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A Simple Technique for the DEA Deformation Control by the Constraint Impose using an Adhesive

Fahmi Khairil[1], Wenyi Lin[2], Gakuji Nagai[1], Keishi Naito[1], Takahiro Nitta[3], Minoru Sasaki[1] and Hirohisa Tamagawa[1]*

[1]*Department of Mechanical Engineering, Gifu University, Japan*

[2]*Kawamura Electric Inc., Japan*

[3]*Department of Electrical, Electronic and Computer Engineering, Gifu University, Japan*

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***Corresponding author:** Hirohisa Tamagawa, Department of Mechanical Engineering, Gifu University, Japan

Abstract

Dielectric elastomer actuator, abbreviated DEA, is an unconventional soft material actuator but yet to be practical. However, owing to its promising potential, it has been broadly and intensively investigated. Induction of in-plane deformation of DEA is a well-known simple task. Induction of more complex deformation is as intuitively understood necessary for its practical use, though so far no one has achieved such a practical one. We achieved an out of the in-plane deformation of DEA by simply imposing a local deformation constraint of the active part of the DEA adhesives. Furthermore, we achieved an in-plane twisting of DEA employing the same technique. This technique for the induction of complex deformation of DEA could broaden the potential usefulness of the DEA as a soft actuator. We will show it here in detail.

Keywords: DEA; Constraint; Deformation control; Adhesive

Introduction

Being one of the main parts of a mechanical system, an actuator is an essential piece when it comes to transforming energy into a certain motion. These motion deriving devices are basically composed of mechanically hard materials, metal or ceramics. Such actuators are durable and can generate high force. For example, a metal-based actuator is employed in the basic study of robotics in a lab and at the same time they are employed for heavy machinery for their practical use as well. This being true for ceramics-based actuators, its applications range from basic science level to the practical industrial product level. Metal and/or ceramics-based actuators are quite close to our daily life, though we rarely think and aware of it. There are innumerable publications dealing with such actuators and we can easily find various books and papers. Due to the existence of the wide variety of actuators, individual books and papers cannot cover the whole range of actuator studies and applications. Those publications focus on a certain type of actuator and describe its characters and etc., and consequently, the individual publications play their own important roles. Hence, we refrain from suggesting the particular publications. Soft actuators provide sharp contrast to hard actuators. As its name suggests, the soft actuators consist of soft materials, mainly polymer. Katchalsky et al. built a collagen fiber-based motion gadget and it is now considered as one of the earliest typical soft actuators [1-5].

Decades later, reports of such works are still being reported all over the world. The discovery of volume phase transition of hydrogel by Tanaka [6] prompted researchers to achieve a practical hydrogel-based soft actuator. It is quite natural to imagine that researchers conceived that the enormously large volume change of hydrogel in the phase transition process can be used as an extremely energy-efficient hydrogel-based actuator material, since slight environmental condition can trigger the significant hydrogel volume change. In the 1990's, another type of a soft actuator attracted researchers' attention. Oguro et al. [7] reported a new bending mode polymer-based actuator called Ionic Polymer Metal Composite (IPMC). IPMC is an ionic polymer sheet sandwiched between thin metal plates. Despite such a simple structure, IPMC exhibits extremely large and fast that undergo changes by applying low voltage such as a few volts [7,8]. Conducting polymer is a fascinating substance. Our common notion to polymer are "low mass", "soft", "flexible" and "insulating". However, conducting polymers are highly electrically conductive.

There are a wide variety of conducting polymers [9,10]. Its typical application is acting as capacitors and are already on the market for some time. One of the other applications is a conducting polymer-based soft actuator. It is known that polypyrrole, one of the conducting polymers, exhibits volume change in accordance with the external electric stimulation. Hence, it has been studied as a soft actuator material [11-13]. Other than polymer-based actuators described above, there are, of course, various types of soft actuators. DEA is an unusual type of soft actuator [14-17].

