(12) UK Patent Application (19) GB (11) 2593130 (13) A

(43) Date of A Publication 22.09.2021

(21) Application No: 1915461.6

(22) Date of Filing: 24.10.2019

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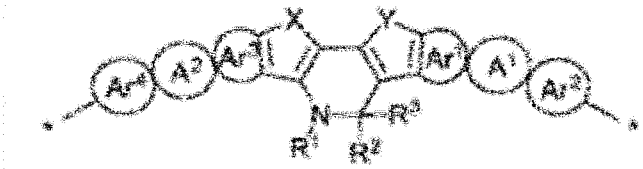
(51) INT CL:
C09K 11/06 (2006.01) ***C07D 495/04*** (2006.01)
C07D 519/00 (2006.01) ***C08G 61/12*** (2006.01)
H01L 51/00 (2006.01)

(56) Documents Cited:
WO 2012/146504 A1 **JP 2015189853 A**
Pan et al, "A facilely synthesized lactam acceptor unit for high-performance polymer donors", RSC Adv., 2017, 7, 3439-3442
Schneider et al, "Wide bandgap OPV polymers based on pyridinonedithiophene unit with efficiency>5%", Chem. Sci., 2015, 6, 4860-4866

(58) Field of Search:
INT CL **C07D, C08G, C09K**
Other: **WPI, EPODOC, CAS ONLINE**

(54) Title of the Invention: **Photoactive materials**
Abstract Title: **Photoactive materials**

(57) A photoactive material comprises a compound of formula (I):

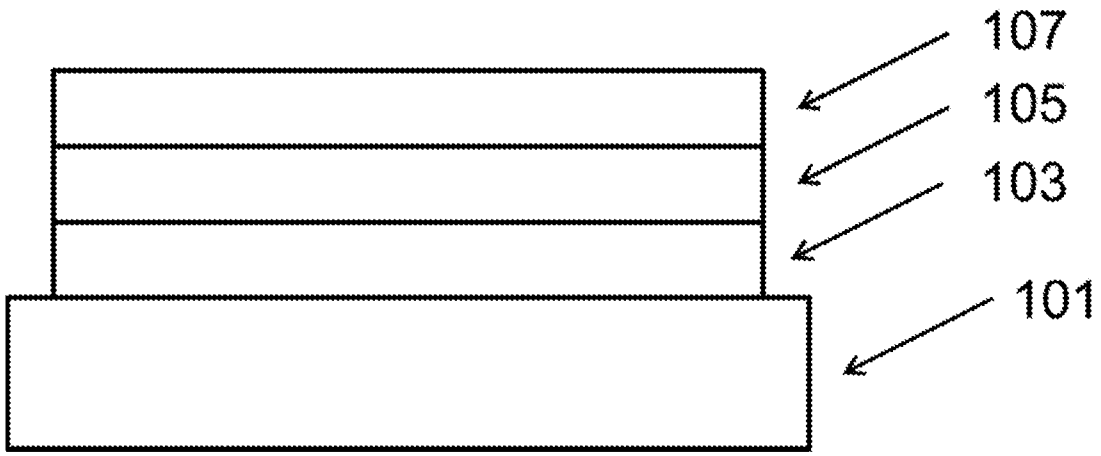


(I)

Wherein A^1 and A^2 are each independently an unsubstituted or a substituted benzene, an unsubstituted or a substituted 5- or 6- membered heteroaromatic group or are absent; Ar^1-Ar^4 are each independently an unsubstituted or a substituted benzene, an unsubstituted or a substituted 5- or 6- membered heteroaromatic group, a non-aromatic 6-membered ring having ring atoms from C, N and O or are absent;, R^1 is a substituent; R^2 and R^3 are each independently H or a substituent; X and Y are independently selected from S, O or Se. Also shown is a photoresponsive device i.e. an organic photodetector comprising the material; and a method of forming the organic photosensor. A method of detection and/or concentration determination of a target substance is also shown.

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FIGURE 1



PHOTOACTIVE MATERIALS

BACKGROUND

Embodiments of the present disclosure relate to photoactive compounds and more specifically, but not by way of limitation, to photoactive compounds comprising electron donating groups.

Organic photovoltaic devices and organic photodetectors (OPDs) are known.

JP2015189853 relates to a polymer compound and an electronic element using the same.

WO 2017/155030 and WO 2019/054402 relate to tetrazolopyridine compounds.

WO 2017/078182 relates to benzimidazole fused heteroaryls.

WO 2012/146504 is directed to semiconductor materials based on dithienopyridone copolymers.

CN104211926 relates to a polymerization monomer for a donor material of a polymer solar battery.

KR2013070431 is directed to a multicyclic aromatic compound and organic light emitting device including the same.

US 2018/0175307 relates to organic electroluminescent materials and devices.

Pan et al., RSC Advances, volume 7, pages 3439–3442 is directed to a facilely synthesized lactam acceptor unit for high-performance polymer donors.

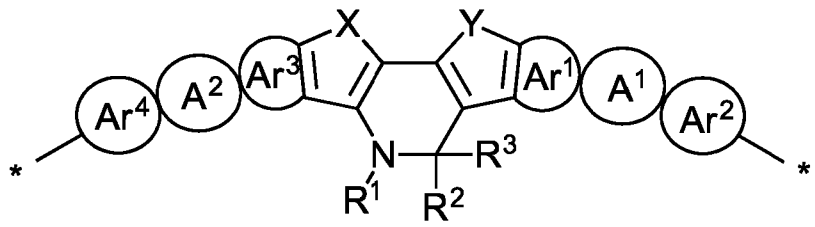
Cao et al., Dyes and Pigments, volume 139, pages 201–207 relates to D-A copolymers based on lactam acceptor unit and thiophene derivatives for efficient polymer solar cells.

SUMMARY

A summary of aspects of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects and/or a combination of aspects that may not be set forth.

According to some embodiments, the present disclosure provides a material comprising an electron donor material.

The material may comprise a group of formula (I):



(I)

wherein:

X and Y are each independently selected from S, O or Se;

Ar^1, Ar^2, Ar^3 and Ar^4 are each independently an unsubstituted or a substituted benzene, an unsubstituted or a substituted 5- or 6- membered heteroaromatic group or are absent;

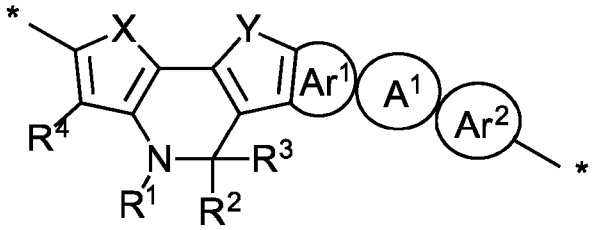
A^1 and A^2 are each independently an unsubstituted or a substituted benzene, an unsubstituted or a substituted 5- or 6- membered heteroaromatic group, a non-aromatic 6-membered ring having ring atoms selected from C, N and O or are absent;

R^1 is a substituent;

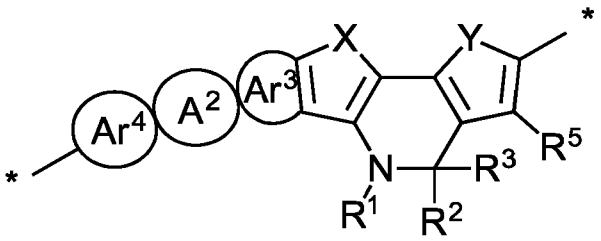
R^2 and R^3 are each independently H or a substituent; and

* represents a point of attachment to a hydrogen or non-hydrogen group.

The group of formula I may have formula (Ia) or formula (Ib):



formula (Ia)



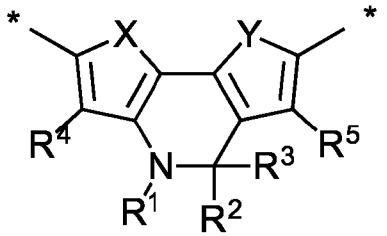
formula (Ib)

wherein:

X, Y, R^1, R^2 and R^3 and * are as defined previously; and

R^4 and R^5 are each independently H or a substituent.

In some embodiments, Ar^1, A^1, Ar^2, Ar^3 A^2 and Ar^4 are absent and the group of formula (I) has formula (Ic):

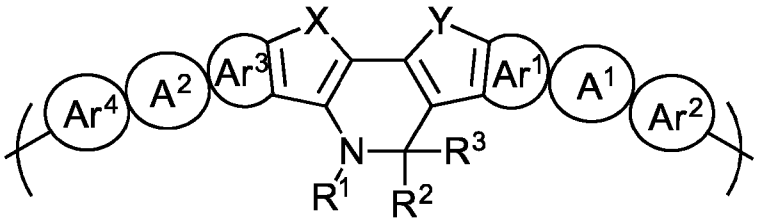


formula (Ic)

wherein:

X, Y, R^1, R^2, R^3, R^4, R^5 and * are as defined previously.

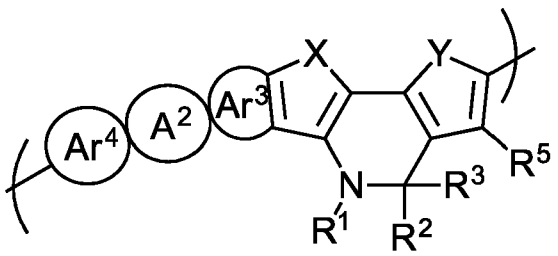
In some embodiments, the material is a polymer comprising a repeat unit of formula (Id):



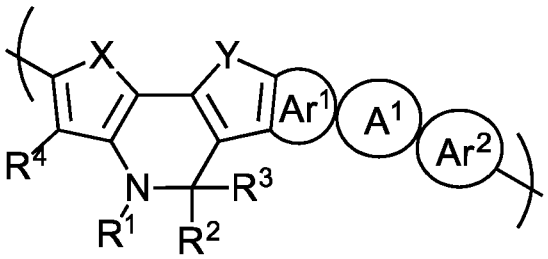
formula (Id)

wherein X, Y, R^1 to R^5, Ar^1 to Ar^4, A^1 and A^2 are as previously defined previously.

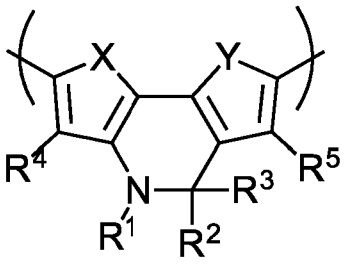
Exemplary repeat units of formula (Id) are formulae (**Ie**), (If) and (Ig):



formula (Ie)



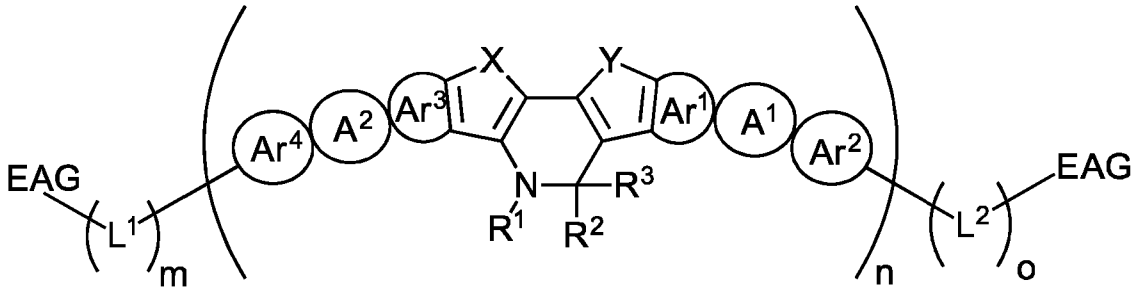
formula (If)



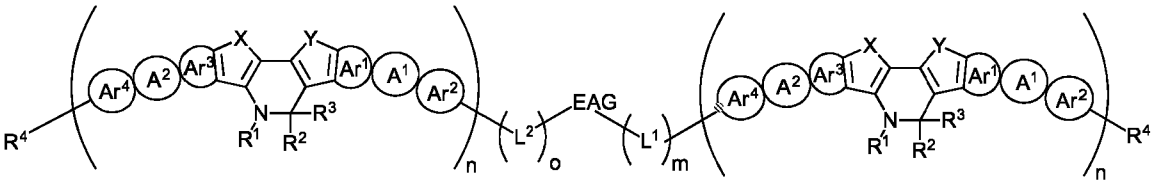
formula (Ig)

In some embodiments, the material comprises an electron accepting group, EAG.

