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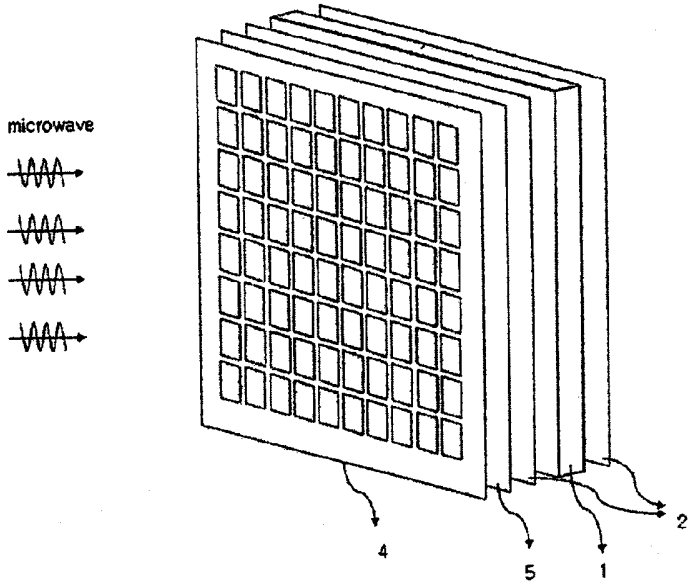
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(54) **Title:** BIOMIMETIC ELECTRO-ACTIVE PAPER ACTUATORS



(57) **Abstract:** This invention relates to biomimetic electro-active paper actuators which is ultra light, has large deformation feature, is operated with low power, consumes a little power, and suitable response speed, which comprises a paper that micro fibrils of cellulose are arranged in predetermined direction, electrodes which are disposed in both sides of the paper, a film rectenna which receives electric field from outside and converts it into direct power, and a PAD logic circuit (power allocation & distribution) which receives signal of direct power and convert/controls it into power force.

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BIOMIMETIC ELECTRO-ACTIVE PAPER ACTUATORS

BACKGROUND OF THE INVENTION

1. Field of the invention

The present invention relates to biomimetic electro-active paper actuators, which is ultra light, has large deformation feature, is operated with low power and consumes a little power, and has suitable response speed, and relates to a method thereof.

2. Description of the Prior Art

Electro-active polymer (EAP) is an industry that interest has been increased because of the possibility of artificial muscle as functional materials capable of deforming largely have been developing from ten odd years ago. EAP has flexibility like muscle as well as it can be deformed largely by outer stimulation, and has features and functions other materials have not. EAP creates the applications of artificial muscle actuators such as the next generation robot, entertainment industry or the actuators of micromini plane. The application of EAP actuators is broad, and provides utility to many industry fields. Howeyer, since the EAP developed until now has limited function, new EAP materials development is essential at present. There are many problems in EAP study, which has to be solved, including operation force

increase, rapid response, low power signal, and durability etc. Particularly, in ultra light EAP actuators, power supplying is very important when associated with application device.

Generally EAP is classified with operating principle as following electronic EAP and ionic EAP:

1. Electronic EAP: Dr.Zhang of Pennsylvania University has obtained remarkable piezoelectric phenomenon from electronic radiated P(VDF-TrFE) copolymer. When 150 V/μ m is applied at low frequency into copolymer, about 4% piezoelectric deformation rate can be obtained and it has elasticity constant more than 1GPa. However, a disadvantage is high production cost because of electronic radiation usage. This is used in acoustic transducer development to be used in medical probing apparatus, underwater acoustic, stereo speaker and the like. SRI International has been developing EAP actuators based on response of elastic copolymer covered with flexible electrode according to electric field applying past 10 odd years. Double bow-tie or roll typed linear actuators using acryl film is utilized in the artificial muscle of biomimetic robot such as 6-axials walking robot, flapping wing of micromini plane and the like. However, there are disadvantages that high voltage of about 200 V/μ m must be applied and prestrain must be given in lengthwise. NASA Langly institute has developed

piezoelectric polymer of Grafted elastic copolymer that has deformation rate of about 4% and high physical elasticity constant of 560 MPa at 140 V/μ m. Grafted elastic copolymer comprises Grafted polymer composing crystal in backbone having flexibility. These electronic EAPs have a problem which needs high operating voltage, resulting in that there are many difficulties in voltage breakdown, packaging, miniaturization, device design and implementation.

