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[Continued on next page]

(54) Title: MULTIFUNCTIONAL CERIUM-BASED NANOMATERIALS AND METHODS FOR PRODUCING THE SAME

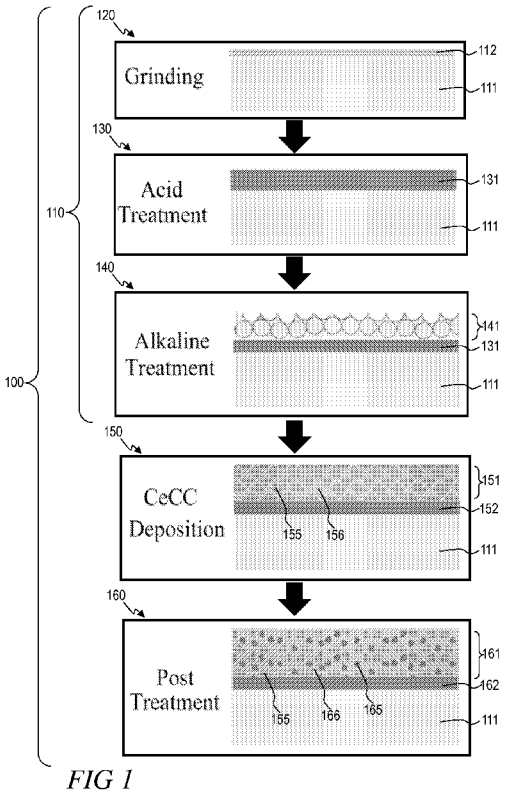

FIG 1

(57) Abstract: Embodiments relate to a cerium-containing nano-coating composition, the composition including an amorphous matrix including one or more of cerium oxide, cerium hydroxide, and cerium phosphate; and crystalline regions including one or more of crystalline cerium oxide, crystalline cerium hydroxide, and crystalline cerium phosphate. The diameter of each crystalline region is less than about 50 nanometers.

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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).

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INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B01J 23/10 (2015.01)
CPC - B01D 53/945; B01J 23/63 and B01J 23/10
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 23/10 (2015.01)
CPC - B01D 53/945; B01J 23/63 and B01J 23/10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - B82Y30/00, C01P2004/64, C09C1/3661, C23C18/127, C23C18/1216, C23C18/1241, C23C18/1233, C01B15/047, C09D183/04 and Y10S977/773 (Search terms - See below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase and Google. Search terms: cerium, ce, crystal, amorphous, noncrystal, non-crystal, oxide, hydroxide, phosphate, redox, reduction, couple, self, auto, seal, mend, close, nano, band, gap, differential, self, healing, tetravalent and trivalent

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Singh et al., 'A phosphate-dependent shift in redox state of cerium oxide nanoparticles and its effects on catalytic properties', Biomaterial October 2011, 32(28): 6745-6753. entire document, especially pg 6, para 1; pg 7, para 3-4 and pg 13, Fig 2b	1-17
Y	US 2004/0265590 A1 (Schichtel) 30 December 2004 (30.12.2004). Entire document, especially para [0012], [0016], [0021] [0024], [0026] and [0034]	1-17
Y	WO 94/24321 (Sekhar et al.) 27 October 1994 (27.10.1994) Entire document, especially pg 5, ln 7-12	7
Y	Samiee et al., 'Optical Properties of Ceria Nanoparticles', Proceedings of the 4th International Conference on Nanostructures (ICNS4) 12-14 March, 2012, Kish Island, I.R. Iran; retrieved from the internet 02-25-2015 URLhttp://icns4.nanosharif.ir/proceedings/files/proceedings/APP220.pdf entire document, especially pg 1222, col 2, para 1 and pg 1224 col 1, Fig 3. (a), (b) and (c).	8-9
Y	US 2013/0001094 A1 (Cable et al.) 03 January 2013 (03.01.2013) Entire document, especially para [0034 and [0130].	11
Y	US 7,507,480 B2 (Sugama) 24 March 2009 (24.03.2009) Entire document, especially col 6, ln 13-17; col 7, 29-32; col 8 , ln 4-57 and col 31, ln 9-15	14-16

☐ 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
25 February 2015 (25.02.2015)	13 MAR 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: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 14/42738

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 1-11, directed to a cerium-containing nano-coating composition

Group II: Claims 12-17 directed to a method for producing a composition

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:

---Continue on first 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.:

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.

Continuation of Box III

Special technical features:

The special technical feature of Group II is a method of making a slow release fertilizer composition, not required by group I

Common technical features:

Group I and II share the technical feature of cerium-containing nano-coating composition, the composition comprising: an amorphous matrix including one or more of cerium oxide, cerium hydroxide, and cerium phosphate; and crystalline regions including one or more of crystalline cerium oxide, crystalline cerium hydroxide, and crystalline cerium phosphate; wherein the diameter of each crystalline region is less than 50 nanometers

However, these shared technical features do not represent a contribution over prior art, because the shared technical feature is being obvious over US 2004/0265590 A1 to Schichtel in view of the article entitled: 'A phosphate-dependent shift in redox state of cerium oxide nanoparticles and its effects on catalytic properties' by Singh et al. (hereinafter 'Singh').

Regarding claim 1, Schichtel discloses a cerium-containing nano-coating composition (para [0021] 'The precipitation may lead directly or in some cases after a heat treatment to a crystalline coating. In the case of the precipitation of CeCl3, for example, crystalline cerium oxide is formed directly as a coating'), the composition comprising crystalline regions including of crystalline cerium oxide (para [0021]), crystalline cerium hydroxide (para [0024] 'After the hydrothermal treatment, the substantially crystalline oxide or oxide hydroxide'), and cerium phosphate (para [0016] 'phosphates, of Al, Ce,'); wherein the diameter of each crystalline region is less than 50 nanometers (para [0026] 'coating thicknesses of from 0.2 to 1.2 nm can be calculated'). However, Schichtel does not disclose an amorphous matrix including one or more of cerium oxide, cerium hydroxide, and cerium phosphate. Singh disclose cerium oxide (pg 6, para 1 'The SAED patterns (Inset, Figure C) from the nanoparticles matched with the fluorite lattice of cerium oxide. High resolution TEM images show the presence of amorphous particles along with the crystalline CeNPs which clearly suggests the presence of two different types of particles in solution'). In view of the fact that both Schichtel and Singh relate to cerium coating of materials, it would have been obvious to one of ordinary skill in the art to modify the disclosure of Schichtel with the disclosure of Singh and provide both crystalline and amorphous cerium to make available multiple forms of cerium to promote different reaction mechanisms, thereby permitting the formation of desired products.

Groups I-II, therefore, lack unity under PCT Rule 13.2, because they do not share a same or corresponding special technical feature providing a contribution over the prior art.

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.