


Shape Change and Soft Matter

A close-up photograph showing a hand holding a metal spherification needle, dipping it into a glass filled with a thick, orange-red tomato sauce. The needle is positioned to create a small droplet on the surface of the sauce. The background is dark and out of focus.

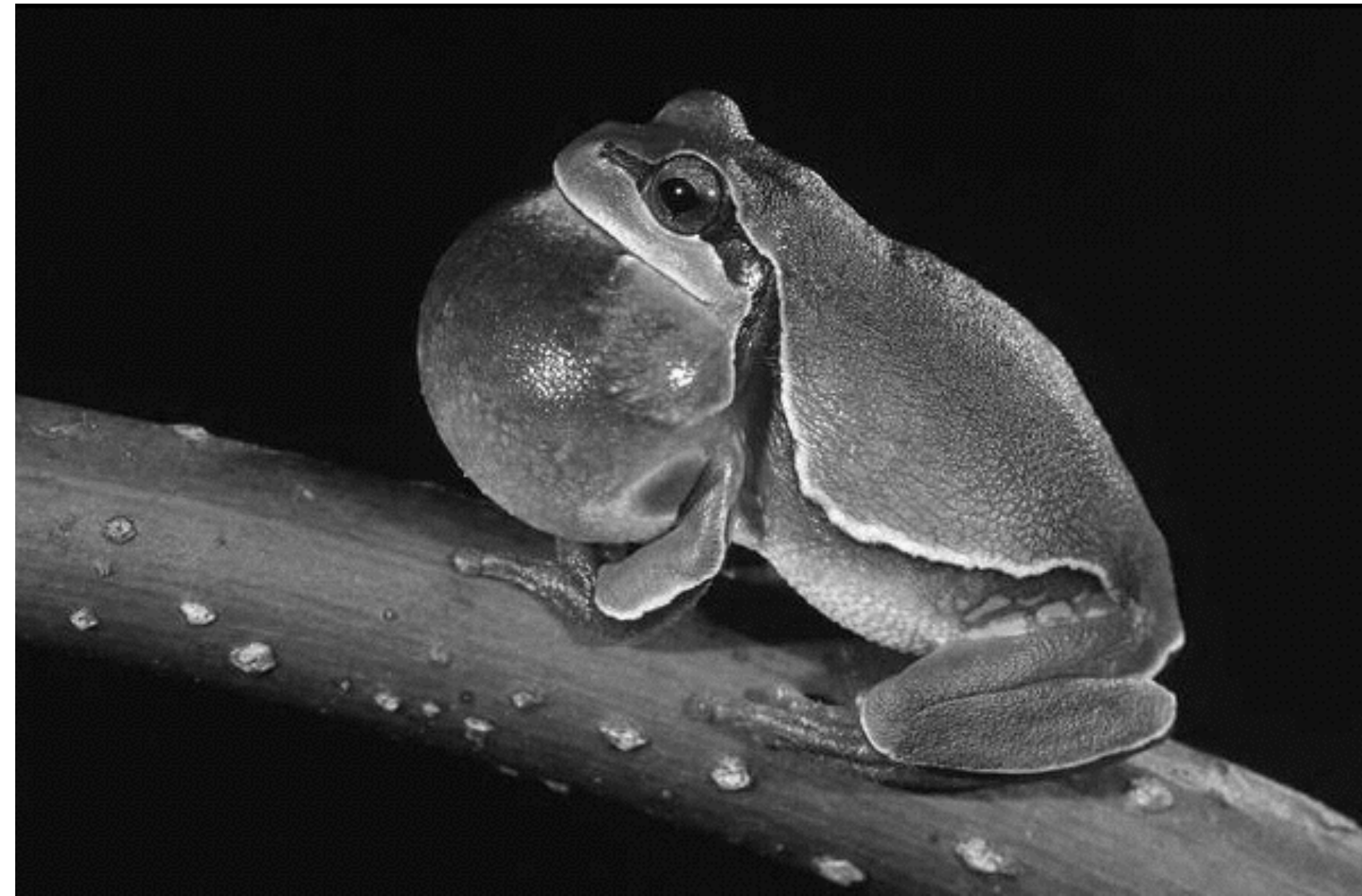
(Dried tomatoes)