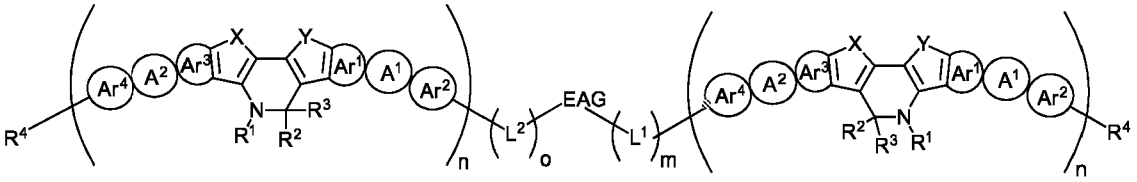
In some embodiments, the compound comprising the group of formula (I) has formula (Ih), (Ii), (Ij) or formula (Ik):



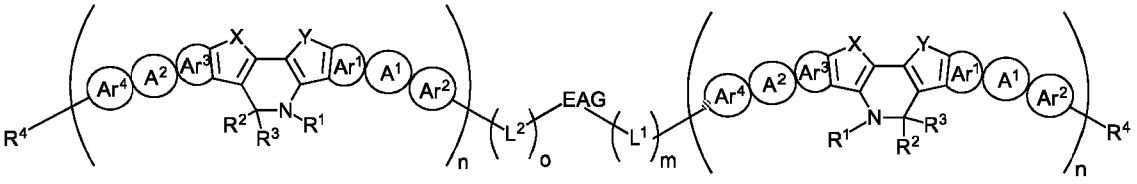
formula (Ih)



formula (Ii)



formula (Ij)



formula (Ik)

wherein:

n is an integer of 1 or more;

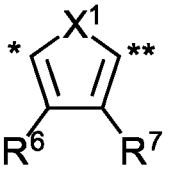
m and o are each independently 0 or an integer of 1 or more;

L^1 and L^2 each independently represent a bridging group when m and o are 1 or more or a direct bond when m and o are 0;

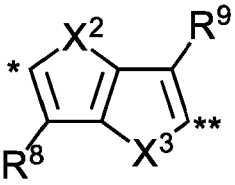
EAG represents an electron accepting group; and

X, Y, R^1 to R^4, Ar^1 to Ar^4, A^1 and A^2 are as previously defined previously.

In some embodiments, L^1 and L^2 are each independently a group of formula (II) or formula (III):



formula (II)



formula (III)

wherein:

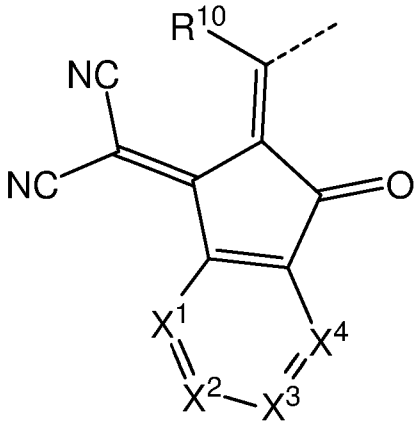
X^1, X^2 and X^3 are each independently S, O or Se;

* represents a point of attachment to Formula (Ih), Formula (Ii) or Formula (Ij);

** represents a point of attachment to EAG; and

R^6, R^7, R^8 and R^9 are each independently H or a substituent.

In some embodiments, each EAG is a group of formula (Via):



(VIa)

wherein:

R^{10} in each occurrence is H or a substituent selected from the group consisting of: C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F; and an aromatic group Ar^2 which is unsubstituted or substituted with one or more substituents selected from F and C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO;

---- represents a linking position to Formula (I), L^1 or L^2; and

each X^1-X^4 is independently CR^{12} or N wherein R^{12} in each occurrence is H or a substituent selected from C_{1-20} hydrocarbyl and an electron withdrawing group.

Optionally, at least one R^{12} is an electron-withdrawing group selected from F, Br, Cl and CN.

According to some embodiments, the material as claimed is dissolved or dispersed in one or more solvents.

According to some embodiments, the present disclosure provides a photoresponsive device comprising an anode, a cathode and a photosensitive layer disposed between the anode and the cathode, wherein the photosensitive layer comprises a material as previously described.

The photoresponsive device may be an organic photodetector.

According to some embodiments, the present disclosure provides a photosensor comprising a light source and a photoresponsive device as described previously, wherein the photosensor is configured to detect light emitted from the light source.

According to some embodiments, the present disclosure provides a method of forming the organic photoresponsive device described previously comprising formation of the photosensitive organic layer over one of the anode and cathode and formation of the other of the anode and cathode over the photosensitive organic layer.

In some embodiments, the method comprises formation of the photosensitive organic layer comprises deposition of a formulation comprising composition dissolved or dispersed in one or more solvents.

In some embodiments, the light source emits light having a peak wavelength greater than 750 nm.

In some embodiments, the photosensor is configured to receive a sample in a light path between the organic photodetector and the light source.

According to some embodiments, the present disclosure provides a method of determining the presence and / or concentration of a target material in a sample, the method comprising illuminating the sample and measuring a response of a photoresponsive device as described previously.

DESCRIPTION OF DRAWINGS

The disclosed technology and accompanying figures describe some implementations of the disclosed technology.

Figure 1 illustrates an organic photoresponsive device according to some embodiments.

The drawings are not drawn to scale and have various viewpoints and perspectives. The drawings are some implementations and examples. Additionally, some components and/or operations may be separated into different blocks or combined into a single block for the purposes of discussion of some of the embodiments of the disclosed technology. Moreover, while the technology is amenable to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and are described in detail below. The intention, however, is not to limit the technology to the particular implementations described. On the contrary, the technology is intended to cover all modifications, equivalents, and alternatives falling within the scope of the technology as defined by the appended claims.

DETAILED DESCRIPTION

Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to." Additionally, the words "herein," "above," "below," and words of similar import, when used in this application, refer to this application as a whole and not to any particular portions of this application. Where the context permits, words in the Detailed Description using the singular or plural number may also include the plural or singular number respectively. The word "or," in reference to a list of two or more items, covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.

The teachings of the technology provided herein can be applied to other systems, not necessarily the system described below. The elements and acts of the various examples described below can be combined to provide further implementations of the technology. Some alternative implementations of the technology may include not only additional elements to those implementations noted below, but also may include fewer elements.

These and other changes can be made to the technology in light of the following detailed description. While the description describes certain examples of the technology, and describes the best mode contemplated, no matter how detailed the description appears, the technology can be practiced in many ways. As noted above, particular terminology used when describing certain features or aspects of the technology should not be taken to imply that the terminology is being redefined herein to be restricted to any specific characteristics, features, or aspects of the technology with which that terminology is associated. In general, the terms used in the following claims should not be construed to limit the technology to the specific examples disclosed in the specification, unless the Detailed Description section explicitly defines such terms. Accordingly, the actual scope of the technology encompasses not only the disclosed examples, but also all equivalent ways of practicing or implementing the technology under the claims.

To reduce the number of claims, certain aspects of the technology are presented below in certain claim forms, but the applicant contemplates the various aspects of the technology in any number of claim forms.

In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of implementations of the disclosed technology. It will be apparent, however, to one skilled in the art that embodiments of the disclosed technology may be practiced without some of these specific details.

The present inventors have found that materials comprising a group of formula (I) may be used in a donor-acceptor system used in an organic photoresponsive device, e.g. a photovoltaic device such as a solar cell or an organic photodetector.

The materials may absorb long wavelengths of light, e.g. greater than about 750 nm, making them suitable for use in organic photodetectors for detection of light in the near-infrared range such as in the range of greater than about 750 nm or greater than about 1000 nm. The materials may absorb wavelengths of light that are between about 750 nm and about 2000 nm, between about 750 nm and about 1000 nm or between about 1000 nm to about 2000 nm.

Figure 1 illustrates an organic photoresponsive device according to some embodiments of the present disclosure. The organic photoresponsive device comprises a cathode 103, an anode 107 and a bulk heterojunction layer 105 disposed between the anode and the cathode. The organic photoresponsive device may be supported on a substrate 101, optionally a glass or plastic substrate.

The organic photoresponsive device as described herein may be an organic photovoltaic device or an organic photodetector. An organic photodetector as described herein may be used in a wide range of applications including, without limitation, detecting the presence and / or brightness of ambient light and in a sensor comprising the organic photodetector and a light source. The photodetector may be configured such that light emitted from the light source is incident on the photodetector and changes in wavelength and / or brightness of the light may be detected, e.g. due to absorption by,

reflection by and / or emission of light from an object, e.g. a target material in a sample disposed in a light path between the light source and the organic photodetector. The sensor may be, without limitation, a gas sensor, a biosensor, an X-ray imaging device, an image sensor such as a camera image sensor, a motion sensor (for example for use in security applications) a proximity sensor or a fingerprint sensor. A 1D or 2D photosensor array may comprise a plurality of photodetectors as described herein in an image sensor.

Figure 1 illustrates an arrangement in which the cathode is disposed between the substrate and the anode. In other embodiments, the anode may be disposed between the cathode and the substrate.

The bulk heterojunction layer comprises an electron donor and an electron acceptor. Optionally, the bulk heterojunction layer consists of the electron donor and the electron acceptor.

Each of the anode and cathode may independently be a single conductive layer or may comprise a plurality of layers.

The organic photoresponsive device may comprise layers other than the anode, cathode and bulk heterojunction layer shown in Figure 1. In some embodiments, a hole-transporting layer is disposed between the anode and the bulk heterojunction layer. In some embodiments, an electron-transporting layer is disposed between the cathode and the bulk heterojunction layer. In some embodiments, a work function modification layer is disposed between the bulk heterojunction layer and the anode, and / or between the bulk heterojunction layer and the cathode.

The bulk heterojunction layer may be formed by any process including, without limitation, thermal evaporation and solution deposition methods.

Preferably, the bulk heterojunction layer is formed by depositing a formulation comprising the acceptor material and the electron donor material dissolved or dispersed in a solvent or a mixture of two or more solvents. The formulation may be deposited by any coating or printing method including, without limitation, spin-coating, dip-coating,

roll-coating, spray coating, doctor blade coating, wire bar coating, slit coating, ink jet printing, screen printing, gravure printing and flexographic printing.

The one or more solvents of the formulation may optionally comprise or consist of benzene substituted with one or more substituents selected from chlorine, C1-10 alkyl and C1-10 alkoxy wherein two or more substituents may be linked to form a ring which may be unsubstituted or substituted with one or more C1-6 alkyl groups, optionally toluene, xylenes, trimethylbenzenes, tetramethylbenzenes, anisole, indane and its alkyl-substituted derivatives, and tetralin and its alkyl-substituted derivatives.

The formulation may comprise a mixture of two or more solvents, preferably a mixture comprising at least one benzene substituted with one or more substituents as described above and one or more further solvents. The one or more further solvents may be selected from esters, optionally alkyl or aryl esters of alkyl or aryl carboxylic acids, optionally a C1-10 alkyl benzoate, benzyl benzoate or dimethoxybenzene. In preferred embodiments, a mixture of trimethylbenzene and benzyl benzoate is used as the solvent. In other preferred embodiments, a mixture of trimethylbenzene and dimethoxybenzene is used as the solvent.

The formulation may comprise further components in addition to the electron acceptor, the electron donor and the one or more solvents. As examples of such components, adhesive agents, defoaming agents, deaerators, viscosity enhancers, diluents, auxiliaries, flow improvers colourants, dyes or pigments, sensitizers, stabilizers, nanoparticles, surface-active compounds, lubricating agents, wetting agents, dispersing agents and inhibitors may be mentioned.

