Spring, 2017
Materials Science and Engineering

Special Topic

Electroactive Polymers (EAPs)

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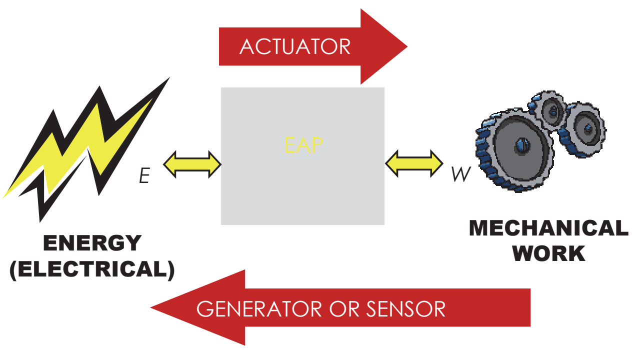
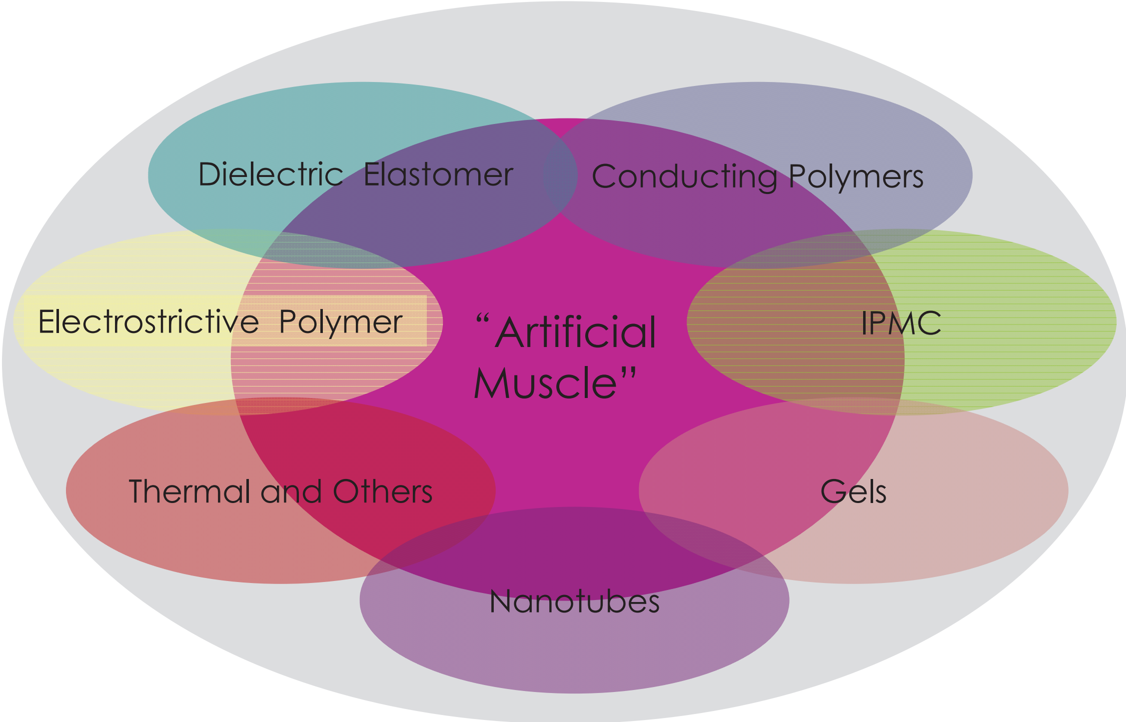
Why are Electroactive Polymers (EAPs)

- **Transducers are a critical part of MEMS/MOEMS devices**
- **EAPs have unique characteristics and bring new possibilities**
  - New materials
  - New fabrication techniques
  - New performance



- What's wrong with current MEMS actuators?
  - Electrostatic – low forces, small scale only (high tolerance), stiction
  - Electromagnetic – inefficient at small scales
  - Piezoelectric – small strain, high tolerances, more complex fabrication, Pb
  - Thermal and Bubble – inefficient, not reversible (actuator only), relatively slow, proportional control difficult
  - Shape Memory Alloy – inefficient, not reversible (actuator only), relative slow, complex fabrication, proportional control difficult

Many Types of EAPs

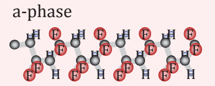


Electroactive Polymer (Artificial Muscle)