Unlike the hydrogel- and conducting polymer-based actuators, DEA does not require a solvent for its activation, while it is electroactive like hydrogel- and conducting polymer-based actuators. Demand of solvent use is in a sense, a merit for an actuator, since such an actuator can be used even in the wet state. But it is at the same time a drawback, since we have to find a mean to maintain the wet state of the actuators when used in air. We think it is an important characteristic for the practical application of a soft actuator and have been studying the DEA. Intriguingly, the huge DEA strain induction is not accompanied by the volume change unlike the hydrogel-based soft actuator strain change especially triggered by the volume phase transition absorbing (or desorbing) a solvent [6]. So, the DEA is a dry state efficient actuator. Owing to such characteristics, broad range of DEA applications have been studied such as a micro speaker [18], a vibration-control device [19], biomimetic robot [20]. However, it may not be inappropriate to say that there have been for a long while no drastic progress which could directly lead to the achievement of a practical DEA, despite the not-so-short history of the DEA study [15]. Of course, some useful DEA characteristics such as electro adhesion [21], the low voltage activation [17] etc. have been reported. But still, huge room for a practical DEA to be investigated exists, and we have to achieve various things gradually to reach the practical DEA. In this study, we have worked especially on finding a way to achieve an induction and control of complex deformations of the DEA and found a way to achieve it to some extent. We would like to introduce it.

A VHB tape-based DEA

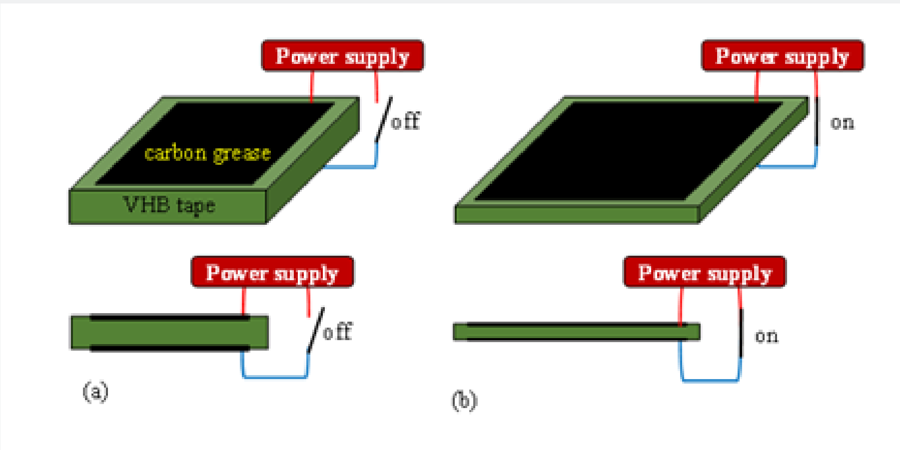

Figure 1: DEA expansion by Maxwell stress (a) Before expansion (b) Expansion under a voltage.

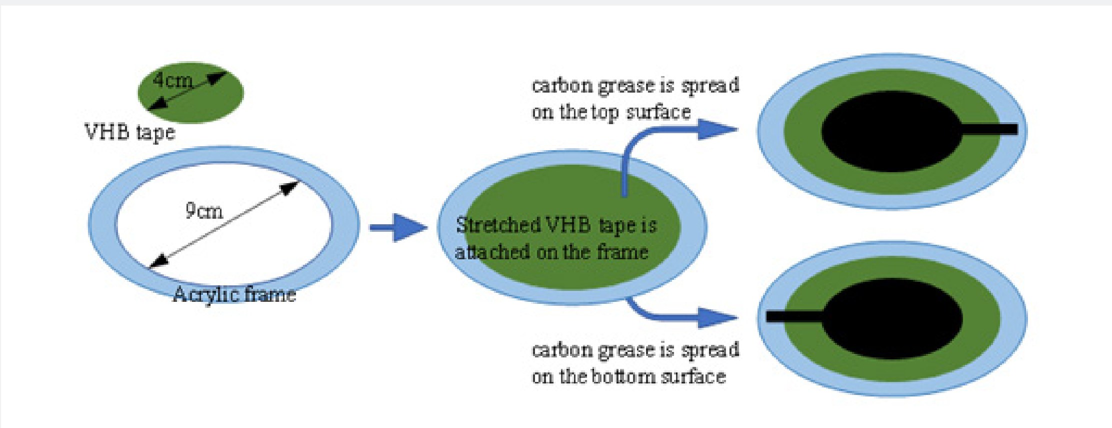

Figure 2: Fabrication procedure of a commonly known VHB tape-based DEA (C-DEA) Illustration of bottom surface is provided here just for helping understand the DEA structure.