Spherification by Chef Jose Andres

Soft Shape Change in Food

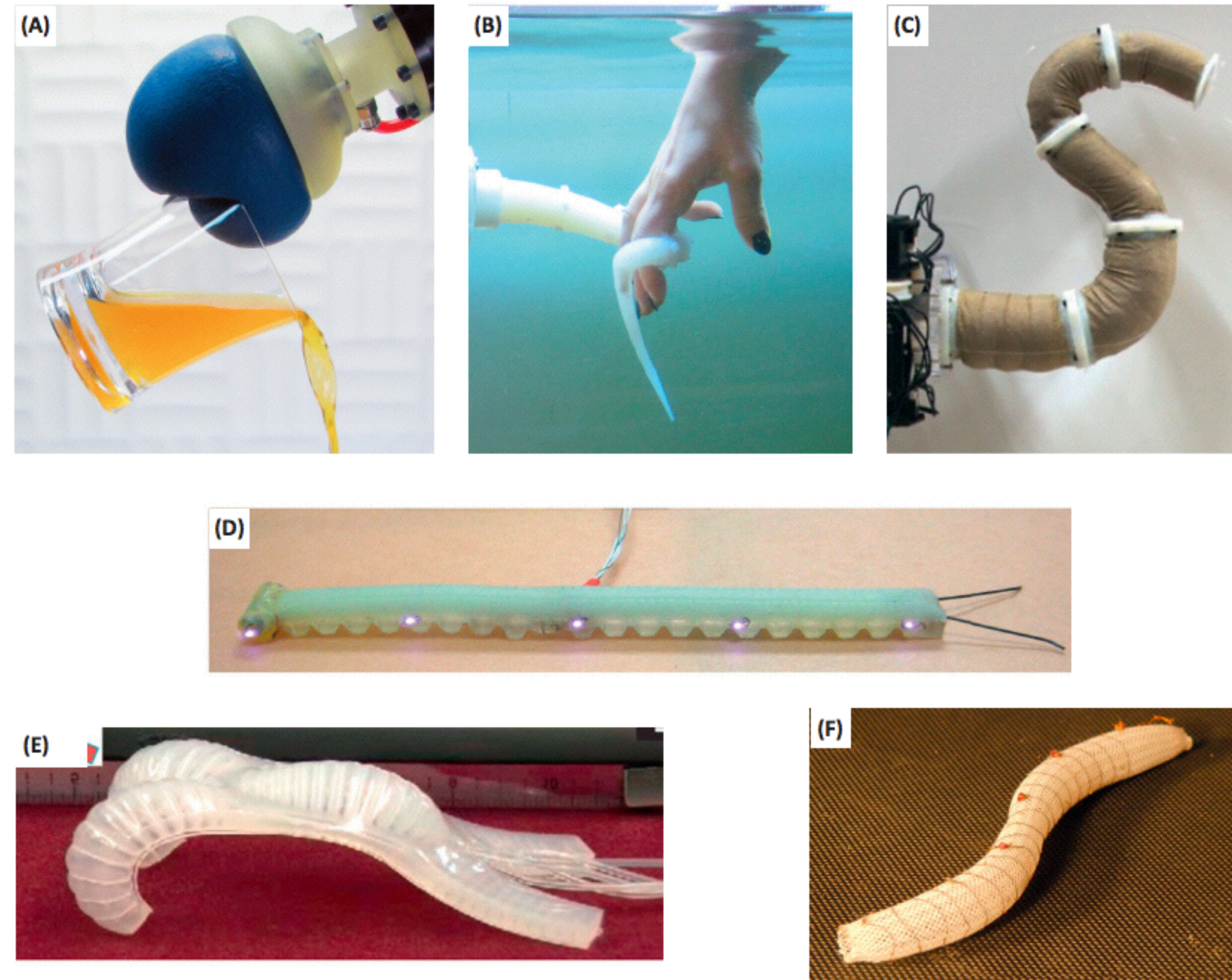


Soft Shape Change in Nature

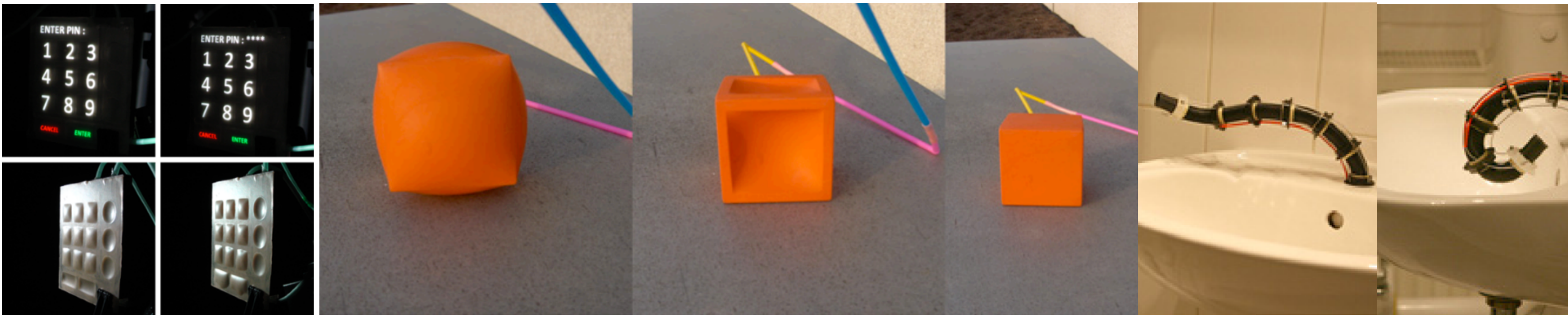


For sound

Soft Shape Change in Robotics



Soft Shape Change in HCI



From the left to the right:

1. Harrison, C. and Hudson, S.E. Providing dynamically changeable physical buttons on a visual display. Proc. of CHI 2009, ACM Press (2009), 299–308.
2. Gomes, A. and Nesbitt, A. MorePhone : A Study of Actuated Shape Deformations for Flexible Thin-Film Smartphone Notifications. (2013), 583–592.
3. Jonas Togler, Fabian Hemmert, and Reto Wettach. 2009. Living interfaces: the thrifty faucet. In Proceedings of the 3rd International Conference on Tangible and Embedded Interaction (TEI '09). ACM, New York, NY, USA, 43-44.