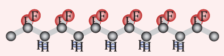
Electronic EAP
(high voltage, fast response)

Ferroelectric polymers

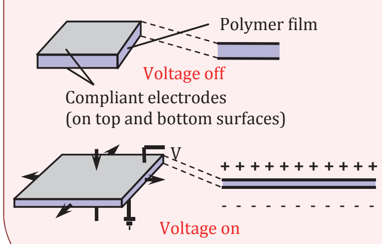
a-phase



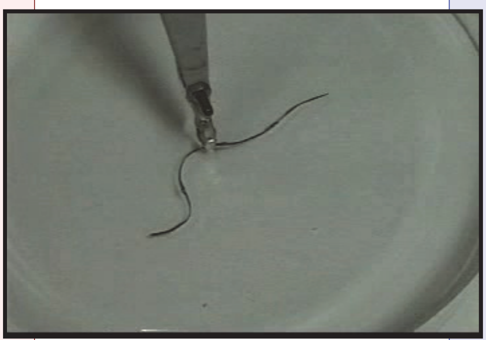
b-phase



Dielectric elastomer actuator



Electroactive Polymers

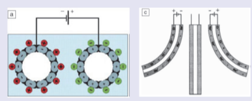


(http://ndeaa.jpl.nasa.gov/)

- Light weight
- Large deformation
- Mechanical flexibility
- Easy process

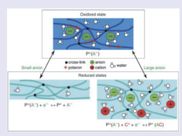
Ionic EAP
(low voltage, slow response)

CNT-EAP



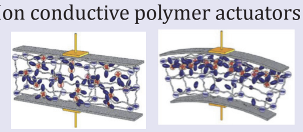
(Qu et al., MRS Bulletin, 2008)

Conjugated polymer actuators



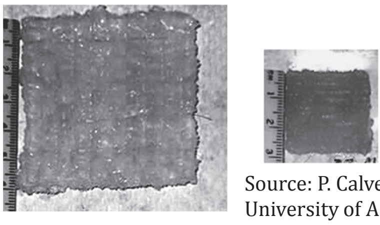
(Smela, MRS Bulletin, 2008)

Ion conductive polymer actuators



(Park et al., MRS Bulletin, 2008)

Ionic EAPs

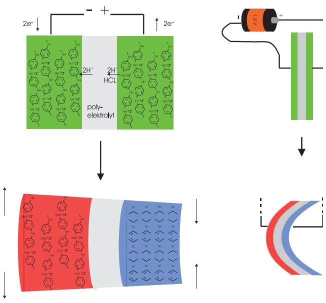


Source: P. Calvert, University of Arizona

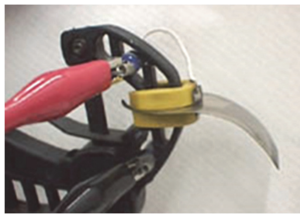
Ionic Polymer Gel

- Large strain
- Slow response
- Low force and energy output
- Poor long-term stability and environmental tolerance

Conductive Polymers and IPMC



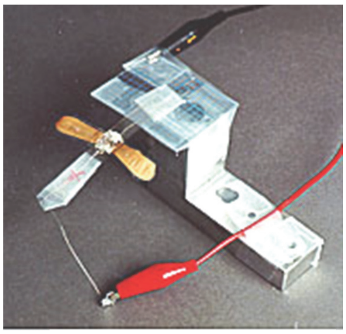
- High energy output
- Small strain
- Slow response
- Energy inefficient
- Poor long-term stability and environmental tolerance
- Compatible with MEMS fabrication



Source: Biomimetics Products Inc.

Source: Condensed Matter Physics and Chemistry Department at Risø National Laboratory, Denmark

Electronic EAPs



Source: Q. Zhang, Penn State

Electrostrictive polymers

- fast response
- high efficiency
- high energy output
- high force
- good long-term stability
- small strain
- fair environmental tolerance

