylenes such as polyfluorenes.

US 7,329,466 discloses the following bis(azinyl) methane boron complex light-emitting compound:



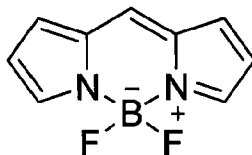
The luminescence maximum emission of these bis(azinyl) methane boron compounds is in the green region of the visible spectrum (around 520 nm).

US 6,903,214 and US 2003/0201415 disclose light-emitting devices comprising the following bis(azinyl)amine boron complex compound:



These compounds produce exciplex emission following excitation which results in poor colour purity.

F. Jäkle (*Chemical Reviews*, **2010**, *110*, 3985-4022) and Loudet & Burgess (*Chemical Reviews*, **2007**, *107*, 4891) disclose polymers with organoborane pendant groups having the following formula:

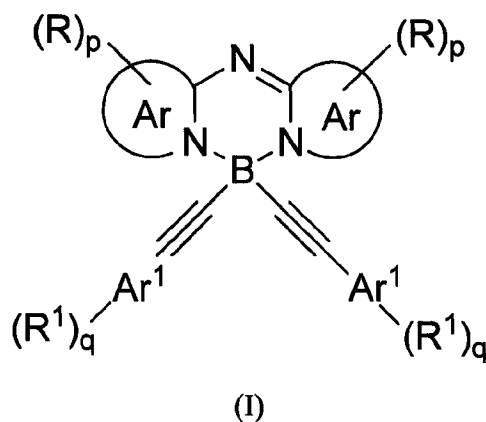


These publications provide examples of substitutions of the fluoride anions with carbon ligands and their incorporation into polymeric materials. These compounds provide fluorescent emission with a peak of above 500 nm.

It is an object of the present invention to provide boron-containing light-emitting materials, including deep blue fluorescent light-emitting materials, which have an improved efficiency of emission and increased stability compared to prior art compounds.

Summary of invention

The present inventors have identified materials that allow for efficient transport of holes and electrons whilst maintaining a HOMO-LUMO gap suitable for deep blue emission. The invention provides a material comprising a group of formula (I):



wherein:

each Ar is independently a heteroaryl group;

Ar¹ is independently selected from aryl and heteroaryl groups;

each R is independently a substituent;

each R^1 is independently a substituent; and
each p and q is independently 0 or a positive integer.

Preferably, the Ar groups are unsubstituted, (i.e. $p=0$ in formula I).

Preferably, the photoluminescent spectrum of the material has a peak at a wavelength of less than 450nm.

Preferably, the material has a CIE y co-ordinate of less than 0.1, preferably of less than 0.08.

The invention further provides a composition comprising a charge-transporting host material and a material as described above.

The invention further provides a formulation comprising a material as described above and at least one solvent.

The invention further provides an organic light-emitting device comprising an anode, a cathode and a light-emitting layer between the anode and the cathode, wherein the light-emitting layer comprises a material as described above.

The invention further provides a method of forming the organic light-emitting device, the method comprising the step of forming the light-emitting layer over one of the anode or cathode, and forming the other of the anode or cathode over the light-emitting layer.

Brief description of Figures

The invention will now be described in more detail with reference to the Figures, in which:

Figure 1, illustrates schematically a prior art OLED having a substrate (1) an anode (2), a light-emitting layer (3) and a cathode (4);

Figure 2 illustrates schematically an energy level diagram for the device of the invention; and

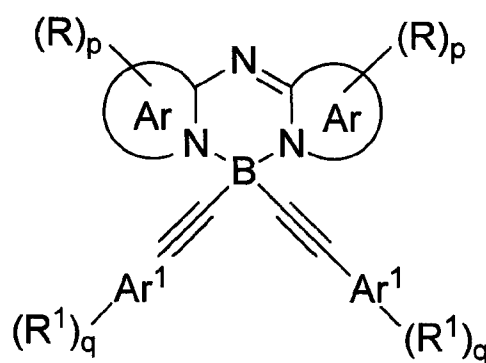
Figure 3 shows the emission spectra of the materials of the invention and comparative emitters.

Detailed Description of the Invention

The invention will now be described in more detail, with reference to the accompanying figures.

Fluorescent material

In a first aspect the invention provides a material comprising a group of formula (I):



(I)

wherein:

each Ar is independently a heteroaryl group;

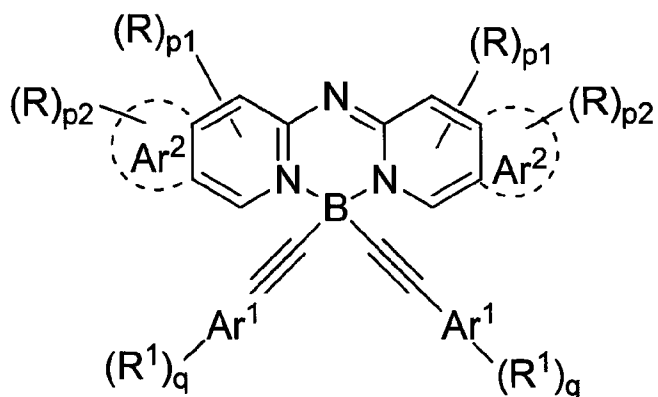
Ar¹ is independently selected from aryl and heteroaryl groups;

each R is independently a substituent;

each R¹ is independently a substituent;

each p and q are independently 0 or a positive integer.

In one optional arrangement according to the first aspect the material comprises a group of formula (II):



(II)

wherein:

R, R¹, Ar¹, and q are as defined above;

p1 and p2 in each occurrence are independently 0 or a positive integer and p1+p2 = p as defined above; and

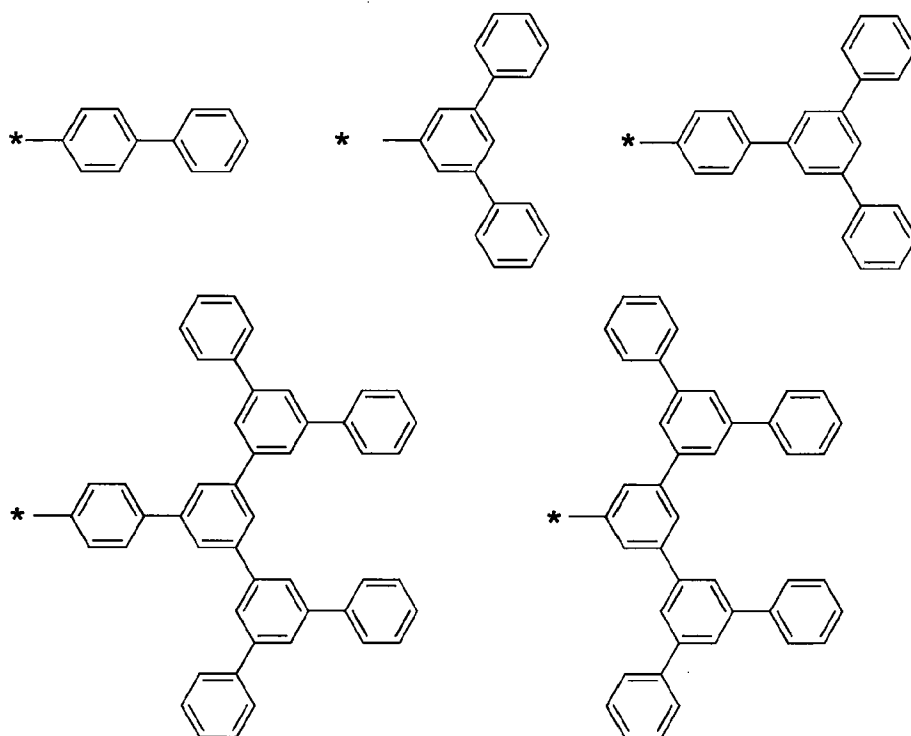
Ar² in each occurrence may be present or absent from formula (II) and is independently selected from aryl and heteroaryl groups.

Exemplary R and R¹ substituents include fluorine, hydrocarbyl groups, optionally C₁₋₆₀ hydrocarbyl, -OR¹², -NR¹²₂ or -BR¹²₂, wherein R¹² independently in each occurrence is a hydrocarbyl, optionally C₁₋₃₀ hydrocarbyl, optionally C₁₋₂₀ alkyl, unsubstituted phenyl or phenyl substituted with one or more C₁₋₂₀ alkyl groups.

Exemplary hydrocarbyl substituents R and R¹ include the following:

- C₁₋₂₀ alkyl
- Phenyl substituted with one or more C₁₋₂₀ alkyl groups
- A branched or linear chain of two or more phenyl rings, each of which ring may be substituted with one or more C₁₋₂₀ alkyl groups.

Exemplary substituents having branched or linear phenyl chains include the following, each of which may be substituted with one or more C₁₋₂₀ alkyl groups:



wherein * represents a point of attachment of the substituent to the boron complex.

Optionally, each R and R¹ is independently selected from the group consisting of fluorine and C₁₋₄₀ hydrocarbyl wherein one or more H atoms of the hydrocarbyl may be replaced by F.

Exemplary R and R¹ substituents also include a linear, branched or cyclic alkyl, aryl that may be unsubstituted or substituted with one or more C₁₋₂₀ alkyl groups or a linear or branched chain of aryl groups wherein each aryl may be unsubstituted or substituted with one or more C₁₋₂₀ alkyl groups.

Hydrocarbyl substituents may improve solubility of the materials of the invention in common organic solvents, for example mono- or poly-alkyl benzenes and anisole, as compared to materials in which such hydrocarbyl substituents are absent.

