Chapter 2
Current Status of Applications and Markets of Soft Actuators

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Abstract In this chapter, the current status of applications and markets of soft actuators will be described with reference to some published patents in the expected application fields.

Keywords Electroactive polymer · Consumer electronics · Biomedical device · Automobile · Haptics · Energy harvesting · Sensor · Robotics

2.1 Introduction

Soft actuators are one of the most promising technologies of various emerging applications such as haptics, biomedical fields, MEMS, robotics, etc. Among the various materials of soft actuators reported in this book, electrically driven polymer actuators, so-called electroactive polymer (EAP) actuators, are especially of practical interest for various industries [1–4]. The EAP actuators are broadly classified as electronic and ionic EAPs. Electronic EAPs respond to an electronic field, whereas ionic EAPs change shape by the transfer of ions by applying voltages [1]. Each type has various advantages and disadvantages. Table 2.1 lists main EAP materials and the properties thereof.

Due to various properties, such as lightness, softness, ease of processing, high compliance, and low cost of soft actuators, they have become very attractive for applications in various fields, such as consumer electronics, biomedical applications, robotics, etc. In this chapter, applications of soft actuators will be described with reference to some published patents in the expected application fields.

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Table 2.1 List of main EAP materials and the properties thereof

EAP type	EAP materials	Advantages	Disadvantages
Ionic EAP	Ionic polymer (IP)	Low drive voltage	Low electrome-chanical efficiency
	Nafion/Pt, Au	Relatively high response	
	Flemion/Pt, Au	Large displacement	
	Ionic gel/nano-carbon	Soft material	Relatively low actuation force (bending EAPs)
	Conducting polymer (CP)	Can be activated in both wet and dry conditions	
	Polypyrrole		
	Polythiophene		
	Polyaniline		
	Carbon nanotube (CNT)		
Electronic EAP	Piezo-electric (PE)	High response	High drive voltage
	PVdF, PVdF-TrFE	Large actuation force	
	Electrostrictive (ES)	High mechanical energy density	No effect of volt-age polarity
	PVdF-TrFE		
	Dielectric elastomer (DE)	High efficiency	
	Acryle, silicone		
	Dielectric gel (DG)		
	Plasticized PVC		

2.2 Current Status of Applications of Soft Actuators

2.2.1 Groundbreaking Studies

Soft actuator researches started from the research of direct transfer from chemical energy to mechanical work by using polymer gels [5]. As a Japanese pioneer patent relating to this research, Japanese Unexamined Patent Application Publication No. 1977-28482 (JP-A-1977-28482), "ENERGY CONVERSION AND SHAPE CONVERSION METHODS THROUGH THE MEDIUM OF POLYMERIC COMPOSITIONS" (Applicant: HIDETOSHI TSUCHITANI, YOSHIIHITO OSADA), discloses a method that transfers chemical energy to mechanical work and changes shape by deforming polymer gels by pH changes reversibly. In this patent, with the application of this method, liquid and gas flow control valves and destruction of the bedrock were presented as examples. Among various driving methods of soft actuators, for example, by pH control, temperature control, solvent control, etc., electrical control is the best method for the various applications, since the system itself becomes compact by using this method. As the Japanese pioneer patent of the electrically driven polymer gel, Japanese Patent No. 01592684 (JP 01592684), "BENDING METHOD OF POLYMER MATERIALS" (Toyota Central Labs., Inc.), discloses a bending actuator based on electrically driven polymer gels. With the application of JP 01592684, an artificial fish with a fin of electrically driven bending polymer gel was developed.

Based on these groundbreaking studies, JP 1966645; US 5268082 (OSAKA NATIONAL RESEARCH INSTITUTE) discloses an ionic polymer metal composite actuator, which opened the door to the research and development of the practical device of soft actuators. This patent is known to be a representative patent of ionic polymer actuators. As representative patents of electronic-type polymer actuators, US 6343129, 6940211, 7049732, (SRI INTERNATIONAL) discloses dielectric elastomer actuators.

Based on these studies, research and development of practical devices of EAP actuators has become vigorous worldwide including in Japan, Europe, and North America.

2.2.2 Current Status of Technology of EAP Actuators for Applications

As previously described in Sect. 2.1, EAP actuators are broadly classified as ionic and electronic types; and nowadays, there are various kinds of EAP actuators that have different responses and mechanical properties [4]. There are many patents about materials, structures, and production methods of EAP actuators. Table 2.2 summarizes the representative recent patents of EAP actuators for applications. Therefore, it is possible to select the EAP actuators for each application.