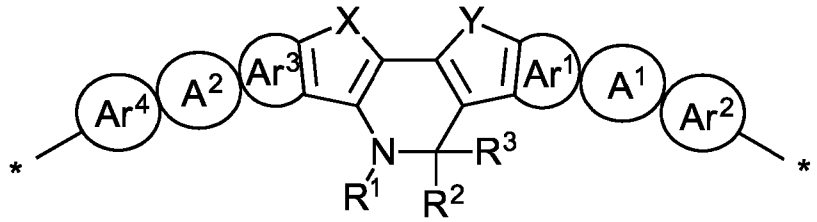
In the case where the organic photoresponsive device is an organic photodetector (OPD), it may be connected to a voltage source for applying a reverse bias to the device and / or a device configured to measure photocurrent. The voltage applied to the photodetector may be variable. In some embodiments, the photodetector may be continuously biased when in use.

In some embodiments, a photodetector system comprises a plurality of photodetectors as described herein, such as an image sensor of a camera.

In some embodiments, a sensor may comprise an OPD as described herein and a light source wherein the OPD is configured to receive light emitted from the light source.

In some embodiments, the light from the light source may or may not be changed before reaching the OPD. For example, the light may be reflected, filtered, down-converted or up-converted before it reaches the OPD.

At least one of the electron donor and electron acceptor of the bulk heterojunction layer is a material comprising a group of formula (I):



(I)

wherein:

X and Y are each independently selected from S, O or Se;

Ar^1, Ar^2, Ar^3 and Ar^4 are each independently an unsubstituted or a substituted benzene, an unsubstituted or a substituted 5- or 6- membered heteroaromatic group or are absent;

A^1 and A^2 are each independently an unsubstituted or a substituted benzene, an unsubstituted or a substituted 5- or 6- membered heteroaromatic group, a non-aromatic 6-membered ring having ring atoms selected from C, N and O or are absent;

R^1 is a substituent;

R^2 and R^3 are each independently H or a substituent; and

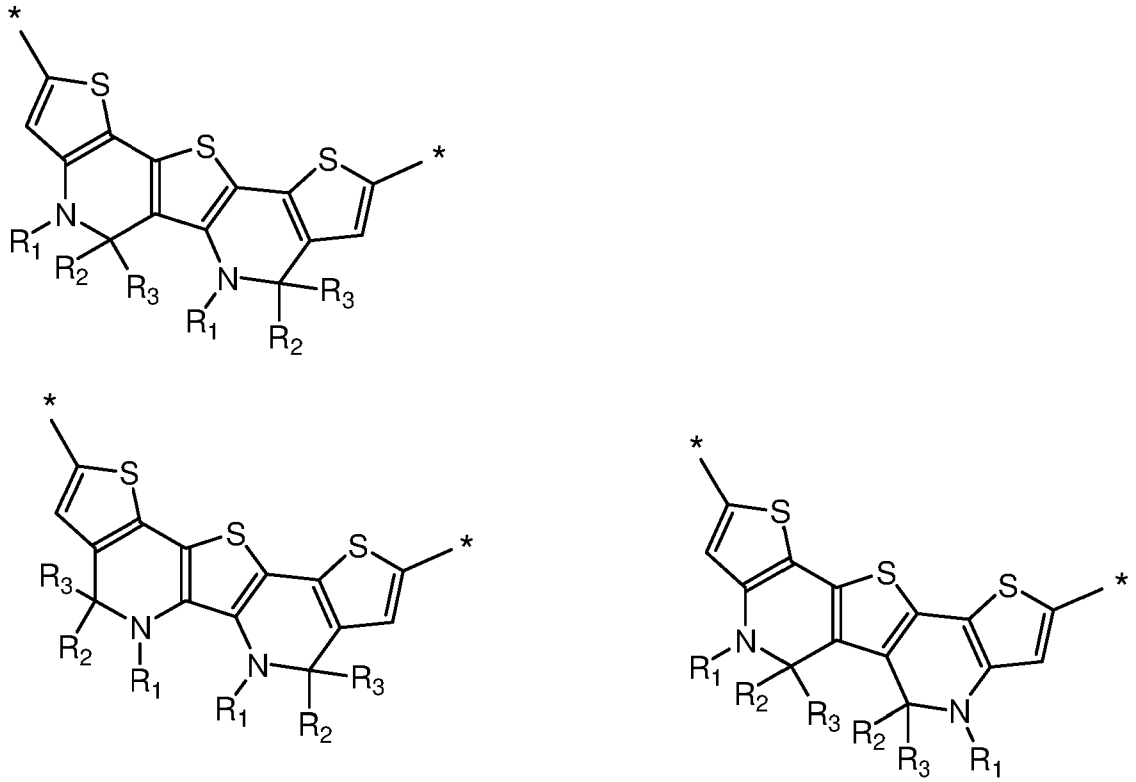
* represents a point of attachment to a hydrogen or non-hydrogen substituent.

In a preferred embodiment, A^1 and A^2 are each independently a cyclohexane, wherein optionally one or more carbon atoms are replaced with S, NR^1 or O.

In some embodiments, the material comprising the group of formula (I) is a polymer comprising a repeat unit of formula (I). Preferably, the polymer is an electron donor of the bulk heterojunction layer.

In some embodiments, the material comprising the group of formula (I) is a non-polymeric compound containing at least one group of formula (I), optionally 1 or 2 groups of formula (I). Preferably, the non-polymeric compound is an electron acceptor of the bulk heterojunction layer and comprises at least one, optionally 1 or 2, electron donating groups of formula (I) and at least one electron-accepting group.

In preferred embodiments, the group of formula (I) hasone of the following formulae:

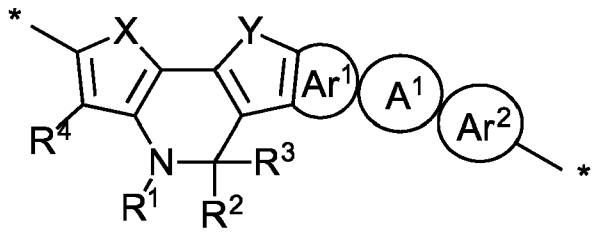


wherein R^1 is a substituent;

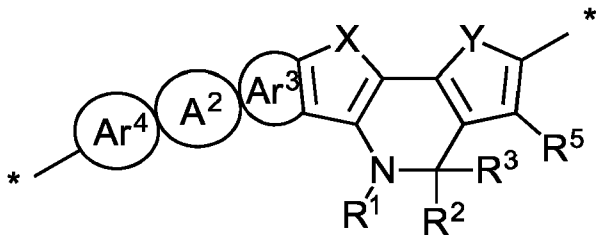
R^2 and R^3 are each independently H or a substituent; and

* represents a point of attachment to a hydrogen or non-hydrogen group.

In some embodiments, the group of formula (I) is a group of formula (Ia) or formula (Ib):



formula (Ia)



formula (Ib)

wherein:

X, Y, R^1, R^2 and R^3 and * are as described previously for formula (I); and

R^4 and R^5 are each independently H or a substituent.

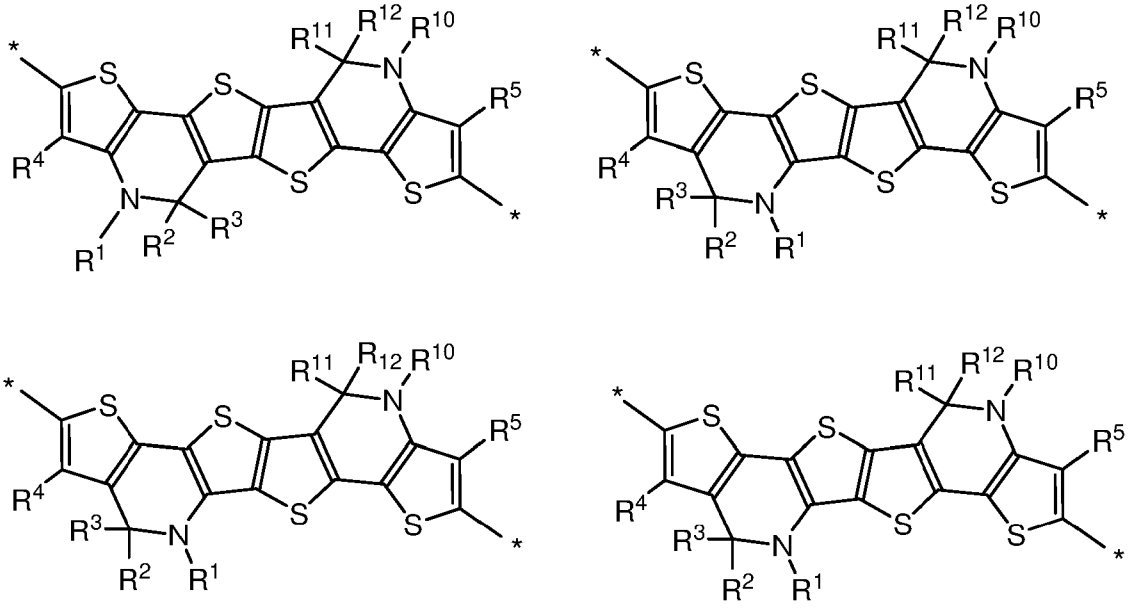
Optionally, R^1 is selected from: C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F; and phenyl which is unsubstituted or substituted with one or more substituents, optionally one or more C1-12 alkyl groups wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F.

Optionally, R^2 and R^3 are each independently selected from H; C_{1-20} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F; and an aromatic group Ar^2, optionally phenyl, which is unsubstituted or substituted with one or more substituents selected from F and C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO. R2 and R3 may be linked to form a ring, e.g. a cycloalkyl ring or an aromatic or heteroaromatic ring, e.g. fluorene.

Optionally, R^4 and R^5 are each independently selected from H; F; and C_{1-20} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F.

Ar^1-Ar^4 are preferably each benzene or thiophene, each of which is optionally and independently unsubstituted or substituted with one or more substituents, optionally one or more substituents of formula R^4.

In preferred embodiments, the group of formula (I) is a group of one of the following formulae:



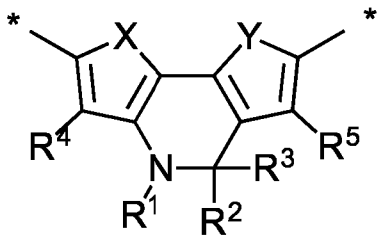
wherein:

* represents a point of attachment to a hydrogen or a non-hydrogen substituent;

R^1, R^2, R^3, R^4 and R^5 are as defined previously for formulae Ia and Ib; and

R^{10}, R^{11} and R^{12} are each independently H or a substituent, preferably a substituent selected from the group consisting of C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F; and an aromatic group Ar^2, optionally phenyl, which is unsubstituted or substituted with one or more substituents selected from F and C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO.