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As described in the Introduction, DEA deformation is caused by the Maxwell stress as depicted in Figure 1 [22]. In the DEA study, the Very High Bond tape abbreviated VHB tape, is broadly used as an active part of the DEA [22,23]. VHB tape is a high-strength double-sided adhesive tape and a commercially available engineering purpose adhesive tape manufactured by 3M Japan Limited. We fabricated a commonly studied VHB tape-based DEA by following the procedure illustrated in Figure 2. This common DEA is hereafter called "C-DEA". C-DEA exhibits deformation under high constant voltage of a few kV, and its deformation image is illustrated in Figure 3(a) & 3(b) is the actual C-DEA photos in the rest and the electrically-activated states. Maxwell stress exerted on the carbon grease-coated part of VHB tape in C-DEA causes the vertical compression and horizontal expansion of the VHB-tape. Structure of the C-DEA and its deformation shown in Figure 3 is quite well-known in the DEA study and there is nothing new to it.

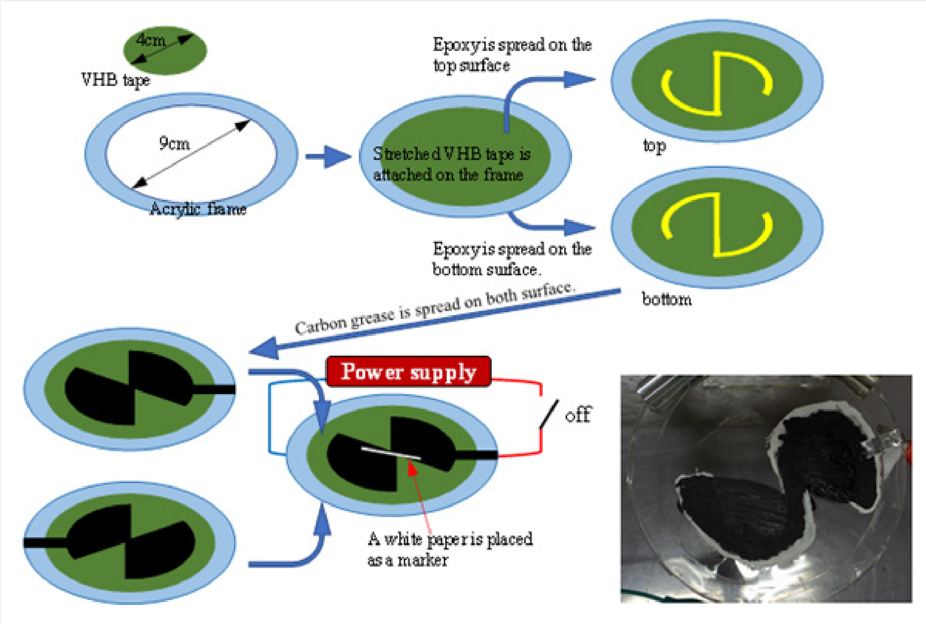

Figure 3: (a) Horizontal expansion of VHB tape part in C-DEA under the voltage imposed Illustration of bottom surface is just for clearly showing the electrical wiring. (b) photos of C-DEA under 0.0 kV and 2.0 kV.

Complex deformation of DEA

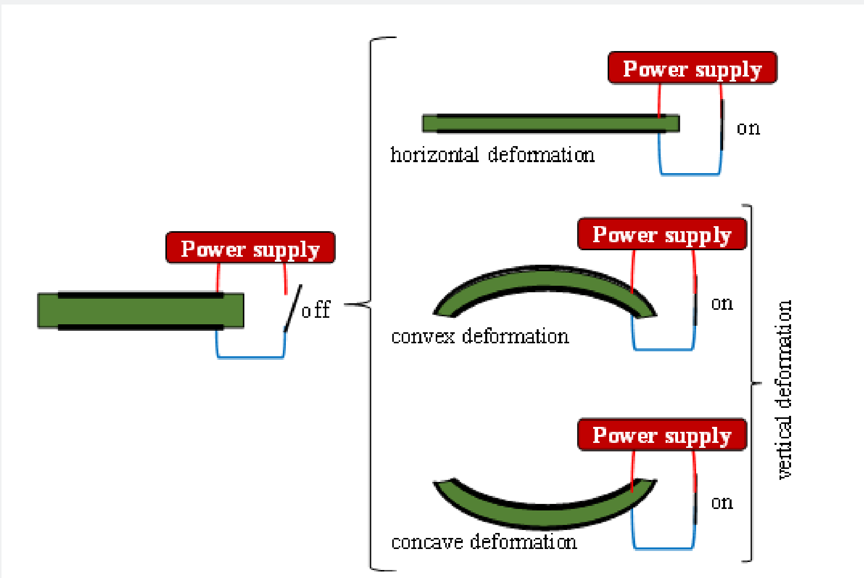

Figure 4: Vertical deformation of DEA.