Soft Shape Change in Design and Life



For inflation



For floating



For stiffness changing

Overview of Soft Shape Change

Soft Shape Change in Robotics - “Soft Robotics”

Guest Lecture by Dr. Kevin C. Galloway from Harvard Microrobotics Laboratory, Wyss Institute
“History, applications and fabrication recipes of soft robotics”

Soft Shape Change in HCI and Design - Case Studies and Reflection

Overview on history and applications in HCI

Case study 1: PneuUI, by Lining Yao from TMG

Case study 2: JamSheets, by Jifei Ou from TMG

Reflection: Unique contribution of soft shape change in HCI and design

Soft Shape Change - Toolkits

Fabrication

Actuation Mechanisms

Material Composition and Material Structure

Part list

Electronic and Pneumatic Circuit

Fabrication 1: Elastomeric Actuators (Silicon Rubber)

Fabrication 2: Non-elastic Actuators, with live demonstration

Soft Shape Change in Robotics - “Soft Robotics”

Guest Lecture by Dr. Kevin C. Galloway from Harvard Microrobotics Laboratory, Wyss Institute
“History, applications and fabrication recipes of soft robotics”

Soft Shape Change in HCI and Design - Case Studies and Reflection

Overview on history and applications in HCI

Case study 1: PneuUI, by Lining Yao from TMG

Case study 2: JamSheets, by Jifei Ou from TMG

Reflection: Unique contribution of soft shape change in HCI and design



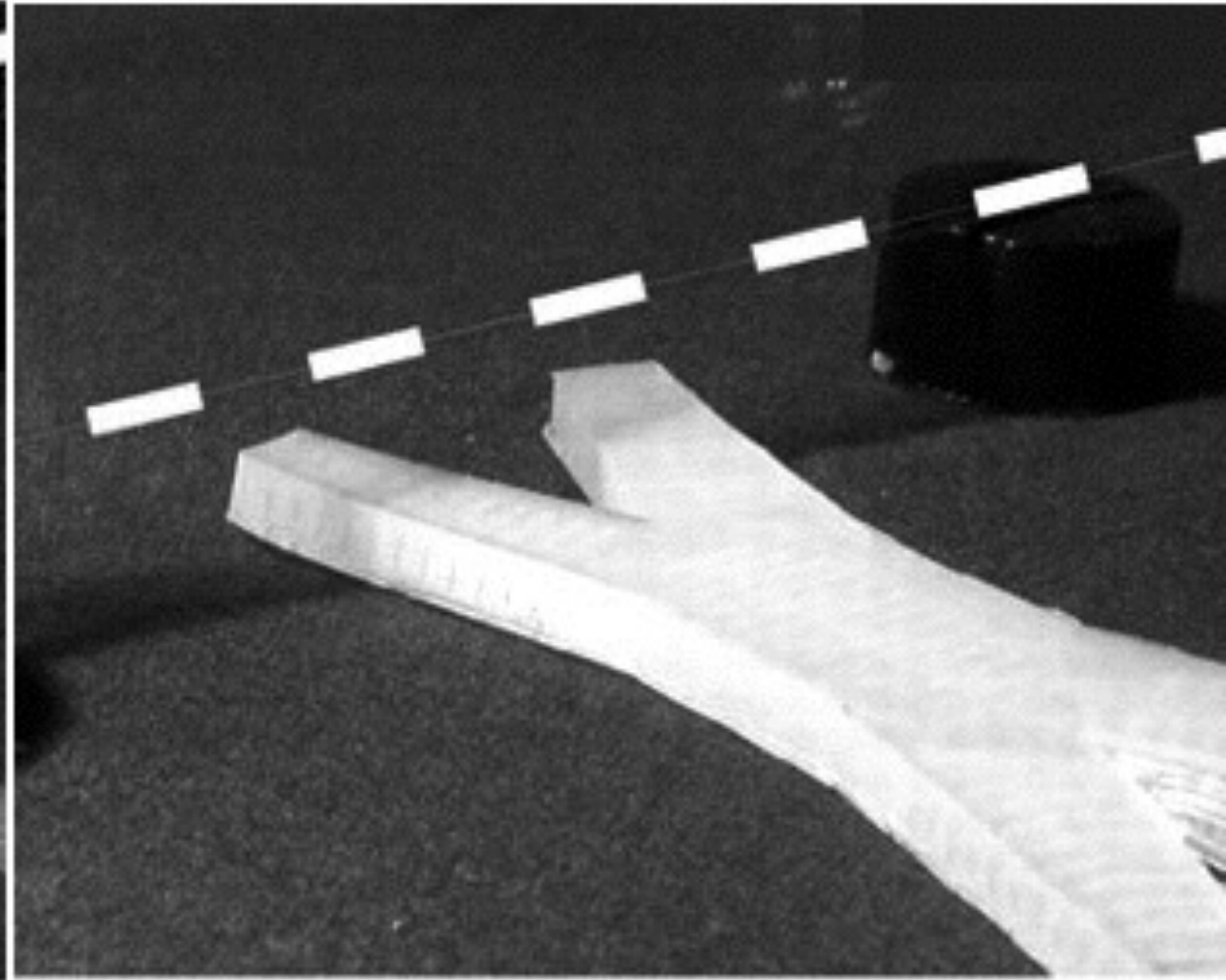
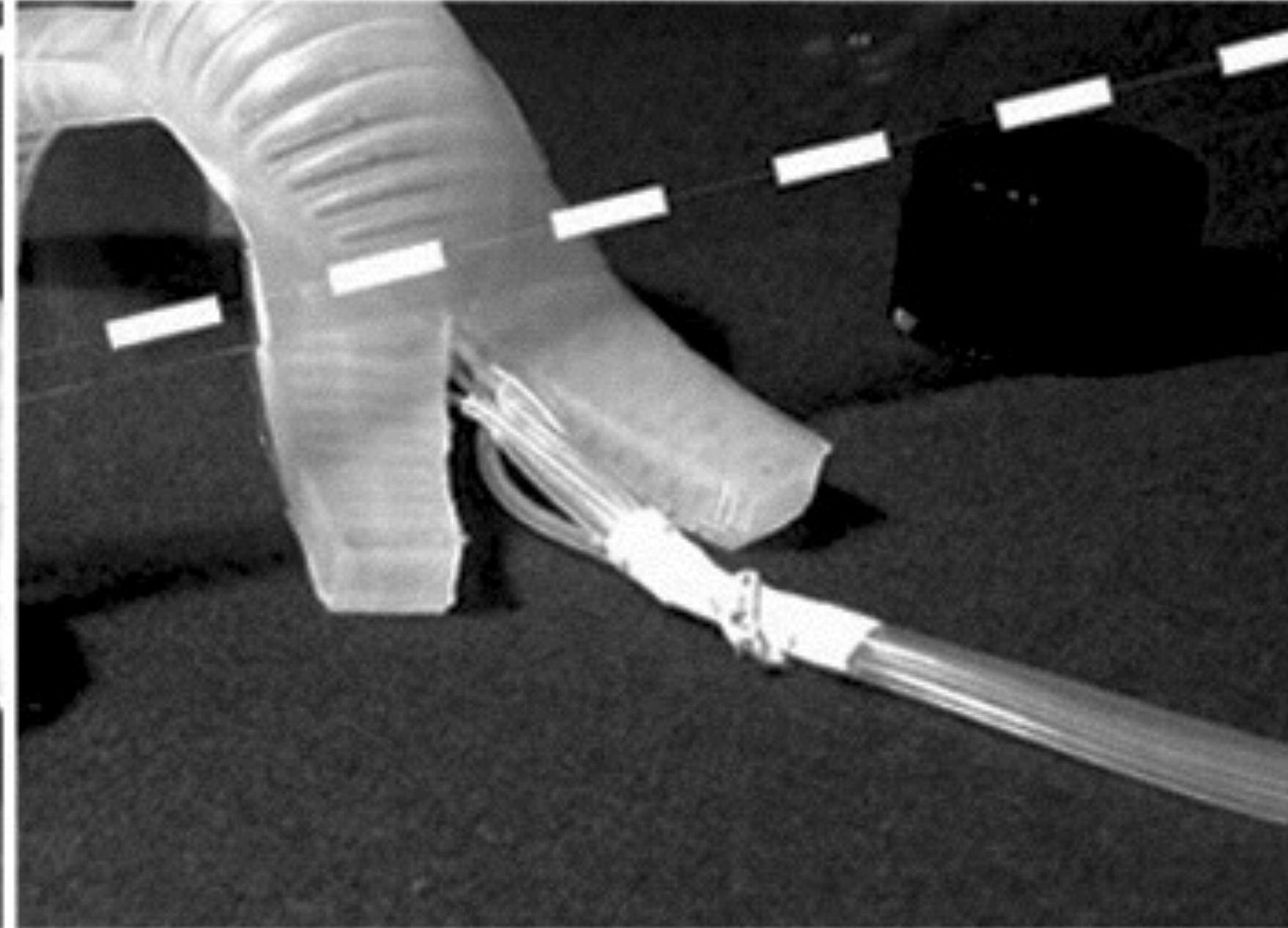
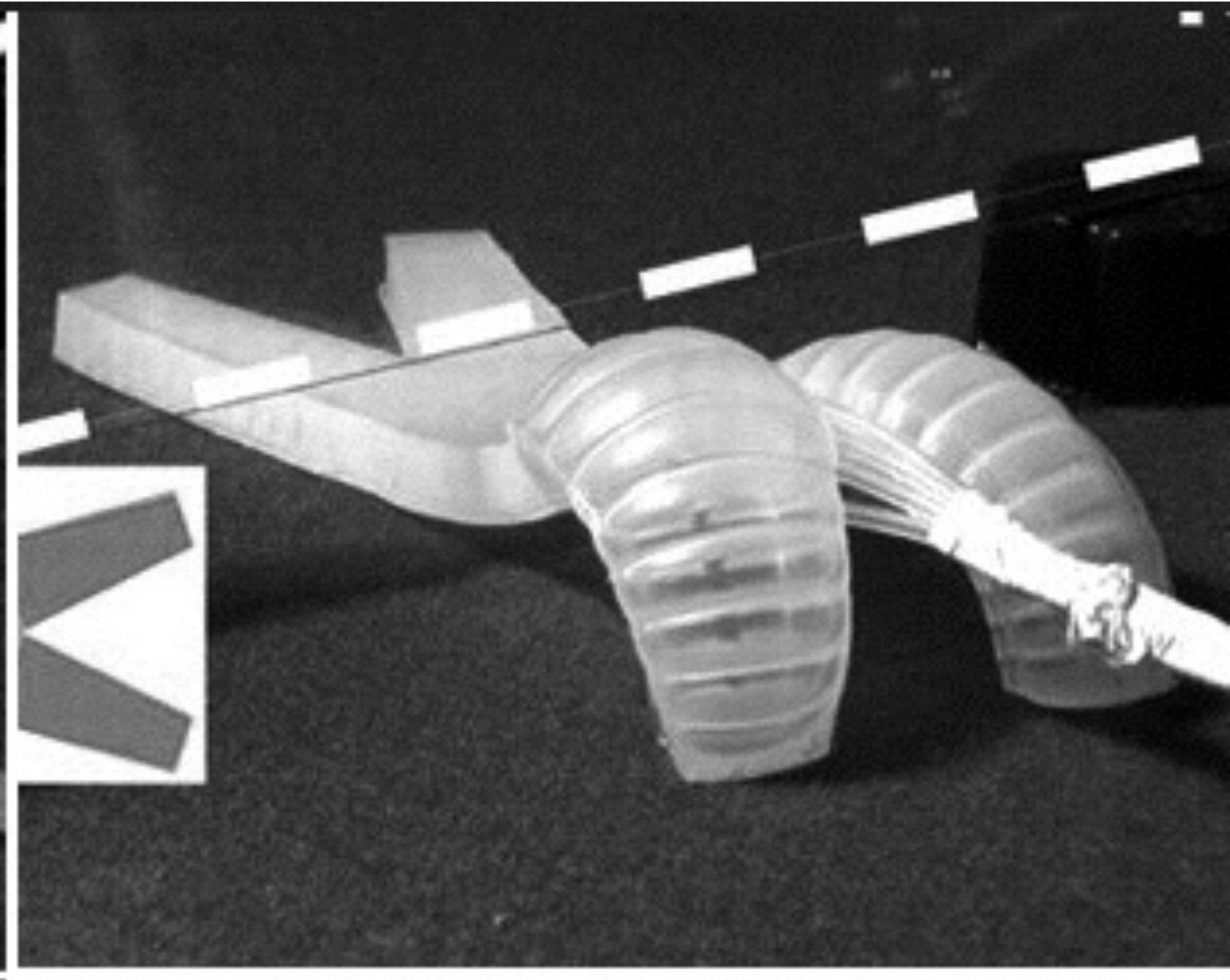
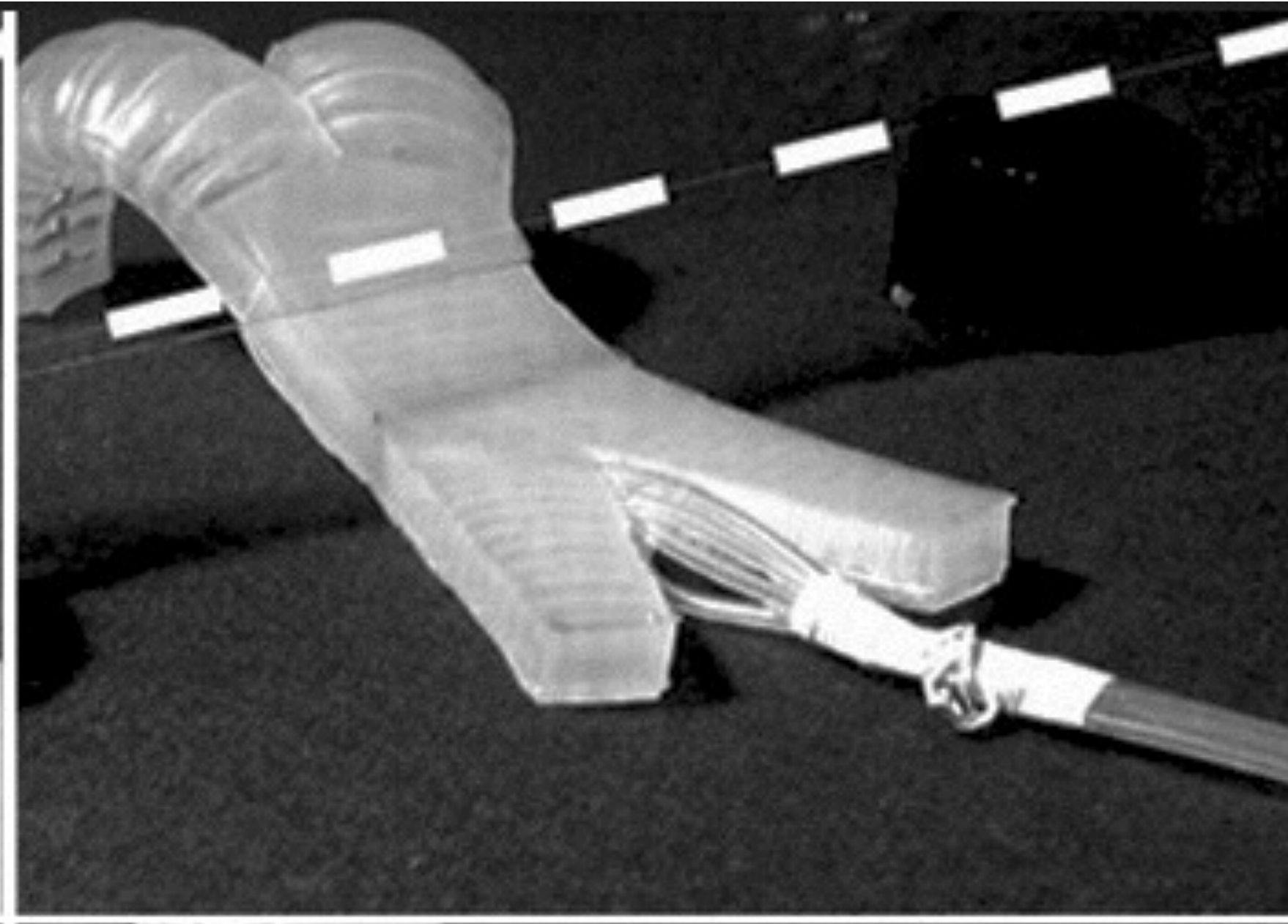
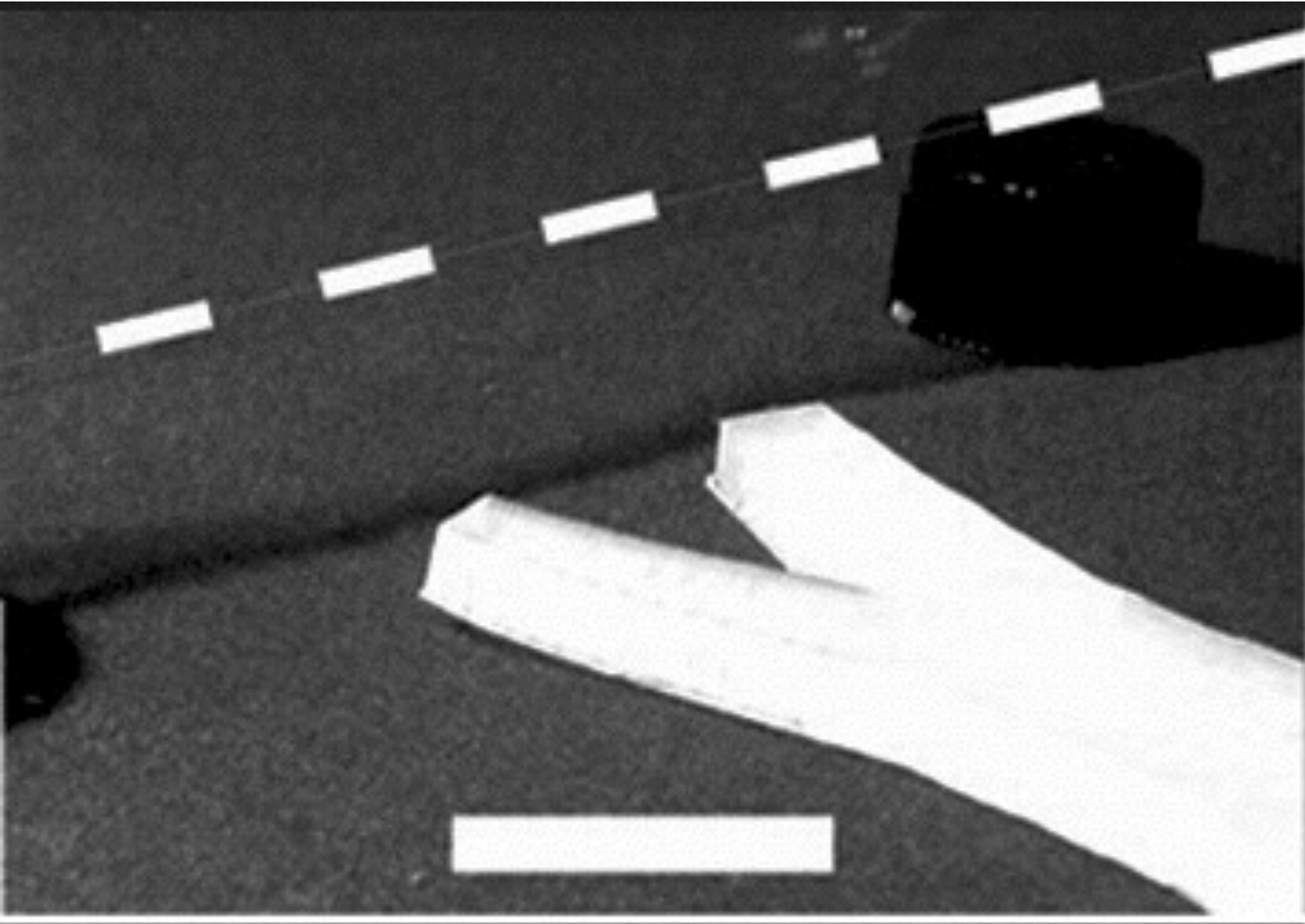
氣

