An Architecture For the Semiautomatic Fabrication of Multilayer Stacked Contractile and Expanding Dielectric Elastomer Actuators

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Abstract:
We present a semiautomatic manufacturing process that allows fabrication of macroscopic stack-like actuators from rolls of raw dielectric elastomer material. The proposed geometry and fabrication procedure incorporates thin films of dielectric material, allowing a drastic reduction of the typical high voltages required by dielectric elastomer actuators. Moreover, the semiautomatic process overcomes many traditional manufacture difficulties, such as the handling and packaging of dielectric films, and power distribution to the compliant electrodes of the actuator. Furthermore, the resultant multilayer devices can be used either as contractile or expanding actuators.

Keywords: multilayer dielectric elastomer actuators, thin films, semi-automatic fabrication process

Introduction

Dielectric elastomers represent one class of electroactive polymers (i.e. polymers that respond to electrical stimulation, modifying their shape when an external voltage is applied [1]) that have already demonstrated potential for use with actuating devices in mechatronic and robotic applications, especially in the fields of biomimetic mechanisms, humanoid robotics, prosthetics, telepresence, rehabilitation etc. Dielectric elastomer actuators can achieve lightweight, fast and energy efficient actuation, with generated forces and strains approaching the typical values of mammalian muscles [2].
In their basic configuration, dielectric elastomer actuators are composed of a single layer of elastomeric film (that acts as dielectric) with both faces coated with a compliant, conductive electrode material [3][4]. When a significant electric potential is applied to the two electrodes, an electrostatic attractive force, known as Maxwell stress, rises between them. This pressure is equal to the permittivity of the dielectric material multiplied by the square of the applied electric field. Since the dielectric material situated between the two electrodes is typically an incompressible elastomer exhibiting low Young's modulus and high breakdown strength, the Maxwell pressure will simultaneously squeeze the material in the direction perpendicular to its face and, in preserving its volume, expand the area of the film, as depicted in Fig. 1.

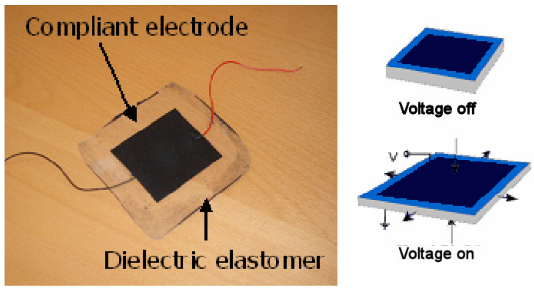

Fig. 1: Basic planar configuration (left) and operating principle (right) for dielectric elastomer actuators.

Existing literature demonstrates that many different approaches and geometries have been investigated in order to obtain a multilayer configuration. For example, helical structures, folded geometries and spinned or assembled multilayer actuators [5-8] are some effective possibilities able to obtain a linear contractile motion, whereas diamond, cone and spring rolled geometries [9-11] are typically used to obtain an expanding motion. Besides the challenge of having an optimal multilayer configuration that maximizes the electromechanically performances of the device, another typical problem that affects macroscopic dielectric elastomer actuators are the high voltages usually required to obtain a satisfying displacement of the actuator. Since soft elastomers materials typically used as dielectric have a relatively low permittivity, high electric fields are necessary to obtain high Maxwell pressures. For this reason, macroscopic dielectric elastomer actuators usually require high actuating voltages, often in the kilovolt range, which requires particular care in the insulation of the actuator from the surrounding environment. This high actuation voltage, however, can be drastically reduced using a thin film of dielectric elastomer. Indeed, if the thickness of the dielectric material is, for example, reduced by a factor of ten, the required actuating voltage to obtain the same electrostatic pressure will also be reduced by a factor of ten. This means that the required insulation of the actuator package and the driving electronics can be dimensioned to appropriately insulate hundreds of volts rather than thousand of volts, simplifying many common problems of working in kilovolt range. Nevertheless, even though it is highly desirable to work in low voltage range, the fabrication of macroscopic devices starting from thin films can present manufacturing challenges.

We propose a semiautomatic fabrication process that allows the manufacture of contractile or expanding multilayer actuators starting from thin-film of dielectric elastomer.