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The structure of the C-DEA is quite simple and easy to fabricate. On top of that, the strain of the C-DEA is quite large. However, for the practical use of the DEA, a more complex deformation induction is needed. We would like to introduce a simple technique of inducing a complex deformation of the DEA. With the DEA deformation mechanism in mind, we attempted to induce the vertical deformation instead of horizontal deformation. Namely, the deformation illustrated in Figure 1 is the horizontal deformation, but we dared to induce the vertical deformation (concave and convex deformation) such as illustrated in Figure 4.

Convex and Concave deformation

Imagine the top surface of the VHB-tape is coated with epoxy and both top and bottom surfaces are coated with carbon grease which serves as a compliant electrode as Illustrated in Figure 5. The VHB tape is a highly stretchable tape. Hence, the C-DEA exhibits a large horizontal deformation. If the top surface of VHB tape is coated with epoxy, the epoxy-VHB tape surface becomes rigid while the carbon grease-VHB tape surface remains stretchable (Figure 5). Such an active part of the DEA is expected to exhibit a concave deformation as illustrated in Figure 5(b) because of the asymmetric deformation between the top surface of VHB tape and its bottom surface. We fabricated a DEA which could exhibit the concave deformation where this DEA specimen is denoted by V-DEA. Figure 6 shows the fabrication process of the V-DEA. The top surface of VHB tape of V-DEA is coated with epoxy. Figure 7 shows the cross sectional view of active part (VHB tape part) of the V-DEA along the dotted line on the carbon grease surface illustrated in Figure 7. So, the downward deformation is expected to emerge by the voltage imposed. The downward deformation of V-DEA by the impose of voltage shown in Figure 8(a) is shown by the thin line in Figure 8(b), but it might be partially caused by the softening of active part of the V-DEA and gravitational force. Namely, upward deformation may not take place in the V-DEA. If the deformation constraint of active part of the V-DEA using epoxy can truly cause the downward deformation of it regardless of the gravitational force, the flipped V-DEA should exhibit the upward deformation as illustrated in Figure 9. The thick line in Figure 8(b) represents the experimentally measured vertical deformation of the flipped V-DEA against the voltage imposed shown in Figure 8(a). As clearly seen, the upward deformation is repeatedly induced in accordance with the oscillation of voltage.

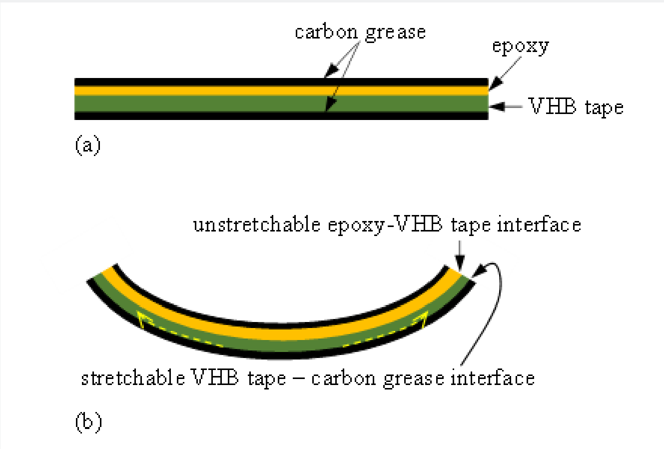

Figure 5: Deformation control of DEA by the stretch constraint of active part of DEA using epoxy.

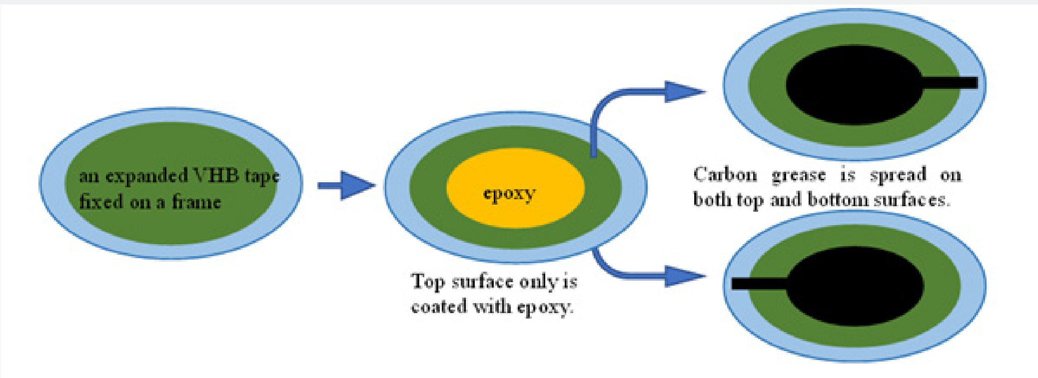

Figure 6: Fabrication process of V-DEA.

