



(51) **International Patent Classification:**
C08G 61/12 (2006.01) **H01L 51/42** (2006.01)
C08L 65/00 (2006.01)

(21) **International Application Number:**
PCT/IB2015/000511

(22) **International Filing Date:**
12 March 2015 (12.03.2015)

(25) **Filing Language:** English

(26) **Publication Language:** English

(71) **Applicants:** **CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE** [FR/FR]; 3, rue Michel-Ange, F-75016 Paris (FR). **UNIVERSITE DE PAU ET DES PAYS DE L'ADOUR** [FR/FR]; Bâtiment Sciences, Avenue de l'Université, F-64000 Pau (FR).

(72) **Inventors:** **BEGUE, Didier**; Chemin de la Houn, F-64160 Serres Morlaàs (FR). **HIORNS, Roger, Clive**; 27 rue Bersaout, F-64260 Arudy (FR). **IRATCABAL, Pierre**; 1 rue Jean Plaa, F-64000 Pau (FR). **DAGRON-LARTIGAU, Christine**; 11, avenue du Baron Séguier - Bât B, F-64140 Billère (FR). **SANTOS-SILVA, Hugo**; 12 rue du Marcadou, F-64000 Pau (FR). **GUILLE, Emilie**; 4 rue du Balaitous, F-64150 Angais (FR).

(74) **Agents:** **ORES, Béatrice** et al.; Gevers & Orès, 41 Avenue de Friedland, 75008 Paris (FR).

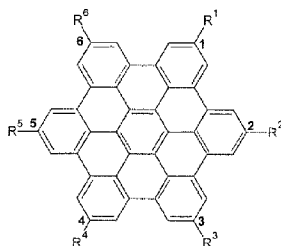
(81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) **Title:** HEXABENZOCORONENE-BASED COMPOUND FOR ORGANIC PHOTOVOLTAIC CELLS



(I)

(57) **Abstract:** The invention relates to a hexabenzocoronene-based compound, to a donor: acceptor layer comprising this compound. The invention also relates to a photovoltaic cell comprising at least one hexabenzocoronene-based compound of the invention. Hexabenzocoronene-based compound of the invention has following formula (I), wherein R¹, R³, R⁴ and R⁶ are independently from each other chosen among a carboxylic (-COOH) group, a cyano (-C≡N) group, an isocyano (-N≡C⁺) group, a cyanate (-O-C≡N) group and a -F group, and R² and R⁵ are, independently from each other, chosen among a poly(3-oxypentylthiophene) (P3OPT) substituent and a poly(3-hexylthiophene) (P3HT) substituent. The invention has an application in the field of photovoltaic cells, in particular.

HEXABENZOCORONENE-BASED COMPOUND FOR ORGANIC PHOTOVOLTAIC CELLS.

The invention relates to a hexabenzocoronene-based compound, to a donor:
5 acceptor layer comprising this compound. The invention also relates to a photovoltaic cell comprising at least one hexabenzocoronene-based compound of the invention.

The search for new donor: acceptor pairs for organic photovoltaic (OPV) applications is highly important for socio-economic and environmental reasons.

From the point of view of performance and stability, the composite couple of
10 poly(3-hexylthiophene):[6,6]-phenyl-C₆₁-methyl butyrate (P3HT:PCBM) has long been the standard bearer.

However the poor electronic correlation between the donor (P3HT) and the acceptor (PCBM), combined with numerous morphological instabilities at the heart of the heterojunction are two of the major problems that are tackled through diverse solutions
15 proposed in the literature.

The search for a better correlation in the electronic properties ranges from minor modifications in the chemical structures of one of the pair components to complete replacement of the donor or acceptor molecule.

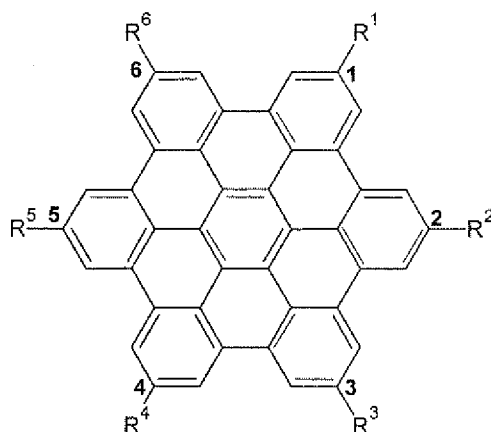
Due to the inherent difficulties of synthesising or grafting groups onto
20 fullerene, the precursor of PCBM, numerous authors have sought to replace it.

Accordingly, graphene-based materials have rapidly appeared as good acceptor candidates, primarily because of their remarkable semiconducting properties.

Materials in organic photovoltaic cells should ideally be adapted and optimized for maximum efficiency at each stage of the process of converting solar energy into
25 electricity.