2.2.3 Consumer Electronics

The field that is applied most for is "image device and image apparatus." Table 2.3 lists the representative patents. For instance, JP 4972779, "OPTICAL UNIT AND IMAGING APPARATUS," discloses an optical unit and an imaging apparatus that have the features of "autofocus" and "hand shake correction" driven by EAP actuators. Since a small "image apparatus," which can be mounted on mobile phones, needs low costs, scalability, and high functions, EAP actuators are very attractive devices in this field, since they have a high power density, are lightweight and noiseless, require a low driving voltage, and have an ease of molding into any shape. JP 5029140, "VARIABLE SHAPE OPTICAL ELEMENTS, OPTICAL APPARATUS AND IMAGING APPARATUS," and WO200585930, "ADAPTIVE OPTICAL ELEMENT COMPRISING A POLYMER ACTUATOR," disclose shape-variable lenses using EAP actuators, which is quite a different method from mechanical transfer of optical lenses that is disclosed in other patents.

Another important field in consumer electronics is haptics. Many patents which provide haptic (touch-sense) feedback to the user interface (such as touch panel, etc.)

Table 2.2 Representative recent patents relating to EAP actuators

Bulletin number	Title	Applicant	EAP actuator used
JP-A-2015-164979	Deformable polymer, deformable material and actuator	Seiko Epson Co.	IP
JP-A-2017-184586	Ion exchange polymer actuator	Asahi Kasei Co.	IP
JP-A-2016-144295	Sealed polymer actuator and manufacturing method thereof	Alps Electric Co. Ltd.	IP
JP-A-2016-146716	Polymer actuator element	Alps Electric Co. Ltd.	IP
JP-A-2014-220949	Actuator element, actuator, flexible sheet, and manufacturing method of the actuator element	Bando Chemical Industries Co.	DE
JP-A-2015-223049	Gel actuator	Shinshu Univ.	DG
JP-A-2017-132903	(Meth) acrylic dielectric material	Osaka Organic Chem. Industries Ltd.	DE
JP-A-2017-132905			
JP-A-2018-033293	Dielectric elastomer actuator and its drive system	Rohm Co. Ltd.	DE

have already been filed. Table 2.4 lists the representative patents. This technology can be applied to all types of user interfaces, such as touch pads, touch screens, and keypads of PCs, mobile phones, PDAs, video game consoles, GPS, etc. Therefore, this technology can contribute remarkably to a wide range of user interfaces and is expected to be a significant development in the near future. Furthermore, with recent developments of the Internet of things (IoTs), various wearable devices have been developed. Fibrous input/output devices for the intelligent cloths based on the EAP materials can be realized (JP-A 2015-198154). It is predicted that these technologies become further important in future.

Other important patents in relation to consumer electronics are as follows.

JP-A-2010-140717, "SWITCHING ELEMENT WITH MECHANICAL MOVEMENT" (Hitachi Electric Co.), and JP-A-2010-159780, "BRAKE DEVICE USING CONDUCTING POLYMER ACTUATORS" (Panasonic Co.), disclose devices that make use of the advantages of EAP actuators such as the capability for low power

Table 2.3 Representative patents relating to consumer electronics

Bulletin number	Title	Applicant	EAP actuator used
JP 4758211	Camera shake correction unit and photographing apparatus	Fujifilm Co.	DE
JP 4972779	Optical unit and imaging apparatus	Konica Minolta Opto Products Co., Ltd.	DE, ES, IP
JP 4324743	Stage structure of the imaging element and imaging device	Casio Computer Co., Ltd.	IPMC
JP 4501085	Optical element module and imaging device	Sony Co.	IP
JP 4435290	The lens holder driving device and imaging device using a surface-driven polymer actuator	Panasonic Co.	IP
JP 5029140	Variable shape optical elements, optical device and imaging apparatus	Konica Minolta Opto Products Co., Ltd.	EAP
JP 5188924	Imaging lens unit	Kantatsu Co., Ltd.	EAP
WO200585930	Adaptive optical element comprising a polymer actuator	SIEMENS	DE
US7679839	Optical lens displacement systems	Bayer MaterialScience	DE
EP2270555	Optical liquid lens with a buffer elastic film	Samsung Electronics	DE, ES, IP
JP-A-2014-153690	Lens driving device	Alps Electric Co. Ltd.	EAP
JP-A-2014-215488	Polymer device, method of manufacturing the same, lens module, and imaging unit	Sony Co.	IP
JP-A-2014-215530	A polymer element, its manufacturing method, a camera module, and imaging device	Sony Co.	IP
JP-A-2015-022290	Imaging device	Olympus Co.	ES, IP
JP-A-2015-195645	Polymer element, electronic apparatus, a camera module, and imaging apparatus	Dexerials Co.	IP
JP-A-2016-218139	Lens unit for camera and on-vehicle camera	Hitachi Maxell Ltd.	EAP

consumption operation and being small and light. The EAP actuators are the best devices for the application of these small apparatuses.

