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[Continued on next page]

(54) **Title:** DEVICES WITH ORGANIC SEMICONDUCTOR LAYERS ELECTRICALLY-DOPED OVER A CONTROLLED DEPTH

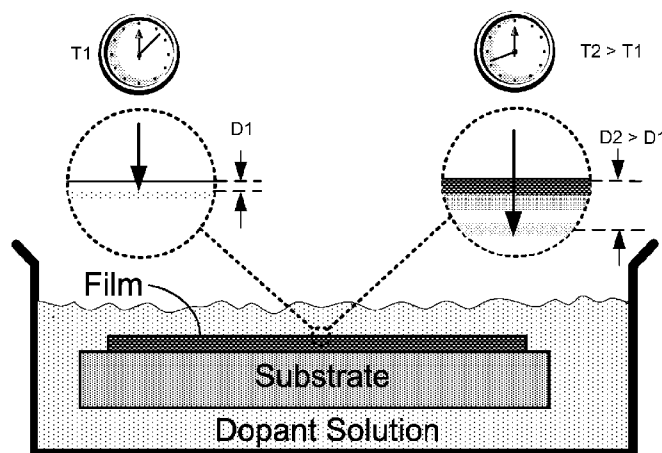


FIG. 2

(57) **Abstract:** The disclosed technology includes systems, devices, and methods associate with producing an organic semiconductor film having electrical dopant molecules distributed to a controlled depth. In an example implementation, a semiconductor device is provided. The semiconductor device can include a first substrate and an organic semiconductor film disposed on the first substrate. The organic semiconductor film includes a first region characterized by electrical dopant molecules distributed to a controlled depth with respect to a first surface of the organic semiconductor film. The semiconductor device further can include an electrode in contact with at least a portion of the first region of the organic semiconductor film.

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- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/35790

A. CLASSIFICATION OF SUBJECT MATTER
 IPC(8) - H01L 51/44, H01L 31/04, H01L 51/52 (2016.01)
 CPC - H01L 51/426, H01L 51/5052

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)
 IPC(8) - H01L 51/44, H01L 31/04, H01L 51/52 (2016.01)
 CPC - H01L 51/426, H01L 51/5052

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 Patents and non-patent literature (classification, keyword; search terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 PatBase, Google Scholar (NPL), Google Patents; search terms: semiconductor device, organic semiconductor film, electrode, dopant, depth, charge carrier, "P-I-N" junction

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/0042346 A1 (Kugler) 12 February 2009 (12.02.2009) para [0084], [0086]-[0087], [0089]-[0095], [0098], [0147]-[0148], Fig. 2C	1, 4-6, 8, 10, 12, 14-15, 18-19
Y		2-3, 7, 9, 11, 13, 16-17
Y	US 3,980,507 A (Carley) 14 September 1976 (14.09.1976) col 1 ln 5-14, col 5 ln 26-51, Fig. 1	2-3
Y	US 2009/0004772 A1 (Jinbo et al.) 01 January 2009 (01.01.2009) abstract, para [0017], [0193]	7, 16
Y	US 5,478,776 A (Luftman et al.) 26 December 1995 (26.12.1995) abstract, col 4 ln 1-8, ln 18-23	9
Y	US 4,461,691 A (Frank) 24 July 1984 (24.07.1984) abstract, col 10 ln 54-59, col 7 ln 66 to col 8 ln 6	11
Y	WO 2015/063492 A1 (The University of Court of the University of Glasgow) 07 May 2015 (07.05.2015) abstract, pg 14 para 4, pg 27 para 3-4	13, 17
A	US 3,574,009 A (Chizinsky et al.) 06 April 1971 (06.04.1971) col 1 ln 59-65, col 2 ln 40-55	1



Further documents are listed in the continuation of Box C.