In this context, the invention aims to propose materials for organic photovoltaic applications based on graphene enabling to obtain such a maximum efficiency.

For attaining this aim, the invention proposes a hexabenzocoronene-based compound of following formula I:



wherein R^1 , R^3 , R^4 and R^6 are independently from each other chosen among a carboxylic ($-\text{COOH}$) group, a cyano ($-\text{C} \equiv \text{N}$) group, an isocyano ($-\text{N}^+ \equiv \text{C}^-$) group, a cyanate ($-\text{O}-\text{C} \equiv \text{N}$) group and a $-\text{F}$ group, and

5 R^2 and R^5 are, independently from each other, chosen among a poly(3-oxypentylthiophene) (P3OPT) substituent and a poly(3-hexylthiophene) (P3HT) substituent.

Preferably in the hexabenzocoronene-based compound of the invention, R^1 , R^3 , R^4 and R^6 are identical.

10 Still preferably in the hexabenzocoronene-based compound of the invention, R^2 and R^5 are identical and are a poly(3-oxypentylthiophene) substituent.

Again preferably in the hexabenzocoronene-based compound of the invention, R^1 , R^3 , R^4 and R^6 are identical and are carboxylic groups.

The invention also proposes a donor: acceptor layer comprising a stack of
15 hexabenzocoronene-based compound according to the invention.

A device comprising at least one hexabenzocoronene-based compound according to the invention is also proposed by the invention.

Preferably, this device is a photovoltaic cell.

The invention will be better understood and other advantages and
20 characteristics thereof will appear more clearly when reading the following description which is made in reference to the figures in which:

- figure 1 shows the band-structure of the donor: acceptor P3HT:PCBM compared to that of an ideal donor: acceptor pair,

- figure 2 shows the band-structure of a donor: acceptor pair which is a
25 compound of the invention compared to that of the donor: acceptor P3HT:PCBM,

- figure 3 schematically shows the molecule structure of a compound of the invention,

- figure 4 schematically represents the stacking pattern at the start of the stacked molecules of the invention,

- figure 5 schematically represents a top view on the stacked molecules of the invention,

5 - figure 6 is a curve showing the stacking pattern of the molecules of the invention,

- figure 7 schematically represents a device comprising a stacking of compounds of the invention forming a donor: acceptor layer located between an anode and a cathode.

10 Based on a comparison between the band-structure of P3HT:PCBM and that of an ideal donor: acceptor pair, schematically represented in figure 1, the key parameters to be optimized for obtaining a material adapted and optimized for maximum efficiency of an organic photovoltaic cell at each stage of the process for converting solar energy into electricity are briefly summarized as being:

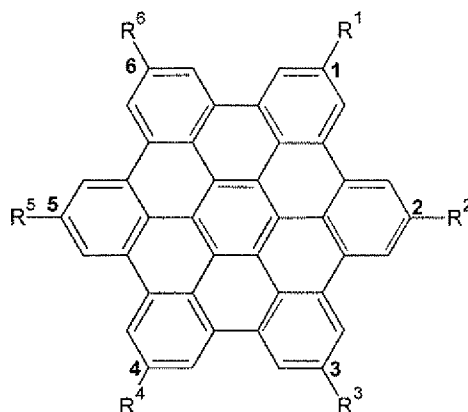
15 i) the energy difference between the LUMO of the donor and the LUMO of the acceptor (ΔE^{LUMO}), which should be of the order of 0.3 eV to ensure ideal efficiencies during exciton transfer. This value is sufficient to provoke ultra-fast electron transfer from the donor to the acceptor and cannot be reduced due to the possibility of charge transfer reversal.

20 ii) the bandgap (E_g) of the donor molecule which should be close to 1.5 eV. For P3HT this value is about 1.9 eV and therefore too high, thus limiting the absorption of light in the infrared range by the polymer.

25 iii) the open circuit voltage (V_{oc}) must be adjusted: if it is too high, a large amount of the energy is lost. If it is too low, the resulting OPV would work at an unnecessary low voltage, making the potential energy conversion inefficient.

The inventors have now discovered that graphene-based materials, namely hexabenzocoronene (HBCs), meet the requirements of the whole set of parameters that govern the efficiency of the organic photovoltaic (OPV) device from both electronic and oxidative stability points of view.

30 More precisely, hexabenzocoronene-based compound (HBC) having the formula I below:



wherein R^1 , R^3 , R^4 and R^6 are independently from each other chosen among a carboxylic ($-\text{COOH}$) group, a cyano ($-\text{C} \equiv \text{N}$) group, an isocyano ($-\text{N}^+ \equiv \text{C}^-$) group, a cyanate ($-\text{O}-\text{C} \equiv \text{N}$) group and a $-\text{F}$ group, and

5 R^2 and R^5 are, independently from each other, chosen among a poly(3-oxypentylthiophene) (P3OPT) substituent and a poly(3-hexylthiophene) (P3HT) substituent,

were proven to have the expected electronic properties.