JP 5151896, "VIBRATION DAMPING DEVICE" (Konica Minolta Co.), discloses vibration damping devices using the EAP actuators. Although vibration damping devices using piezoelectric actuators are well-known, to use EAP actuators gives the possibility of application to a vibration body which piezoelectric actuators cannot control. Nowadays, various information apparatuses are used in the home and

Table 2.4 Representative patents relating to haptics

Bulletin number	Title	Applicant	EAP actuator used
JP 4633074	Polyelectrolyte film actuator and touch panel using the same	Japan Aviation Electronics Industry Ltd.	IP
JP-A-2010-86500	Operation device	KDDI Co., Hitachi, Ltd.	CP
JP-A-2011-22495	Protrusion pattern forming device with the display function	Sony Co.	IP
WO2010054014	Electroactive polymer transducers for tactile feedback devices	Bayer Materials Science	DE
WO2011123599	System and method for providing haptic stimulus based on position	Immersion Co.	EAP
WO2009154158	Actuator and input device using the same	Alps Electric Co. Ltd.	IP
US7342573	Electrostrictive polymer as a combined haptic-seal actuator	NOKIA	IP
JP-A-2015-198154	Piezoelectric element	Teijin Co., Kansai Univ.	PE
JP 4705992	Dot display device	Alps Electric Co.	IP
JP-A-2012-508421	Electroactive polymer transducer for haptic feedback device	Bayer Materials Science AG	DE
JP-A-2013-524351	System and method for providing tactile stimulation on the basis of the position	Immersion Co.	EAP
JP-A-2016-127202	Piezoelectric element	Teijin Co. Kansai Univ.	PE

office, and noises generated by them are a serious problem. The vibration damping devices using EAP actuators may be adopted as one of the solutions in the near future.

JP-A-2011-123685, "ANTENNA DEVICE AND COMMUNICATION APPRATUS" (Sony Mobile Communications Inc.), discloses antenna devices that can be applied to small communication devices such as mobile phone terminals, etc. JP-A-2008-206144, "SELF-DEFORMABLE ANTENNA APPARATUS" (JAMSTEC, RIKEN, AIST), provides a technology for controlling the direction of an antenna freely by using an ionic EAP actuator. The technology for controlling the direction of the antenna and a solar cell panel in aerospace by using EAP actuators was also reported. JP-A-2014-016616, "FLEXIBLE DISPLAY DEVICE" (Samsung Display Co.), discloses the technologies which develop the portability and usability of the flexible display devices such as organic EL display by controlling their flexibility using the EAP actuators.

2.2.4 Biomedical Devices

Biomedical fields are also among those to which many application patents of EAP actuators have already been filed. Table 2.5 lists the representative patents. From Table 2.5, it can be interpreted that the most important applications are micro-pumps for medical uses and microchips for analysis, and various EAP actuators have been adopted as electromechanical parts for these devices, such as diaphragms of micro-pumps and micro-valves of microchips. For instance, JP-A-2011-208597 discloses a micro-pump based on a conducting polymer actuator, and JP-A-2010-175360 discloses microchips for analysis including a micro-pump based on a conducting polymer actuator. Another important application is the "artificial organ," which is disclosed in JP 4646530, "ACTUATOR ELEMENT AND ITS DRIVING METHOD." This application was expected since the early stages of the research into EAP actuators. Moreover, many application patents for active catheters, active endoscopes, ultrasonic therapy apparatuses, and medical treatment tools have been filed.

Recently, with the improvement of the performances of various EAP actuators, wearable robotics based on the EAP actuators can be realized. Therefore, the patents of the EAP actuators for the applications including power assists for rehabilitations and cares and electric prosthetic hands have been published. For instance, JP-A-2014-094034 discloses the technology of an electric prosthetic hand which is capable of gripping largely and stably by combining wire mechanism of electromagnetic motors and elongation/contraction mechanism of EAP actuators.