2. Ionic EAP: ionic polymer Gel is capable of synthesizing the actuators exhibiting force and energy density similar to human muscle. Gilvert of Arizona University made an actuator capable of operating like muscle by stacking cross-linked polyacrylamide and polyacrilic acid hydrogel alternately between electrodes. It is bended according to electric field when hydrogel is placed on water between two electrodes. However, since this multilayer ionic gel structure has needs time for ion to be diffused into gel, the response is slow. Ionomeric polymer-metal composites (IPMC) are ionic EAP well known that polymer net is bended by cation migration at electric field applied. Many researchers including Oguro of Japan Osaka National Research Institute (ONRI), Shahinpoor of America New Mexico University etc. has been developing about operating principle and functions of IPMC. By using these products, there were trial performances such as dust

wiper, gripper, non-noise swimming robot, positive catheter, and chillums assembled robot, artificial tactile system similar to coral reef, and the like. Conducting polymer (CP)is operated by reversible counter-ion charge and discharge generating during redox cycle. The actuators using CP has been developing in many countries including USA, Japan, Australia, Italia, Spain etc, and bilayer structure and trilayer structure have been developed until now according to stack of CP film and film without volume deformation. Sweden Linkopings university succeeded in making robot arm having elbow, wrist and 2~4 fingers able to control separately by using conducting polymer actuator, and in moving 0.1 mm glass ball about 0.25 mm. the actuator using Single-walld carbon nanotube generates strain more than that of natural muscle and higher deformation more than ferroelectrics having high elasticity constant. Macro SWNT actuator such as natural muscle is a type that several billions nanotubes are combined, and long durability because of not needing ion exchange reducing life, and is operated at low voltage. This ionic EAP has disadvantages that operating speed is slow and there must be an electrolyte and water while having advantage that the operating voltage is low.

As described above, electronic EAP developed until now has rapid response and large deformation rate but needs high operating voltage,

while ionic EAP can be deformed at low operating voltage and have elasticity like muscle but response speed is low and there must be kept water.

On other hand, in applications needing ultra light and large deformation features such as micromini warm robot, micromini plane, and entertainment apparatus, above-mentioned requirements are essential. For application needing ultra light and large deformation features, EAP needs rapid response, low power consume, and long durability. Particularly, since ultra light EAP application device has a problem that power source is difficult to be mounted, it is desirable to use remote power source for reducing weight as well as minimizing consume power. If this remote power source is used, EAP application can be extended due to EAP application device being lighter, consume power decreased and prompt of device improved.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other object, features and advantages of the present invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

Fig.1 is a schematic diagram showing a state being bended by electric

field, wherein electrodes are disposed in both cellulose papers,

Fig.2 is a schematic diagram showing another state being deformed in lengthwise, wherein cellulose paper is disposed in a plane,

Fig.3 is a block diagram showing a biomimetic electro-active paper actuator according to the present invention,

Fig.4 is a perspective view showing an embodiment according to the present invention, and

Fig.5 is a perspective view showing another embodiment according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention is proposed for solving above mentioned problems, and purposed for providing ultra light biomimetic electro-active paper actuators having large deformation rate, low energy consume, rapid response, durability and able to remote. And the present invention is purposed for providing operating method of the actuator associated with remote operating tech using microwave for implementing the paper actuator.

According to the present invention, the paper actuator is made of paper comprising cellulose, wherein the paper is made by arranging micro fibril in a predetermined orient and disposing electrodes in the

paper. Therefore, the actuator is deformed when electric field is applied.

In these functional materials, it is very important that the paper is made by arranging micro fibril of cellulose in a predetermined direction. For implementing the paper, cellulose solution is prepared by dissolving cellulose pulp through viscose method like using a strong alkali, and then micro fibril is arranged in predetermined direction by the centrifugal force after spin-coating the cellulose solution, or by applying some strain force while extruding the cellulose solution through a slit.