They are superior to PCBM by way of their two-dimensionality, they avoid
10 micro aggregations resulting in a disruption of the morphology and a rupture of the active layer and the device, they increase exciton pathway lengths and facilitate charge transport.

This is due to the columnar structure of these compounds which provides a channel for the electron flux and thus enables charges to diffuse to the electrode through a favourable graphene/electrode interaction.

15 The columnar structure is obtained by the choice of the position and nature of the substituents R^1 , R^3 , R^4 and R^6 in formula I. Such a choice permits to obtain an optimal close stacking of the different layers of the HBC of the invention.

This columnar structure is very stable due to the choice of the substituents R^1 , R^3 , R^4 and R^6 .

20 Furthermore, all these substituents permits to fit the electronic levels of graphene of the HBC core so that these levels are in optimal phase for the electronic transfer from the donor system to the acceptor system.

Among the substituents which are chosen among a carboxylic group, a cyano group, an isocyano group, a cyanate group and a $-\text{F}$ group, for R^1 , R^3 , R^4 and R^6 a
25 carboxylic group is particularly preferred because it is easier to graft on the HBC core.

In the compound of the invention, the positions 2 and 5 are occupied with a conductor polymer which is, in the invention, chosen among a poly(3-oxypentylthiophene)

(P3OPT) and a poly(3-hexylthiophene) (P3HT) substituent. Thus R^2 and R^5 in formula I may be both a P3OPT or a P3HT or one of R^2 and R^5 is P3OPT and the other is P3HT.

However, preferably R^2 and R^5 are identical.

In the preferred compound of the invention of formula I, R^1 , R^3 , R^4 and R^6 are identical and are a carboxylic group and R^2 and R^5 are also identical and are P3OPT substituents because when different layers of these compounds are formed, they are perfectly stacked.

The compound of the invention has the structure shown in figure 3.

When stacked, the different layers formed of the compound of formula I are stacked as shown in figure 4 at the beginning of the stacking and as shown in figure 5 at the end of this stacking.

As one can see from figures 3 and 4, the compound of the invention forms a compact stack while providing a columnar structure as shown on the right on of figure 7.

Thus, by appropriate chemical functionalization of circular hexabenzocoronenes (circ-HBCs) the inventors have found an acceptor compound with electronic properties that match the donor compound, in the present case P3OPT or P3HT or a mixture thereof.

The substituents used for this chemical functionalization, which are to be grafted on positions 1, 3, 4 and 6 of the HBC core, are independently from each other chosen among a carboxylic ($-\text{COOH}$), cyano ($-\text{C} \equiv \text{N}$), isocyano ($-\text{N}^+ \equiv \text{C}^-$), cyanate ($-\text{O}-\text{C} \equiv \text{N}$) and $-\text{F}$ group.

Preferably, the substituent R^1 , R^3 , R^4 and R^6 are identical and more preferably, they are a carboxylic group.

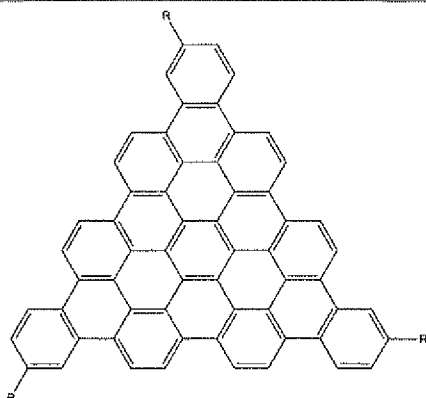
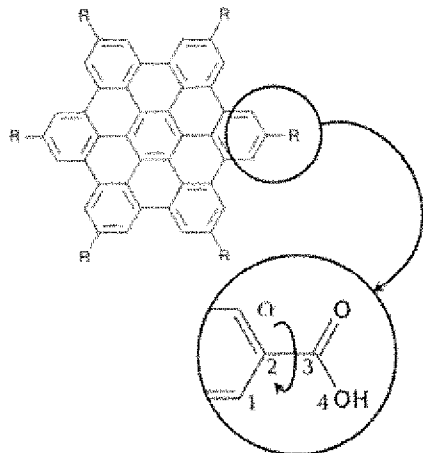
The substituents R^1 , R^3 , R^4 and R^6 modulate the electronic position of the LUMO's acceptor according to the electronic HOMO-LUMO electronic position of the selected donor.

Moreover, their steric effect enables to obtain a columnar structure which channel the electron flux and thus enable charges to diffuse to the electrode.

The HOMO and LUMO energy of the two donor systems (P3HT and P3OPT) with an acceptor according to the invention which is an HBC of formula I in which R^1 , R^3 , R^4 and R^6 are identical and are either an hexyl, CO_2H , $-\text{CO}_2\text{C}_4\text{H}_9$ and $-\text{CO}_2\text{C}_6\text{H}_{13}$ are given in following table 1.