Optionally, each R and R¹ may be independently selected from a linear, branched or cyclic C₁₋₂₀ alkyl, and may comprise a tertiary carbon atom such as a tert-butyl group; aryl that may be unsubstituted or substituted with one or more substituents selected from

F, C₁₋₂₀ alkyl and C₁₋₂₀ fluoroalkyl; or a linear or branched chain of aryl groups, wherein each aryl group may be unsubstituted or substituted with one or more substituents selected from F, C₁₋₂₀ alkyl groups and C₁₋₂₀ fluoroalkyl.

Optionally, at least one R or R¹ is C₁₋₂₀ alkyl, optionally a branched C₁₋₂₀ alkyl.

Optionally, at least one of R and R¹ is unsubstituted phenyl or phenyl substituted with one or more C₁₋₂₀ alkyl groups.

Substituents R and R¹ may be selected according to their effect on colour of emission of the boron material. Substituents R and R¹ may also be selected according to their solubilising effect. For example, C₁₋₂₀ alkyl substituents may provide increased solubility of the inventive compounds in non-polar solvents such as mono- or poly-alkylated benzenes.

Each Ar is independently selected from heteroaryl groups and each Ar¹ is independently selected from aryl and heteroaryl groups.

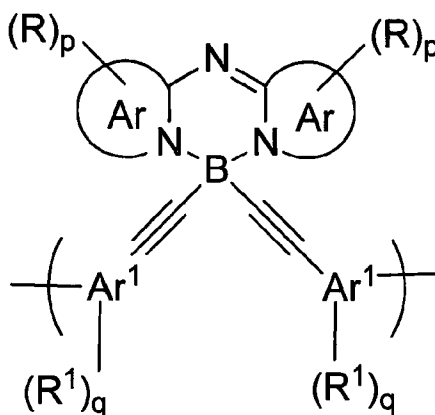
Preferably, at least one Ar¹ is a phenyl group and, optionally, each q is independently selected from 0, 1, 2, 3, 4, or 5.

Preferably, at least one Ar is pyridine or a pyridine ring fused with an aryl or heteroaryl group Ar².

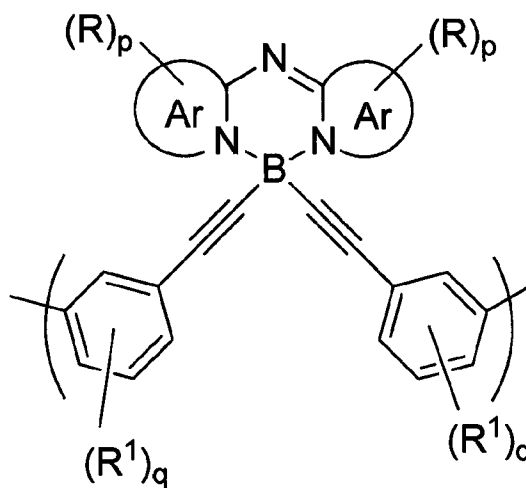
In one embodiment, each p and q may independently be selected from 0, 1, 2, 3 and 4.

The invention contemplates that the material of the invention is a compound of formula (I) or (II), as described above.

The invention also contemplates that the material of the invention is a polymer wherein the group of formula (I) or (II) is provided as a repeat unit of the polymer. Here the polymeric material may comprise a repeat unit of formula (III) or (IV):



(III)



(IV)

wherein R, R¹, Ar, Ar¹, p and q are as described above. In formula (IV) each q is independently selected from 0, 1, 2, 3 or 4.

Within this embodiment the polymer may further comprise charge transporting repeat units.

Optionally, a photoluminescence spectrum of the material of the invention has a peak at a wavelength of less than 450 nm.

Optionally, the material of the invention may have a CIE y co-ordinate of less than 0.1, preferably of less than 0.08.

Unless stated otherwise, “aryl” and “heteroaryl” as used herein includes monocyclic and polycyclic aromatic and heteroaromatic groups.

Compositions & formulations

In a further aspect the invention provides a composition comprising a charge-transporting host material and a material according to the invention.

Optionally according to this aspect, the light-emitting material of the invention is provided in an amount of 0.5-10 mol % of the host + light-emitting material weight..

The charge-transporting host material may be a polymer.

In another aspect the invention provides a formulation comprising a material or composition according to the invention and at least one solvent.

The invention also relates to a white light emitting composition comprising a material of the invention.

Host Material

Host materials for use in combination with the materials of the invention include hole-transporting and electron-transporting host materials.

The host material preferably has a singlet excited state energy level S_1 that is no more than 0.1 eV lower than, and more preferably the same as or higher than, the S_1 energy level of the material of the invention.

The material of the invention may be a compound mixed with the host material or may be covalently bound to the host material. In the case where the host material is a

polymer, the material of the invention may be provided as a main chain unit, a side group or an end group of the polymer.

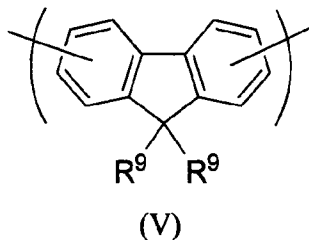
In the case where the material of the invention is provided as a side group, the material may be directly bound to a main chain of the polymer or spaced apart from the main chain by a spacer group. Exemplary spacer groups include C₁₋₂₀ alkyl groups, aryl-C₁₋₂₀ alkyl groups and C₁₋₂₀ alkoxy groups.

If the material of the invention is bound to a polymer comprising conjugated repeat units then it may be bound to the polymer such that there is no conjugation between the conjugated repeat units and the material of the invention, or such that the extent of conjugation between the conjugated repeat units and the material of the invention is limited.

Exemplary host polymers include polymers having a non-conjugated backbone with charge-transporting groups pendant from the non-conjugated backbone, for example poly(9-vinylcarbazole), and polymers comprising conjugated repeat units in the backbone of the polymer.

Exemplary repeat units of a conjugated polymer include optionally substituted monocyclic and polycyclic arylene repeat units as disclosed in for example, Adv. Mater. 2000 12(23) 1737-1750 and include: 1,2-, 1,3- and 1,4-phenylene repeat units as disclosed in J. Appl. Phys. 1996, 79, 934; 2,7-fluorene repeat units as disclosed in EP0842208; indenofluorene repeat units as disclosed in, for example, Macromolecules 2000, 33(6), 2016-2020; and spirofluorene repeat units as disclosed in, for example EP0707020. Each of these repeat units is optionally substituted. Examples of substituents include solubilising groups such as C₁₋₂₀ alkyl or alkoxy; electron withdrawing groups such as fluorine, nitro or cyano; and substituents for increasing glass transition temperature (T_g) of the polymer.

One exemplary class of arylene repeat units is optionally substituted fluorene repeat units, such as repeat units of formula V:



wherein R^9 in each occurrence is the same or different and is H or a substituent, and wherein the two groups R^9 may be linked to form a ring.

Each R^9 is preferably a substituent, and each R^9 may independently be selected from the group consisting of:

- optionally substituted alkyl, optionally C_{1-20} alkyl, wherein one or more non-adjacent C atoms may be replaced with optionally substituted aryl or heteroaryl, O, S, substituted N, C=O or -COO-;
- optionally substituted aryl or heteroaryl;
- a linear or branched chain of aryl or heteroaryl, each of which groups may independently be substituted, for example a group of formula $-(Ar^6)_r$, as described below with reference to formula (VI); and
- a crosslinkable-group, for example a group comprising a double bond such as a vinyl or acrylate group, or a benzocyclobutane group.

In the case where R^9 comprises aryl or heteroaryl ring system, or a linear or branched chain of aryl or heteroaryl ring systems, the or each aryl or heteroaryl ring system may be substituted with one or more substituents R^3 selected from the group consisting of:

- alkyl, for example C_{1-20} alkyl, wherein one or more non-adjacent C atoms may be replaced with O, S, substituted N, C=O and -COO- and one or more H atoms of the alkyl group may be replaced with F or aryl or heteroaryl optionally substituted with one or more groups R^4 ,
- aryl or heteroaryl optionally substituted with one or more groups R^4 ,
- NR^5_2 , OR^5 , SR^5 , and
- fluorine, nitro and cyano;

wherein each R^4 is independently alkyl, for example C_{1-20} alkyl, in which one or more non-adjacent C atoms may be replaced with O, S, substituted N, C=O and -COO- and one or more H atoms of the alkyl group may be replaced with F, and each R^5 is independently selected from the group consisting of alkyl and aryl or heteroaryl optionally substituted with one or more alkyl groups.

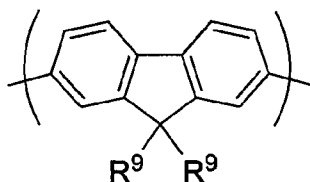
Optional substituents for one or more of the aromatic carbon atoms of the fluorene unit are preferably selected from the group consisting of alkyl, for example C_{1-20} alkyl, wherein one or more non-adjacent C atoms may be replaced with O, S, NH or substituted N, C=O and -COO-, optionally substituted aryl, optionally substituted heteroaryl, alkoxy, alkylthio, fluorine, cyano and arylalkyl. Particularly preferred substituents include C_{1-20} alkyl and substituted or unsubstituted aryl, for example phenyl. Optional substituents for the aryl include one or more C_{1-20} alkyl groups.

Where present, substituted N may independently in each occurrence be NR^6 wherein R^6 is alkyl, optionally C_{1-20} alkyl, or optionally substituted aryl or heteroaryl. Optional substituents for aryl or heteroaryl R^6 may be selected from R^4 or R^5 .