In some embodiments, Ar^1, A^1, Ar^2, Ar^3 A^2 and Ar^4 of formula (I) are absent and the material has formula (Ic):



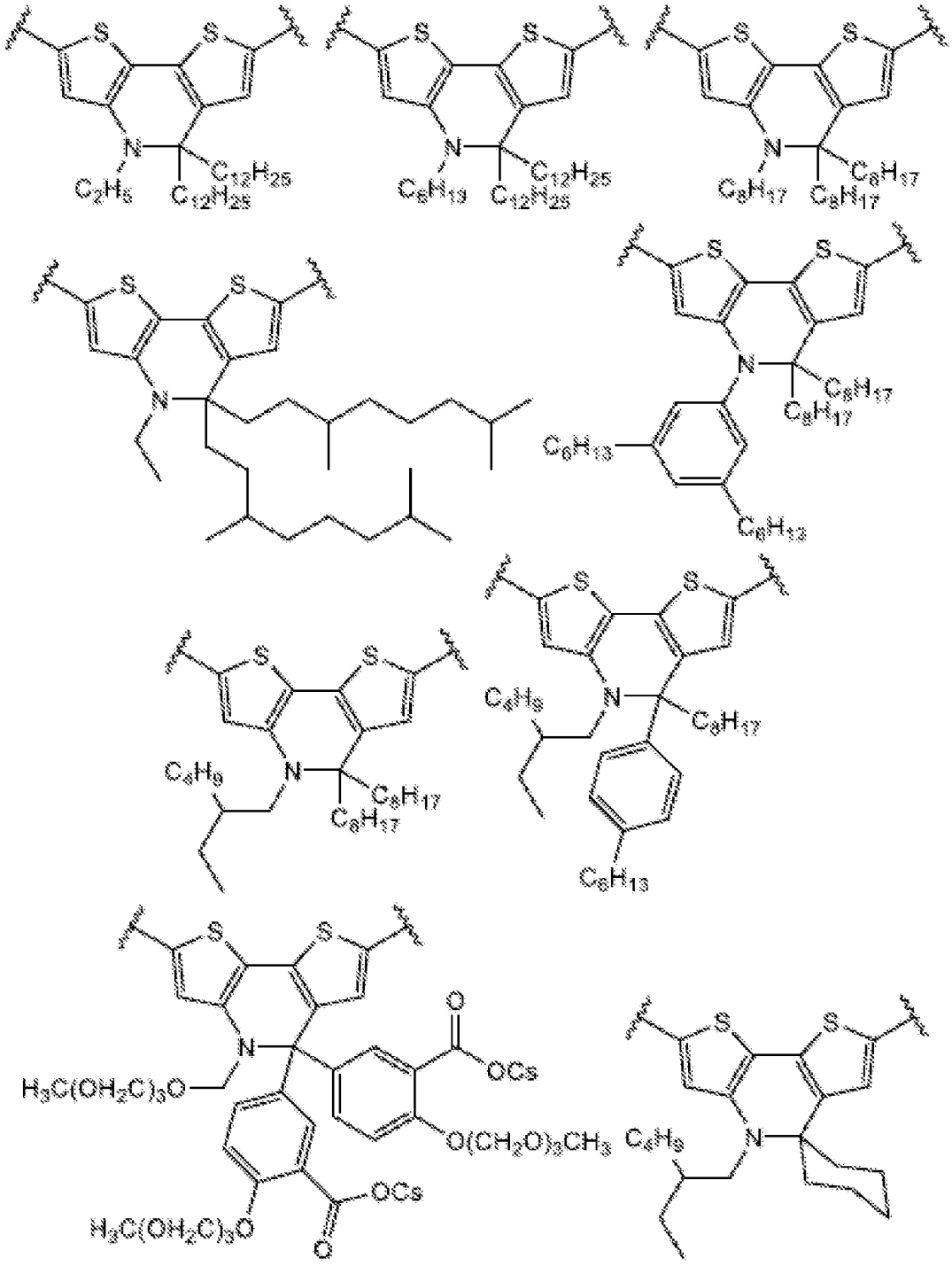
formula (Ic)

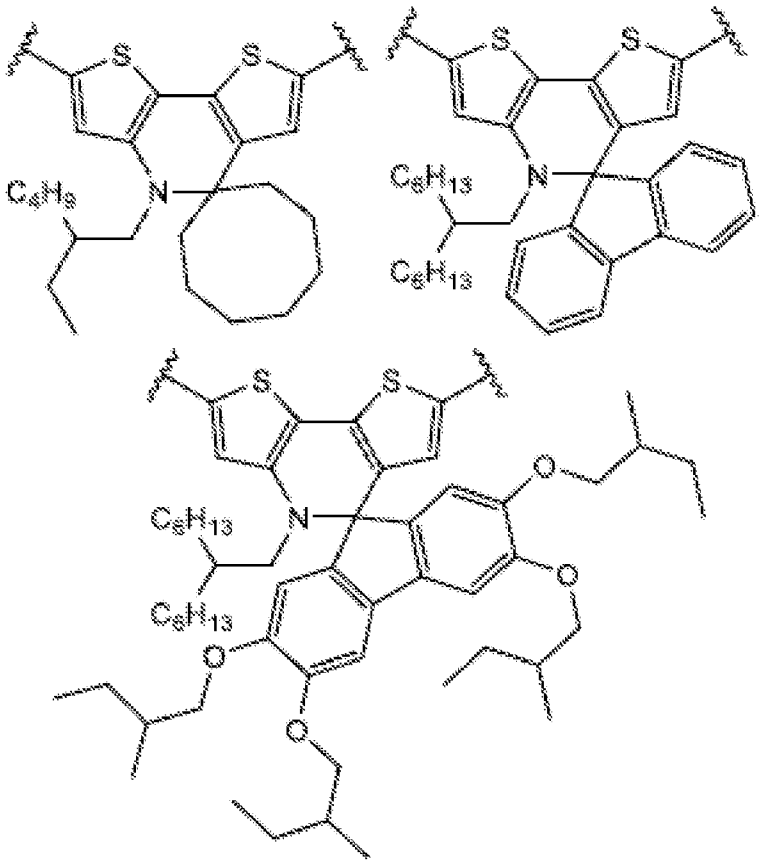
wherein:

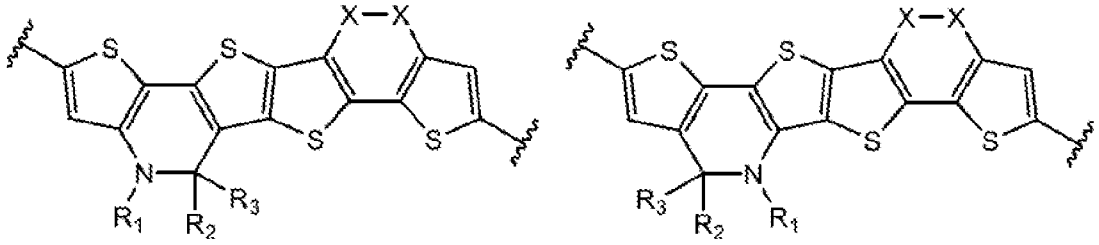
X, Y, R^1, R^2 and R^3 and * are as described previously for formula (I); and

R^4 and R^5 are as described previously form formulas (Ia) and (Ib).

In preferred embodiments, the group of formula (I) is selected from the following formulae:

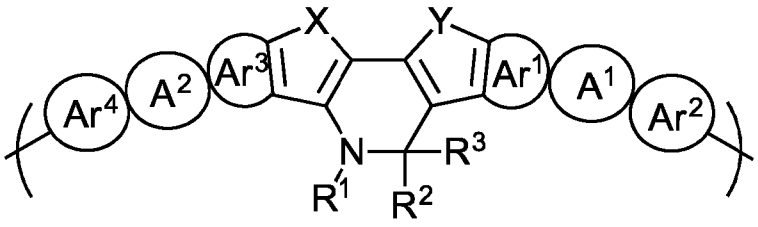






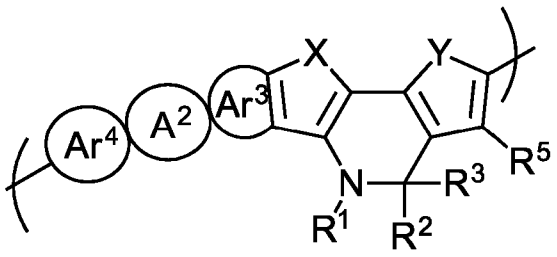
wherein one X is CR^2R^3 and the other X is O, S or NR^1.

In the case where the material comprising the group of formula (I) is a polymer, the polymer comprises a repeat unit of formula (Id):

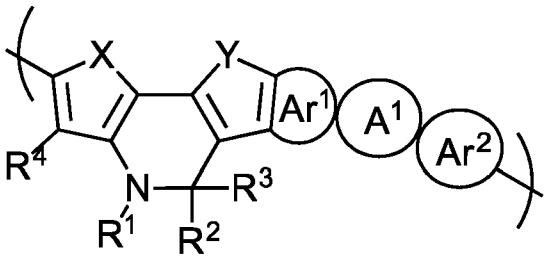


formula (Id)

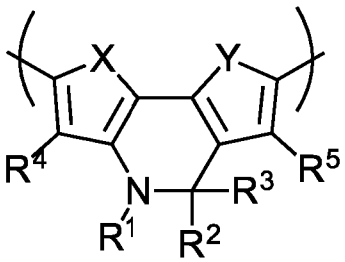
Optionally, the repeat unit of formula (Id) has formula (Ie), (If) or (Ig):



formula (Ie)



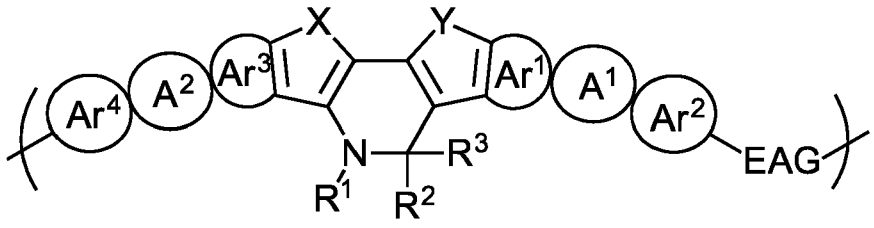
formula (If)



formula (Ig)

wherein X, Y, R^1 to R^5, Ar^1 to Ar^4, A^1 and A^2 are as previously defined.

The polymer is preferably a copolymer comprising electron-donating repeat units of formula (Id) and electron-accepting co-repeat units. Repeat units of formula (I) and the electron-accepting co-repeat units may together form a repeating structure in the polymer backbone of formula:



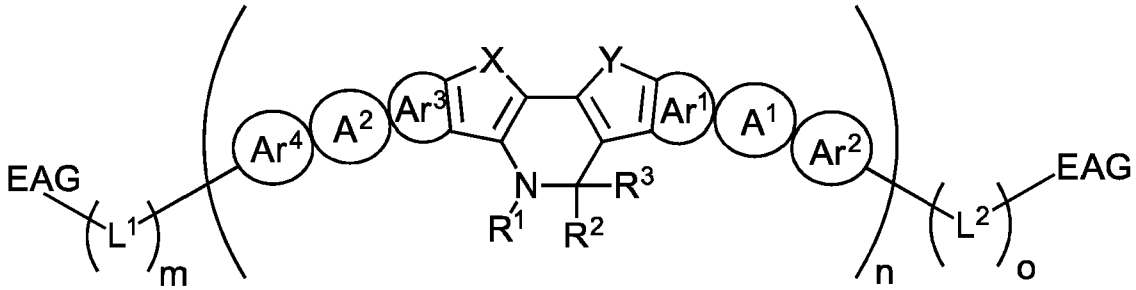
Optionally, each EAG repeat unit of the polymer (except any terminal EAG repeat unit) is adjacent to a repeat unit of formula (Id).

Optionally, each repeat unit of formula (Id) of the polymer, except any terminal repeat unit of formula (Id), is adjacent to an EAG repeat unit.

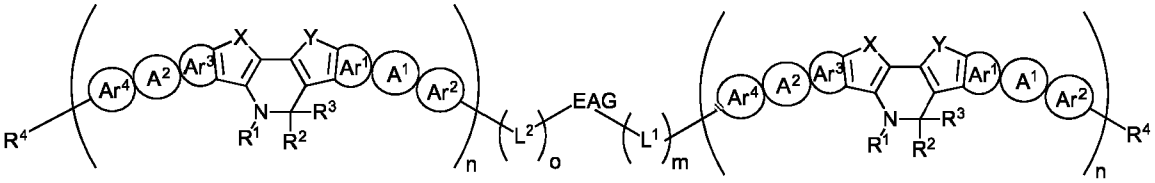
In the case where the material comprising a group of formula (I) is a non-polymeric compound, the compound preferably contains at least one
electron accepting group (EAG) which may be directly or indirectly bound to the group of formula (I).

In a preferred embodiment, A^1 and A^2 are each independently a cyclohexane, wherein optionally one or more carbon atoms are replaced with S, NR^1 or O.
The, or each, EAG has a LUMO level that is deeper (i.e. further from vacuum) than EDG, preferably at least 1 eV deeper. The LUMO levels of EAG and EDG may be as determined by modelling the LUMO level of EAG-H or H-EAG-H with that of H-EDG-H, i.e. by replacing the bonds between EAG and EDG with bonds to a hydrogen atom. Modelling may be performed using Gaussian09 software available from Gaussian using Gaussian09 with B3LYP (functional) and LACVP* (Basis set).