2.2.5 Robotics

Applications of soft actuators to robotics are not only the purpose of the research at the early stage; the ultimate goal of the research is to realize artificial muscles by applying soft actuators. In the current stage, the practical application of soft actuators to robotics to realize artificial muscles is difficult. Here, the following two patents are shown as examples of the application of EAP actuators to robotics:

1. JP 3976129, "PARALLEL LINK MECHANISM AND ARTIFICIAL JOINT DEVICE USING THE SAME" (Honda Motor Co. Ltd.)
2. JP 3817259, "CONDUCTING POLYMER ACTUATOR" (Panasonic Co.)

US7966074, "APPARATUS AND METHOD FOR ENHANCING MUSCULAR MOVEMENT" (Samsung Electronics Co.), and JP-A-2010-051416, "MOTION ASSISTING APPARATUS OF ANKLE JOINT AND ITS CONTROL METHOD" (Nabtesco Co.), disclose the applications of the motion assisting apparatus for the nursing of elderly people and rehabilitation work.

Table 2.5 Representative patents relating to biomedical devices

Bulletin number	Title	Applicant	EAP actuator used
JP 3071524	Micro-pump	Nidec Co.	
JP 4646530	Actuator element and method of driving the same	Eamex	IP
JP 4481826	Catheter for thrombolysis	Boston Scientific	CP
JP 4374436	Grip forceps system	Tohoku University	IP
JP 4679241	Endoscope	Olympus Medical Systems	DE
JP 4657082	Ultrasound therapeutic apparatus	Olympus Medical Systems	ES
JP 4961898	Capsule type medical apparatus	Konica Minolta Opto Products	CP
JP 5021366	Treatment implement and endoscope operation system with the same	Olympus Medical Systems	EAP
JP-A-2010-175360	Microchemical chip	Panasonic	CP
JP-A-2011-208597	Micro-pump	Eamex	CP
US20050085693	Activated polymer articulated instruments and methods of insertion	Intuitive Surgical	IP
US7407074	Electroactive polymer-based actuation mechanism for multi-fire surgical fastening instrument	Ethicon Endo-Surgery, Inc.	EAP
US7566297	Electroactive polymer-based artificial sphincters and artificial muscle patches	Boston Scientific Scimed	CP
JP-A-2013-146328	Device for supporting operation	Seiko Epson Co.	IP
JP-A-2013-169035	Attachment structure of polymer actuator	Toyoda Gosei Co. Ltd.	DE
JP-A-2014-079329	Wearable muscle strength detection tool, control device, and muscle strength detection system	Nikon Co.	EAP
JP-A-2013-085579	Electric artificial hand	Toyoda Gosei Co., Ltd.	DE
JP-A-2014-094030			
JP-A-2015-211577	Actuator, laminated actuator and auxiliary tool	Nikon Co.	DG
JP-A-2016-168205	Ocular function assisting device	Topcon Co.	EAP
JP-A-2017-500936	Cushion element for a patient interface	Koninklijke Philips N.V.	EAP

Table 2.6 Representative patents relating to robotics

Bulletin number	Title	Applicant	EAP actuator used
JP-A-2013-146328	Device for supporting operation	Seiko Epson Co.	IP
JP-A-2013-169035	Attachment structure of polymer actuator	Toyoda Gosei Co. Ltd.	DE
JP-A-2013-220496	Power transmission device	Honda Motor Co. Ltd.	CP
JP-A-2014-050490	Stretchable clothing	Shinshu Univ.	DG
JP-A-2014-079329	Wearable muscle strength detection tool, control device, and muscle strength detection system	Nikon Co.	EAP
JP-A-2013-085579	Electric artificial hand	Toyoda Gosei Co. Ltd.	DE
JP-A-2014-094030			
JP-A-2015-171225	Actuator device and unit of the same	Shinshu Univ.	DG
JP-A-2015-211577	Actuator, laminated actuator, and auxiliary tool	Nikon Co.	DG
JP-A-2017-024117	Spirally deformable soft device and robot system using the same	Canon Inc.	EAP

These early patents were conceptional. However, although the practical application of EAP actuators to realize artificial muscles is still difficult, some recent patents disclose a realization of soft actuators for wearable robots. Table 2.6 summarizes the representative patents. (Several patents in Table 2.6 are also listed in Table 2.5.) For instance, JP-A-2014-050490 discloses the technology of a power assist for human movements by using the wearable robots based on stacked Dielectric Gel Actuators. It is expected that various EAP actuators can be applied to wearable robotics in medical and welfare fields including rehabilitations, nursing cares, prosthetic artificial hands and legs, etc.