Also, for comparison, the HOMO and LUMO energy of the same donor systems with an acceptor which is also an HBC but not according to the invention are given in table 1. These HBC based-compounds are triangular HBCs.

5 Table 1. Calculated ΔE^{LUMO} and V_{oc} (eV) values of the graphene-based molecules relative to that of P3HT and P3OPT donors.

acceptor:		ΔE^{LUMO} (eV) vs. donor		V_{oc} (eV) vs. donor	
		P3HT	P3OPT	P3HT	P3OPT
R=					
	H	-0.15	-0.38	2.15	1.79
	hexyl	-0.26	-0.49	2.26	1.90
	CO ₂ H	0.18	-0.05	1.82	1.46
	CO ₂ C ₄ H ₉	-0.03	-0.26	2.03	1.67
	CO ₂ C ₆ H ₁₃	-0.03	-0.26	2.03	1.67
	H	-0.35	-0.58	2.35	1.99
	hexyl	-0.45	-0.68	2.45	2.09
	CO ₂ H	0.55	0.32	1.45	1.09
	CO ₂ C ₄ H ₉	0.24	0.01	1.76	1.40
	CO ₂ C ₆ H ₁₃	0.23	0.00	1.75	1.39
PCBM		1.00	0.77	1.00	0.64
Ideal					
P3HT:PCBM		0.3		1.3	

These HOMO and LUMO energy are also given in figures 1 and 2.

In figure 1, the donor systems P3HT and PCBM are compared to the ideal donor and in figure 2, the donor system comprising a circ-HBC in which the substituents R^1 , R^3 , R^4 and R^6 are identical and are carboxylic groups, are compared to that of the donor system P3HT-OR in which R is also a carboxylic group.

In this donor system, P3OPT is used as it has already showed a reduced intrinsic bandgap of 1.4 eV, making it possible to attain the theoretically optimised value of 1.5 eV, and is expected to demonstrate high stability and photostability.

In addition, P3OPT gives rise to a greater electronic delocalisation which can favour the transfer of charges between the donor and the acceptor.

The chosen acceptor, i.e. the two-dimensional HBC, also shows a greater electronic delocalisation than that of PCBM due to the greater accessibility of the involved π -orbitals. As a consequence, the global delocalisation of electrons over the whole donor:acceptor system favours the transfer of charges.

The electronic levels of grafted circ-HBC molecules which are compounds of the invention, are in good agreement with both an 'ideal electronic situation' (Figure 1), the experimental attempt and the data reported by Gupta *et al.* into "Graphene Quantum Dots" *J. Am Chem. Soc.*, **2011**, *133*, 9960. Interestingly, the theoretical data gathered on HBC systems demonstrate that the shape and functionalization of these molecules lead to a wealth of possibilities to modulate the electronic properties on a wide energy range. Both triangular and circular functionalized HBCs could get close to the ideal configuration (regarding V_{oc} and ΔE^{LUMO}) to match the target donor material P3OPT. However, it is clear that circ-HBC, allows much greater modularity when grafted by electron-withdrawing substituents. The systems constituted of a circ-HBC grafted with a CO_2H substituent combined with P3OPT as donor material was calculated to possess a ΔE^{LUMO} of 0.32 eV and an open-circuit voltage of 1.09 eV. These two values, jointly to the Density Functional Theory (DFT) calculated HOMO/LUMO orbitals of the single P3OPT-circ-HBC($R=CO_2H$)—P3OPT of the invention depicted in figure 3 get very close to an ideal OPV system and provide an extremely good test candidate for future studies.

The intrinsic ability of the compound of the invention to form ordered stacks - the structure of which depends on the type of HBC substituents - is a useful property in that charge may be more easily transposed to the electrodes.

Additional investigations on the π -stacking properties using *ab initio*, DFT and molecular dynamics (MD) simulations were carried out. While using graphene-based

acceptor molecules for the *ab initio* and DFT simulations, molecular dynamic simulations were applied to the combined donor:acceptor molecule of the invention (P3OPT—circ-HBC(R=CO₂H)—P3OPT, see figures 4 and 5, to investigate the stability of these π -stacked arrangements of HBC molecules of the invention in solution with an organic solvent.

An evaluation of the geometrical and electronic properties was performed and compared with graphite itself. The inter-HBC equilibrium distances was calculated to be 3.43 and 3.47 Å at ω B97XD/6-31G* and SAPT-DFT [PBE0/cc-pVDZ] levels of calculation respectively. These results compare favourably to the inter-sheet distance of graphite (3.35 Å) and also to the results reported by Mackie *et al* (*J. Phys. Chem. A* **2008**, *112*, 10968 and references therein). using various levels of theory. Further performance enhancements for OPVs are expected to be possible from directly linking donor and acceptor in a single molecule due to improved electron transfer rates. To ensure already at an early stage that the changes to the HBC core does not in principle infringe the π -stacking, the behaviour of functionalized circ-HBC in solution was dynamically-simulated.