Multilayer Fabrication procedure

We report on the development of a machine capable of semiautomatic fabrication of multilayer stack actuators (Fig. 2). The machine is composed of a motorized winding unit, a masking unit, an automatic airbrush and a microcontroller that coordinates and synchronizes the fabrication process. Initially, a roll of raw dielectric elastomer material is loaded into the machine. The fabrication process then involves the cyclic, automatic repetition of a sequence of steps programmed in the microcontroller. Firstly, a turn of dielectric elastomer is wound by the motor unit. An encoder is used to keep track of the angular position of the rotor. During this first turn, the motor is stopped at pre-programmed angular positions and the electro-valve connected to the automatic airbrush is activated. The compliant electrode material is then airbrushed on the dielectric elastomer through a mask (mask A) that exposes a particular lateral area of the elastomer. When the second turn begins, this mask is automatically exchanged with a second one (mask B), that exposes a different area. The winding and airbrushing process is subsequently repeated to fabricate the second layer of the actuator. After one complete turn, at the end of the second layer, mask B is exchanged again with mask A, and the process is repeated until the desired number of layers is reached. The two masks are designed to allow the contaction of alternate electrodes on the sides of the multilayer stack. Depending on the required geometries and sizes of the actuators, the machine can be programmed to fabricate many multilayer stacks on the same roll. After the desired number of layers is achieved, the multilayer roll is cut radially to obtain multilayer stacks that will become contractile or expanding actuators.

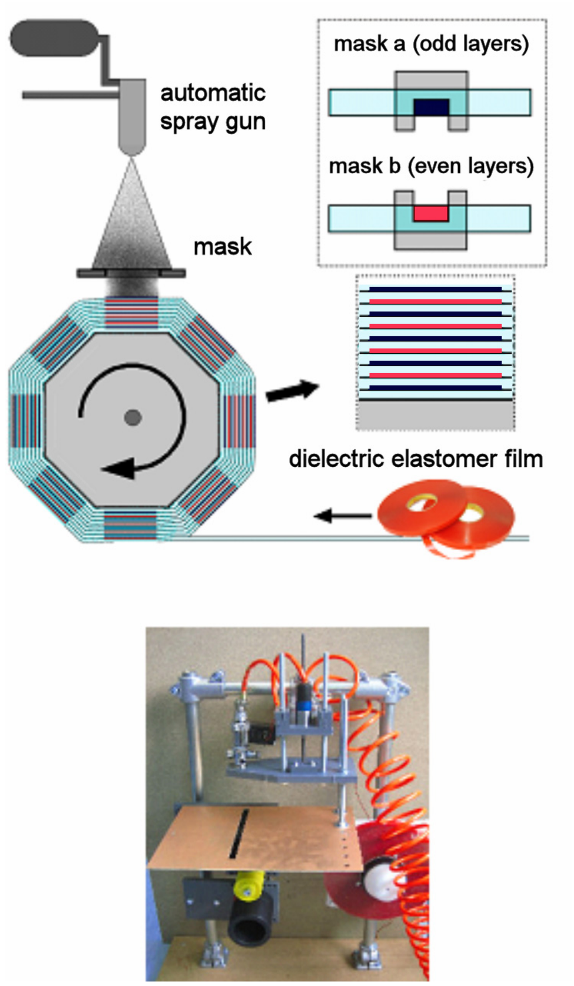

Fig. 2: Semiautomatic machine for the fabrication of multilayer stack actuators.

Materials

For the fabrication of actuator prototypes, two commercial acrylic elastomers by 3M were used. In particular, the acrylic tapes VHB4905 (500um thick) and VHB9460 (50um thick) were selected for their well known good dielectric properties [4][12]. Compliant electrodes were fabricated by airbrushing a conductive mixture based on carbon black suitably dispersed in toluene. Polyurethane was chosen as a polymeric matrix for the elastomeric electrodes because of its strong adhesive properties that allow it to act as a bind between the different layers of the acrylic dielectric. Experimental measurements showed a good, low overall resistivity (in the 10-100Kohm range) for the compliant rubber electrodes made of carbon black filled polyurethane elastomer. It was demonstrated that the material keeps sufficient conductivity even when the dielectric elastomer substrate is biaxially stretched, allowing a moderate prestretching (up to 200%) of multilayer devices after the process of deposition of the compliant electrodes.

Contractile Multilayer Actuators

Contractile actuators are obtained by cutting the previously fabricated roll radially and contacting the electrodes on the two sides of the stacks, applying the same conductive elastomer used for the fabrication of compliant electrodes (Fig 3). Multilayer stack actuators of up to 20 layers (using the VHB4905, 500um thick dielectric tape) and up to 200 layers (using the VHB9460, 50um thick film) can be fabricated with the described procedure (Fig 4). The required fabrication time varies depending upon the number of the fabricated layers (typically around 10 minutes for a 20-layer VHB4905 actuator, and about one hour and a half for a 200-layer VHB9460 actuator). In order to save fabrication time and raw material, many actuators can be fabricated on the same roll simultaneously. The obtained devices can be subsequently used as contractile modules that can be assembled in series or in parallel in order to obtain actuators with larger displacement and actuating force.