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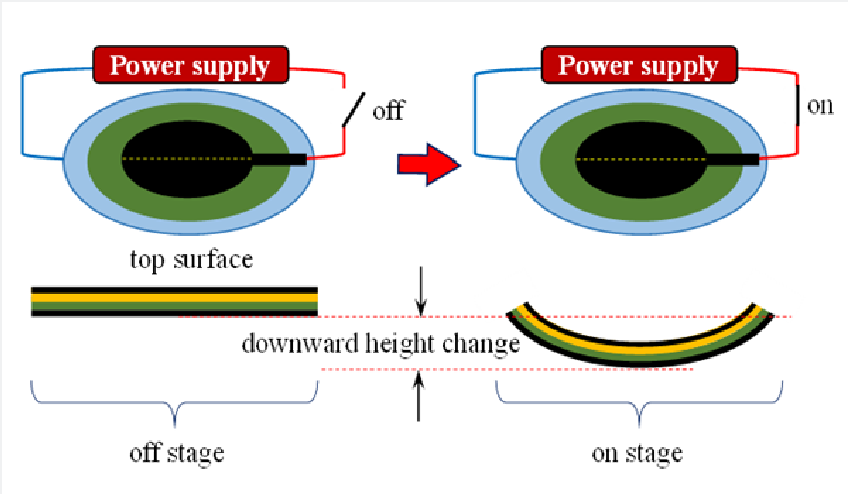

Figure 7: Downward deformation of V-DEA by the voltage impose The bottom illustrations show the cross sectional views of active part of the V-DEA along the dotted line.

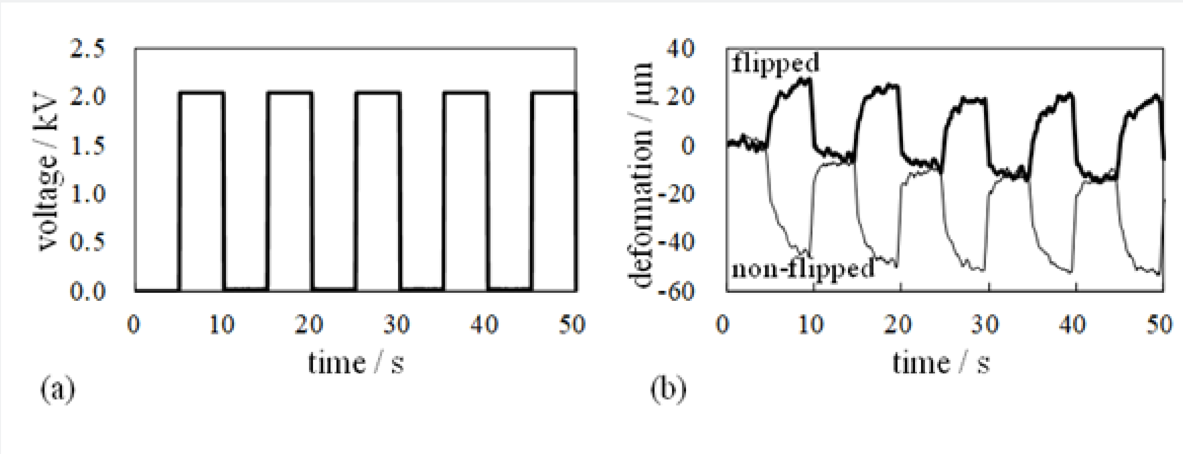

Figure 8: (a) The voltage imposed on the V-DEA (b) Deformation of V-DEA.