Figure 4 shows the π -stacking of the functionalized circ-HBC of the invention at the start and figure 5 shows this π -stacking at the end of.

After equilibrating the system for 1 ns (releasing more and more parts of the systems), a convergence via energy and structural features is obtained.

For the production run of 2.5 ns, an average distance of 3.45 Å between two circ-HBC molecules of the invention is obtained, which is in very good agreement with experimental (B. Park *et al.*, *Synth. Met.* **1993**, *56*, 3258) and theoretical (B. R. Brooks *et al.*, *J. Comp. Chem.* **2009**, *30*, 1545, and D. Andrienko *et al.*, *J. Chem. Phys.* **2006** *125*, 124902) results for similar systems. The π -stacked structure remains stable throughout the whole simulation time and the stacking of the molecules is illustrated in figures 4, 5 and figure 6. Figure 6 provides the distribution function g_z , in dependency of the z-coordinate.

The HBC based-compound of the invention was demonstrated to be a suitable model of graphene, its size and structure being well adapted to replace PCBM because of its two-dimensionality. In addition to its electronic properties, its columnar structure (which should resolve the weak efficiency observed by Gupta *et al.* with Graphene Quantum Dots) channels the electron flux and thus enable charges to diffuse to the electrode through a favorable graphene/electrode interaction. The influence of the substitution by side chains on the energy of the LUMO level of HBC provided exactly what the inventors were hoping to achieve: for a two component system consisting of a

circ-HBC grafted with a $-\text{CO}_2\text{H}$ substituent as acceptor and P3OPT as donor, the obtained $\Delta E^{\text{LUMO}} = 0.32$ and $V_{\text{oc}} = 1.09$ eV, both excellent values to form a highly efficient solar cell.

Thus, the compound of formula I of the invention has been proved to be quite
5 appropriate for forming the donor: acceptor layer.

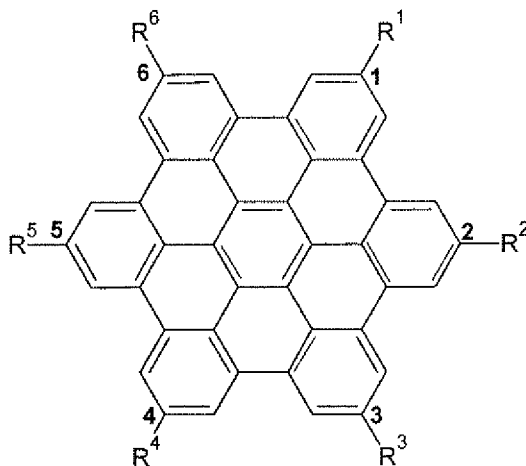
Figure 7 schematically shows such a donor: acceptor layer located between the two electrodes.

Accordingly, a donor: acceptor layer comprising at least one compound of formula I of the invention is also a subject matter of the invention as well as any device
10 comprising at least one compound of formula I of the invention.

More particularly, this device is an organic photovoltaic cell.

CLAIMS

1. Hexabenzocoronene-based compound of following formula I:



5

wherein R^1 , R^3 , R^4 and R^6 are independently from each other chosen among a carboxylic ($-\text{COOH}$) group, a cyano ($-\text{C} \equiv \text{N}$) group, an isocyano ($-\text{N}^+ \equiv \text{C}^-$) group, a cyanate ($-\text{O}-\text{C} \equiv \text{N}$) group and a $-\text{F}$ group, and

R^2 and R^5 are, independently from each other, chosen among a poly(3-oxypentylthiophene) (P3OPT) substituent and a poly(3-hexylthiophene) (P3HT) substituent.

2. Hexabenzocoronene-based compound of claim 1, wherein R^1 , R^3 , R^4 and R^6 are identical.

3. Hexabenzocoronene-based compound of claim 1 or 2, wherein R^2 and R^5 are identical and are a poly(3-oxypentylthiophene) substituent.

4. Hexabenzocoronene-based compound according to anyone of the preceding claims, wherein R^1 , R^3 , R^4 and R^6 are identical and are carboxylic groups.

5. Donor: acceptor layer comprising a stack of hexabenzocoronene-based compound according to anyone of the preceding claims.

