ROBUST MOS2/GRAFNEH COMPOSITE ELECTRODES FOR Na+ BATTERY

Abstract: The synthesis of layered free-standing papers, films, tapes, and printed coatings composed of acid-functionalized, few-layer molybdenum disulfide (MoS2) and reduced graphene oxide (rGO) flakes for use as a binder-free conducting electrode in Na-ion applications is described. The mechanical and electrochemical performance of the layered free-standing papers is also described. Synthesis was achieved through vacuum filtration of highly homogenous dispersions comprising varying weight percentages of exfoliated MoS2 flakes in graphene oxide in DI water, followed by thermal reduction. The electrochemical behavior of the composite paper was evaluated as a counter electrode against pure Na foil in a half-cell configuration. In addition, the uniaxial tensile testing of the composite papers demonstrated their exceptionally high fracture strength.

Fig. 1
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(b))
A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B01J 19/10; C30B 29/16; C01G 39/06 (2015.01)
CPC - B01J 19/10; C30B 29/16; C01G 39/06
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): B01J 19/10; C30B 29/16, 29/32, 29/46, 29/66, 29/68, 31/02, 31/04, 33/06; C01G 39/06 (2015.01); CPC: B01J 19/10; C30B 29/16, 29/32, 29/46, 29/66, 29/68, 31/02, 31/04, 33/06; C01G 39/06; USPC: 106/287.18, 287.19, 287.2, 287.21, 287.24, 287.26, 287.32

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 database and, where practicable, search terms used)
PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); Google; Google Scholar; ProQuest; KEYWORDS: composition carbonaceous material graphene reduced graphene oxide sodium ion dichalcogenide homogeneously dispersed layers porous channels storing

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
</table>

* 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 on which it is cited to establish the publication date of another citation or on 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
03 February 2015 (03.02.2015)

Date of mailing of the international search report
20 APR 2015

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: Shane Thomas
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PCT OSP: 571-272-7774
INTERNATIONAL SEARCH REPORT

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.: 6-24, 30-35, 40-41
   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.: 1-5, 25-29, 36

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.

Form PCT/ISA/210 (continuation of first sheet (2)) (July 2009)
The 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 fee must be paid.


Group II: Claims 37-38 and 39/37-39/38 are directed towards a method of preparing an exfoliated dichalcogenide.

Group III: Claims 42-43, 44/42-44/43, 45-46, 47/45-47/46 and 48-50 are directed towards a method of forming a composition useful as an electrode.

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. Group I has at least sodium ions in a number of channels within the porous carbonaceous layers that Groups II and III do not have. Group II has at least contacting an exfoliated dichalcogenide with a superacid that Groups I and III do not have. Group III has at least an electrode; a sodium capacity of at least 110 mAh/g for at least 40 cycles; and a heating of graphene at a temperature for a period of time that Groups I and II do not have.

The common technical features of Groups I, II and III are a carbonaceous material and a dichalcogenide.

These common features are disclosed by WO 2012/028724 A1 to THE COLLEGE OF THE HOLY AND UNDIVIDED TRINITY OF QUEEN ELIZABETH (hereinafter “Queen Elizabeth”), which discloses a carbonaceous material (graphene and single walled nanotubes; page 12, lines 1-5) and a dichalcogenide (graphene and single walled nanotubes were exfoliated in an aqueous sodium cholate solution and then blended with an aqueous MoS2 (dichalcogenide) and SC dispersion to form layers of MoS2 and graphene; page 12, lines 1-6).

Since the common technical features are previously disclosed by the Queen Elizabeth reference, these common features are not special and so Groups I, II and III lack unity.