Preferably, each R^9 is selected from the group consisting of C_{1-20} alkyl and optionally substituted phenyl. Optional substituents for phenyl include one or more C_{1-20} alkyl groups.

If the material of the invention is provided as a side-chain of the polymer then at least one R^9 may comprise a material of the invention that is either bound directly to the 9-position of a fluorene unit of formula (VI) or spaced apart from the 9-position by a spacer group.

The repeat unit of formula (V) may be a 2,7-linked repeat unit of formula (Va):

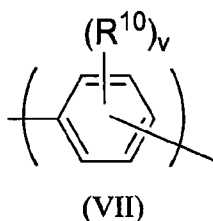


(Va)

Optionally, the repeat unit of formula (Va) is not substituted in a position adjacent to the 2- or 7- positions.

The extent of conjugation of repeat units of formulae (V) may be limited by (a) linking the repeat unit through the 3- and / or 6- positions to limit the extent of conjugation across the repeat unit, and / or (b) substituting the repeat unit with one or more further substituents R^1 in or more positions adjacent to the linking positions in order to create a twist with the adjacent repeat unit or units, for example a 2,7-linked fluorene carrying a C_{1-20} alkyl substituent in one or both of the 3- and 6-positions.

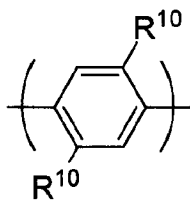
Another exemplary class of arylene repeat units is phenylene repeat units, such as phenylene repeat units of formula (VII):



wherein v is 0, 1, 2, 3 or 4, optionally 1 or 2, and R^{10} independently in each occurrence is a substituent, optionally a substituent R^9 as described above with reference to formula (V), for example C_{1-20} alkyl, and phenyl that is unsubstituted or substituted with one or more C_{1-20} alkyl groups.

The repeat unit of formula (VII) may be 1,4- linked, 1,2-linked or 1,3-linked.

If the repeat unit of formula (VII) is 1,4-linked and if v is 0 then the extent of conjugation of repeat unit of formula (VII) to one or both adjacent repeat units may be relatively high. If v is at least 1, and / or the repeat unit is 1,2- or 1,3 linked, then the extent of conjugation of repeat unit of formula (VII) to one or both adjacent repeat units may be relatively low. In one preferred arrangement, the repeat unit of formula (VII) is 1,3-linked and v is 0, 1, 2 or 3. In another preferred arrangement, the repeat unit of formula (VII) has formula (VIIa):



(VIIa)

A host polymer may comprise charge-transporting units CT that may be hole-transporting units or electron transporting units.

A hole transporting unit may have a low electron affinity (2 eV or lower) and low ionisation potential (5.8 eV or lower, preferably 5.7 eV or lower, more preferred 5.6 eV or lower).

An electron-transporting unit may have a high electron affinity (1.8 eV or higher, preferably 2 eV or higher, even more preferred 2.2 eV or higher) and high ionisation potential (5.8 eV or higher). Suitable electron transport groups include groups disclosed in, for example, Shirota and Kageyama, Chem. Rev. 2007, 107, 953-1010.

Electron affinities and ionisation potentials may be measured by cyclic voltammetry (CV) wherein the working electrode potential is ramped linearly versus time.

When cyclic voltammetry reaches a set potential the working electrode's potential ramp is inverted. This inversion can happen multiple times during a single experiment. The current at the working electrode is plotted versus the applied voltage to give the cyclic voltammogram trace.

Apparatus to measure HOMO or LUMO energy levels by CV may comprise a cell containing a tert-butyl ammonium perchlorate/ or tertbutyl ammonium hexafluorophosphate solution in acetonitrile, a glassy carbon working electrode where the sample is coated as a film, a platinum counter electrode (donor or acceptor of electrons) and a reference glass electrode no leak Ag/AgCl. Ferrocene is added in the cell at the end of the experiment for calculation purposes.

Measurement of the difference of potential between Ag/AgCl/ferrocene and sample/ferrocene.

Method and settings:

3mm diameter glassy carbon working electrode

Ag/AgCl/no leak reference electrode

Pt wire auxiliary electrode

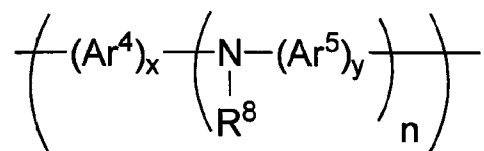
0.1 M tetrabutylammonium hexafluorophosphate in acetonitrile

LUMO = 4.8 - ferrocene (peak to peak maximum average) + onset

Sample: 1 drop of 5mg/mL in toluene spun at 3000rpm

LUMO (reduction) measurement: A good reversible reduction event is typically observed for thick films measured at 200 mV/s and a switching potential of -2.5V. The reduction events should be measured and compared over 10 cycles, usually measurements are taken on the 3rd cycle. The onset is taken at the intersection of lines of best fit at the steepest part of the reduction event and the baseline.

Exemplary hole-transporting units CT include optionally substituted (hetero)arylamine repeat units, for example repeat units of formula (VIII):



(VIII)

wherein Ar⁴ and Ar⁵ in each occurrence are independently selected from optionally substituted aryl or heteroaryl, n is greater than or equal to 1, preferably 1 or 2, R⁸ is H or a substituent, preferably a substituent, and x and y are each independently 1, 2 or 3.

Ar⁴ and Ar⁵ may each independently be a monocyclic or fused ring system.

R^8 , which may be the same or different in each occurrence when $n > 1$, is preferably selected from the group consisting of alkyl, for example C_{1-20} alkyl, Ar^6 , a branched or linear chain of Ar^6 groups, or a crosslinkable unit that is bound directly to the N atom of formula (VIII) or spaced apart therefrom by a spacer group, wherein Ar^6 in each occurrence is independently optionally substituted aryl or heteroaryl. Exemplary spacer groups are as described above, for example C_{1-20} alkyl, phenyl and phenyl- C_{1-20} alkyl.

Ar^6 groups may be substituted with one or more substituents as described below. An exemplary branched or linear chain of Ar^6 groups may have formula $-(Ar^6)_r$, wherein Ar^6 in each occurrence is independently selected from aryl or heteroaryl and r is at least 1, optionally 1, 2 or 3. An exemplary branched chain of Ar^6 groups is 3,5-diphenylbenzene. Any of Ar^4 , Ar^5 and Ar^6 may independently be substituted with one or more substituents. Preferred substituents are selected from the group R^{11} consisting of:

- alkyl, for example C_{1-20} alkyl, wherein one or more non-adjacent C atoms may be replaced with O, S, substituted N, C=O and -COO- and one or more H atoms of the alkyl group may be replaced with F or aryl or heteroaryl optionally substituted with one or more groups R^4 ,
- aryl or heteroaryl optionally substituted with one or more groups R^4 ,
- NR^5_2 , OR^5 , SR^5 ,
- fluorine, nitro and cyano;

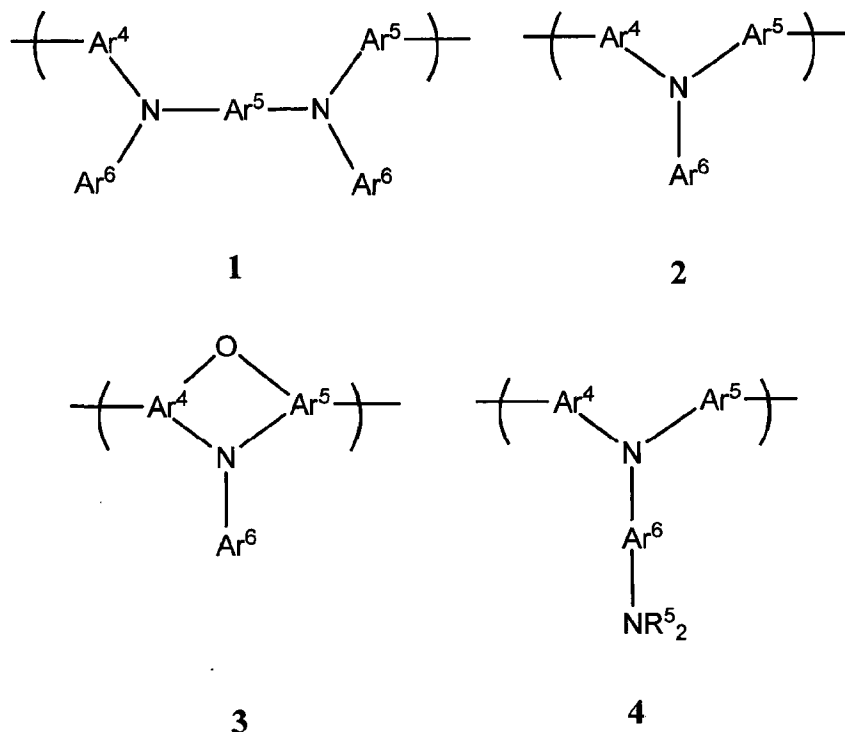
wherein each R^4 is independently alkyl, for example C_{1-20} alkyl, in which one or more non-adjacent C atoms may be replaced with O, S, substituted N, C=O and -COO- and one or more H atoms of the alkyl group may be replaced with F, and each R^5 is independently selected from the group consisting of alkyl and aryl or heteroaryl optionally substituted with one or more alkyl groups.

Any two of Ar^4 , Ar^5 and, if present, Ar^6 in the repeat unit of Formula (VIII) that are directly linked to a common N atom may be linked by a direct bond or a divalent linking atom or group. Preferred divalent linking atoms and groups include O, S; substituted N; and substituted C.