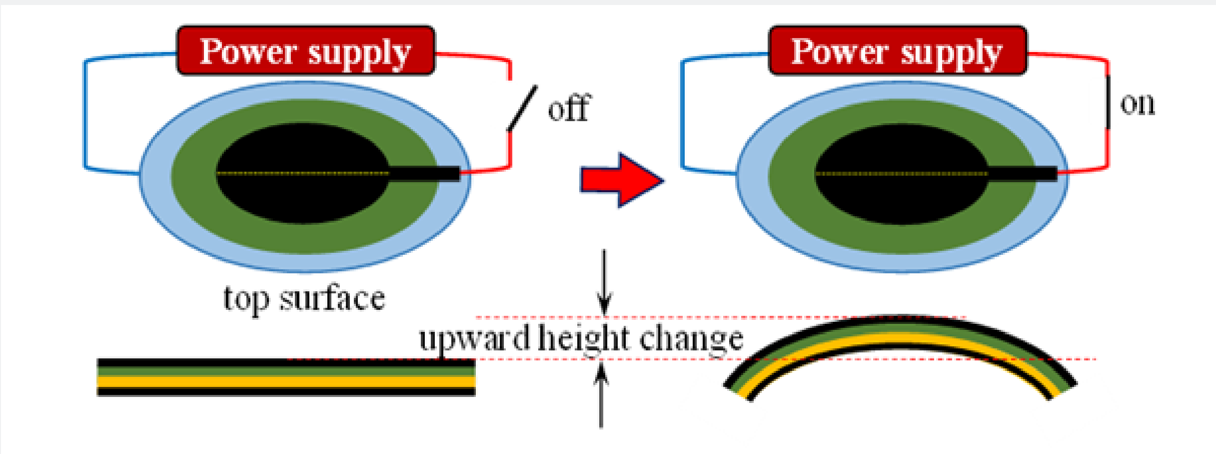

Figure 9: The bottom illustrations show the cross sectional views of active part of V-DEA along the dotted line on the carbon grease surface.

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Simultaneous induction of convex and concave deformation

We fabricated another DEA which the structure is shown in Figure 10(a). Due to the symmetric structure of the O-DEA about its central point (Figure 10(b)), the simultaneous downward and upward deformation are expected to be induced simply by imposing the voltage as illustrated in Figure 11 & 12 shows the experiment's time course of the vertical displacement of both left and right sides of the O-DEA by repetitive induction of 0V (for 10s) → 2kV (for 10s).

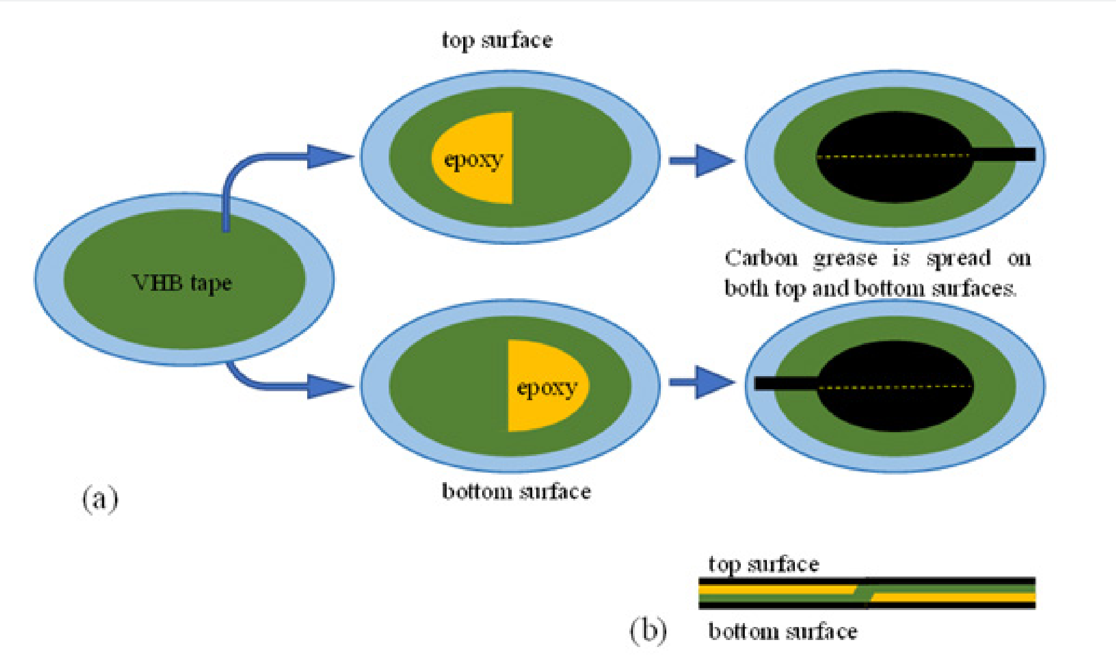

Figure 10: (a) Fabrication process of O-DEA (b) Cross sectional view of active part of O-DEA along the dotted line on the carbon grease surface.