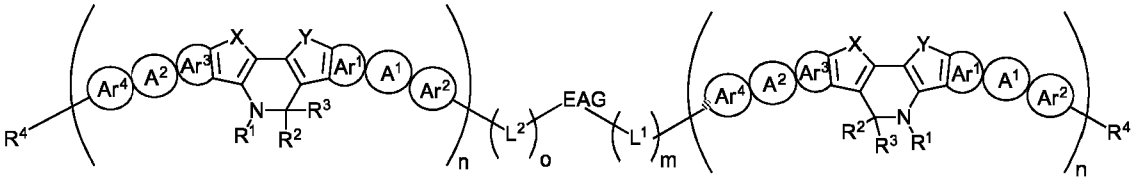
Accordingly, in some embodiments, there is provided a material comprising a group of (Ih), formula (Ii), formula (Ij) or formula (Ik):



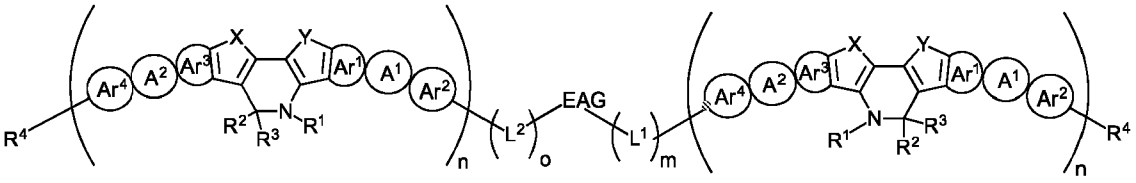
formula (Ih)



formula (Ii)



formula (Ij)



formula (Ik)

wherein:

n is an integer of 1 or more;

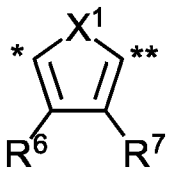
m and o are each independently 0 or an integer of 1 or more;

L^1 and L^2 each independently represent a bridging group when m and o are 1 or more or a direct bond when m and o are 0;

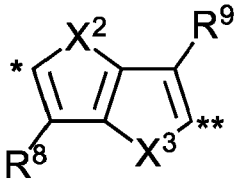
EAG represents an electron accepting group; and

X, Y, R^1 to R4, Ar^1 to Ar^4, A^1 and A^2 are as previously defined.

Where the bridging groups L^1 and L^2 are present, L^1 and L^2 may each independently be a group of formula (II) or formula (III):



formula (II)



formula (III)

wherein:

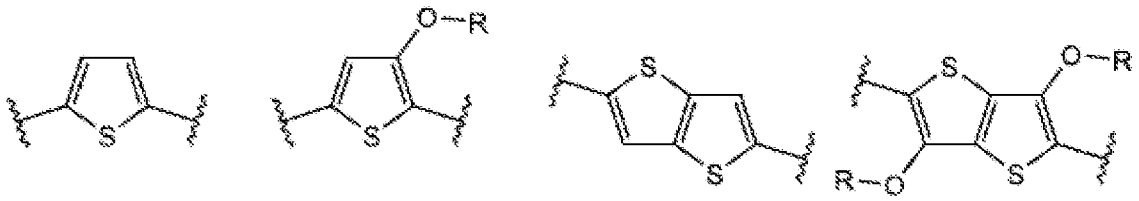
X^1, X^2 and X^3 are each independently S, O or Se;

* represents a point of attachment to Formula (Ih), Formula (Ii), Formula (Ij) or formula (Ik);

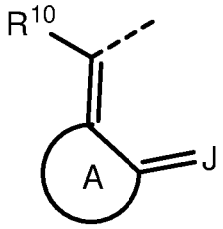
** represents a point of attachment to EAG; and

R^6, R^7, R^8 and R^9 are each independently H or a substituent.

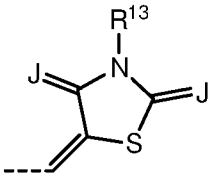
Preferably, L^1 and L^2 are each independently selected from the following formulae:



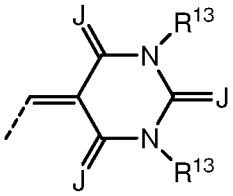
The monovalent EAGs of formula (Ih) may be the same or different, preferably the same. Optionally, each EAG of formula (Ih) is selected from formulae (III)-(XIV):



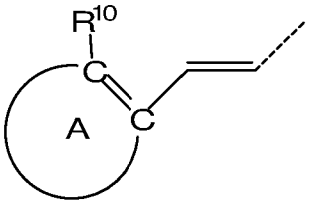
(III)



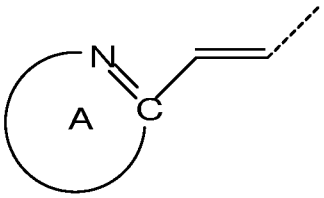
(IVa)



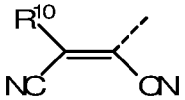
(IVb)



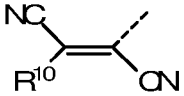
(Va)



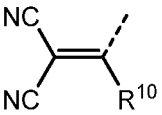
(Vb)



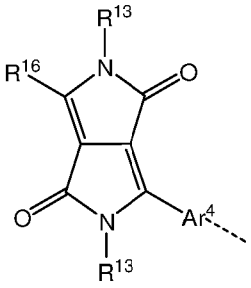
(VIa)



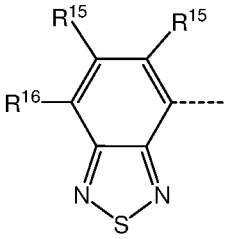
(VIb)



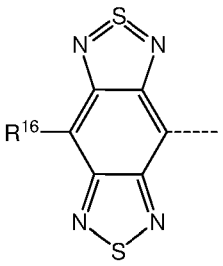
(VIc)



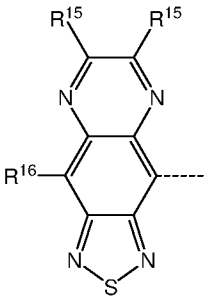
(VII)



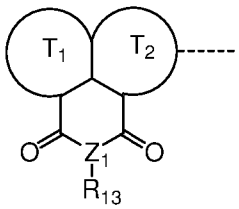
(VIII)



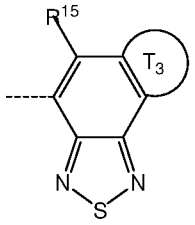
(IX)



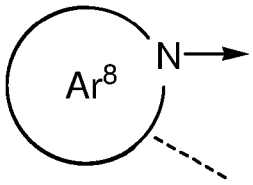
(X)



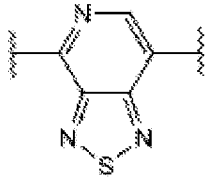
(XI)



(XII)



(XIII)



(XIV)

--- represents a bond to L^1, L^2 or a position denoted by * Formula (I)

A is a 5- or 6-membered ring which is unsubstituted or substituted with one or more substituents and which may be fused to one or more further rings.

R^{10} is H or a substituent, preferably a substituent selected from the group consisting of C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F; and an aromatic group Ar^2, optionally phenyl, which is unsubstituted or substituted with one or more substituents selected from F and C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO.

Preferably, R^{10} is H.

J is O or S.

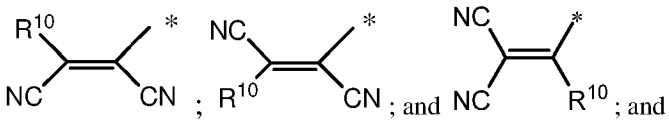
R^{13} in each occurrence is a substituent, optionally C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F.

R^{15} in each occurrence is independently H; F; C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F; or an aromatic group Ar^2, optionally

phenyl, which is unsubstituted or substituted with one or more substituents selected from F and C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO.

R^{16} is a substituent, preferably a substituent selected from:

$-(Ar^3)_w$ wherein Ar^3 in each occurrence is independently an unsubstituted or substituted aryl or heteroaryl group, preferably thiophene, and w is 1, 2 or 3;



C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F.

Ar^4 is a 5-membered heteroaromatic group, preferably thiophene or furan, which is unsubstituted or substituted with one or more substituents.

Substituents of Ar^3 and Ar^4, where present, are optionally selected from C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F.

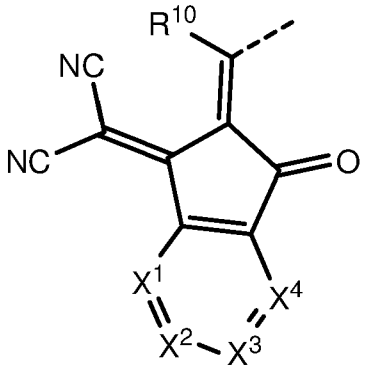
Z^1 is N or P

T^1, T^2 and T^3 each independently represent an aryl or a heteroaryl ring which may be fused to one or more further rings. Substituents of T^1, T^2 and T^3, where present, are optionally selected from non-H groups of R^{15}.

Ar^8 is a fused heteroaromatic group which is unsubstituted or substituted with one or more non-H substituents R^{10}.

A preferred group of formula (III) is formula (IIIa).

Preferably at least one, more preferably each, EAG is a group of formula (IIIa):



(IIIa)

wherein:

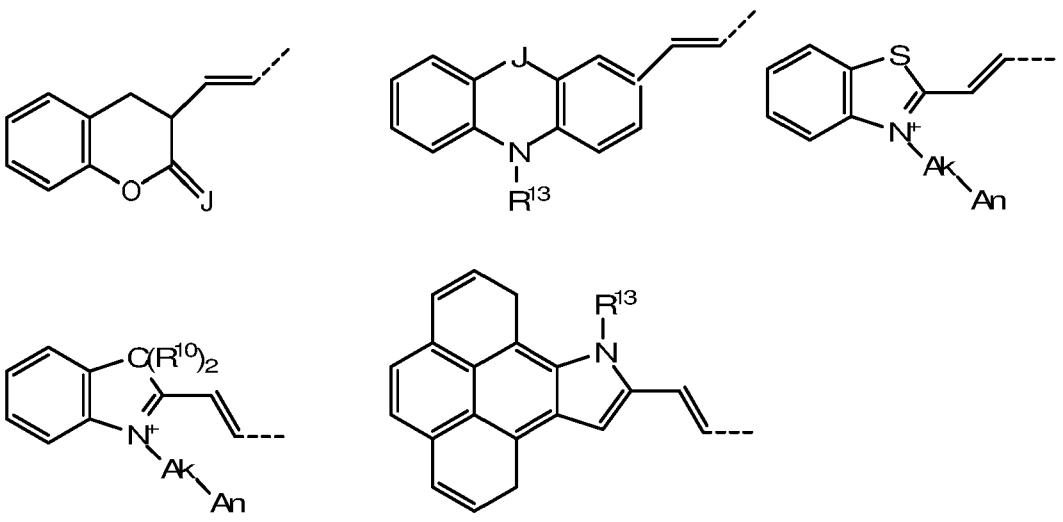
R^{10} is as described above;

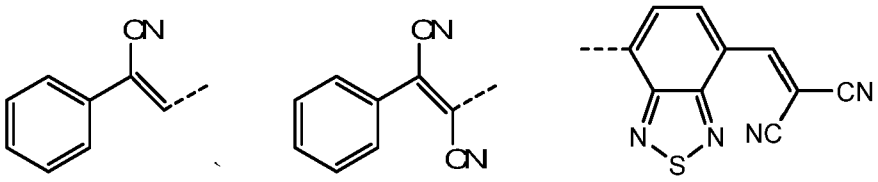
---- represents a linking position to L^1, L^2 or * of formula (I); and

each X^1-X^4 is independently CR^{12} or N wherein R^{12} in each occurrence is H or a substituent selected from $C_{1\text{-}20}$ hydrocarbyl and an electron withdrawing group. Optionally, the electron withdrawing group is F, Cl, Br or CN.