Where present, substituted N or substituted C of R^{11} , R^4 or of the divalent linking group may independently in each occurrence be NR^6 or CR^6_2 respectively wherein R^6 is alkyl or optionally substituted aryl or heteroaryl. Optional substituents for aryl or heteroaryl R^6 are C_{1-20} alkyl.

In one preferred arrangement, R^8 is Ar^6 and each of Ar^4 , Ar^5 and Ar^6 are independently and optionally substituted with one or more C_{1-20} alkyl groups.

Particularly preferred units satisfying Formula (VIII) include units of Formulae 1-4:



Where present, preferred substituents for Ar^6 include substituents as described for Ar^4 and Ar^5 , in particular alkyl and alkoxy groups.

Ar^4 , Ar^5 and Ar^6 are preferably phenyl, each of which may independently be unsubstituted or substituted with one or more substituents as described above.

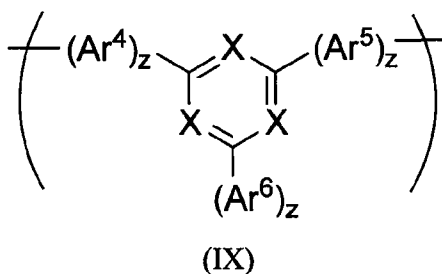
In another preferred arrangement, Ar^4 , Ar^5 and Ar^6 are phenyl, each of which may be unsubstituted or substituted with one or more C_{1-20} alkyl groups, and $r = 1$.

In another preferred arrangement, Ar^4 and Ar^5 are phenyl, each of which may be unsubstituted or substituted with one or more C_{1-20} alkyl groups, and R^8 is 3,5-diphenylbenzene wherein each phenyl of R^8 may be unsubstituted or substituted with one or more C_{1-20} alkyl groups.

In another preferred arrangement, n , x and y are each 1 and Ar^4 and Ar^5 are phenyl linked by an oxygen atom to form a phenoxazine ring, and R^8 is phenyl or 3,5-diphenylbenzene that is unsubstituted or substituted with one or more C_{1-20} alkyl groups.

Triazines form an exemplary class of electron-transporting units, for example optionally substituted di- or tri-(hetero)aryltriazine attached as a side group through one of the (hetero)aryl groups. Other exemplary electron-transporting units are pyrimidines and pyridines; sulfoxides and phosphine oxides; benzophenones; and boranes, each of which may be unsubstituted or substituted with one or more substituents, for example one or more C_{1-20} alkyl groups.

Exemplary electron-transporting units CT have formula (IX):



wherein Ar^4 , Ar^5 and Ar^6 are as described with reference to formula (VIII) above, and may each independently be substituted with one or more substituents described with reference to Ar^4 , Ar^5 and Ar^6 , and z in each occurrence is independently at least 1, optionally 1, 2 or 3 and X is N or CR^7 , wherein R^7 is H or a substituent, preferably H or C_{1-10} alkyl. Preferably, Ar^4 , Ar^5 and Ar^6 of formula (IX) are each phenyl, each phenyl being optionally and independently substituted with one or more C_{1-20} alkyl groups.

In one preferred embodiment, all 3 groups X are N.

If all 3 groups X are CR⁷ then at least one of Ar⁴, Ar⁵ and Ar⁶ is preferably a heteroaromatic group comprising N.

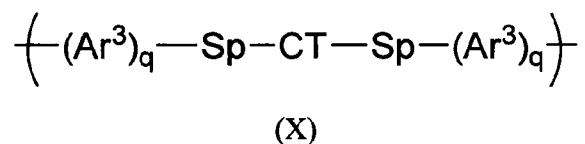
Each of Ar⁴, Ar⁵ and Ar⁶ may independently be substituted with one or more substituents. In one arrangement, Ar⁴, Ar⁵ and Ar⁶ are phenyl in each occurrence. Exemplary substituents include R¹¹ as described above with reference to formula (VIII), for example C₁₋₂₀ alkyl or alkoxy.

Ar⁶ of formula (IX) is preferably phenyl, and is optionally substituted with one or more C₁₋₂₀ alkyl groups or a crosslinkable unit. The crosslinkable unit may be bound directly to Ar⁶ or spaced apart from Ar⁶ by a spacer group.

A preferred repeat unit of formula (IX) is 2,4-6-triphenyl-1,3,5-triazine wherein the phenyl groups are unsubstituted or substituted with one or more C₁₋₂₀ alkyl groups.

Electron transport may also be provided by a conjugated chain of arylene repeat units, for example a conjugated chain of fluorene repeat units of formula (Va) or a conjugated chain of phenylene repeat units of formula (VIIa). A conjugated chain of arylene repeat units may be provided by polymerising monomers containing individual arylene groups, or monomers containing a chain of 2 or more conjugated arylene groups, for example a monomer containing a conjugated chain of 2-4 fluorene units.

The charge-transporting units CT may be provided as distinct repeat units formed by polymerising a corresponding monomer. Alternatively, the one or more CT units may form part of a larger repeat unit, for example a repeat unit of formula (X):



wherein CT represents a conjugated charge-transporting group; each Ar³ independently represents an unsubstituted or substituted aryl or heteroaryl; q is at least 1, optionally 1, 2

or 3; and each Sp independently represents a spacer group forming a break in conjugation between Ar³ and CT.

Sp is preferably a branched, linear or cyclic C₁₋₂₀ alkyl group.

Exemplary CT groups may be units of formula (IX) or (X) described above.

Ar³ is preferably an unsubstituted or substituted aryl, optionally an unsubstituted or substituted phenyl or fluorene. Optional substituents for Ar³ may be selected from R³ as described above, and are preferably selected from one or more C₁₋₂₀ alkyl substituents. q is preferably 1.

The polymer may comprise repeat units that block or reduce conjugation along the polymer chain and thereby increase the polymer bandgap. For example, the polymer may comprise units that are twisted out of the plane of the polymer backbone, reducing conjugation along the polymer backbone, or units that do not provide any conjugation path along the polymer backbone. Exemplary repeat units that reduce conjugation along the polymer backbone are substituted or unsubstituted 1,3-substituted phenylene repeat units, and 1,4-phenylene repeat substituted with a C₁₋₂₀ alkyl group in the 2- and / or 5-position, as described above with reference to formula (VII).

The molar percentage of charge transporting repeat units in the polymer may be in the range of up to 75 mol %, optionally in the range of up to 50 mol % of the total number of repeat units of the polymer.

Devices

In a further aspect the invention provides an organic light-emitting device comprising an anode, a cathode and a light-emitting layer between the anode and the cathode wherein the light-emitting layer comprises a material according to the invention.

Optionally according to this aspect the light-emitting layer comprises a composition according to the invention, as discussed above.

In another optional arrangement the organic light-emitting device according to this aspect further comprises a hole-transporting layer between the anode and the light-emitting layer

In another aspect the invention provides a method of forming an organic light-emitting device according to the invention, the method comprising the step of forming the light-emitting layer over one of the anode and cathode, and forming the other of the anode or cathode over the light-emitting layer.

Optionally, the light-emitting layer is formed by depositing a formulation according to the invention and evaporating the at least one solvent.

With reference to Figure 2A, the light-emitting layer (3) of an OLED according to an embodiment of the invention contains a host material H and a fluorescent material F according to the invention. Host material H has a highest occupied molecular orbital (HOMO) level H_H and a lowest unoccupied molecular orbital (LUMO) level L_H . The fluorescent material has HOMO level H_F and LUMO level L_F .

In operation, holes are injected from the anode (2) and electrons are injected from the cathode (4). The holes and electrons combine in light-emitting layer 3 to form an exciton on fluorescent material F that undergoes radiative decay.

If the fluorescent material has a large host-fluorescent material LUMO energy gap $L_F - L_H$ then electrons may become trapped on the fluorescent material. Furthermore, it will be appreciated that a deeper LUMO of the fluorescent material will result in a smaller host HOMO – fluorescent material LUMO energy gap $H_H - L_F$. Electron trapping and a relatively small $H_H - L_F$ may both increase the probability of undesirable exciplex formation.

The present inventors have found that organoboron light-emitting compounds in which the boron atom is substituted with fluorine have deep LUMO levels and may consequently give rise to exciplex formation when used in combination with a host

material. By using the alkyne groups of the present invention, the present inventors have found that blue light-emitting materials with shallower LUMO levels may be provided.

With reference to Figure 1, further layers may be provided between the anode and the cathode including, without limitation, charge-transporting layers, charge-blocking layers and charge injection layers. The device may contain more than one light-emitting layer.

Exemplary OLED structures including one or more further layers include the following:

Anode / Hole-injection layer / Light-emitting layer / Cathode

Anode / Hole transporting layer / Light-emitting layer / Cathode

Anode / Hole-injection layer / Hole-transporting layer / Light-emitting layer / Cathode

Anode / Hole-injection layer / Hole-transporting layer / Light-emitting layer / Electron-transporting layer / Cathode.

In one preferred embodiment, the OLED comprises at least one, optionally both, of a hole injection layer and a hole transporting layer.

The light-emitting layer may contain further light-emitting materials, for example further fluorescent or phosphorescent light-emitting materials having a colour of emission differing from or the same as that of materials of formula (I).

