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(54) Title: ACTUATING TEXTILES CONTAINING POLYMER FIBER MUSCLES

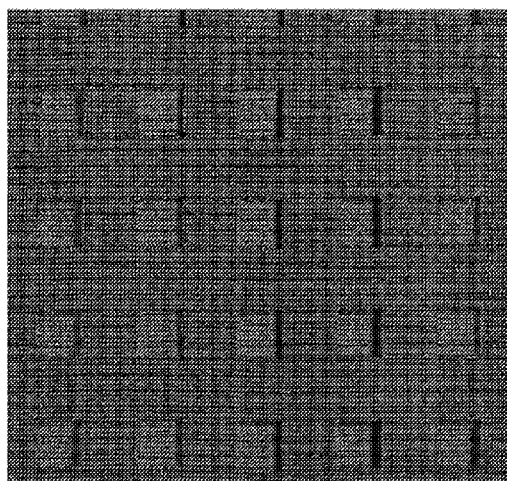


FIG. 30A

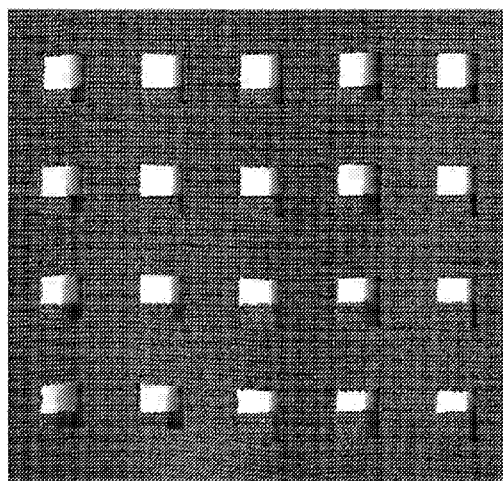


FIG. 30B

(57) Abstract: A smart (intelligent) textile that can control its porosity, shape, texture, loft, stiffness, or color by temperature change or moisture absorption by using polymer fiber torsional and tensile actuators. This temperature change can be due to a change in ambient temperature or by an external stimulus, such as electrothermal heating. Mechanisms to accomplish this include (a) direct actuation (contraction or expansion) of polymer fiber actuators in a textile structure (b) rotation of polymer fiber actuators helically wrapped around warp and/or weft yarns in a textile structure; (c) rotation of chenille type or ribbon-like warp (or weft) ends by polymer fiber torsional actuators; (d) contraction or expansion of piles or loops in a chenille type fancy yarn produced by using mandrel actuators as pile or loop part of the yarn; (e) buckling of warp (or weft) yarns by contraction of tensile polymer fiber actuators; (f) decrease in yarn diameter by a twisting effect of polymer fiber actuators; (g) contraction or expansion of segmented mandrel actuators with core filament, wire or yarns; or (h) rotation of differentially dyed polymer fiber actuators for color changing textiles.

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, 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).

Declarations under Rule 4.17:

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

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:

28 December 2017 (28.12.2017)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/023438

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 additional 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 an 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.:

1-23

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/US2017/023438

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03G7/06 D02G3/26 D03D15/00
ADD.

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)
F03G D02G D03D A41D

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 data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CARTER S. HAINES ET AL: "Artificial Muscles from Fishing Line and Sewing Thread", SCIENCE, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE; BIOSCIENCES INFORMATION SERVICE, PHILADELPHIA, PA, US, vol. 343, no. 6173, 21 February 2014 (2014-02-21), pages 868-872, XP002747796, ISSN: 0036-8075, DOI: 10.1126/SCIENCE.1246906 the whole document ----- -/--	1-5,11, 13-16, 18,23



Further documents are listed in the continuation of Box C.



See patent family annex.

* 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

26 September 2017

Date of mailing of the international search report

30/11/2017

Name and mailing address of the ISA/

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Pollet, Didier

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/023438

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FOROUGH J. ET AL: "Artificial Muscles from Carbon Nanotube and Nylon Fibres", THE FIBER SOCIETY SPRING 2015 CONFERENCE, IN CONJUNCTION WITH THE 2015 INTERNATIONAL CONFERENCE ON ADVANCED FIBERS AND POLYMER MATERIALS: FUNCTIONAL FIBERS AND TEXTILES, 1 January 2015 (2015-01-01), pages 21-22, XP009195527, DOI: 10.13140/RG.2.1.3921.5205 ISBN: 978-1-5108-1000-6 the whole document -----	1-5,13, 16,18,23
X	MADDEN JOHN D. W. ET AL: "Twisted Lines: Artificial muscle and advanced instruments can be formed from nylon threads and fabric", IEEE PULSE, IEEE, USA, vol. 6, no. 1, 1 January 2015 (2015-01-01), pages 32-35, XP011570822, ISSN: 2154-2287, DOI: 10.1109/MPUL.2014.2366896 [retrieved on 2015-01-20] page 34; figure 4 -----	1-5,13, 18,23
X	US 2015/247267 A1 (COREY JOHN A [US]) 3 September 2015 (2015-09-03) paragraph [0022] - paragraph [0029] paragraph [0032] - paragraph [0033]; figure 5 -----	1-5,11, 13,16,23
X	WO 2014/022667 A2 (UNIV TEXAS [US]) 6 February 2014 (2014-02-06) cited in the application paragraph [00113] - paragraph [00115] paragraph [00162] - paragraph [00165]; examples 34-35 -----	1-5, 13-15, 18,23

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/023438

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015247267	A1	03-09-2015	NONE

WO 2014022667	A2	06-02-2014	CN 104769834 A 08-07-2015
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			EP 2880755 A2 10-06-2015
			EP 3082248 A2 19-10-2016
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			JP 6228605 B2 08-11-2017
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			JP 2016042783 A 31-03-2016
			KR 20150038475 A 08-04-2015
			US 2015152852 A1 04-06-2015
			US 2015219078 A1 06-08-2015
			WO 2014022667 A2 06-02-2014

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-23

A textile comprising at least one twisted or coiled polymer fiber actuator operable to reversibly change either the porosity of at least one single layer of the textile, textile coloration, or combinations thereof, in response to a change in temperature or moisture absorption, without substantially changing either overall textile width or length.