* 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

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/35790

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010/0044682 A1 (Bolink et al.) 25 February 2010 (25.02.2010) para [0005]	9
A	US 2004/0084724 A1 (Kapels et al.) 06 May 2004 (06.05.2004) para [0122]	10
A	US 4,387,387 A (Yamazaki) 07 June 1983 (07.06.1983) col 2 ln 32-41	16
A	US 2006/0216851 A1 (Russell et al.) 28 September 2006 (28.09.2006) para [0004]	18

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/35790

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
---See Supplemental Box---

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-19

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/35790

Continuation of Box III:

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: Claims 1-19, directed to a semiconductor device, comprising an electrode in contact with at least a portion of the first region of the organic semiconductor film.

Group II: Claims 20-35, directed to a method, comprising: forming a layer of an organic semiconductor film on a substrate; exposing a first region of an outer surface of the organic semiconductor film to a doping environment, the doping environment comprising both dopant and solvent molecules, wherein the dopant comprises an electrical dopant; controlling a depth of diffusion of the electrical dopant into a bulk of the organic semiconductor film by a duration of the exposure to the doping environment; wherein the dopant is selected to produce a film that: reduces a solubility of the film; increases a photo-oxidation stability of the film; and facilitates one or more of transport, injection and collection of charge carriers in the film.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special Technical Features:

Group I does not require a method, comprising: forming a layer of an organic semiconductor film on a substrate; exposing a first region of an outer surface of the organic semiconductor film to a doping environment, the doping environment comprising both dopant and solvent molecules, wherein the dopant comprises an electrical dopant; controlling a depth of diffusion of the electrical dopant into a bulk of the organic semiconductor film by a duration of the exposure to the doping environment; wherein the dopant is selected to produce a film that: reduces a solubility of the film; increases a photo-oxidation stability of the film; and facilitates one or more of transport, injection and collection of charge carriers in the film as required by Group II

Group II does not require a semiconductor device, comprising an electrode in contact with at least a portion of the first region of the organic semiconductor film, as required by Group I.

Common Technical Features:

Group I and II share the technical feature of semiconductor, comprising: a first substrate; an organic semiconductor film disposed on the first substrate, the organic semiconductor film having a first region characterized by electrical dopant molecules distributed to a controlled depth with respect to a first surface of the organic semiconductor film. However, these shared technical features do not represent a contribution over prior art, because the shared technical feature is being obvious over US 2009/0042346 A1 Kugler (hereinafter 'Kugler'). Kugler teaches a semiconductor device (para [0086]; FIG. 2 shows a top view (a) and two cross sections along the lines B-B' (b) and A-A' (c) of a second stage in manufacturing the transistor. FIG. 2 shows the device of FIG. 1 after a second manufacturing step), comprising: a first substrate (Fig. 2C; 1)(para [0086]; insulating substrate 1); an organic semiconductor film (Fig. 2C; 5) (para [0086]; in which a thin semiconductor layer 5)(para [0089]; The semiconductor 5 in the transistor channel may be a p-type organic semiconductor material) disposed on the first substrate (Fig. 2C; 1), the organic semiconductor film (Fig. 2C; 5) having a first region characterized by electrical dopant molecules (para [0089]; The semiconductor 5 in the transistor channel may be a p-type organic semiconductor material)(para [0087]; For an electrochemical transistor (ECT), when a p-type semiconductor is used doping occurs anodically); and an electrode (Fig. 2C; 2,3) in contact with at least a portion of the first region of the organic semiconductor film (Fig. 2; 5), but does not teach distributing the electrical dopant molecules to a controlled depth with respect to a first surface of the organic semiconductor film. However, it would have been obvious to one with skill in the art to control the depth of the electrical dopant molecules with respect to a first surface of the organic semiconductor film into the semiconductor device of Kugler, in order to increase the speed in which the semiconductor is produced. The two variables affecting the doping depth, time and temperature, can be optimized through routine experimentation (see US 4,374,009 A to Chizinsky et al. col 2 ln 40-55).

As the shared technical features were known in the art at the time of the invention, they cannot be considered common technical features that would otherwise unify the groups. Therefore, Groups I-II lack unity under PCT Rule 13.