a i r

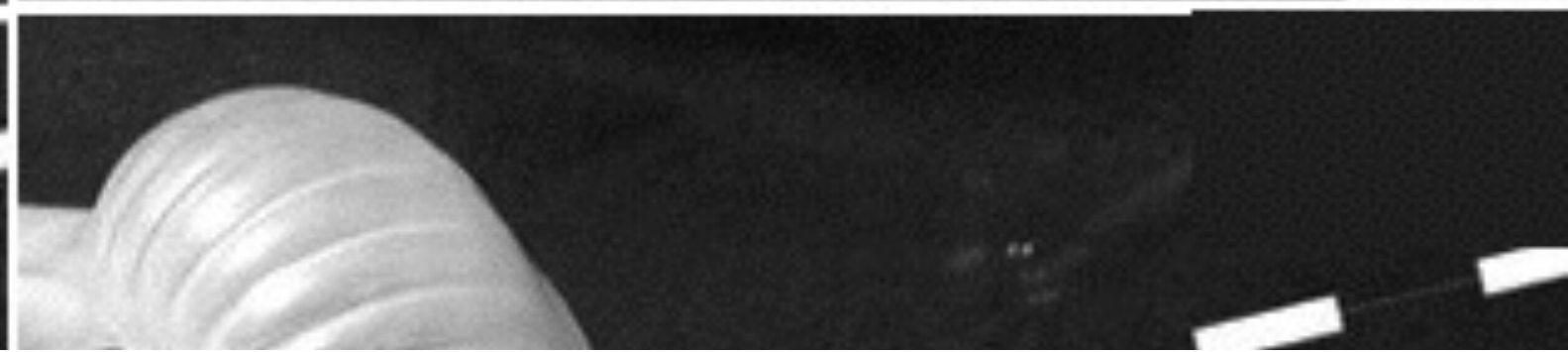
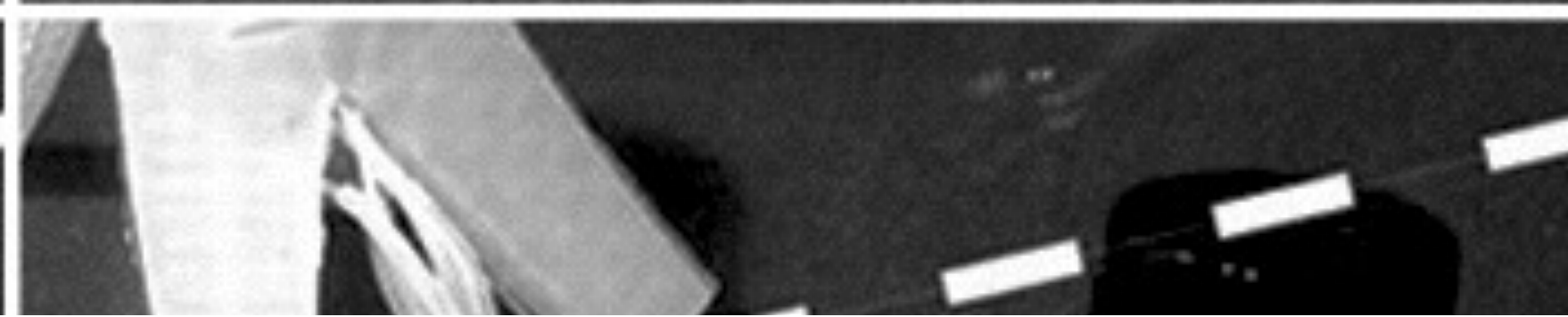
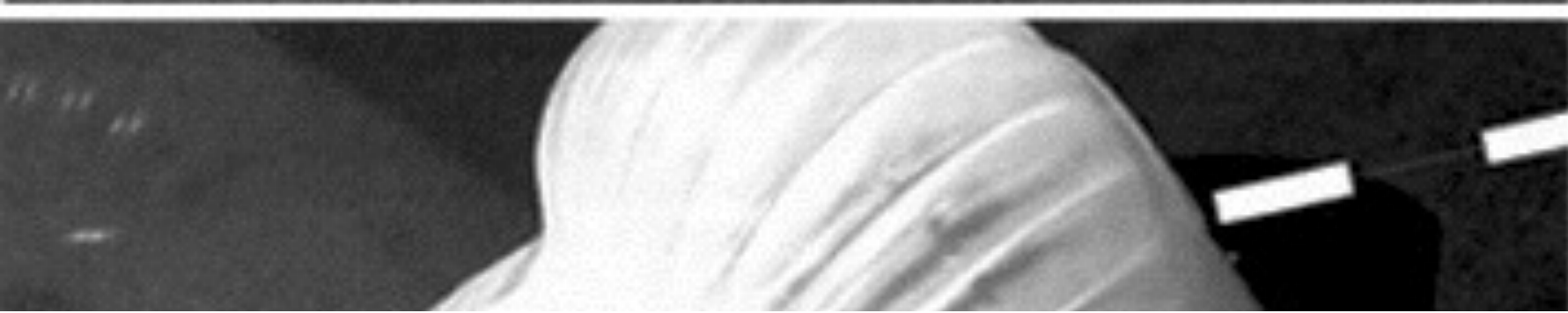
Surrounding the earth is a blanket of air