2.2.6 Other Applications of Soft Actuators

Many applied patents have already been filed in other fields including the field of automobiles. Table 2.7 lists the representative patents. It can be seen from Table 2.7 that there are patents of EAP actuators that apply to various parts of automobiles, such as dampers, steering, power transmission devices, tires, sheets, air bags, etc. However, there are few patents that are truly effective in this field. For instance, JP-A-2006-348085, "CUSHION ACTUATOR OBTAINED USING IONIC LIQUID, AND PART FOR VEHICLE COMPOSED OF THE SAME" (Nissan Motor Co. Ltd.), discloses interior part for automobile based on cushion actuator capable of reducing weight and saving space by using the EAP actuator based on an ionic liquid gel. JP-A-2014-074419 and JP-A-2015-121233, "VALVE DEIVCE" (Honda Motor Co. Ltd.), disclose the technologies about miniaturization, weight reduction, and cost reduction of the valve devices which are most suitable for a hydraulic control apparatus for an automobile transmission by using dielectric elastomer actuators. Furthermore, JP-A-2013-023107, "VEHICLE SYSTEM," and JP-A-2013-023108, "AIR-CONTAINING TIRE" (Sumitomo Rubber Industries, Ltd.), disclose the technologies about the deformation of the tires by controlling the EAP actuators which are implanted in the tires in response to the environment of the vehicle in order to improve the running performance and to avoid the danger of the automobile accident at the time of flat tire while maintaining the ride comfort during ordinary drive.

In recent patents, as summarized in Table 2.8, new applications for information apparatuses based on EAP actuators were provided in the field of automobiles. For instance, JP 5182353, "INFORMATION PRESENTING DEVICE," discloses a steering device with EAP actuators for providing a driver with support information by means of haptics. JP-A-2013-023107, "VEHICLE SYSTEM," discloses a control method of the deformation of EAP actuators which are embedded in the tires of a vehicle in order to improve the running performance thereof.

2.2.7 Energy Harvesting and Sensor

Table 2.9 summarizes the representative patents in this field. JP-A-2012-16917, "ELECTROSTATIC CAPACITY VARIATION TYPE POWER GENERATION ELEMENT," discloses energy harvesting devices using dielectric elastomer EAP devices. In recent years, the research of the energy harvesting, based on various EAPs, is being developed from a basic and practical point of view.

Among them, electric-capacitor-type stretching stress sensors and stress sensors using the same materials as the dielectric elastomer actuators (JP-A-2010-223953, 2011-002256, 2011,075322, 2013-072753, 2014-081355, 2014-219623) are commercialized as the products for the stretching sensors for the wearable robots and the body pressure distribution measurements for the purpose of the investments of

Table 2.7 Representative patents on automobile

Bulletin number	Title	Applicant	EAP actuator used
JP-A-2005-083530	Variable damping force damper	Honda Motor	CP
JP-A-2005-104416	Steering device	Honda Motor	CP
JP-A-2005-112200	Pneumatic tire	Honda Motor	CP
JP-A-2006-348085	Cushion actuator obtained using ionic liquid, and part for vehicle composed of the same	Nissan Motor	IP
JP-A-2011-106564	Power transmission device	Honda Motor	EAP
JP-A-2009-216130	Shock absorber	KYB	EAP
JP-A-2012-203798	Information presentation system	Denso IT Laboratory	EAP
US20030168936	Electroactive polymer as a fuel vapor control valve actuator	SIEMENS VDO Automotive	DE
US7516982	Gas bag module	TRW Automotive Safety Systems	EAP
WO2006062608	Tunable vehicle structural members and methods for selectively changing the mechanical properties thereto	General Motors	PE
DE102012013972	Retention device for holding object such as beverage container, of motor car, has electroactive polymer actuator unit which is partially extended to inward of recess along axial direction in use state	Daimler AG	EAP
JP-A-2013-023107	Vehicle system	Sumitomo Rubber Industries, Ltd.	IP, DE
JP-A-2013-023108	Pneumatic tire	Sumitomo Rubber Industries, Ltd.	IP, DE
JP-A-2014-074419	Valve device	Honda Motor	DG
JP-A-2015-121233	Valve device	Honda Motor, Shinshu Univ.	DG

comfort of the cushion of the wheelchair and those of bedsore prevention of bedding. Also, research and developments of energy harvestings using human motion and natural energy such as ocean waves and wind powers have been developing based on a large change of the electric capacitance due to the deformation of dielectric elastomer.