Polymer synthesis

Preferred methods for preparation of conjugated polymers, such as polymers comprising one or more of the repeat units (III) – (X) described above, comprise a “metal insertion” wherein the metal atom of a metal complex catalyst is inserted between an aryl or heteroaryl group and a leaving group of a monomer. Exemplary metal insertion methods are Suzuki polymerisation as described in, for example, WO00/53656 and Yamamoto polymerisation as described in, for example, T. Yamamoto, "Electrically Conducting And Thermally Stable pi-Conjugated Poly(arylene)s Prepared by Organometallic Processes", Progress in Polymer Science 1993, 17, 1153-1205. In the case of Yamamoto

polymerisation, a nickel complex catalyst is used; in the case of Suzuki polymerisation, a palladium complex catalyst is used.

For example, in the synthesis of a linear polymer by Yamamoto polymerisation, a monomer having two reactive halogen groups is used. Similarly, according to the method of Suzuki polymerisation, at least one reactive group is a boron derivative group such as a boronic acid or boronic ester and the other reactive group is a halogen. Preferred halogens are chlorine, bromine and iodine, most preferably bromine.

It will therefore be appreciated that repeat units illustrated throughout this application may be derived from a monomer carrying suitable leaving groups. Likewise, an end group or side group may be bound to the polymer by reaction of a suitable leaving group. Suzuki polymerisation may be used to prepare regioregular, block and random copolymers. In particular, homopolymers or random copolymers may be prepared when one reactive group is a halogen and the other reactive group is a boron derivative group. Alternatively, block or regioregular copolymers may be prepared when both reactive groups of a first monomer are boron and both reactive groups of a second monomer are halogen.

As alternatives to halides, other leaving groups capable of participating in metal insertion include sulfonic acids and sulfonic acid esters such as tosylate, mesylate and triflate.

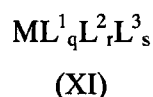
White OLEDs

An OLED containing a material of the invention may emit white light.

The emitted white light may have a CIE x coordinate equivalent to that emitted by a black body at a temperature in the range of 2500-9000K and a CIE y coordinate within 0.05 or 0.025 of the CIE y co-ordinate of said light emitted by a black body, optionally a CIE x coordinate equivalent to that emitted by a black body at a temperature in the range of 2700-4500K.

White light may be formed from blue emission from a material of the invention, and one or more fluorescent or phosphorescent materials emitting light at longer wavelengths that, together with emission of the material invention, provide white light. The further light-emitting materials may be provided in the same layer as the material of the invention or in one or more further light-emitting layers.

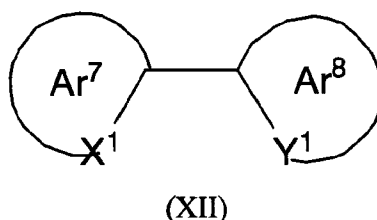
Exemplary longer wavelength phosphorescent light-emitting materials include metal complexes comprising substituted or unsubstituted complexes of formula (XI):



wherein M is a metal; each of L^1 , L^2 and L^3 is a coordinating group; q is a positive integer; r and s are each independently 0 or a positive integer; and the sum of (a. q) + (b. r) + (c.s) is equal to the number of coordination sites available on M, wherein a is the number of coordination sites on L^1 , b is the number of coordination sites on L^2 and c is the number of coordination sites on L^3 .

Suitable heavy metals M include d-block metals, in particular those in rows 2 and 3 i.e. elements 39 to 48 and 72 to 80, in particular ruthenium, rhodium, palladium, rhenium, osmium, iridium, platinum and gold. Iridium is particularly preferred.

One, two or all of L^1 , L^2 and L^3 may include carbon or nitrogen donors such as porphyrin or bidentate ligands of formula (XII):



wherein Ar^7 and Ar^8 may be the same or different and are independently selected from substituted or unsubstituted aryl or heteroaryl; X^1 and Y^1 may be the same or different and are independently selected from carbon or nitrogen; and Ar^7 and Ar^8 may be fused together. Ligands wherein X^1 is carbon and Y^1 is nitrogen are preferred, in particular ligands in which Ar^8 is a single ring or fused heteroaromatic of N and C atoms only, for

example pyridyl or isoquinoline, and Ar⁸ is a single ring or fused aromatic, for example phenyl or naphthyl. Exemplary substituents for Ar⁷ and Ar⁸ are substituents R⁹ as described above with reference to formula (V), for example one or more C₁₋₆₀ hydrocarbyl groups.

Exemplary combinations for obtaining white light include blue and yellow emitters and blue, red and green emitters.

A green emitter may have a photoluminescent peak in the range of 490 nm to less than 580 nm. Exemplary phosphorescent green emitters include *fac*-tris(2-phenylpyridine)iridium(III), which may be substituted with one or more substituents, for example one or more C₁₋₆₀ hydrocarbyl groups.

Red emitters may have a photoluminescent peak wavelength of at least 580 nm, optionally in the range 580-700 nm. Exemplary phosphorescent red emitters include *fac*-tris(1-phenylisoquinoline)iridium(III), which may be substituted with one or more substituents, for example one or more C₁₋₆₀ hydrocarbyl groups.

A white-emitting OLED may have a single light-emitting layer emitting white light, or may contain two or more light-emitting layers wherein the light emitted from the two or more layers combine to provide white light.

Hole injection layer

A conductive hole injection layer, which may be formed from a conductive organic or inorganic material, may be provided between the anode and the light-emitting layer or layers of an OLED to improve hole injection from the anode into the layer or layers of semiconducting polymer. Examples of doped organic hole injection materials include optionally substituted, doped poly(ethylene dioxythiophene) (PEDT), in particular PEDT doped with a charge-balancing polyacid such as polystyrene sulfonate (PSS) as disclosed in EP0901176 and EP0947123, polyacrylic acid or a fluorinated sulfonic acid, for example Nafion®; polyaniline as disclosed in US 5,723,873 and US 5,798,170; and optionally substituted polythiophene or poly(thienothiophene). Examples of conductive

inorganic materials include transition metal oxides such as VOx MoOx and RuOx as disclosed in Journal of Physics D: Applied Physics (1996), 29(11), 2750-2753.

Charge transporting and charge blocking layers

A hole transporting layer may be provided between the anode and the light-emitting layer or layers. Likewise, an electron transporting layer may be provided between the cathode and the light-emitting layer or layers.

Similarly, an electron blocking layer may be provided between the anode and the light-emitting layer and a hole blocking layer may be provided between the cathode and the light-emitting layer. Transporting and blocking layers may be used in combination. Depending on its HOMO and LUMO levels, a single layer may both transport one of holes and electrons and block the other of holes and electrons.

A charge-transporting layer or charge-blocking layer may be cross-linked, particularly if a layer overlying that charge-transporting or charge-blocking layer is deposited from a solution. The cross-linkable group used for this cross-linking may be a cross-linkable group comprising a reactive double bond such as a vinyl or acrylate group, or a benzocyclobutane group.

If present, a hole transporting layer located between the anode and the light-emitting layers preferably has a HOMO level of less than or equal to 5.5 eV, more preferably around 4.8-5.5 eV as measured by cyclic voltammetry. The HOMO level of the hole transport layer may be selected so as to be within 0.2 eV, optionally within 0.1 eV, of an adjacent layer (such as a light-emitting layer) in order to provide a small barrier to hole transport between these layers.

If present, an electron transporting layer located between the light-emitting layers and cathode preferably has a LUMO level of around 2.5-3.5 eV as measured by square wave cyclic voltammetry. For example, a layer of a silicon monoxide or silicon dioxide or other thin dielectric layer having thickness in the range of 0.2-2nm may be provided

between the light-emitting layer nearest the anode and the cathode. HOMO and LUMO levels may be measured using cyclic voltammetry.

A hole transporting layer may contain a hole-transporting (hetero)arylamine, such as a homopolymer or copolymer comprising hole transporting repeat units of formula (VIII). Exemplary copolymers comprise repeat units of formula (VIII) and optionally substituted (hetero)arylene co-repeat units, such as phenyl, fluorene or indenofluorene repeat units as described above, wherein each of said (hetero)arylene repeat units may optionally be substituted with one or more substituents such as alkyl or alkoxy groups. Specific co-repeat units include fluorene repeat units of formula (V) and optionally substituted phenylene repeat units of formula (VI) as described above.

If a charge-transporting layer is provided adjacent to a light-emitting layer containing a material or compound of formula (I) then the singlet energy level of the material or materials of the charge transporting layer are preferably at least the same as or higher than that of the material or compound of formula (I).

An electron transporting layer may contain a polymer comprising a chain of optionally substituted arylene repeat units, such as a chain of fluorene repeat units.

Cathode

The cathode is selected from materials that have a work function allowing injection of electrons into the light-emitting layer. Other factors influence the selection of the cathode such as the possibility of adverse interactions between the cathode and the light-emitting material. The cathode may consist of a single material such as a layer of aluminium. Alternatively, it may comprise a plurality of metals, for example a bilayer of a low work function material and a high work function material such as calcium and aluminium as disclosed in WO98/10621. The cathode may contain a layer of elemental barium as disclosed in WO98/57381, Appl. Phys. Lett. 2002, 81(4), 634 and WO02/84759. The cathode may contain a thin layer of metal compound between the light-emitting layer(s) of the OLED and one or more conductive cathode layers, for example one or more metal layers, to assist electron injection. Metal compounds include,

in particular, an oxide or fluoride of an alkali or alkali earth metal, for example lithium fluoride as disclosed in WO00/48258; barium fluoride as disclosed in Appl. Phys. Lett. 2001, 79(5), 2001; and barium oxide. In order to provide efficient injection of electrons into the device, the cathode preferably has a work function of less than 3.5 eV, more preferably less than 3.2 eV, most preferably less than 3 eV. Work functions of metals can be found in, for example, Michaelson, J. Appl. Phys. 48(11), 4729, 1977.