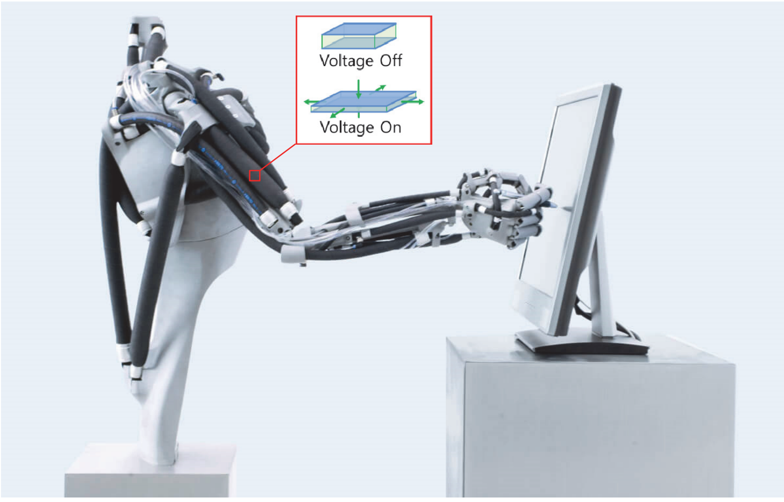
Piezoelectric polymers

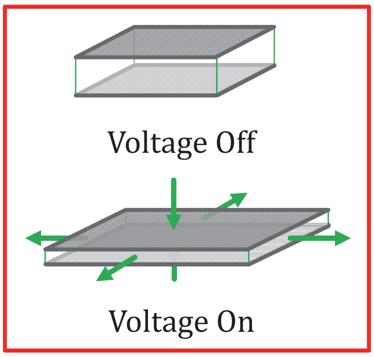
- fast response
- high efficiency
- low energy output
- good long-term stability
- small strain
- fair environmental tolerance
- commercially available (primarily used for sensors)

Source: Measurement Specialties Inc.

유전 탄성 중합체

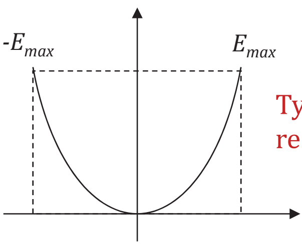
(DIELECTRIC ELASTOMERS)





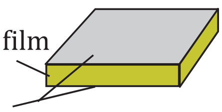
Dielectric Elastomer Actuators

- ❑ Rubbery polymers with compliant electrodes
- ❑ Electromechanical response is dominated by electrostatic forces a.k.a. Maxwell stress

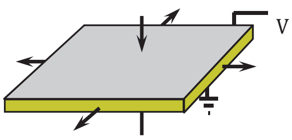


Strain up to 380% measured!

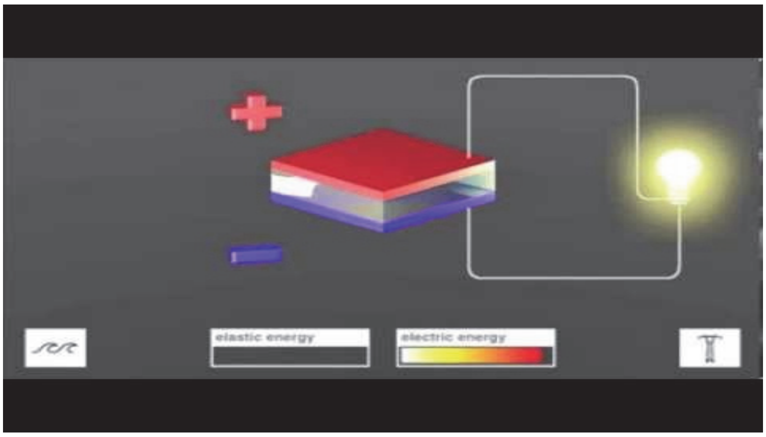
Typical strain or pressure response of the polymer