Table 2.8 Representative patents relating to information apparatuses in the field of automobiles

Bulletin number	Title	Applicant	EAP actuator used
JP-A-2011-242386	Transparent compound piezoelectric material aggregate of contact sensor and tactile sense actuator	Immersion Co.	PE
JP-A-2012-062040	Information presentation device	Nippon Soken, Denso Co.	ES
JP-A-2012-203798	Information presentation system	Denso IT Laboratory	EAP
JP-A-2013-023107	Vehicle system	Sumitomo Rubber Industries	EAP
JP-A-2014-052586	Free shape presentation device	Denso Co.	CP
JP-A-2015-133109	Gesture-based input system in vehicle with haptic feedback	Immersion Co.	EAP
JP 5253282	Input device	Mitsubishi Electric Co.	EAP
JP-A-2016-057529	Three-dimensional shape creation device	Denso Co.	IP

2.3 Current and Expected Markets for Soft Actuators

JP 4245964, "DECORATIVE AQUARIUM AND DECORATIVE DISPLAY UNIT" (Eamex Co.), discloses a robotic ornamental fish with an ionic EAP actuator as a fin thereof, which is the world's first commercial product using an EAP actuator. Hereafter, more commercial products using EAP actuators will be expected in various fields. Here, current and future expected markets for soft actuators will be discussed.

In recent years, parts which are mounted on portable terminals need not only to be smaller and lighter but also have more sophisticated functions. Therefore, soft actuators, which can meet both needs, are a very attractive technology for these kinds of new fields. They are being applied to apparatuses for everyday uses as driving units that are noiseless and can be driven with low drive voltages and low power consumption.

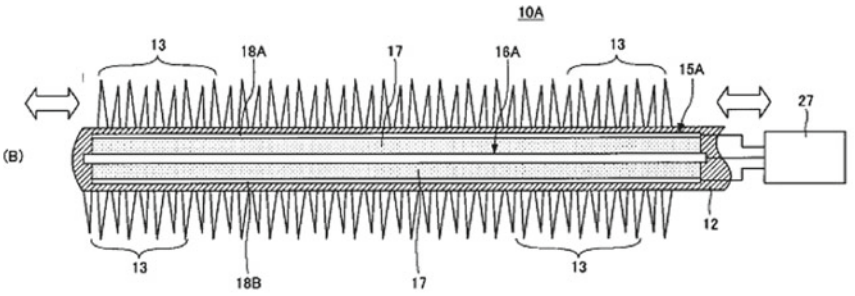
Figure 2.1 shows schematic view of some examples. An example of an applied patent of EAP actuators to a new field that utilizes the advantage of their noiselessness as compared to other actuators is JP-A-2013-063262, "COSMETIC TOOL" (Shiseido Co., Ltd.). Previously, an electric mascara applicator was proposed which was rotated

Table 2.9 Representative patents relating to energy harvesting and sensors

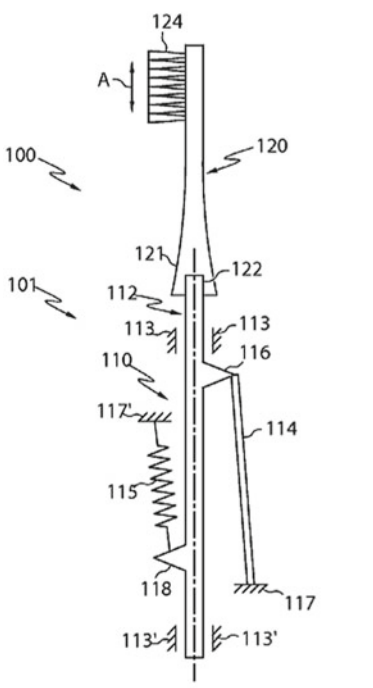
Bulletin number	Title	Applicant	EAP actuator used
JP-A-2011-087387	Polymer actuator and polymer sensor using the same	Eamex	IP
WO10/095581	Multi-laminating transformation sensor	Kuraray	IP
JP-A-2012-164917	Electrostatic capacity variation type power generation element	Fuji film	DE
US7034432	Electroactive polymer generators	SRI International	DE
JP-A-2010-223953	Capacitance type pressure-sensitive sensor and method of manufacturing the same	Tokai Rubber Ind. Ltd.	DE
JP-A-2011-002256	Sensor using electroactive polymer	Hyper Drive Co.	DE
JP-A-2011-075322	Capacitance type sensor	Tokai Rubber Ind. Ltd.	DE
JP-A-2013-072753	Capacitance type sensor device	Tokai Rubber Ind. Ltd.	DE
JP-A-2014-081355	Electrostatic capacitance type sensor sheet and electrostatic capacitance type sensor sheet manufacturing method	Bando Chem. Ind. Ltd.	DE
JP-A-2014-219263	Capacitance type sensor sheet and sensor	Bando Chem. Ind. Ltd.	DE