Various deformations can be obtained according to the method of disposing electrodes on the paper, and these examples are shown in Figs.1~2. Fig.1 illustrates bending deformation occurred in a state that conducting electrodes are disposed on both paper sides, one end of paper being fixed, and electric field is applied. Fig.2 illustrates lengthwise deformation occurred in another state that paper having two electrodes is disposed on a plane and electric field is applied. In these cases, if the length varies, width deformation occurs according to Poisson`s ratio.

Detailed operating principle, the crystal area and non-crystal area of

cellulose fibril are deformed by piezoelectric effect and ionic transition effect reacted with the applied electric field. When micro fibril is arranged in a specific direction, piezoelectric effect occurred due to the crystal structure in crystal area. It is well known that tree and cellulose have piezoelectric effect. Meanwhile, paper is known as an ionic conductor. In paper producing step, various metal ions can be dissolved into pulp and water is present as absorbed water or free water interior paper. These ions or water are migrated into cathode or anode according to the applied electric field, resulting in that deformation occurs.

Microwave remote principle is shown Figs 3~5. When microwave is received, rectenna converts the received microwave into direct power. There are two typed rectennas, e.g., patch type and dipole type both can be used. Since the size of rectenna varies according to frequency, rectenna size is decreased and can be arranged in a specific direction when high frequency is used. Further, rectenna can be integrated with an actuator because of being film. In Dipole rectenna, microwave is converted into direction power, and the signal is applied into EAPap actuator through power conversion/control circuit of power allocation & distribution (PAD) logic circuit. PAD implements the principle by supplying power when horizontal and vertical directional signals are all given using dual gate MOSFET. At

this time, since the electrodes are disposed separately on both sides of EAPap, the deformation of paper actuator can be desired type by controlling the applied voltage. This method is an ultra light actuator operating technology overcame the limit of prior art, and therefore it can make EAPap actuator being ultra light and can be utilized in various industry fields. This remote operation is possible because that the consume power of EAPap is as low as it does not harm human beings. Since power battery necessary to operating is not needed any more when power is supplied by using microwave, ultra light remote operating EAPap can be implemented.

Although the preferred embodiments of the present invention have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible, without departing from the scope and spirit of the invention as disclosed in the accompanying claims.

What is claimed is:

1. Biomimetic electro-active paper actuator comprising:

paper (1) wherein micro fibril of cellulose is arranged in a specific direction,

electrodes (2) disposed on both sides of the paper,

film rectenna (4) converting received electric field from out into direct power, and

PAD (power allocation & distribution)(5) logic circuit converts/controls the received signal of direct power.

2. The biomimetic electro-active paper actuator in claim 1, wherein ultra film batter layer (6) can be used by associating with the actuator when microwave is not transmitted.

3. The method for operating the biomimetic electro-active paper actuator, comprising:

disposing conducting electrodes on both sides of the cellulose paper,

fixing one end of the paper in order to generate bending deformation when electric field is applied, and

displacing the paper between two planes in order to generate lengthwise deformation when electric field is applied.

4. The method in claim 3, further comprising:

remote operating the actuator by transmitting microwave.

5. The method for preparing paper wherein micro fibril of cellulose is arranged in a specific direction, comprising steps of:

preparing cellulose solution by dissolving cellulose pulp, and

arranging micro fibril in a specific direction by centrifugal force after spin-coating the cellulose solution, or arranging micro fibril in a specific direction by applying some strain force while extruding the cellulose solution through a slit.