The cathode may be opaque or transparent. Transparent cathodes are particularly advantageous for active matrix devices because emission through a transparent anode in such devices is at least partially blocked by drive circuitry located underneath the emissive pixels. A transparent cathode comprises a layer of an electron injecting material that is sufficiently thin to be transparent. Typically, the lateral conductivity of this layer will be low as a result of its thinness. In this case, the layer of electron injecting material is used in combination with a thicker layer of transparent conducting material such as indium tin oxide.

It will be appreciated that a transparent cathode device need not have a transparent anode (unless, of course, a fully transparent device is desired), and so the transparent anode used for bottom-emitting devices may be replaced or supplemented with a layer of reflective material such as a layer of aluminium. Examples of transparent cathode devices are disclosed in, for example, GB2348316.

Encapsulation

Organic optoelectronic devices tend to be sensitive to moisture and/or oxygen. Accordingly, the substrate preferably has good barrier properties for prevention of ingress of moisture and oxygen into the device. The substrate is commonly glass, but alternative substrates may also be used, in particular where flexibility of the device is desirable. For example, the substrate may comprise one or more plastic layers, for example a substrate of alternating plastic and dielectric barrier layers or a laminate of thin glass and plastic.

The device may be encapsulated with an encapsulant (not shown in Figures) to prevent ingress of moisture and/or oxygen. Suitable encapsulants include a sheet of glass, films

having suitable barrier properties such as silicon dioxide, silicon monoxide, silicon nitride or alternating stacks of polymer and dielectric or an airtight container. In the case of a transparent cathode device, a transparent encapsulating layer such as silicon monoxide or silicon dioxide may be deposited to micron levels of thickness, although in one preferred embodiment the thickness of such a layer is in the range of 20-300 nm. A getter material for absorption of any atmospheric moisture and/or oxygen that may permeate through the substrate or encapsulant may be disposed between the substrate and the encapsulant.

Formulation processing

A material of the invention may be dispersed or dissolved in a solvent or mixture of two or more solvents to form a formulation that may be used to form a layer containing the material or compound by depositing the formulation and evaporating the solvent or solvents. The formulation may contain one or more further materials in addition to a material of the invention, for example the formulation may contain a host material. All of the components of the formulation may be dissolved in the solvent or solvent mixture, in which case the formulation is a solution, or one or more components may be dispersed in the solvent or solvent mixture. Exemplary solvents for use alone or in a solvent mixture include aromatic compounds, preferably benzene, that may be unsubstituted or substituted with one or more substituents selected from C₁₋₁₀ alkyl, C₁₋₁₀ alkoxy and halogens preferably chlorine, for example toluene, xylene or anisole.

Techniques for forming layers from a formulation include printing and coating techniques such spin-coating, dip-coating, flexographic printing, gravure printing, screen printing and inkjet printing.

Multiple organic layers of an OLED may be formed by deposition of formulations containing the active materials for each layer.

During OLED formation, a layer of the device may be cross-linked to prevent it from partially or completely dissolving in the solvent or solvents used to deposit an overlying layer. Layers that may be cross-linked include a hole-transporting layer prior to

formation by solution processing of an overlying light-emitting layer, or crosslinking of one light-emitting layer prior to formation by solution processing of another, overlying light-emitting layer.

Suitable cross-linkable groups include groups comprising a reactive double bond such as a vinyl or acrylate group, or a benzocyclobutane group. Where a layer to be cross-linked contains a polymer, the cross-linkable groups may be provided as substituents of repeat units of the polymer.

Coating methods such as spin-coating are particularly suitable for devices wherein patterning of the light-emitting layer is unnecessary, for example for lighting applications or simple monochrome segmented displays.

Printing methods such as inkjet printing are particularly suitable for high information content displays, in particular full colour displays. A device may be inkjet printed by providing a patterned layer over the first electrode and defining wells for printing of one colour (in the case of a monochrome device) or multiple colours (in the case of a multicolour, in particular full colour device). The patterned layer is typically a layer of photoresist that is patterned to define wells as described in, for example, EP0880303.

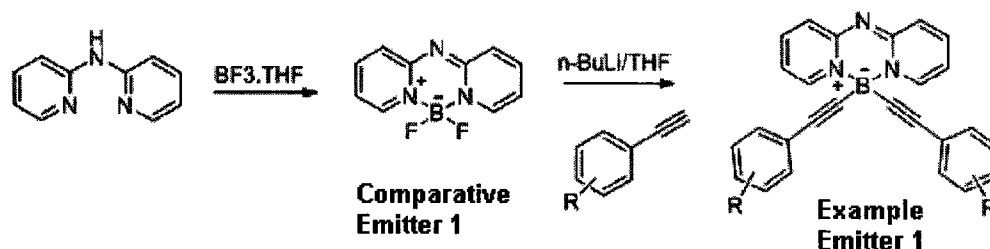
As an alternative to wells, the ink may be printed into channels defined within a patterned layer. In particular, the photoresist may be patterned to form channels which, unlike wells, extend over a plurality of pixels and which may be closed or open at the channel ends.

Examples

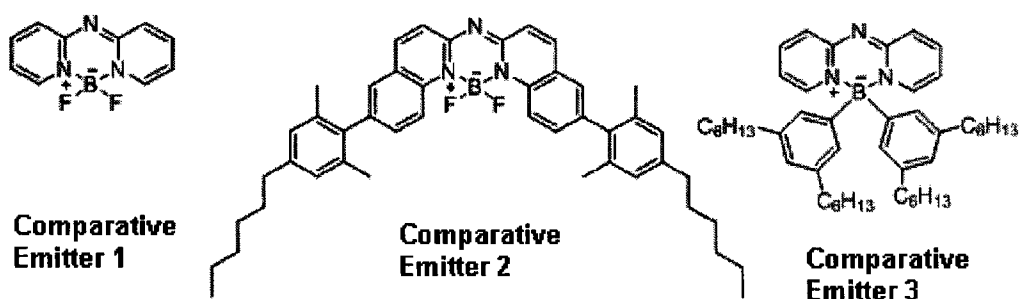
The invention will now be described by means of example only by reference to the following Examples.

Preparation and stability of Emitters

Example Emitter 1 is prepared according to the following reaction scheme:



The following boron based emitters have been made and tested as comparative emitters 1-3:



Linear alkyne groups of Example Emitter 1 provide a planar N-B-N arrangement. This avoids potential strain-induced colour shift and chemical instability from, for example, direct phenyl attachment to the Boron atom e.g. in comparative example 3.

Comparison of emission properties

Electronic and photoluminescent properties of Example Emitter 1 and the comparative emitters are provided in Table 1, below.

Table 1: Emission Properties

Emitter	CIE _x	CIE _y	Peak Abs (nm)	Peak PL (nm)	HOMO (eV)	LUMO (eV)
Comparative Compound 1	0.161	0.049	397	402	-5.71	-3.06
Comparative	0.141	0.108	444	447		

Compound 2						
Comparative Compound 3	0.153	0.056	411	433	-5.64	-2.31
Example Compound 1	0.162	0.058	435	430	-5.56	-2.44

HOMO and LUMO energy levels were measured by cyclic voltammetry as described in detail above, using a cell containing a tert-butyl ammonium perchlorate/ or tertbutyl ammonium hexafluorophosphate solution in acetonitrile, a glassy carbon working electrode where the sample is coated as a film, a platinumium counter electrode (donor or acceptor of electrons) and a reference glass electrode no leak Ag/AgCl.

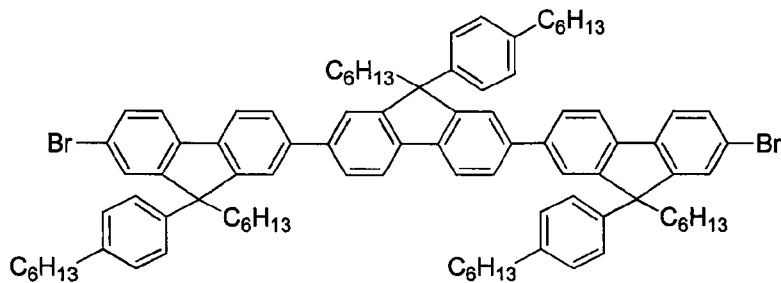
Example Compound 1 has a shallower LUMO energy level than comparative emitters 1 and 2 as shown in Table 1. It has also a peak emission shifted towards a shorter wavelength in the blue region of the spectrum compared to that of the comparative emitters 1 and 3.

Compostion Examples

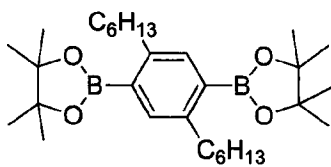
A composition of the Example Emitter 1 or the comparative emitters 1 - 3 and a host polymer Host 1 were dissolved in an organic solvent, and the solution was deposited onto a glass substrate by spin-coating to form a film of the composition. Films were spun from a suitable solvent on quartz disks to achieve transmittance values of 0.3-0.4.

Measurements were performed under nitrogen in an integrating sphere connected to Hamamatsu C9920-02 with Mercury lamp E7536 and a monochromator for choice of exact wavelength.