Voltage off



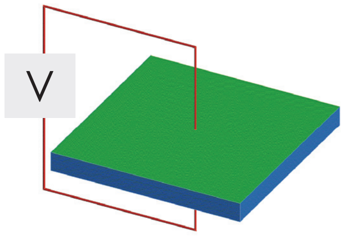
Voltage on



https://www.youtube.com/watch?v=62JQ3DPJ9ek

Dielectric Elastomer Actuators

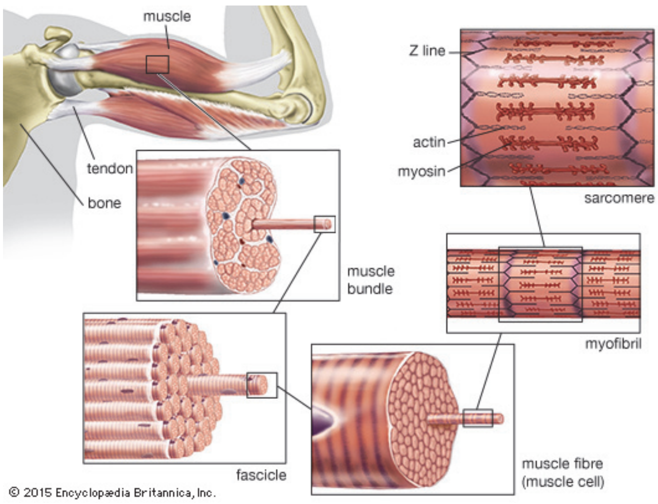
- **Desirable characteristics**
  - Environmentally tolerant and stable (e.g., silicones from –60 °C up to 260 ° C)
  - Fast response (kHz)
  - Energy efficient (over 80% with charge recovery)
  - Controllable (low hysteresis)
  - Durable (e.g., over 10 million cycles, 5 years so far)
  - Reversible – transducers are inherently sensors or generators too
  - Scalable to MEMS/MOEMS - capacitive in nature



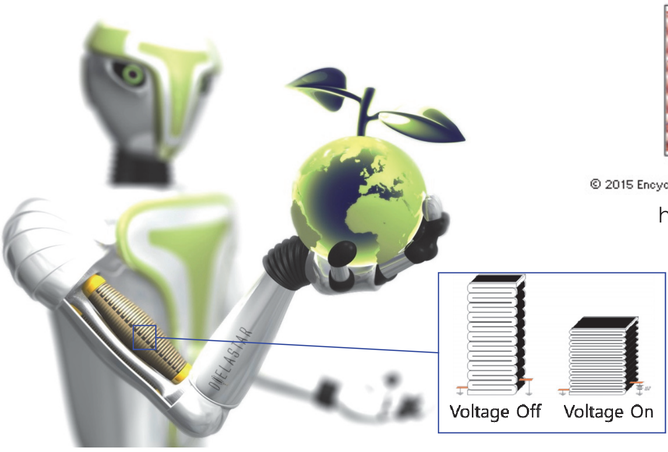
- **But**
  - Typically high voltage, 100s to 1000s of volts (up to 200 V/μm)
  - Thin films at MEMS size cales have been demonstrated at < 50 V
  - Highest efficiency requires charge recovery

Artificial Muscle for Micro Robots?

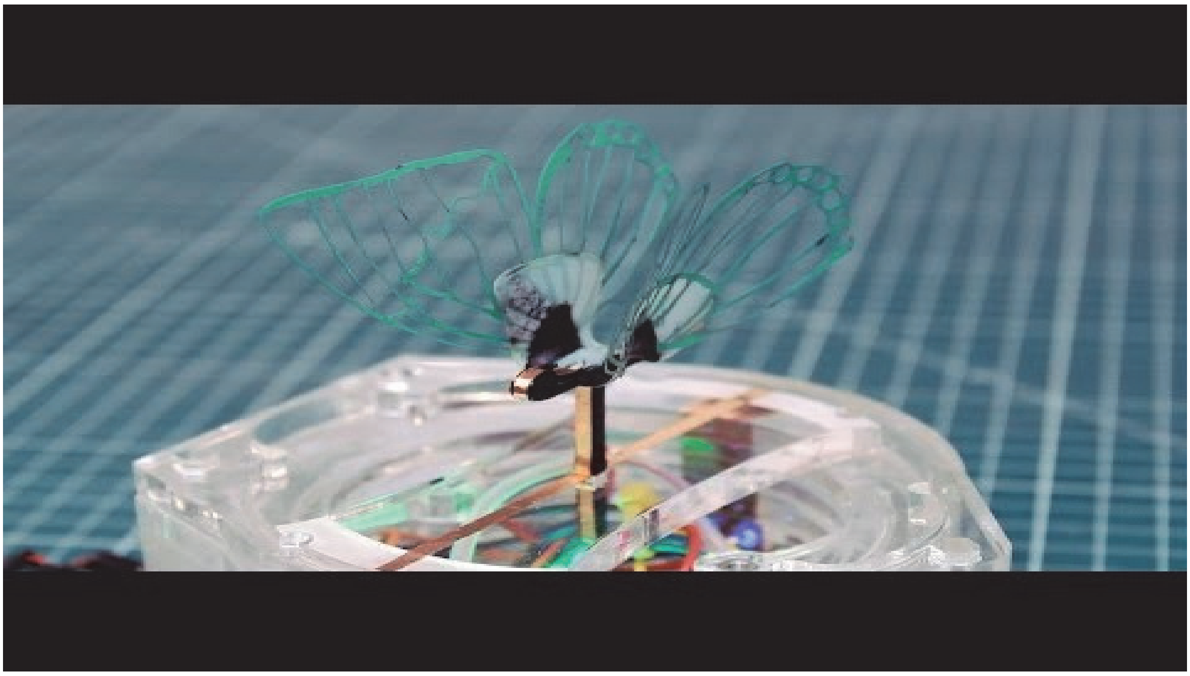
- **EAPs can behave a lot like a muscle**
- **Muscle is a spring-damper system and sensor in addition to a motor**