The $C_{1\text{-}20}$ hydrocarbyl group R^{12} may be selected from $C_{1\text{-}20}$ alkyl; unsubstituted phenyl; and phenyl substituted with one or more $C_{1\text{-}12}$ alkyl groups.

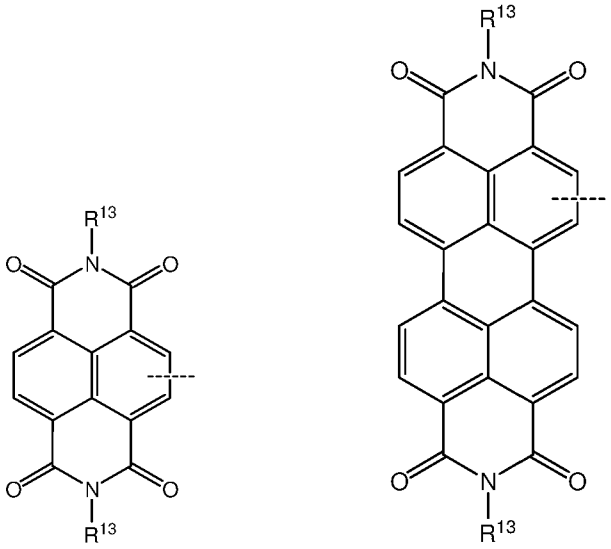
Exemplary compounds of formula (IVa) or (IVb) include:



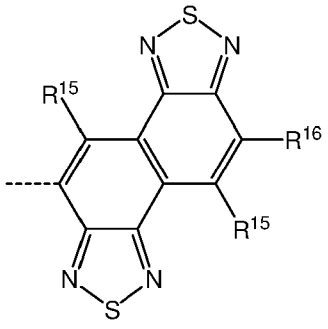


wherein Ak is a C_{1-12} alkylene chain in which one or more C atoms may be replaced with O, S, CO or COO;An is an anion, optionally $-SO_3^-$; and each benzene ring is independently unsubstitued or substituted with one or more substituents selected from substituents described with reference to R^{10}.

Exemplary EAGs of formula (XI) are:



An exemplary EAG group of formula (XII) is:



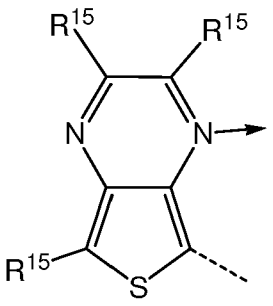
In the case where at least one EAG is a group of formula (XIII), the group of formula (I) is substituted with a group of formula $-B(R^{14})_2$ wherein R^{14} in each occurrence is a

substituent, optionally a C_{1-20} hydrocarbyl group; --- is bound to a position denoted by * in Formula (I); and → is a bond to the boron atom of -$B(R^{14})_2$.

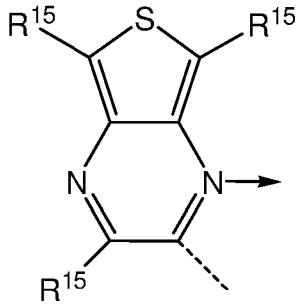
Optionally, R^{14} is selected from C_{1-12} alkyl; unsubstituted phenyl; and phenyl substituted with one or more C_{1-12} alkyl groups.

The group of formula (I), the group of formula (XIII) and the $B(R^{14})_2$ substituent of formula (I) may be linked together to form a 5- or 6-membered ring.

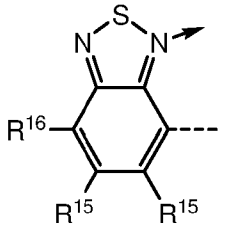
In some embodiments, EAG of formula (XIII) is selected from formulae (XIIIa) ,(XIIIb) and (XIIIc):



(XIIIa)



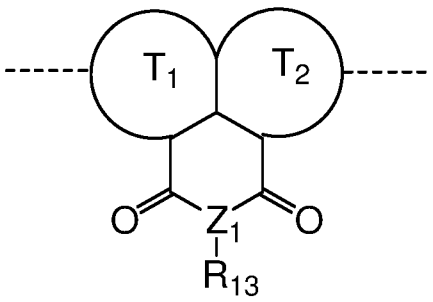
(XIIIb)



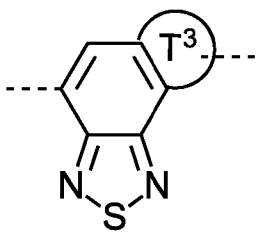
(XIIIc)

Divalent EAGs, for example of formula (Ii), (Ij) or (Ik) or EAG co-repeat units of a polymer comprising a repeat unit of formula (Id), are optionally selected from:

- divalent analogues of formulae (VIII)-(X) wherein R^{16} is a bond to L^1, L^2 or * of formula (I); and
- analogues (XIa) and (XIIa) of formulae (XI) and (XII), respectively:

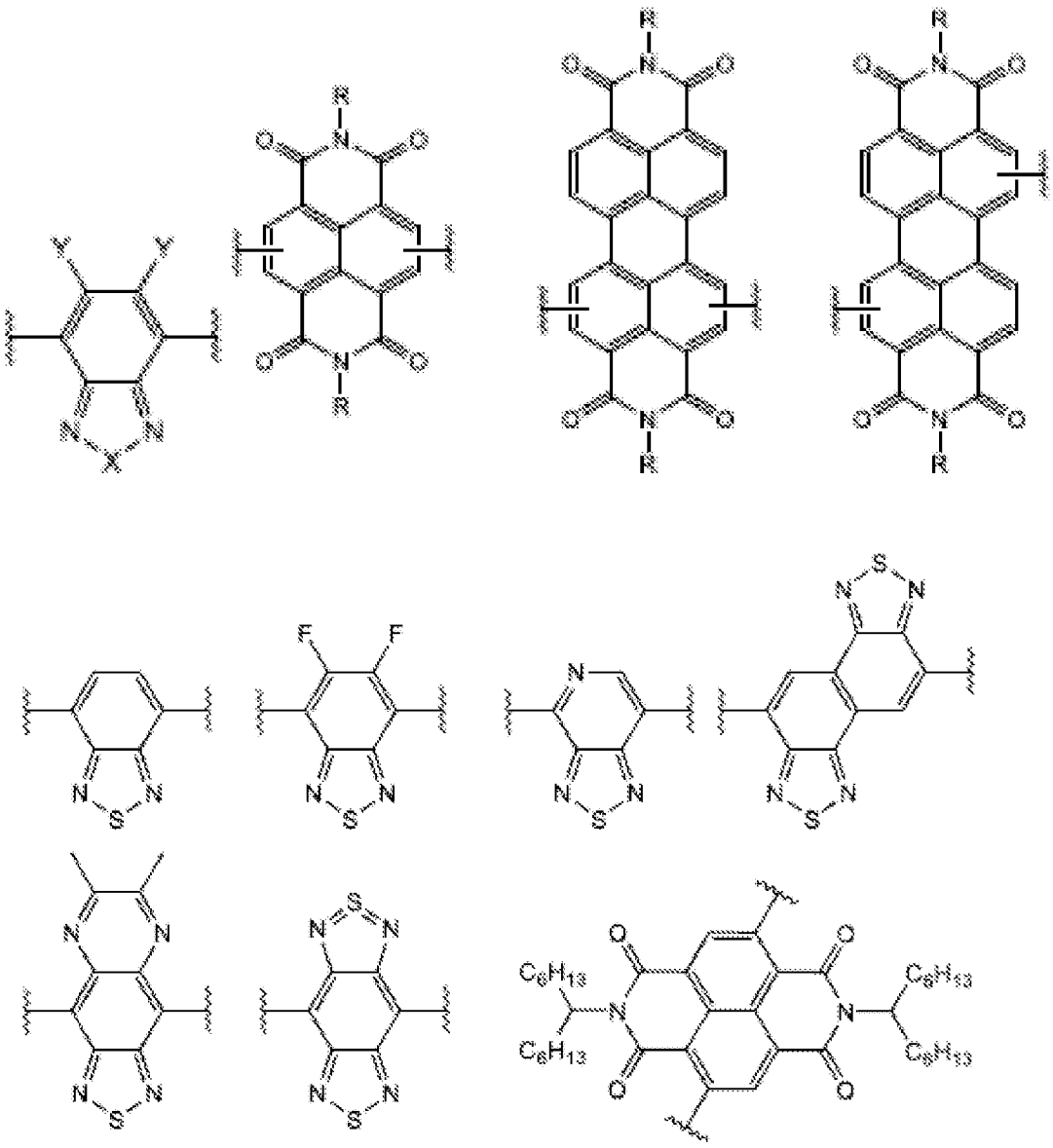


(IV)



(V)

Preferable divalent EAGs, for example EAG repeat units of a polymer or EAG groups of a compound of formula (Ii), (Ij) or (Ik) are:



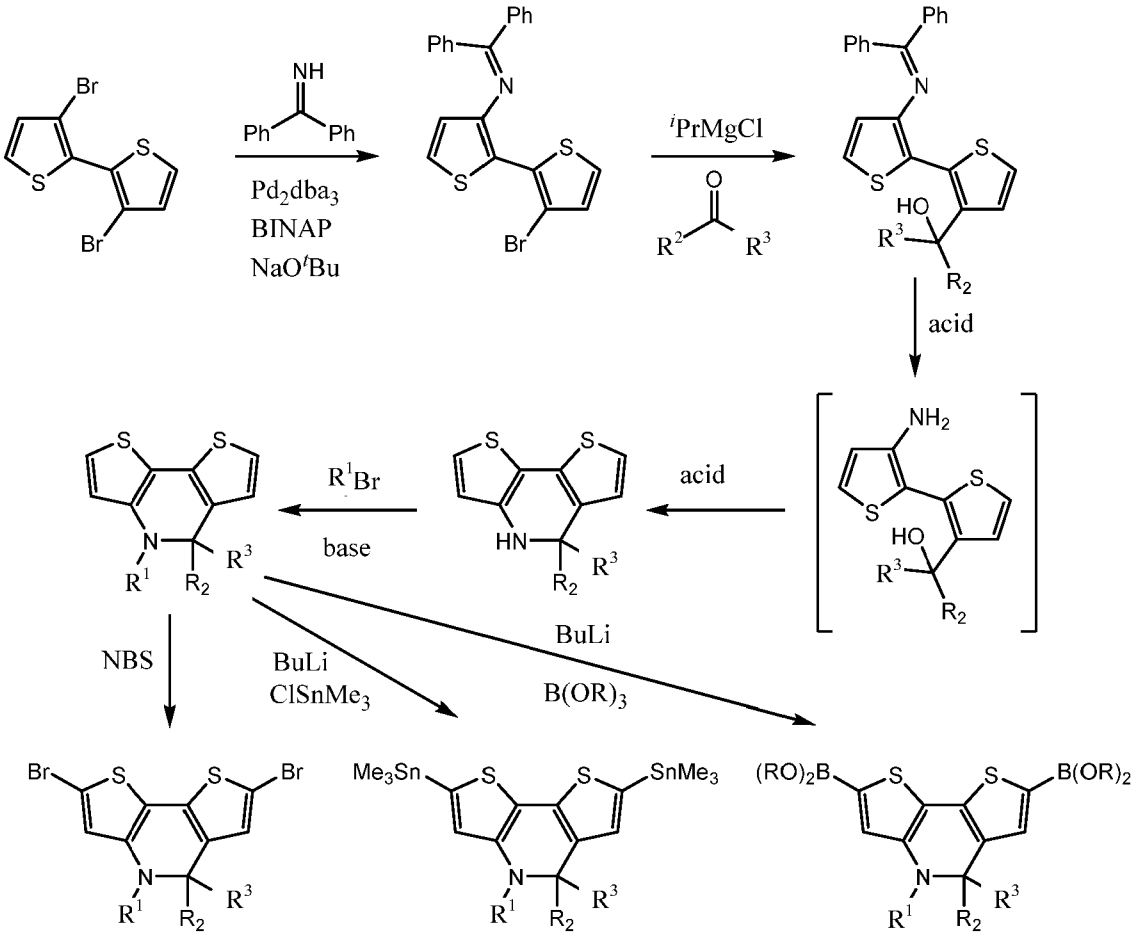
wherein Y is H or a substituent, e.g. a C_{1-12} alkyl or F.