and vibrated by electromagnetic motor for easier application of mascara. However, it had problems: heavy to use and too noisy. In order to solve these problems, the above patent discloses a technology that employs a conducting polymer actuator. JP-A-2013-115951, "Rotary drive device" (Casio Computer Co., Ltd.), discloses a silent low-driving-voltage and power-saving rotary driving device for a watch by transferring an elongation-contraction movement to a rotary movement using a conducting polymer actuator. JP-A-2013-83049, "SLAT ANGLE CHANGE DEVICE" (Aisin Seiki Co., Ltd.), discloses a slat angle adjusting device for horizontal blinds using the EAP actuator in order to solve the same issues. Moreover, various patents which disclose daily necessities using EAP actuators have been filed, e.g., "the electric toothbrush" in US 2013025079, "LINEAR ELECTRO-POLYMER MOTORS AND DEVICES HAVING THE SAME" (Braun); JP-A-2008-142108, "MASSAGING APPARATUS" (Yamaha Co.); and JP-A-2012-64441, "LIGHTING DEVICE" (Konica Minolta Opto Products Co., Ltd.).

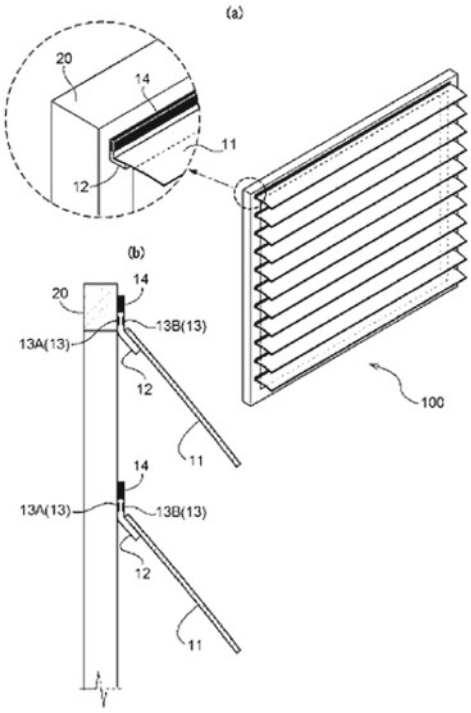
In recent years, growing interest has been focused on environmental issues. One of the most effective methods to solve a part of this issue is to use solar cells as a clean energy source. However, the important issue for the effective use of the solar light and the maintenance of the device is the removal of snow from the solar cell panel. As shown in Fig. 2.2, JP-A-2011-060836, "SOLAR CELL MODULE



JP-A-2013-063262



US2013025079



JP-A-2013-83049

Fig. 2.1 Schematic views of disclosed inventions

APPARATUS" (OBAYASHI Co.), discloses a technique that cleans the snow from the solar cell panel by the vibration which is provided by the deformation of the dielectric elastomer actuators. This method is able to accomplish the purpose using low power consumption compared to using a piezoelectric device.

As the patents of electric-acoustic transducers that can reproduce a music signal with a high sound quality by using a small device producing large vibrational amplitude, two patent applications were filed: one is JP-A-2011-223478,