http://www.britannica.com/science/skeletal-muscle



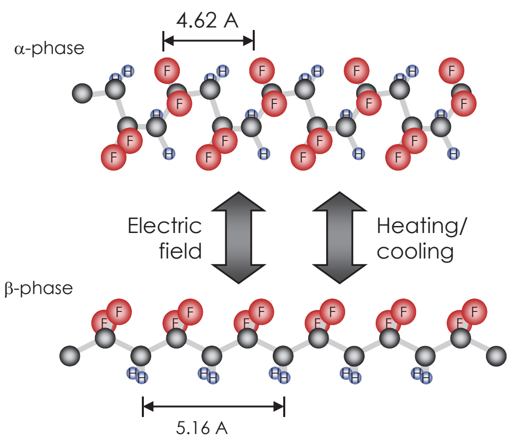
Bioinspired Electroactive Butterflies



https://www.youtube.com/watch?v=NCSG4Vcn4g8

불소계 강유전 고분자

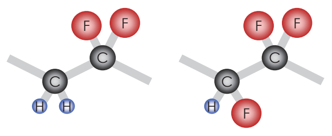
(FLUORINATED FERROELECTRIC POLYMERS)



Ferroelectric Polymers

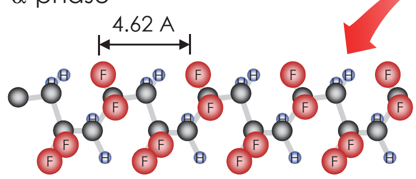
PVDF = Polyvinylidene fluoride &
P(VDF-TrFE) = Poly(vinylidenefluoride-trifluoroethylene)

Ferroelectric behavior due to permanent electric dipoles

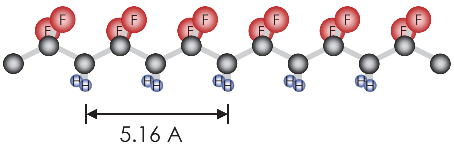


VDF **TrFE**

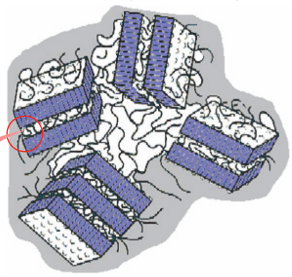
α-phase

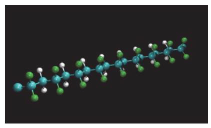


β-phase

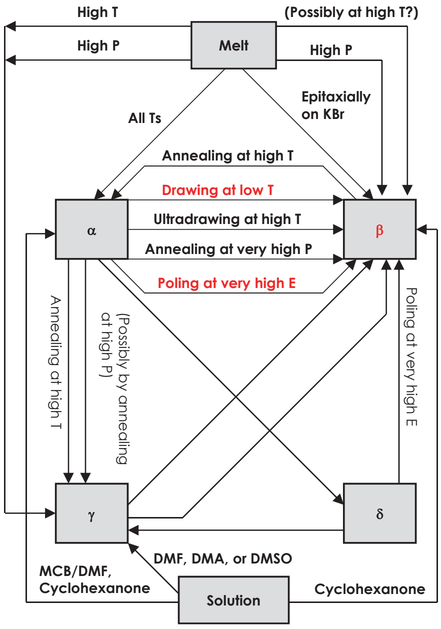


Microstructure of
PVDF or P(VDF-TrFE)



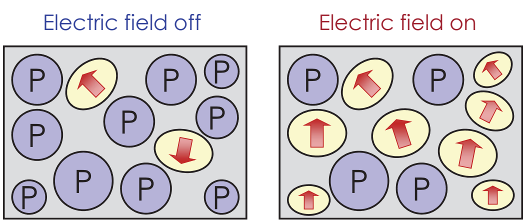


http://canopus.physik.uni-potsdam.de
/research/limm/pvdfspin.gif



완화형 강유전 고분자 구동기

(RELAXOR FERROELECTRIC POLYMER ACTUATORS)