Host 1 was formed by Suzuki polymerisation of the following monomers, following the method described in WO 00/53656:

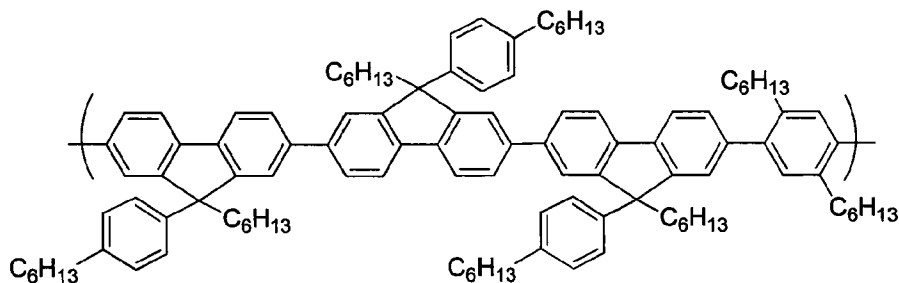


50 mol %



50 mol %

Host 1 is an alternating AB copolymer containing fluorene trimer units separated by phenylene repeat units. The alkyl substituents of the phenylene repeat units cause steric hindrance between the phenylene units and the adjacent trimer units, causing the phenylene units to twist out of the plane of the trimer units and limit the extent of conjugation between fluorene trimer units separated by phenylene repeat units.



The fluorene trimer monomer was prepared according to the following method:

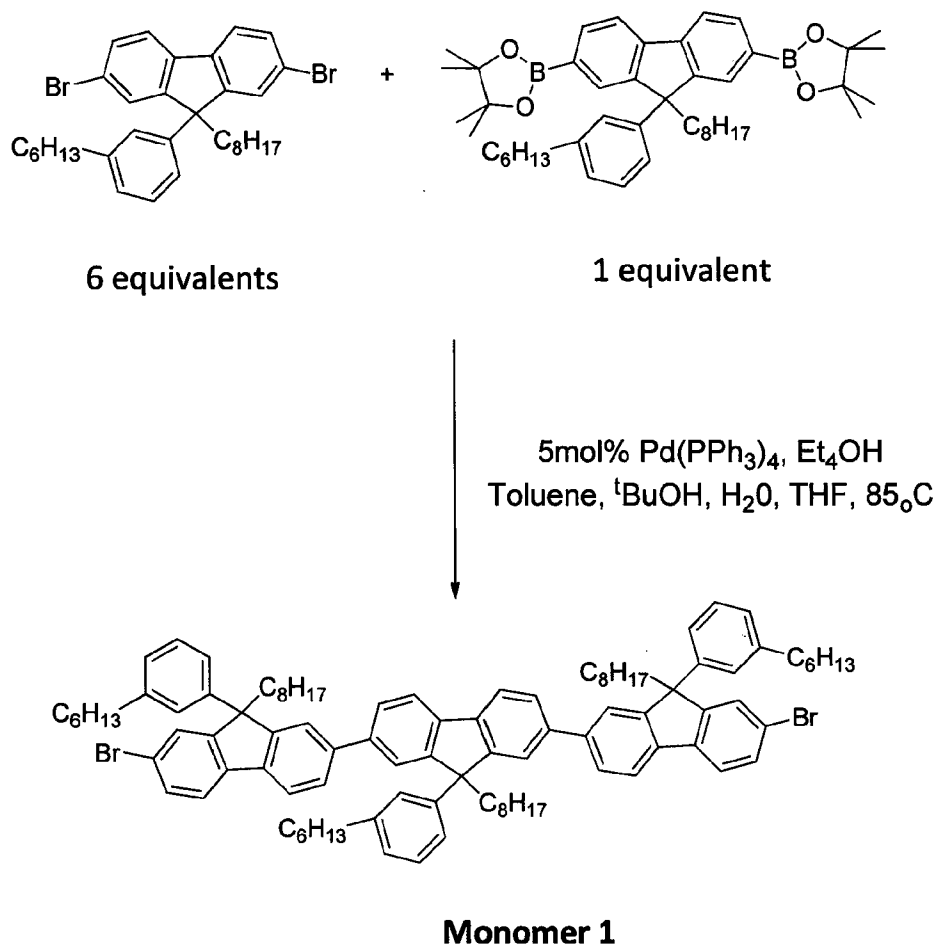


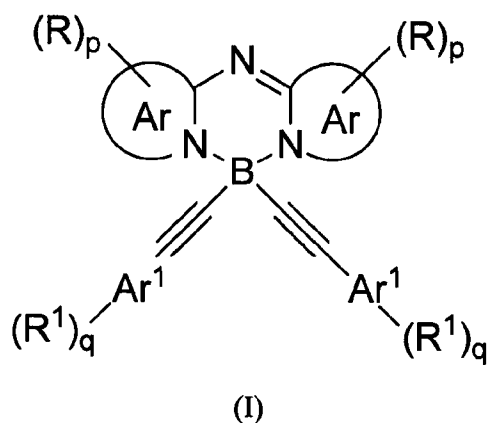
Figure 3A illustrates the photoluminescence spectra for Host 1 : emitter compositions in a 97 : 3 weight ratio. Example Emitter 1 has a peak at around 430 nm. Comparative Emitter 3 has a peak at around 440 nm.

The emission of Comparative Emitter 1 is indistinguishable from that of the host material.

Although the present invention has been described in terms of specific exemplary embodiments, it will be appreciated that various modifications, alterations and/or combinations of features disclosed herein will be apparent to those skilled in the art without departing from the scope of the invention as set forth in the following claims.

CLAIMS

1. A material comprising a group of formula (I):



wherein:

each Ar is independently a heteroaryl group;

Ar¹ is independently selected from aryl and heteroaryl groups;

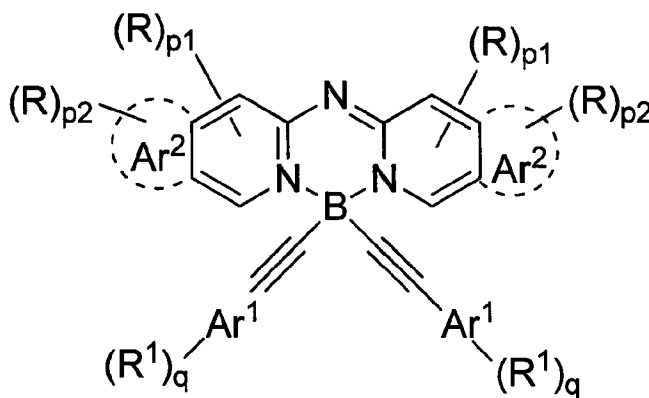
each R is independently a substituent;

each R¹ is independently a substituent; and

each p and q is independently 0 or a positive integer.

2. The material of claim 1 wherein each R and R¹ are independently selected from the group consisting of F; and C₁₋₄₀ hydrocarbyl wherein one or more H atoms of the hydrocarbyl may be replaced by F.
3. The material of claim 1 wherein each R and R¹ are independently selected from a linear, branched or cyclic C₁₋₂₀ alkyl; aryl that may be unsubstituted or substituted with one or more substituents selected from F, C₁₋₂₀ alkyl and C₁₋₂₀ fluoroalkyl; or a linear or branched chain of aryl groups, wherein each aryl group may be unsubstituted or substituted with one or more substituents selected from F, C₁₋₂₀ alkyl groups and C₁₋₂₀ fluoroalkyl.

4. The material according to any preceding claim wherein at least one R or R¹ is C₁₋₂₀ alkyl, optionally a branched C₁₋₂₀ alkyl.
5. The material according to any preceding claim, wherein at least one Ar¹ is a phenyl group and q is 0, 1, 2, 3, 4, or 5.
6. The material according to any preceding claim wherein at least one Ar is pyridine or is a pyridine ring fused with an aryl or heteroaryl group.
7. The material according to claim 6, comprising a group of formula (II)

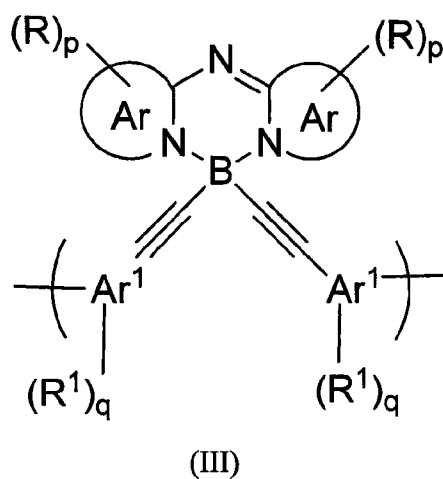


(II)

wherein R, R¹, Ar¹, and q are as defined in any preceding claim;
 p₁ and p₂ in each occurrence are independently 0 or a positive integer and p₁+p₂ = p as defined in any preceding claim;
 and
 Ar² in each occurrence may be present or absent from formula (II) and is independently selected from aryl and heteroaryl groups.

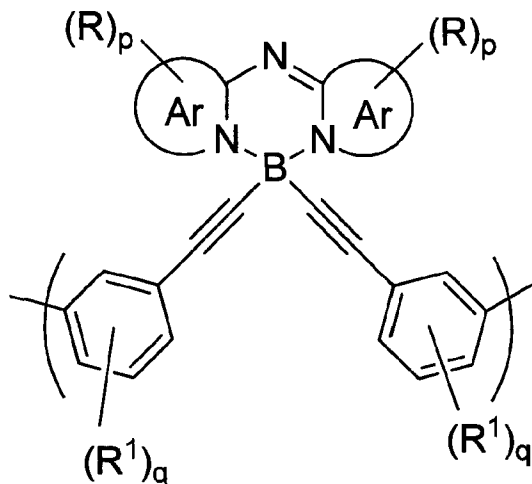
8. A compound of formula (I) or (II) according to any preceding claim.