6. Device comprising at least one hexabenzocoronene-based compound according to anyone of claims 1-4.

7. The device of claim 6 which is a photovoltaic cell.

20

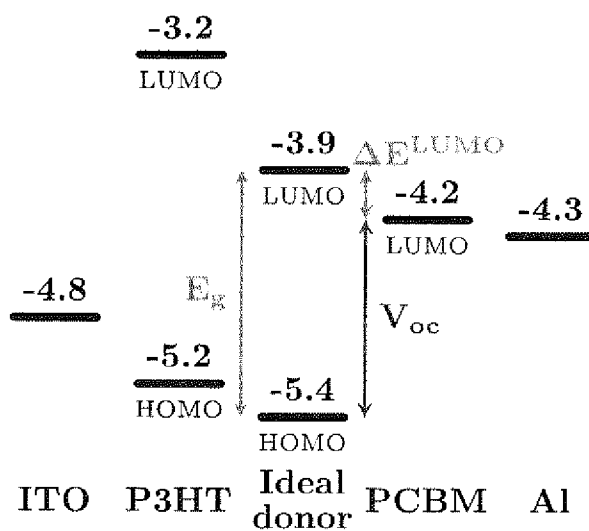


Figure 1

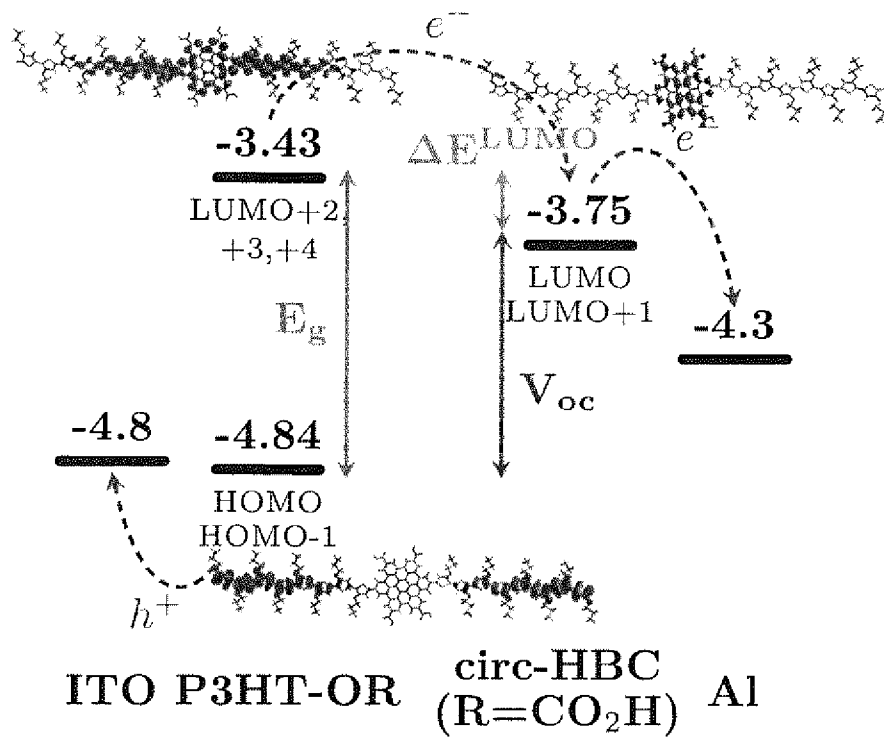


Figure 2

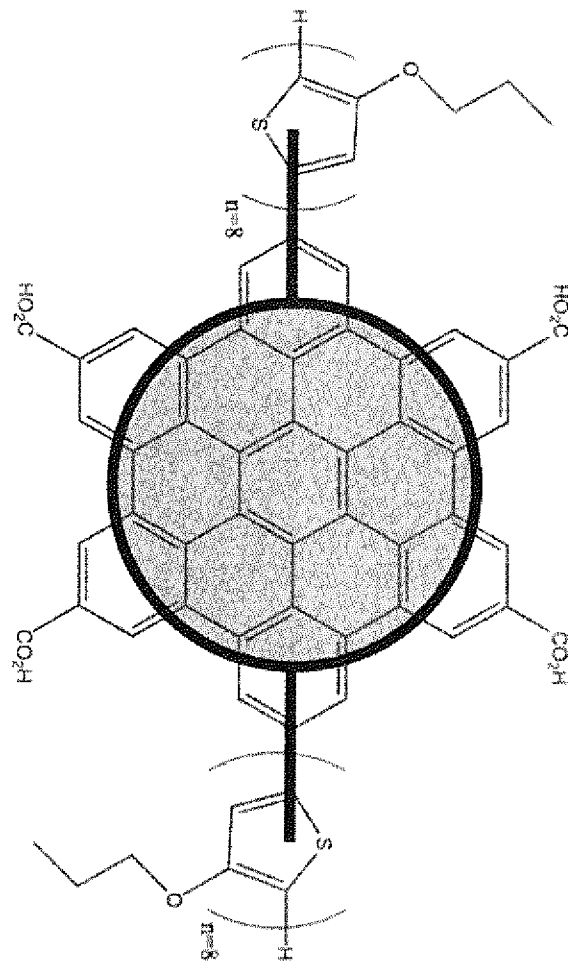


Figure 3

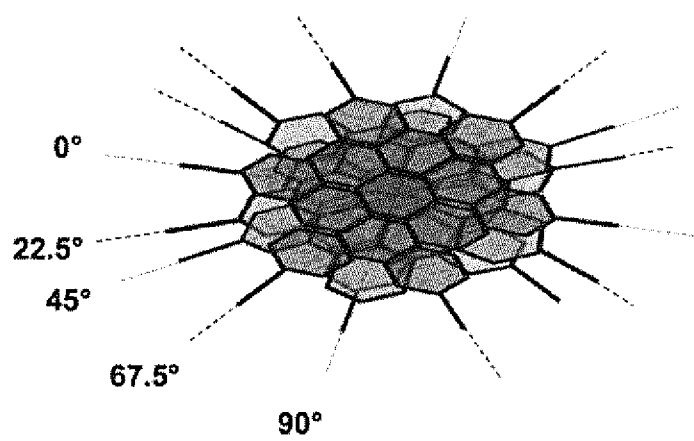


Figure 4

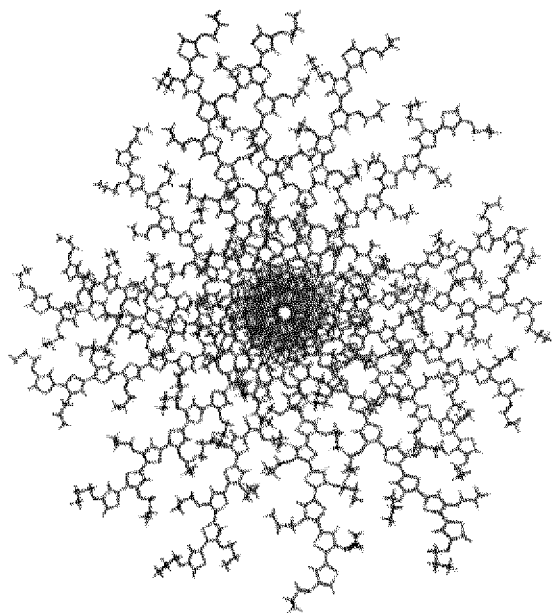


Figure 5

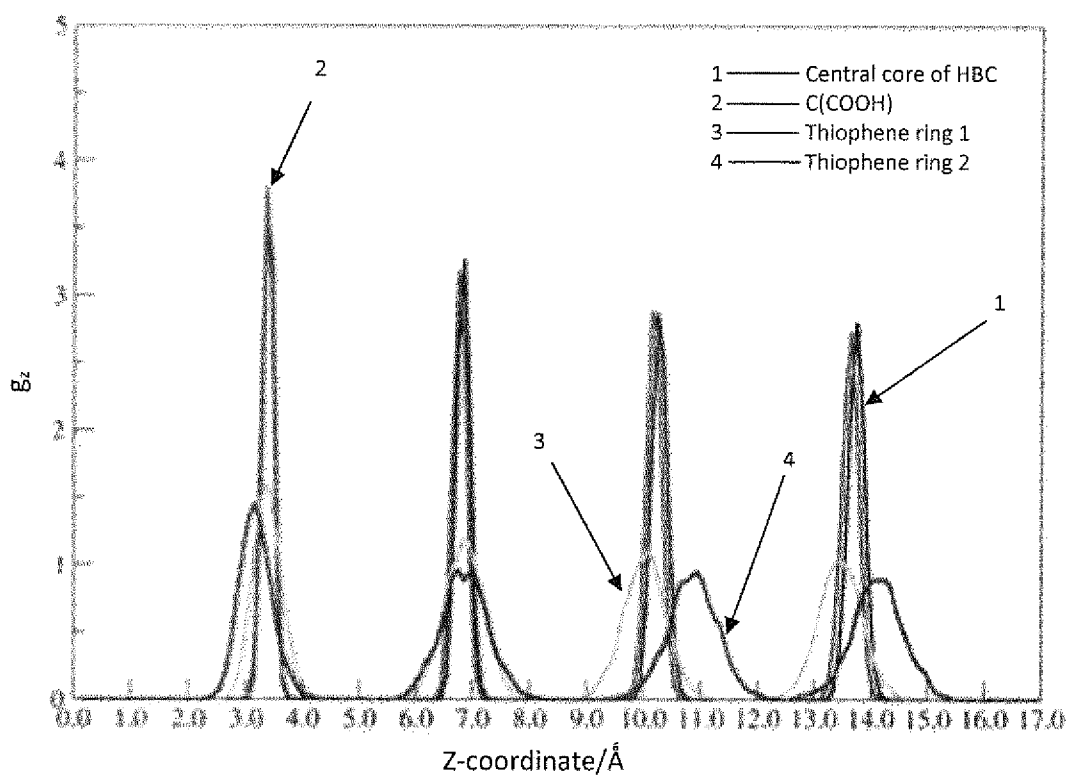


Figure 6

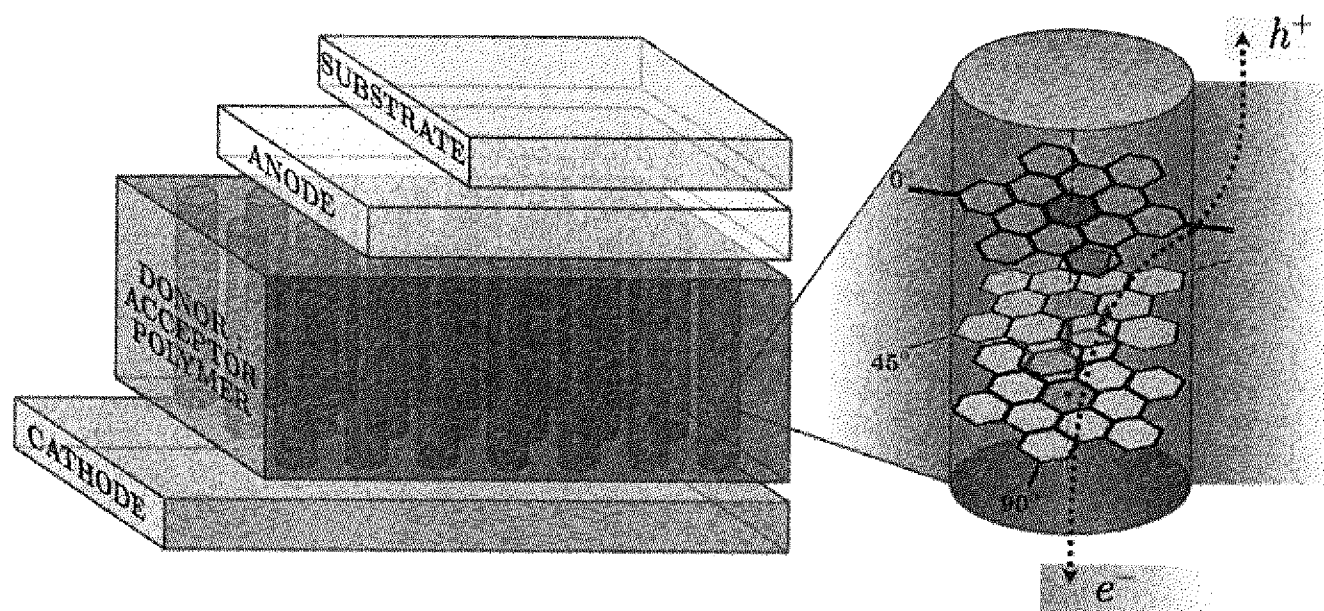


Figure 7

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2015/000511

A. CLASSIFICATION OF SUBJECT MATTER

INV. C08G61/12 C08L65/00 H01L51/42
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)

C08G C08L C09D H01L H01B