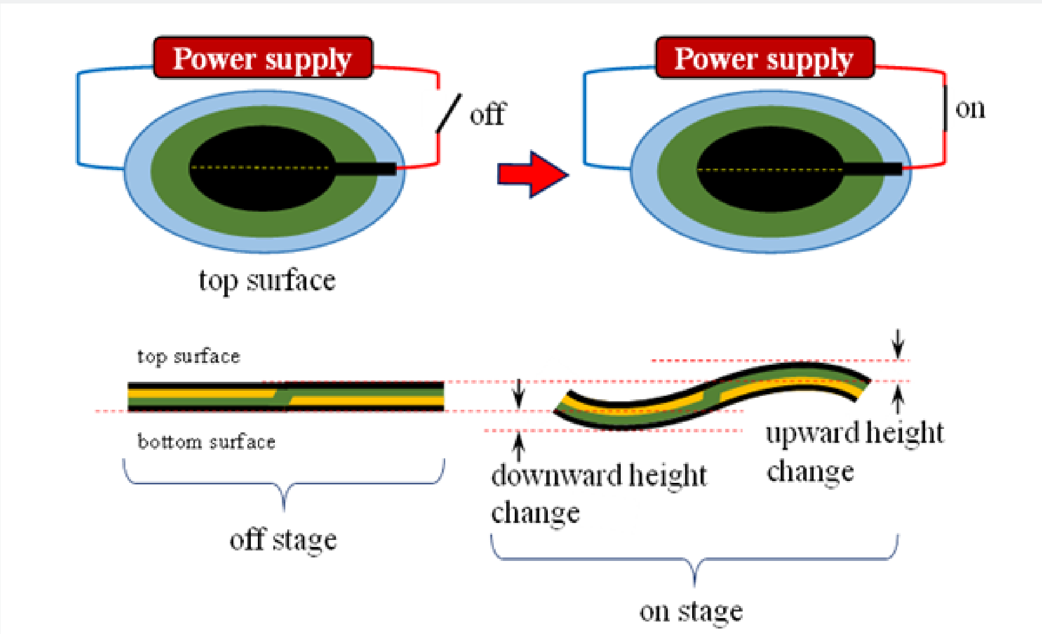

Figure 11: Simultaneous upward and downward deformation of the O-DEA and the cross sectional views of active part of the O-DEA along the dotted lines on the carbon grease surfaces.

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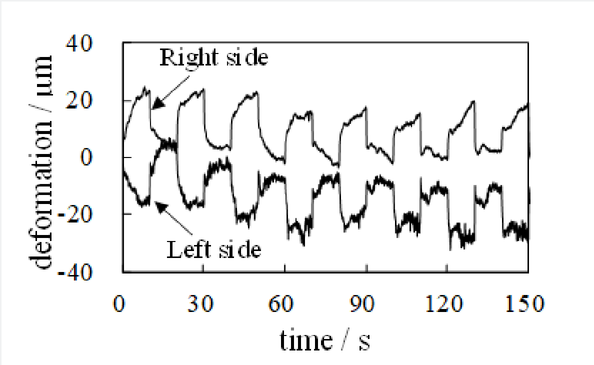

Figure 12: Opposite deformation in the single O-DEA.

Twisting deformation

An even more complex DEA deformation (twisting deformation) was achieved by employing the local deformation constraint of the active part of the DEA. Fabrication procedure is shown in Figure 13. Hereafter, this DEA is called T-DEA. The S-shaped part of the epoxy serves as a partial deformation constraint for its electrically active part. Once 2kV is imposed on the T-DEA, the active parts α and β (Figure14) tends to expand under the constraint by the epoxy. This results in the paper marker being twisted at an angle-` on the T-DEA as illustrated in Figure 14. Experimentally measured the largest θ was 7°.