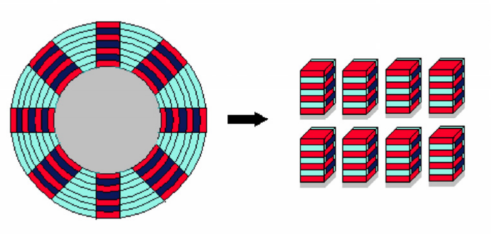

Fig. 3: *Fabrication process for contractile actuators*

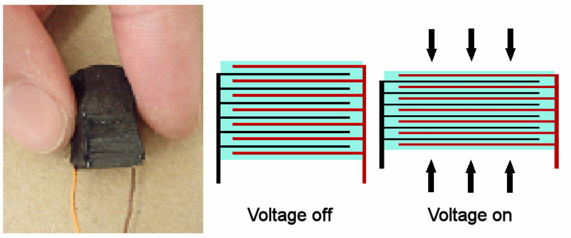

Fig. 4: *Multilayer contractile actuator*

Expanding Multilayer Actuators

The described process also allows the fabrication of expanding actuators. In this case, the rolling machine is programmed to additionally deposit the conductive material during the rotation of the winding unit, in order to obtain large areas of compliant electrodes. The multilayer stacks are subsequently radially cut from the roll as per the contractile case and finally packaged by placing the electrode coated film inside a mould and pouring a hard polyurethane resin on the two extremities of the actuator (Figs 5-6). The hard polyurethane resin bonds strongly to the acrylic VHB tape and allows the application of an uniaxial or biaxial prestrain to the dielectric film, increasing its breakdown strength [4]. In this way, it is possible to apply higher electric fields to the actuator, increasing the resulting Maxwell pressure and the final displacement of the actuator.

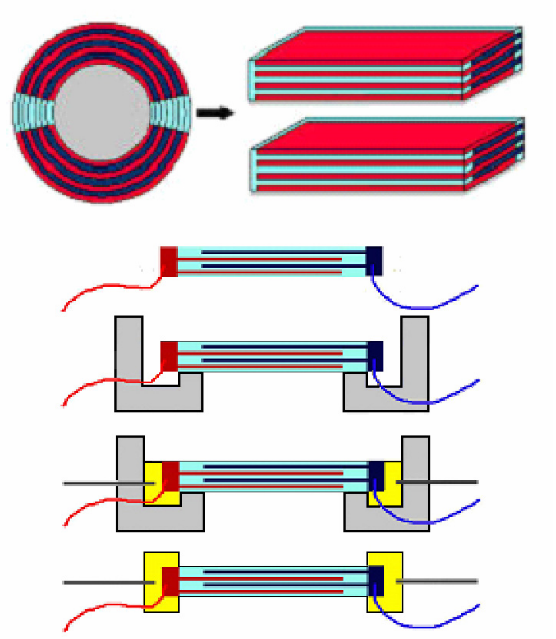

Fig. 5: *Fabrication and packaging process for a multilayer expanding actuator*

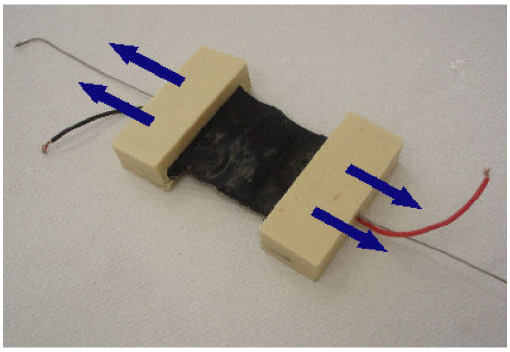

Fig. 6: Finished multilayer expanding actuator

Conclusions and Future work

A semiautomatic process for the fabrication of multilayer stacked devices was described. Besides the advantage of having a single simple process that allows the fabrication of both contractile and expanding actuators, the described fabrication technique can be used to process thin dielectric elastomer films. In this manner, devices that operate at much lower voltages than traditional macroscopic dielectric elastomer actuators (i.e. 500V for VHB9460 vs. 5Kv for VHB4905 actuators) can be obtained.

Experimental measurements on prototypal contractile and expanding actuators are currently in progress in order to characterise the electromechanical properties of fabricated multilayer devices. Preliminary results on prototype actuators showed maximum strains in the range between 5% and 12%, depending on the dielectric material used (VHB 4905, VHB9460), the actuating configuration (contraction/expansion), the amount of initial prestretch, and the geometric parameters of the actuator. It is evident that when the size of the dielectric layer is scaled down to a thickness comparable to one of the deposited electrode (like for 50um thick VHB9460 actuators), its mechanical properties will greatly influence the overall behaviour of the device. For this reason, further investigation will be carried out to better understand how electrodes of different materials and thickness interact with the dielectric layers and affect the macroscopic performances of the actuator.

Finally, the possibility of using custom made silicone rolls obtained by a rotocuring process, instead of commercial VHB acrylic tape (which suffers of strong viscous losses that limit the maximum actuating speed), is currently under investigation.

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