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Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

— *of inventorship (Rule 4.17(iv))*

Published:

— *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))*

(88) Date of publication of the international search report:
1 May 2014

(54) Title: THREE-DIMENSIONAL CRYSTALLINE, HOMOGENOUS, AND HYBRID NANOSTRUCTURES FABRICATED BY ELECTRIC FIELD DIRECTED ASSEMBLY OF NANOELEMENTS

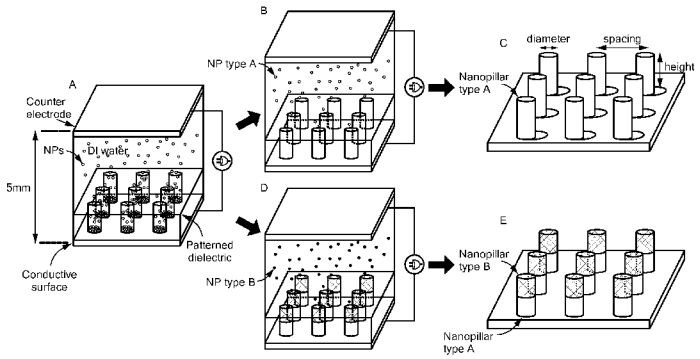


FIG. 1

(57) Abstract: A variety of homogeneous or layered hybrid nanostructures are fabricated by electric field-directed assembly of nanoelements. The nanoelements and the fabricated nanostructures can be conducting, semi-conducting, or insulating, or any combination thereof. Factors for enhancing the assembly process are identified, including optimization of the electric field and combined dielectrophoretic and electrophoretic forces to drive assembly. The fabrication methods are rapid and scalable. The resulting nanostructures have electrical and optical properties that render them highly useful in nanoscale electronics, optics, and biosensors.

WO 2014/005147 A3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/048948

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B32B 9/00 (2014.01)
USPC - 204/477
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) - B32B 9/00; C07K 1/26; H01L 21/768 (2014.01)
USPC - 204/450, 471, 473, 477, 478, 483, 484, 486, 487, 489, 490, 491, 547; 428/156, 170, 172, 173, 367

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - B32B 9/00; C07K 1/26; H01L 21/768, 76804, 76816 (2013.01)

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	WO 2011/041682 A1 (BUSNAINA et al.) 07 April 2011 (07.04.2011) entire document	22,23,26,27,29,48,49,54 --- 1-21,24,25,28,30,42-47, 50-53,55-60,62-66,66a, 66b,67-75
Y	US 2009/0134033 A1 (MEAD et al.) 28 May 2009 (28.05.2009) entire document	10, 24, 28, 43, 53, 55
Y	US 2006/0216740 A1 (EDMAN et al.) 28 September 2006 (28.09.2006) entire document	25, 50-53, 56, 57
Y	US 2007/0182015 A1 (KORNILOVICH et al.) 09 August 2007 (09.08.2007) entire document	2-8,15,16,30, 62-65, 66a, 68, 72, 74
Y	US 2009/0087622 A1 (BUSNAINA et al.) 02 April 2009 (02.04.2009) entire document	1-21, 24, 25, 28, 30, 42-47, 50-53, 55-60, 62-66, 66a, 66b, 67-75
A	US 2010/0038794 A1 (BUSNAINA et al.) 18 February 2010 (18.02.2010) entire document	1-30, 42-60, 62-75
A	US 2009/0278556 A1 (MAN et al.) 12 November 2009 (12.11.2009) entire document	67-75
A	WO 2011/131979 A2 (FAHMI et al) 27 October 2011 (27.10.2011) page 1, lines 4-5, 11-16; page 2, lines 10-15; page 6, lines 6-13.	1-30, 42-60, 62-75

☐ 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	Date of mailing of the international search report
13 February 2014	05 MAR 2014
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/048948

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 extra sheet.

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.:
claims 1-30, 42-60, 62-75

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/US2013/048948

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 1-30, 42-60, 62-75, drawn to a method and hybrid nanostructure, comprising providing a nanosubstrate comprising a base layer, a conductive layer deposited onto the base layer, and an insulating layer deposited onto the conductive layer, the insulating layer comprising a via, the via forming a void in the insulating layer and defining a pathway through the insulating layer that exposes the conductive layer; contacting the nanosubstrate with an aqueous suspension of first nanoelements; applying an electric field between the conducting layer and an electrode in the suspension for a period of time sufficient for migration of first nanoelements from the suspension into the via and their assembly in the via, wherein the electric field consists of the sum of a DC offset voltage and an AC voltage.
Group II, claims 31-41, drawn to a hybrid nanostructure comprising a first portion and a second portion, the first and second portions differing in electrical conductivity.
Group III, claims 61, drawn to a method of increasing the rate, extent, or completeness of formation of a nanostructure by electric field directed assembly of nanoelements, the method comprising a step selected from the group consisting of: increasing the electric field used for assembly; decreasing the frequency of an AC component of the electric field used for assembly; increasing a dielectrophoretic force acting on the nanoelements; increasing an electrophoretic force acting on the nanoelements; increasing a nanoelement concentration used for assembly; decreasing a dimension of a via into which the nanoelements are assembled; decreasing a density of vias into which the nanoelements are assembled; and increasing a dimension of the nanoelements.

The inventions listed as Groups I, II and III 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: the special technical feature of the Group I invention: providing a nanosubstrate comprising a base layer, a conductive layer deposited onto the base layer, and an insulating layer deposited onto the conductive layer, the insulating layer comprising a via, the via forming a void in the insulating layer and defining a pathway through the insulating layer that exposes the conductive layer; contacting the nanosubstrate with an aqueous suspension of first nanoelements; applying an electric field between the conducting layer and an electrode in the suspension for a period of time sufficient for migration of first nanoelements from the suspension into the via and their assembly in the via, wherein the electric field consists of the sum of a DC offset voltage and an AC voltage as claimed therein is not present in the invention of Groups II and III. The special technical feature of the Group II invention: a first portion and a second portion, the first and second portions differing in electrical conductivity as claimed therein is not present in the invention of Groups I or III. The special technical feature of the Group III invention: a method of increasing the rate, extent, or completeness of formation of a nanostructure by electric field directed assembly of nanoelements, the method comprising a step selected from the group consisting of: increasing the electric field used for assembly; decreasing the frequency of an AC component of the electric field used for assembly; increasing a dielectrophoretic force acting on the nanoelements; increasing an electrophoretic force acting on the nanoelements; increasing a nanoelement concentration used for assembly; decreasing a dimension of a via into which the nanoelements are assembled; decreasing a density of vias into which the nanoelements are assembled; and increasing a dimension of the nanoelements as claimed therein is not present in the invention of Groups I or II.

Groups I, II and III lack unity of invention because even though the inventions of these groups require the technical feature of hybrid nanostructure fabrication using an electric field, this technical feature is not a special technical feature as it does not make a contribution over the prior art in view of WO 2011/131979 A2 (FAHMI et al) 27 October 2011 (27.10.2011) page 1, lines 4-5, 11-16; page 2, lines 10-15; page 6, lines 6-13.

Since none of the special technical features of the Group I, II or III inventions are found in more than one of the inventions, unity of invention is lacking.