2. claims: 24-34

A fiber operable to reversibly change at least one fiber thickness direction in response to temperature, wherein the fiber comprises a constituent fiber material and at least one twisted or coiled polymer fiber actuator, and the fiber has a coefficient of thermal expansion in the fiber thickness that is at least 2 times greater in magnitude than the thermal expansion coefficient of the constituent fiber material, and a textile comprising such a fiber.

3. claims: 35-38

A textile structure comprising at least one twisted or coiled polymer fiber actuator, and wherein the textile is operable to reversibly change either the porosity of the textile, textile coloration, or combinations thereof, in response to a change in temperature or moisture and the textile structure further comprises one of the following:

(a) two or more actuating regions that change dimensions such that a first region subset of the two or more actuating regions increases in width or length in response to changes in temperature or moisture absorption, and the increase in width or length of the first region subset is compensated by a second region subset of the two or more actuating regions that decrease in width or length in response to changes in temperature or moisture absorption, such that both the overall width and overall length of the textile does not substantially change,

(b) at least one actuating region that is operable to change dimension in response to a change in temperature or moisture absorption and at least one non-actuating region, such that the non-actuating regions prevent the textile from substantially changing either overall width or overall length, and

(c) at least one actuating region that is operable to change its area in response to a change in temperature or moisture, wherein the actuating region comprises at least one coiled polymer fiber actuator, and does not substantially change dimension along at least one direction, such that the

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

overall textile does not substantially change either width or length.

4. claims: 39-43

An actuating composite structure comprising an elastomeric polymer matrix, and at least one twisted polymer fiber actuator or coiled polymer fiber actuator operable for reversibly actuating in response to a change in temperature or moisture uptake, wherein

(i) the composite is operable for reversibly changing porosity, shape, texture, color, or combinations thereof, upon exposure to a change in temperature or moisture,

(ii) the twist-spun polymer fiber actuator operates by an actuation mechanism selected from a group consisting of: torsional actuation, tensile actuation, and combinations thereof, and

(iii) the actuation mechanism is operable to cause a deformation of the composite structure selected from a group consisting of: torsion, linear dimension change, bending, and combinations thereof.

5. claims: 44-47

A coiled, twisted polymer fiber that is operable to reversibly actuate without being torsionally or positionally tethered, and a textile comprising such a coiled twisted polymer fiber.

6. claims: 48-61

A twisted or coiled polymer fiber actuator, wherein the twisted or coiled polymer fiber actuator is operable to reversibly actuate by changing length, twist or combinations thereof in response to a change in temperature or moisture absorption; the twisted or coiled polymer fiber actuator has a variable property that varies over the length of the actuator; and the variable property is selected from a group consisting of coil diameter, coil pitch, fiber diameter, fiber twist direction, amount of fiber twist, fiber composition, coiling direction, and combinations thereof, and a textile comprising such a twisted or coiled polymer fiber actuator.

7. claims: 62-64

A textile comprising two or more layers of fabric, wherein twisted or coiled polymer fiber actuators are included as a filler material between the two or more layers of fabric, and the textile is operable to change thickness as a consequence of dimensional changes of the filler material in

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

response to a change in temperature or moisture absorption.

8. claims: 65-70

A textile comprising at least two actuating textile elements, wherein the actuating textile elements comprise coiled polymer fiber actuators; and the coiled polymer actuators are incorporated in the width direction of the textile element such that the actuating textile elements are operable to reversibly change in width, without substantially changing length, in response to a change in temperature or moisture absorption, to reversibly change textile porosity without substantially changing either the width or length of the textile.

9. claims: 71-75

A method of making a heterochiral coiled actuator having opposite twist and coiling directions, wherein the method comprises the steps of: making a homochiral coiled actuator by twisting a polymer fiber in a first direction; and reversing the coil direction of the homochiral coiled actuator by twisting in a second direction opposite to the first direction to make the heterochiral coiled actuator.

10. claims: 76-89

A method for making a coiled polymer fiber that reversibly actuates without being positionally or torsionally tethered, wherein the method comprises the steps of: positionally and torsionally tethering a coiled polymer fiber; while maintaining the positional and torsional tethering of the coiled polymer fiber, thermally annealing the coiled polymer fiber at a temperature that is above 150°C and below the melting temperature of the polymer, and after annealing, removing the positional and torsional tethering of the annealed coiled polymer fiber, wherein the annealed coiled polymer fiber can reversibly actuate without being positionally or torsionally tethered, a coiled polymer fiber made by said method and a textile comprising such a coiled polymer fiber.

11. claims: 90-93

A textile comprising at least two fabric layers, wherein each of the fabric layers comprises at least one twisted or coiled polymer fiber actuator, and the at least one twisted or coiled polymer fiber actuator is operable to reversibly change either the porosity of at least one single layer of the textile, textile coloration, or combinations thereof, in response to a change in temperature or moisture absorption.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

12. claims: 94-100

A textile comprising two or more layers of fabric, wherein a twisted or coiled polymer fiber actuator connects at least two layers so that less than 10% of the length of the polymer actuator is in a fabric layer, and separation between fabric layers is operable to change in response to a change in temperature or moisture absorption.
