Silicon usage in Di-Electric Actuators

With time, ‘soft actuation’ has garnered focus from scientists of different fields, including material sciences and roboticists. Human-robot interaction, artificial muscles, and limitations of hard robotics have increased demand for actuation that allows for the delicacy and subtlety observed in human touch. For example, a hard robotic hand cannot grip an egg without crushing it. Soft robotics aims to solve this problem by attempting to replicate the human hand. Different active polymer solutions were proposed, however a quaint application known as Di-electric actuation is the focus of this report.

Di-electric actuators are solid state actuators which have no discrete joints. The infinite degrees of freedom allow for unique devices that are completely bendable and compliant with any surface they are supposed to grip. These can be controlled electrically to produce large strain (strong grip) on par with human muscles. This, in conjunction with the prospect of miniaturization of such grippers allows for versatile implementations of actuators. In simple terms, we can make robotic arms that are small in size but could lift the weight equivalent to multiple times the arm itself. These actuators typically consist of an elastomer membrane sandwiched between two compliant electrodes. These electrodes are powered by a very high potential difference between them to create an electric field that causes the elastomer to bend and hence actuate.

Choice of material for the elastomer membrane is key to formulating an actuator that fulfils all design requirements. As mentioned before, the working principle of a DEA revolves around deformations caused by coulombic forces. The opposite electric potentials on either electrode creates an attractive force that acts through the elastomer thereby subjecting it to a compressive force. A deformation is observed as a decrease in thickness until the net electrostatic attraction is balanced off by the mechanical stress of the elastomer, which at this point in time is resisting the deformation when linear elasticity is being maintained. For common dielectrics like oxides and some polymers, strains are tiny and shear moduli are significantly larger than for silicon elastomers. Hence silicon elastomers experience displacements and strains better than conventional dielectrics. This goes to show that low elastic modulus of silicon elastomers is paramount to maximizing electrostatic energy to mechanical strain energy conversion.

Properties of actuator materials.

Material	Density (kg/m^3)	Shear modulus (MPa)	Poisson ratio	Recoverable elastic limit (%)	Dielectric permittivity
Gold[a]	19 320	30 000	0.3	0.02	N/A
Aluminum[a]	2730	70 000	0.3	0.02	N/A
Low density polyethylene	965	~730	~0.44	0.4	2.2
Polypropylene sheet	913	~612	~0.46	15	2.2
Polyaniline[b]	1360	~1000	N/A	1.0	>100
Conjugated polymer, PDOT[b]	1011	~1200	N/A	2.0	>100
PDMS—Sylgard 10:1	1030	0.44	~0.5	>100	2.7
Acrylic[b]	~960	0.3	~0.5	>100	5.5
Eco-flex	~1050	0.1	~0.5	~500	3.2

[a] Polycrystalline, pure elements.

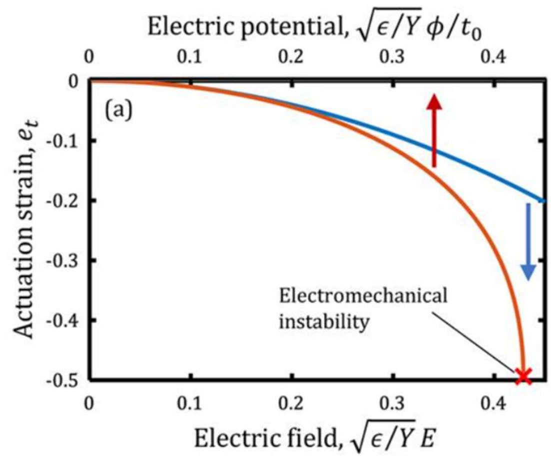
[b] Blends: properties depend on amount of cross-linking.

Alongside this, soft robotic implementations require that elastomer materials endure "stretches" rather than strains. Meaning elastomer materials must experience strains of several hundred percent, without reaching their failure point. Therefore, our material must have low stiffness. This is measured otherwise as the dielectric permittivity, which must be significantly high for our application. The above table proves that silicon elastomers have high dielectric permittivity.

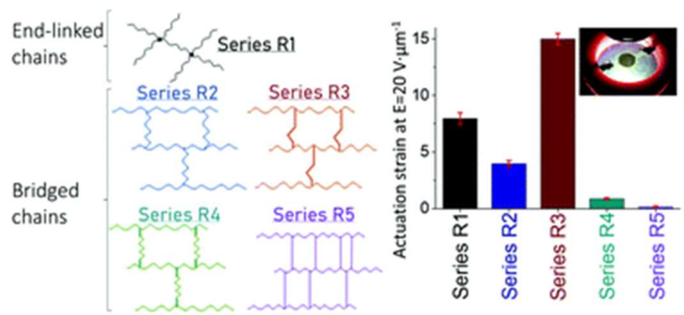
Lastly, since our application will require the di-electric to experience potential differences of the order of kilovolts, our material must have high electrical breakdown as well. This means that our elastomer must remain insulating while it experiences high voltage.

Keeping all this in mind, it can be seen that silicon is highly compatible with our design requirements given its versatility and flexibility to fit any choice of design. Compared to acrylic elastomers, silicon elastomers are known to have a response time 1000 times faster with a large range of hardness on offer. Alongside this, silicon are typically procured in the form of two-part viscous liquid which has to be set and cured in a mold before use. This allows for more independence in terms of designing the size, shape and thickness of the membrane for our application.

Silicon elastomers are manufactured by casting the liquid and curing it at high temperature. A silicon base and solvent are mixed together to decrease the viscosity. This solution is then mixed thoroughly and into a film applicator. The applicator then applies the silicone onto a PET substrate. To achieve large deformations at a lower potential difference, the membrane is fabricated as several ultra-thin layers applied by the film applicator. This is then set aside to let the solvent evaporate from the cast layer. Then this membrane layer is placed in the oven to cure.



Alongside the manufacturing process, some additional modifications are done to the material before it is ready for use. The most primitive and now common, so-called prestretching of the membrane is done to increase the electromechanical failure point of the material. Suo et. al. observed that prestretching causes strain stiffening of the membrane and is the primary reason for preventing electromechanical instability of the material. The figure on the right depicts how prestretched membrane (in blue) no longer faces the instability that non prestretched membrane experiences.



Many innovations have been done to improve elastomer performance. Tugui et. al. observes that variation of crosslinking patterns and molecular weight can be used as parameters to improve the mechanical behaviour of the material when put under cyclic stress. They observed that using the same polymers but with different crosslinking patterns, the Young's modulus can be varied. As seen in the figure, the UV cured elastomeric networks depicted by series R3 exhibited the lowest Young's modulus seen amongst the materials.

Sun et. al. proposed constructing a supramolecular network assembled by ionic and hydrogen bonds allows for synthesizing an elastomer that is self healing. The bonds act as reversible physical crosslinking points that allow for this property to occur. This helps with the sustainability of the elastomer since it can go through fracture and failure due to cyclic stresses.

In conclusion, silicon has properties both natural and modified that allow for the creation of di-electric elastomers that can work sustainably and reliably as actuators.

Works Cited

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