EXAMPLES

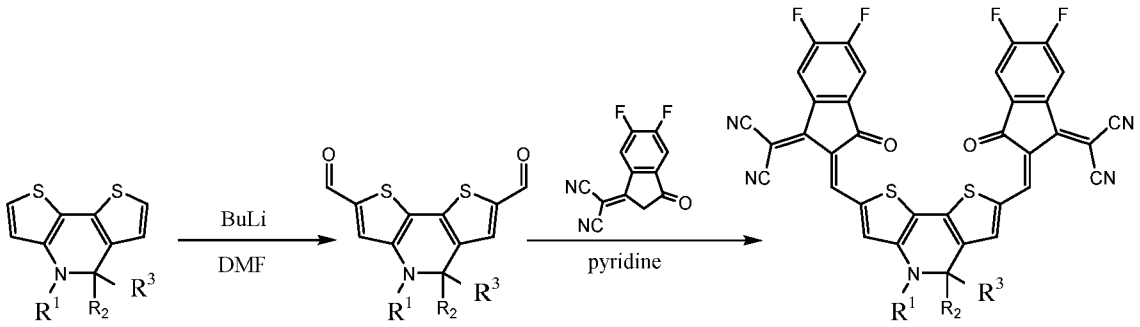
Synthesis

A compound of formula (I) may be prepared according to the following reaction schemes:

Scheme 1

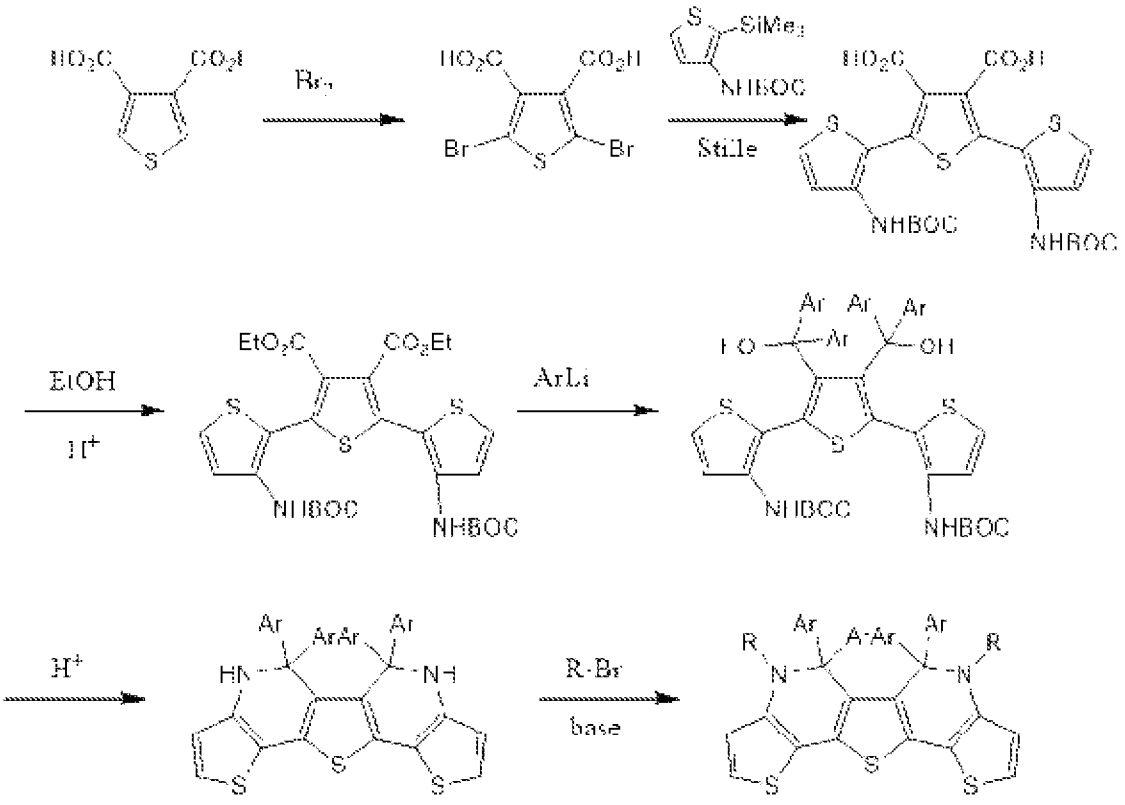


Scheme 2



Scheme 3

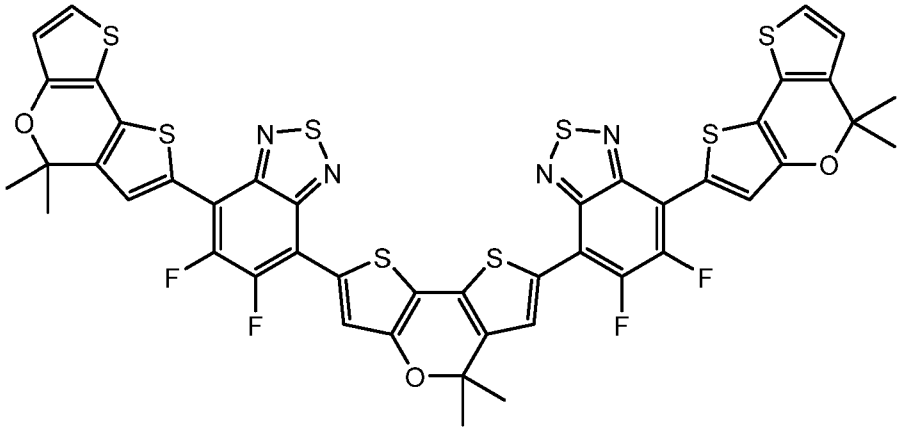
A compound of formula (Id) may be prepared according to the following reaction scheme:



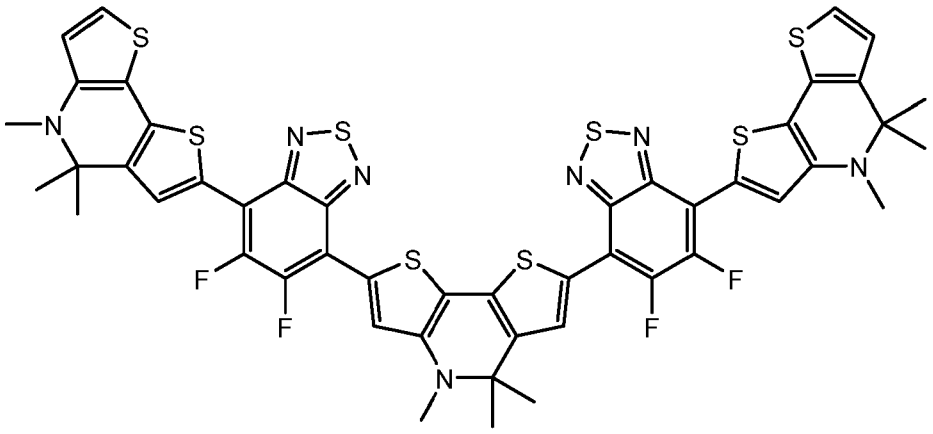
wherein Ar is an aromatic group, optionally phenyl.

Modelling data

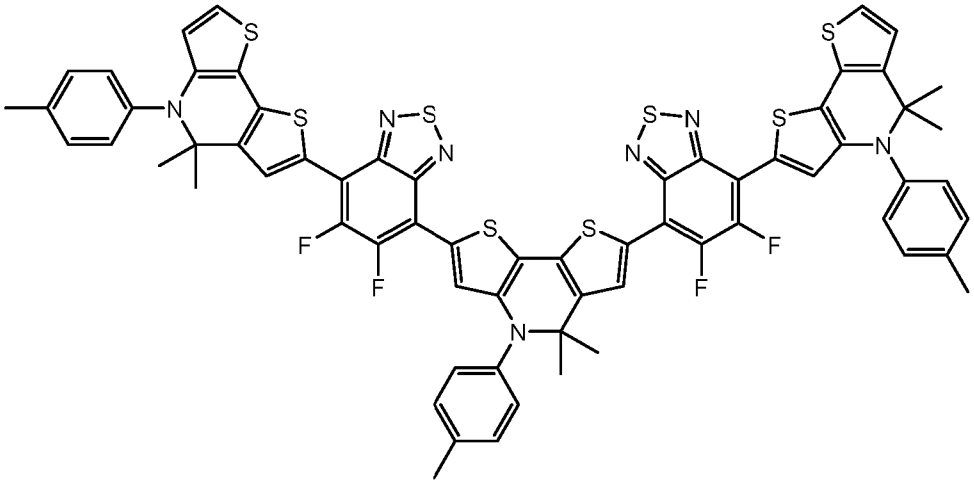
HOMO and LUMO levels of the following compounds were modelled and results are set out in Table 1. Quantum chemical modelling was performed using Gaussian09 software available from Gaussian using Gaussian09 with B3LYP (functional) and LACVP* (Basis set).



Model Comparative Compound 1



Model Compound 1



Model Compound 2

5

Table 1

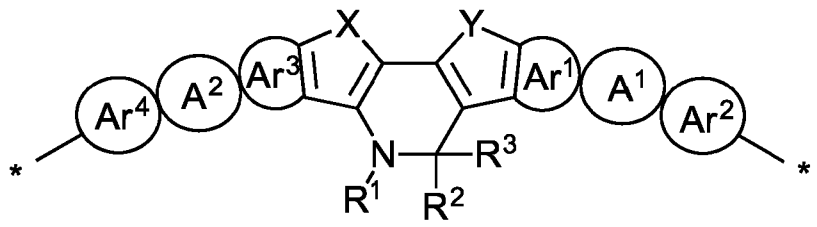
Compound	**HOMO (eV)**	**LUMO (eV)**	**Band gap (eV)**
Model Comparative Compound	-4.654	-2.923	1.731
Model Compound 1	-4.286	-2.744	1.542
Model Compound 2	-4.216	-2.660	1.556

The donor group of Model Compound Example 1 comprising an N-substituted methyl group has a smaller band gap than the Model Comparative Compound with a different central fused group, indicating that Model Compound 1 is capable of absorbing light at longer wavelengths than the Model Comparative Compound.

Model Compound 2, in which the donor group comprises an N-substituted p-tolyl group, has an even smaller band gap than both the Model Comparative Compound and Model Compound 1 and is capable of absorbing light at longer wavelengths than the Model Comparative Compound.

CLAIMS

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



(I)

wherein:

X and Y are each independently selected from S, O or Se;

Ar^1, Ar^2, Ar^3 and Ar^4 are each independently an unsubstituted or a substituted benzene, an unsubstituted or a substituted 5- or 6- membered heteroaromatic group or are absent;

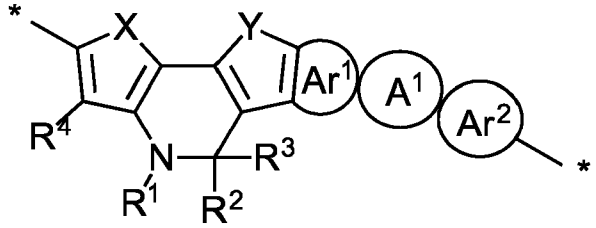
A^1 and A^2 are each independently an unsubstituted or a substituted benzene, an unsubstituted or a substituted 5- or 6- membered heteroaromatic group, a non-aromatic 6-membered ring having ring atoms selected from C, N and O or are absent;

R^1 is a substituent;

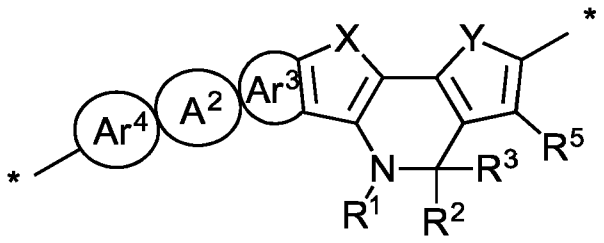
R^2 and R^3 are each independently H or a substituent; and

----- represents a point of attachment to a hydrogen or non-hydrogen group.