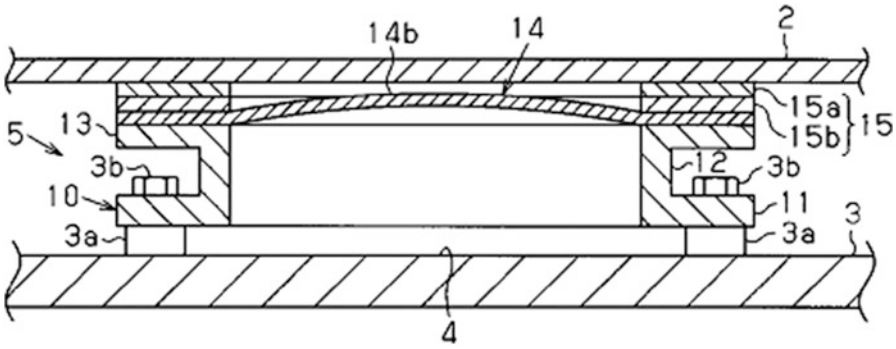


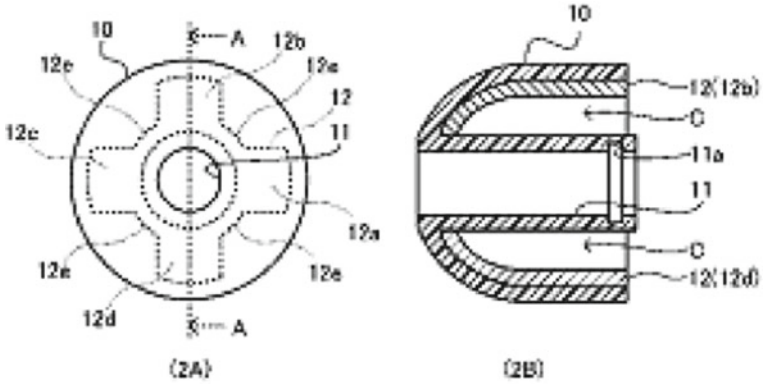
Fig. 2.2 Schematic view of the invention disclosed in JP-A-2011-060836

"POLYMER ACTUATOR AND ELECTROACOUSTIC TRANSDUCER USING THE SAME; AND ELECTRONIC EQUIPMENT" (NEC Co.), which adopts conducting polymer polyaniline actuators as the EAP actuator, and the other is WO2012173669, "AUDIO DEVICES HAVING ELECTROACTIVE POLYMER ACTUATORS" (Bayer MaterialScience Co.), which adopts dielectric elastomer actuators. Meanwhile, JP 5024065, "EARPHONE" (Yamaha Co.), discloses a technique by which an EAP actuator deforms an ear canal insertion part of an earphone in the radial direction of a sound conduction tube so that the earphone can be used more comfortably and held more securely. Schematic view of both inventions is shown in Fig. 2.3. Furthermore, JP-4475248, "PLAYING AUXILIARY STRUCTURE OF A WIND INSTRUMENT"; JP-4225335, "THE KEY DRIVE SYSTEM"; and JP-A-2010-085692, "STRINGED INSTRUMENT" (Yamaha Co.), disclose that EAP actuators can apply to various musical instruments such as wind instruments, keyboard instruments, and stringed instruments in order to support the musical performance of a beginner and a person with less strength.

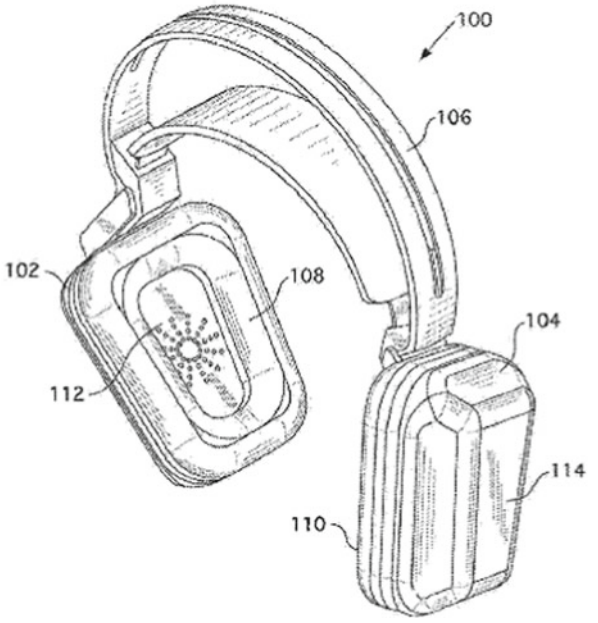
A typical example of an application patent in the welfare field is JP-A-2006-034574, "BEDSORE CONTACT ARRESTER AND BEDSORE CONTACT PREVENTION SYSTEM" (Mitsubishi Electric Co.). Moreover, a Braille display which is disclosed in JP 4705992, "DOT DISPLAY DEVICE" (Alps Electric Co. Ltd.), and JP 5066754, "POLYMER ACTUATOR ELEMENT AND BRAILLE DISPLAY USING THE SAME" (University of Yamanashi, Takano Co., Ltd.), is one of the most promising applications for EAP actuators.

2.4 Conclusion

As previously described, the technical fields for the application patents of EAP actuators have spread through various fields such as daily necessities; consumer electronics; musical instruments; portable terminals including speakers, etc.; environmental applications including solar cells, etc.; and welfare applications including



JP 5024065



WO2012173669

Fig. 2.3 Schematic view of disclosed inventions

Braille devices, etc. As compared to conventional electromagnetic motors with their heavy and hard structures and noise problems, soft, lightweight, and noiseless EAP actuators have an affinity with humans and the advantages of low power consumption and low drive voltages that are strong points for applications both economically and environmentally. Therefore, they will be expected to produce various applied patents in human friendly applied fields.

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