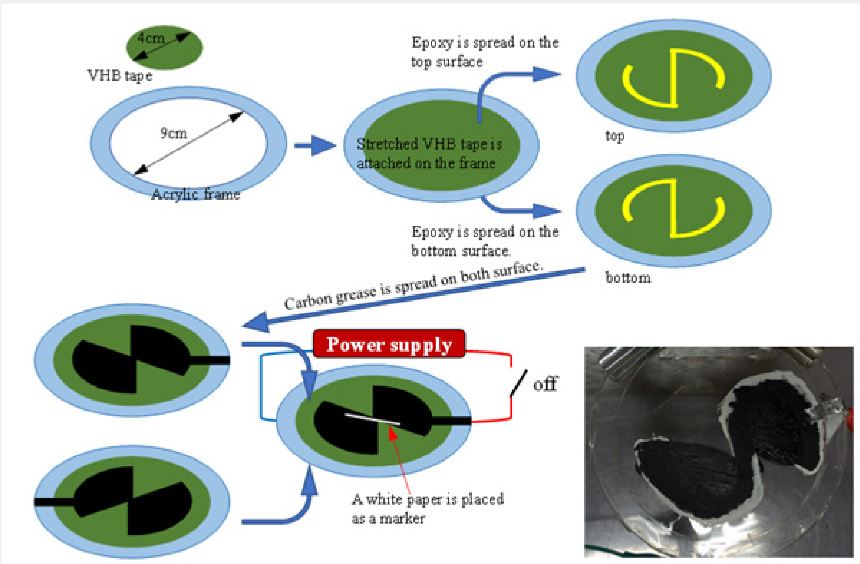

Figure 13: Fabrication procedure of T-DEA A photo of the T-DEA top is shown at the right bottom.

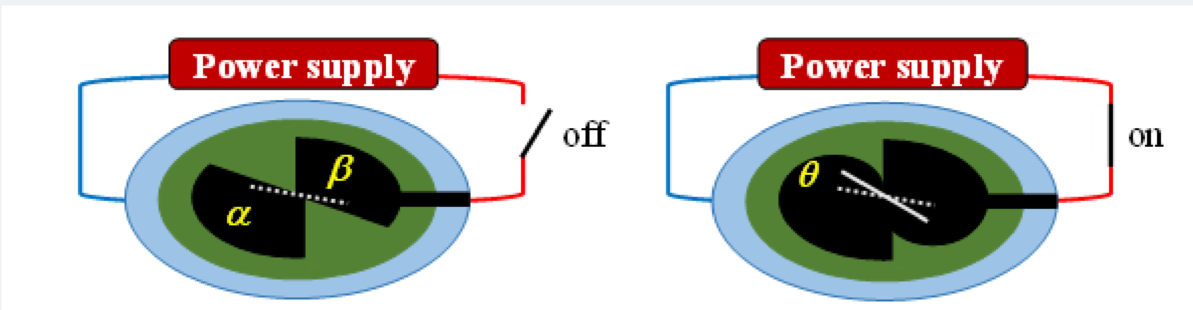

Figure 14: Deformation of T-DEA in the off state and in the on state.

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Meanings of this work

We suggest that the simple method, the usage of epoxy as a component of the DEA, worked as a tool to induce a complex deformation of DEA in this research. Some may argue against the effectiveness of the technique we introduced. They may say that the induced strain is quite small and even the possibility to induce a more complex DEA deformation by employing existing techniques. As cited in the section of Introduction, for example, Petralia and Wood demonstrated several different types of large deformation of DEA [24]. Shintake et al. fabricated a DEA-based soft gripper. It can exhibit a large open-close stroke [21]. Just recently, Minaminosono et al. fabricated a DEA-based rotating device [25]. Hence, the reports on the DEA are too numerous to mention, and we don't intend to deny those accomplishments in the DEA study. But our primary purpose of this work is to suggest that the simple usage of epoxy or so for imposing the local deformation constraint on a DEA can generate various modes of DEA deformation and it could broaden the potential of the DEA for further useful applications.

Conclusion

We were able to achieve the various types of DEA deformation simply by partially imposing the deformation constraint on the DEA active part using epoxy. Therefore, this simple technique must broaden the potential of what a DEA has to offer as a practical soft actuator. Of course, still challenging issues remain to overcome in achieving a practical DEA. Especially due to the polymer's own nature, DEA characteristics inevitably involve the individual DEAs differences and are even prone to change with time and environmental conditions such as temperature. Namely, it is unrealistic to expect the stable deformation DEA performance unlike the conventional metal- or ceramic-based actuators. For achieving the precise DEA deformation control, what we have to do is to take such undesired DEA characteristics as natural and inevitable by coping with them through the application of, for example, feedback control method and such. Hence, as the next task, we plan to proceed with the precision control study with various types of DEAs so far described in this paper.

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