2. A material as claimed in claim 1, wherein the group of formula I has formula (Ia) or formula (Ib):



formula (Ia)



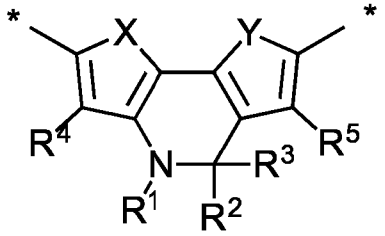
formula (Ib)

wherein:

X, Y, R^1, R^2 and R^3 and ----- are as defined in claim 1; and

R^4 and R^5 are each independently H or a substituent.

3. A material as claimed in either claim 1 or claim 2, wherein Ar^1, A^1, Ar^2, Ar^3 A^2 and Ar^4 are absent and the group of formula (I) has formula (Ic):

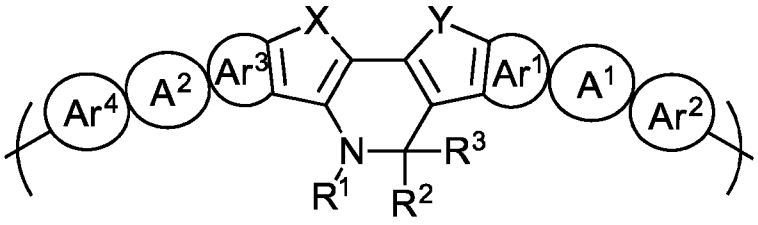


formula (Ic)

wherein:

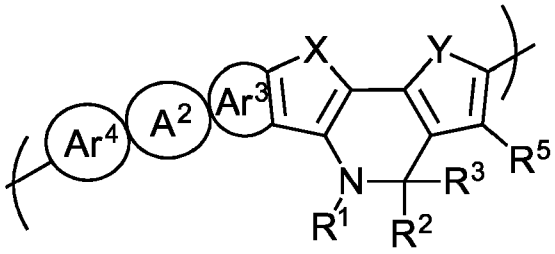
X, Y, R^1, R^2, R^3, R^4, R^5 and * are as defined in claims 1 and 2.

4. A material as claimed in any one of the preceding claims, wherein the material is a polymer comprising a repeat unit of either formula (Id):

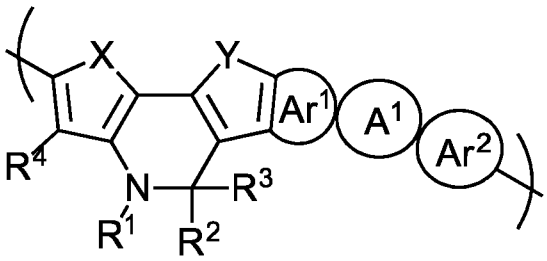


formula (Id)

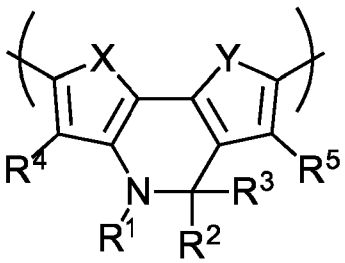
5. A material as claimed in claim 4, wherein the repeat unit of formula (Id) is selected from repeat units of formulae (Ie), (If) and (Ig):



formula (Ie)



formula (If)

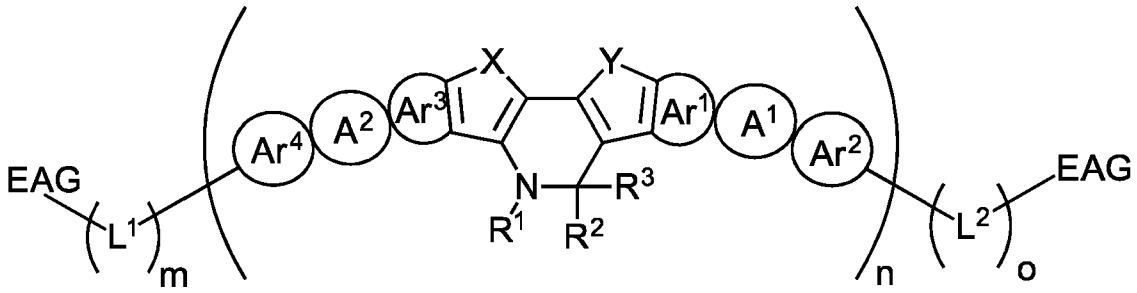


formula (Ig)

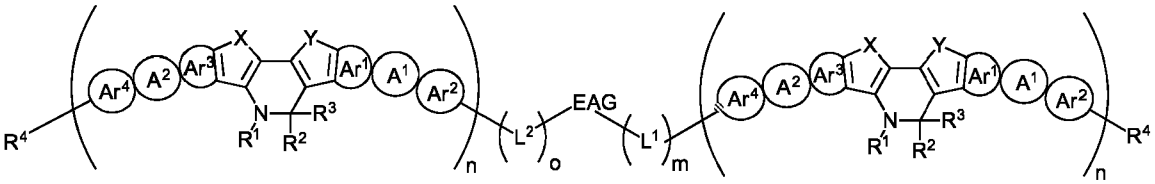
wherein X, Y, R^1 to R^5, Ar^1 to Ar^4, A^1 and A^2 are as previously defined in claims 1 and 2.

6. A material as claimed in any one of the preceding claims, wherein the material comprises an electron accepting group, EAG.

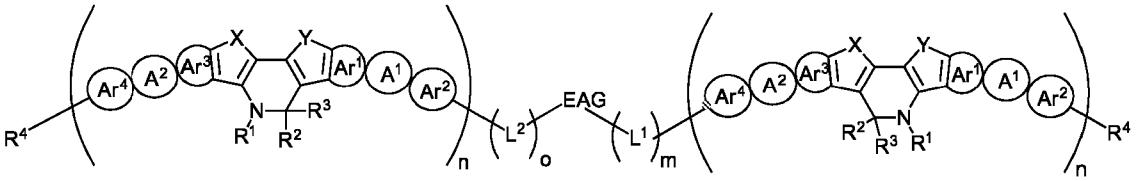
7. A material as claimed in any one of claims 1-3, wherein the material comprising the group of formula (I) is selected from formulae (Ih), (Ii), (Ij) and (Ik):



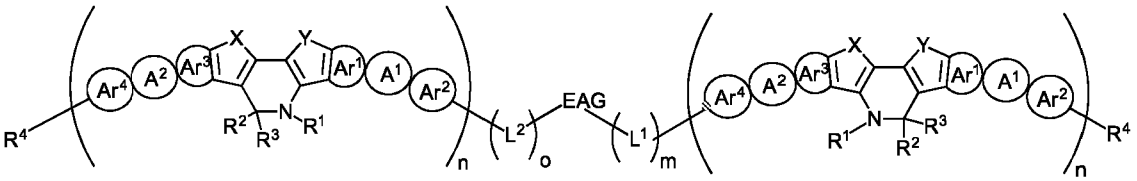
formula (Ih)



formula (Ii)



formula (Ij)



formula (Ik)

wherein:

n is an integer of 1 or more;

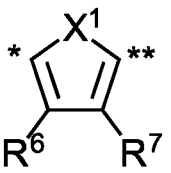
m and o are each independently 0 or an integer of 1 or more;

L^1 and L^2 each independently represent a bridging group when m and o are 1 or more or a direct bond when m and o are 0;

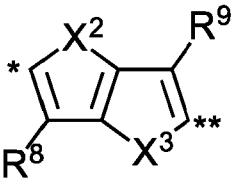
EAG represents an electron accepting group; and

X, Y, R^1 to R^4, Ar^1 to Ar^4, A^1 and A^2 are as previously defined in claims 1 and 2.

8. A material as claimed in claim 7, wherein L^1 and L^2 are each independently a group of formula (II) or formula (III):



formula (II)



formula (III)

wherein:

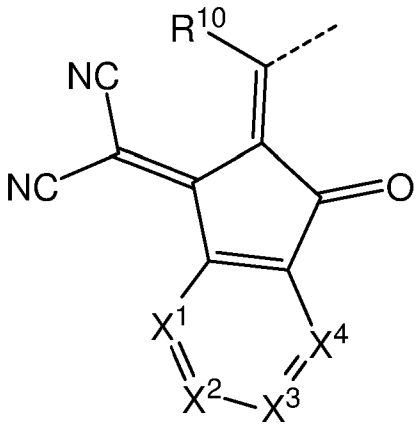
X^1, X^2 and X^3 are each independently S, O or Se;

* represents a point of attachment to Formula (Ih), Formula (Ii) or Formula (Ij);

** represents a point of attachment to EAG; and

R^6, R^7, R^8 and R^9 are each independently H or a substituent.

9. A material according to any one of claims 6 to 8 wherein each EAG is a group of formula (VIa):



(VIa)

wherein:

R^{10} in each occurrence is H or a substituent selected from the group consisting of: C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO and one or more H atoms of the alkyl may be replaced with F; and an aromatic group Ar^2 which is unsubstituted or substituted with one or more

substituents selected from F and C_{1-12} alkyl wherein one or more non-adjacent, non-terminal C atoms may be replaced with O, S, COO or CO;

---- represents a linking position to Formula (Ih), Formula (Ii), Formula (Ij), L^1 or L^2; and

each X^1-X^4 is independently CR^{12} or N wherein R^{12} in each occurrence is H or a substituent selected from C_{1-20} hydrocarbyl and an electron withdrawing group.

10. The material according to claim 9 wherein at least one R^{12} is an electron-withdrawing group selected from F, Br, Cl and CN.

11. A photoresponsive device comprising an anode, a cathode and a photosensitive layer disposed between the anode and the cathode, wherein the photosensitive layer comprises a material according to any one of the preceding claims.

12. A photoresponsive device as claimed in claim 11, wherein the photoresponsive device is an organic photodetector.

13. A photosensor comprising a light source and a photoresponsive device as claimed in either claim 11 or claim 12, wherein the photosensor is configured to detect light emitted from a light source.

14. A method of forming an organic photoresponsive device according to claim 11 or claim 12 comprising formation of the photosensitive organic layer over one of the anode and cathode and formation of the other of the anode and cathode over the photosensitive organic layer.

15. A method according to claim 14 wherein formation of the photosensitive organic layer comprises deposition of a formulation comprising composition dissolved or dispersed in one or more solvents.

16. A photosensor according to claim 13, wherein the light source emits light having a peak wavelength greater than 750 nm.

17. A photosensor according to either claim 13 or claim 14 configured to receive a sample in a light path between the organic photodetector and the light source.

18. A method of determining the presence and / or concentration of a target material in a sample, the method comprising illuminating the sample and measuring a response of a photoresponsive device as claimed in either claim 11 or claim 12.

19. A formulation comprising a material as claimed in any one of claims 1 to 10 dissolved or dispersed in one or more solvents.

Application No:	GB1915461.6	**Examiner:**	Dr Jonathan Corden
Claims searched:	1-19	**Date of search:**	23 April 2020

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 2, 4, 5, 11-17, 19	JP2015189853 A (SUMITOMO CHEMICAL CO) see compound formula 432 especially
A	-	WO2012/146504 A1 (BASF) see formula (I)
A	-	Pan et al, "A facilely synthesized lactam acceptor unit for high-performance polymer donors", RSC Adv., 2017, 7, 3439-3442 Fig. 1
A	-	Schneider et al, "Wide bandgap OPV polymers based on pyridinonedithiophene unit with efficiency>5%", Chem. Sci., 2015, 6, 4860-4866 Fig. 1

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC[X] :

Worldwide search of patent documents classified in the following areas of the IPC

C07D; C08G; C09K

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC, CAS ONLINE

International Classification:

Subclass	Subgroup	Valid From
None		