Fig. 1

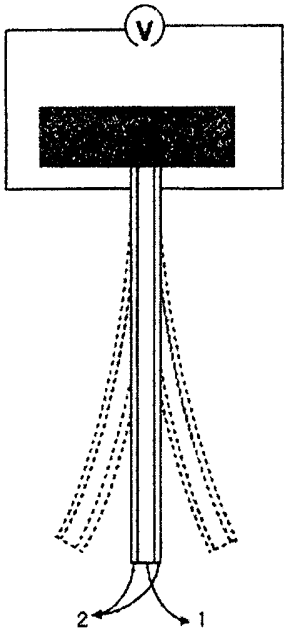


Fig. 2

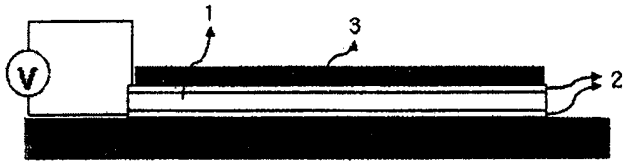


Fig. 3

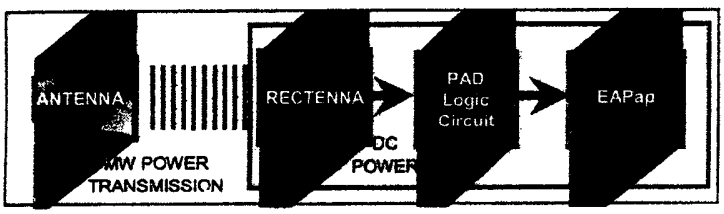


Fig. 4

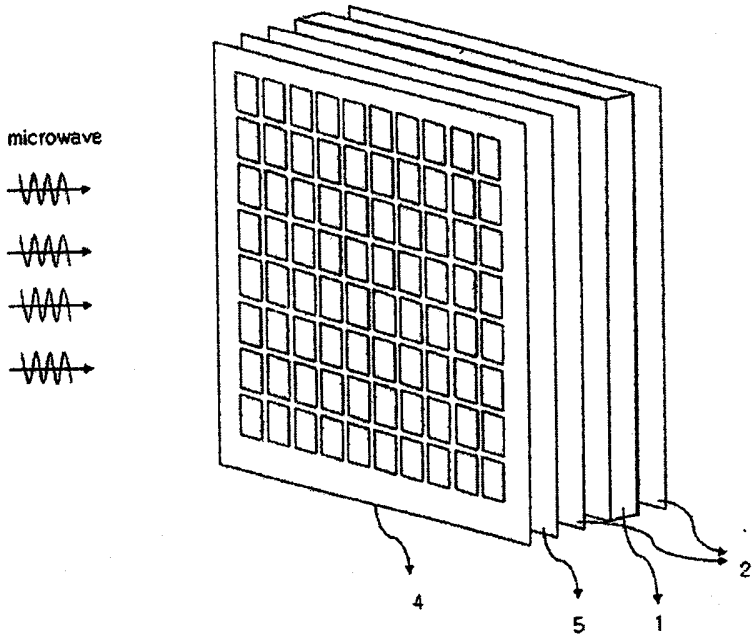
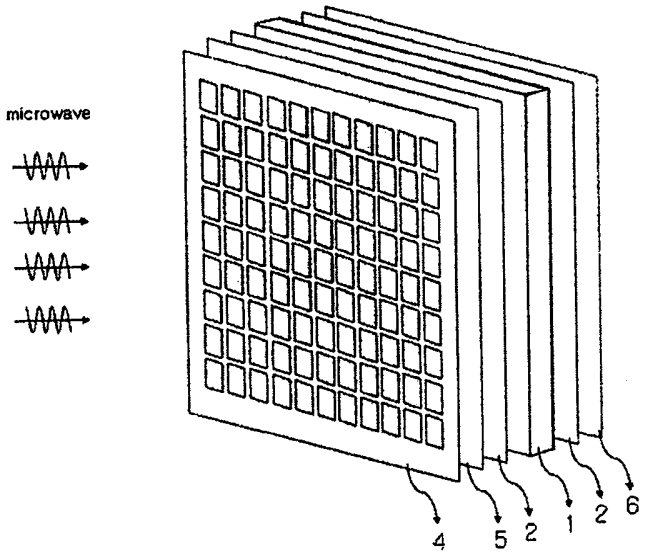


Fig. 5



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2005/002176

A. CLASSIFICATION OF SUBJECT MATTER

IPC7 H02N 2/00

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 7 H01I H02N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Patents and applications for inventions since 1975, Korean Utility models and applications for Utility models since 1975
Japanese Utility models and applications for utility models since 1975

Electronic data base consulted during the intertnational search (name of data base and, where practicable, search terms used)
eKIPASS(Searching System of Korean Intellectual Property Office), IEEE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,664,718 B2 (SRI International, Menlo Park, CA) 16 Dec. 2003 See the whole document	1-5
A	US 6,583,533 B2 (SRI International, Menlo Park, CA) 24 Jun. 2003 See the whole document	1-5
A	2004 NASA/DoD Conference (Yoseph Bar-Cohen) 24-26 June 2004 See PP. 309-317	1-5

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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