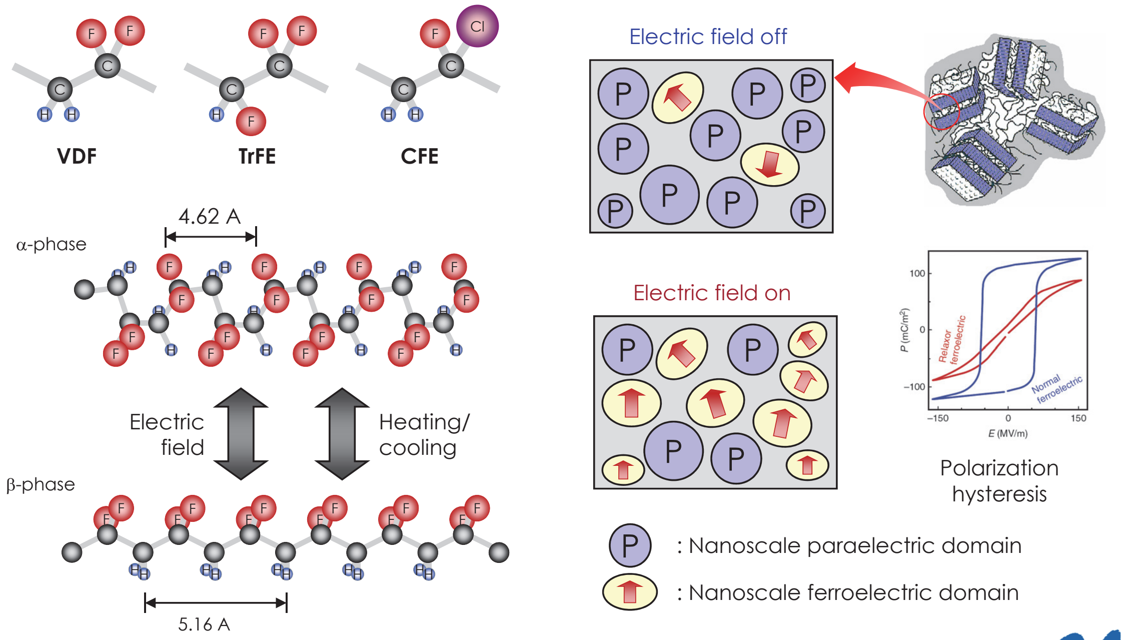


P : Nanoscale paraelectric domain

: Nanoscale ferroelectric domain

Relaxor Ferroelectric Polymers

P(VDF-TrFE-CFE) terpolymer actuator: The large strains associated with the conformation changes between the polar- and non-polar conformations in PVDF-based ferroelectric polymer can be used of to generate high electrostrictive strain

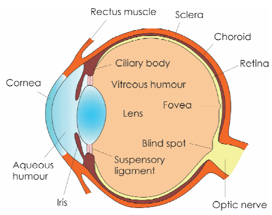
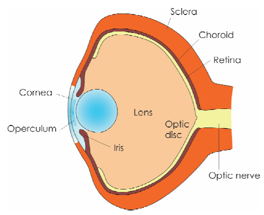


Piezotech FC™ & RT™ in Actuators

Due to the electrostrictive effect, very high strain can be induced in Piezotech® RT terpolymers when exposed to high electric fields. Actuator performance is enabled by the very high deformation rate of these materials at such high electric fields.

Biomimetic Varifocal Lens

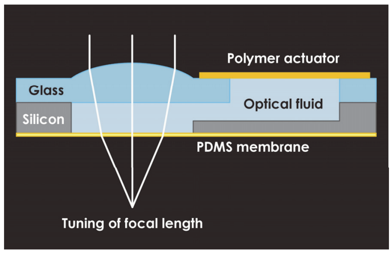
Natural imaging systems

Imaging system	Human eye	Cetacean eye
Eye shape	Spherical eyecup	Hemispherical eyecup
Lens	Elliptic lens	Spherical lens
Major optical power	Convex outer surface of cornea	Strongly convex (spherical) lens
Change of focus	Change of the lens shape by ciliary muscle	Axial displacement of the lens due to changes in intraocular pressure
Anatomy		

Hydraulic pressure eyes

https://www.youtube.com/watch?v=bA-jDk3-Mgs

Varifocal liquid lens



Operation of Varifocal Lens

- Wafer-Level Process: World-First
- Thickness < 0.6 mm: World-Best