9. The material according to any one of claims 1-7, wherein said material is a polymer and wherein groups of formula (I) or (II) are provided as repeat units of the polymer.
10. The material according to claim 9 wherein the polymer further comprises charge transporting repeat units.
11. The material according to claim 9 or 10 comprising a repeat unit of formula (III)



wherein R, R¹, Ar, Ar¹, p and q are as defined in any preceding claim.

12. The material according to any one of claims 9-11 comprising a repeat unit of formula (IV)



(IV)

wherein R, R¹, Ar and p are as defined in any preceding claim and q is 0, 1, 2, 3 or 4.

13. A composition comprising a charge-transporting host material and a material according to any preceding claim.
14. A composition according to claim 13 wherein the charge-transporting host material is a polymer.
15. A composition according to claim 13 or 14 wherein the material of any one of claims 1-12 is mixed with the charge-transporting host material.
16. A white light emitting composition comprising the material of any one of claims 1-12.
17. A formulation comprising a material according to any of claims 1-12 and at least one solvent.

18. A formulation according to claim 19 wherein the formulation comprises a composition according to any one of claims 13-16.
19. An organic light-emitting device comprising an anode, a cathode and a light-emitting layer between the anode and the cathode, wherein the light-emitting layer comprises a material according to any one of claims 1-12.
20. The organic light-emitting device according to claim 19 wherein the light-emitting layer comprises a composition according to any one of claims 13-16.

Figure 1

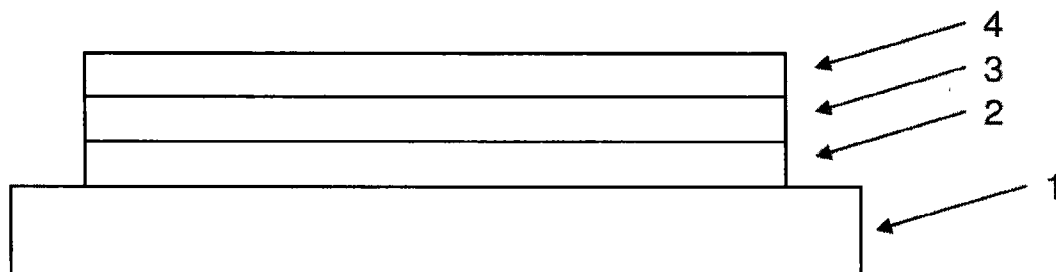


Figure 2

Vacuum level -----

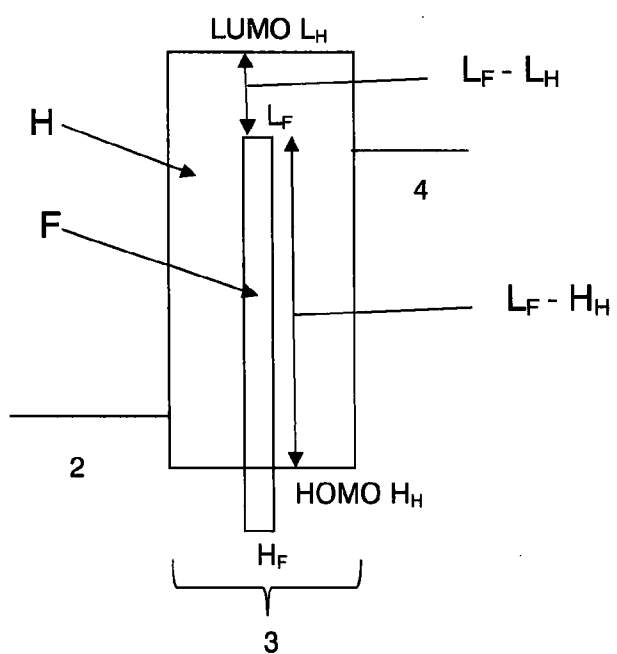
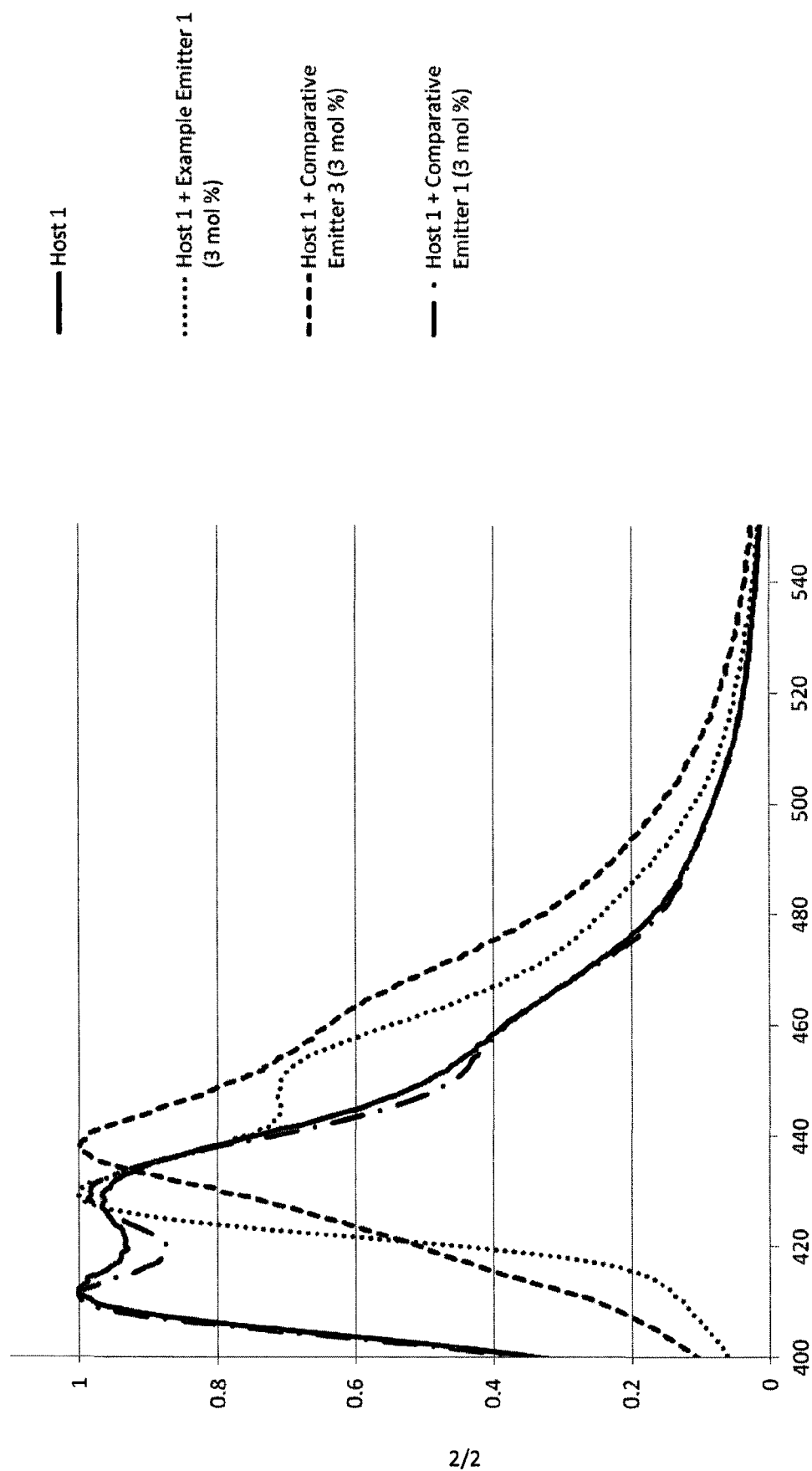


Figure 3



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2013/000516

A. CLASSIFICATION OF SUBJECT MATTER
INV. C09K11/06 H05B33/10 C07F5/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C09K H05B C07F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, CHEM ABS Data, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KAZUO TANAKA ET AL: "Advanced Luminescent Materials Based on Organoboron Polymers", MACROMOLECULAR RAPID COMMUNICATIONS, vol. 33, no. 15, 22 June 2012 (2012-06-22) , pages 1235-1255, XP055098201, ISSN: 1022-1336, DOI: 10.1002/marc.201200239 page 1235 page 1247 - page 1249; figures 19,22 ----- -/--	1-20

☒ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 January 2014

Date of mailing of the international search report

03/02/2014

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Doslik, Natasa

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2013/000516

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ATSUSHI NAGAI ET AL: "Highly Luminescent BODIPY-Based Organoboron Polymer Exhibiting Supramolecular Self-Assemble Structure", JOURNAL OF THE AMERICAN CHEMICAL SOCIETY, vol. 130, no. 46, 19 November 2008 (2008-11-19), pages 15276-15278, XP055098225, ISSN: 0002-7863, DOI: 10.1021/ja806939w page 15276 - page 15278; figures -----	1-20
X	XIN-DONG JIANG ET AL: "Synthesis and properties of NIR aza-BODIPYs with aryl and alkynyl substituents on the boron center", TETRAHEDRON LETTERS, vol. 53, no. 42, 1 October 2012 (2012-10-01), pages 5703-5706, XP055098194, ISSN: 0040-4039, DOI: 10.1016/j.tetlet.2012.08.056 page 5704 - page 5705; table 1; compounds 3-7 -----	1-8,17
X	LOUDET A ET AL: "BODIPY dyes and their derivatives: Syntheses and spectroscopic properties", CHEMICAL REVIEWS, AMERICAN CHEMICAL SOCIETY, US, vol. 107, no. 11, 1 January 2007 (2007-01-01), pages 4891-4932, XP002547571, ISSN: 0009-2665, DOI: 10.1021/CR078381N [retrieved on 2007-10-09] page 4914 - page 4916; compounds 160,161,165-167,171,173-178 -----	1-8,13, 17,18