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DAVID J. JONES ET AL: "Synthesis of electron-poor hexa-peri-hexabenzocoronenes", CHEMICAL COMMUNICATIONS, vol. 48, no. 65, 1 January 2012 (2012-01-01), page 8066, XP055205321, ISSN: 1359-7345, DOI: 10.1039/c2cc33892k the whole document ----- -/--	1-7



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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

30 July 2015

Date of mailing of the international search report

07/08/2015

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

Meiners, Christian

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2015/000511

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	STEVEN E. WHEELER: "Controlling the local arrangements of [pi]-stacked polycyclic aromatic hydrocarbons through substituent effects", CRYSTENGCOMM, vol. 14, no. 19, 1 January 2012 (2012-01-01), page 6140, XP055205323, ISSN: 1466-8033, DOI: 10.1039/c2ce25630d abstract; figure 1; tables 1,2 -----	1-7
Y	HOLGER CHRISTIAN HESSE ET AL: "Large polycyclic aromatic hydrocarbons for application in donor-acceptor photovoltaics", PHYSICA STATUS SOLIDI (A), vol. 209, no. 4, 9 April 2012 (2012-04-09) , pages 785-789, XP55205361, ISSN: 1862-6300, DOI: 10.1002/pssa.201127571 abstract; figures 1,2 -----	1-7
A	PRASHANT SONAR ET AL: "Organic non-fullerene acceptors for organic photovoltaics", ENERGY & ENVIRONMENTAL SCIENCE, vol. 4, no. 5, 1 January 2011 (2011-01-01) , page 1558, XP055075681, ISSN: 1754-5692, DOI: 10.1039/c0ee00668h the whole document figure 5a -----	1-7