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Published:

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(88) Date of publication of the international search report:
30 December 2009

(54) Title: HIGH PERFORMANCE BATTERIES WITH CARBON NANOMATERIALS AND IONIC LIQUIDS

(57) Abstract: The present invention is directed to lithium-ion batteries in general and more particularly to lithium-ion batteries based on aligned graphene ribbon anodes, V_2O_5 graphene ribbon composite cathodes, and ionic liquid electrolytes. The lithium-ion batteries have excellent performance metrics of cell voltages, energy densities, and power densities.

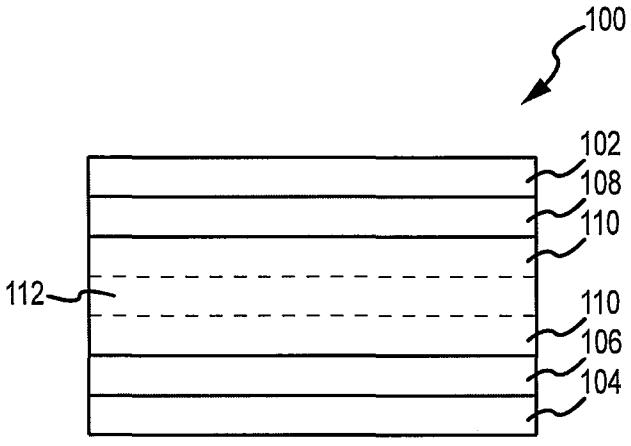

FIG.1

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/38415

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H01M 4/00 (2009.01)
USPC - 429/212
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) - H01M 4/00 (2009.01)
USPC - 429/212

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
429/209 (keyword-limited:see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Google, Google Scholar, Google Patents, PUBWEST (PGPB, USPT, USOC, EPAB, JPAB)
Search Terms Used: Electrochemical, cell, (electrodes or cathode and anode), (carbon nanotubes or carbon nanofibers), plasma etching, (orientation and parallel), (orientation and in-plane), electrolyte, ionic, capacity, intercalation, Li, mAh/g.

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 2008/016990 A2 (LU et al.) 07 February 2008 (07.02.2008) Pg 3, ln 1 - ln 4, Pg 12, ln 5 - ln 12, Figure 1, Pg 11, ln 20 - ln 23, Pg 13, ln 26 - ln 27, g 11, ln 10 - ln 16, Pg 21, ln 16 - ln 24, Pg 27, ln 18 - ln 20, Pg 14, ln 24 to Pg 16, ln 28, Pg 5, ln 3 - ln 5.	1, 2, 4-6, 10-17, 19, 20, 27-31 ---------- 3, 7-9, 18, 21-26
Y	US 6,790,425 B1 (SMALLEY et al.) 14 September 2004 (14.09.2004) col 3, ln 34 - ln 40, col 11, ln 57 - ln 61.	3
Y	PEREBEINOS et al. "Electron-Phonon Interaction and Transport in Semiconducting Carbon Nanotubes". PRL 94, 086802 (2005), [online], [retrieved 05 August 2009 (05.08.2009)]. Retrieved from the Internet: URL< http://www.cmth.bnl.gov/~vasili/Pdffiles/Perebeinos3.pdf> Abstract, Figure 2.	7, 18
Y	US 6,991,876 B2 (NARANG et al.) 31 January 2006 (31.01.2006) col 10, ln 39 - ln 47.	8, 9, 21
Y	US 6,503,660 B2 (BAKER et al.) 07 January 2003 (07.01.2003) col 3, ln 27 - ln 37, col 8, ln 20 - ln 30.	22
Y	KIM et al., "Synthesis and Electrochemical Characterization of Vanadium Oxide on Carbon Nanotube Film Substrate for Pseudocapacitor Applications". Journal of The Electrochemical Society, 153 A989-A996 2006 [online] [retrieved 05 August 2009 (05.08.2009)]. Retrieved from the Internet: URL<http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=JESOAN000153000 00600A989000001&idtype=cvips&gifs=yes>, Pg A994, para 6, Abstract.	23-26

☐ 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
06 August 2009 (06.08.2009)	13 AUG 2009
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: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

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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:

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 1-31, directed to a battery comprising electrodes comprising aligned graphene nano-ribbons, and an electrolyte.
Group II: claims 32-35, directed to a method comprising de-intercalating ions from an anode comprising aligned carbon nano-ribbons, passing the ions via an electrolyte through a microporous separator and intercalating the ions into a cathode comprising aligned carbon nano-ribbons.

- Please see extra sheet for continuation -

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.:
1-31

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.

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Continuation of Box III: Lack of Unity of Invention

Group III: claims 36-39, directed to a process for forming a battery, comprising (a) providing first and second conductive or semiconductive substrates; (b) forming graphene nano-ribbons on one or both of the substrates, such that most of the nano-ribbons are aligned; and positioning a membrane separator and electrolyte between the first and second substrates.

The inventions listed as Groups I - 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 claims is a battery comprising electrodes comprising aligned graphene nano-ribbons, and an electrolyte. The special technical feature of the Group II claims is a method comprising de-intercalating ions from an anode comprising aligned carbon nano-ribbons, passing the ions via an electrolyte through a microporous separator and intercalating the ions into a *cathode comprising aligned carbon nano-ribbons. The special technical features of the Group III claims is a process for forming a* battery, comprising (a) providing first and second conductive or semiconductive substrates; (b) forming graphene nano-ribbons on one or both of the substrates, such that most of the nano-ribbons are aligned; and positioning a membrane separator and electrolyte between the first and second substrates.

The only common technical element shared by the above groups is that they are related to electrochemical devices comprising electrodes with aligned carbon nanostructures and an electrolyte. This common technical element does not represent an improvement over the prior art of US 2007/0258192 A1 to Schindall et al. (see abstract; para [0011]). Therefore, the inventions of Groups I - III lack unity of invention under PCT Rule 13 because they do not share a same or corresponding special technical feature.