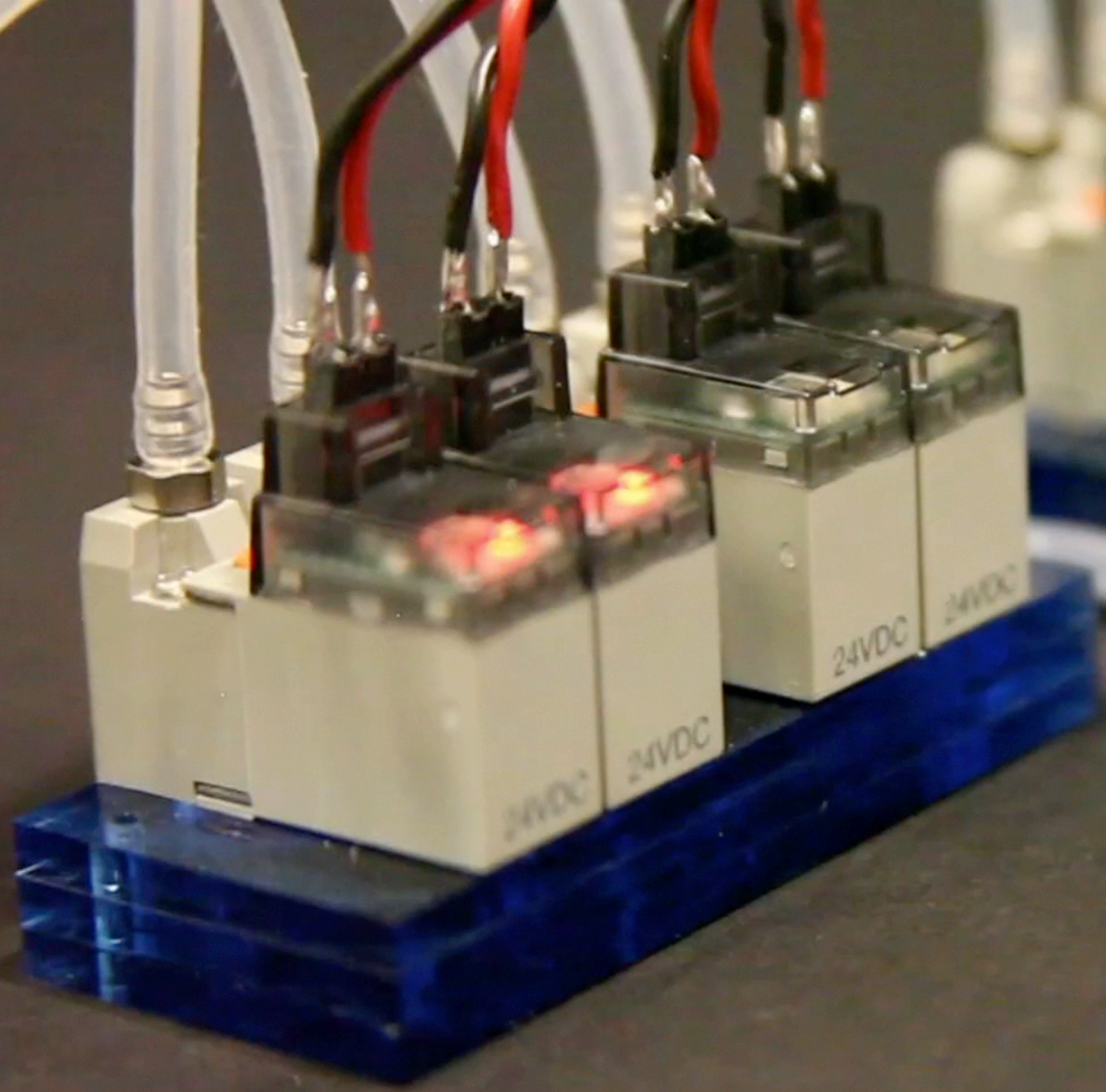


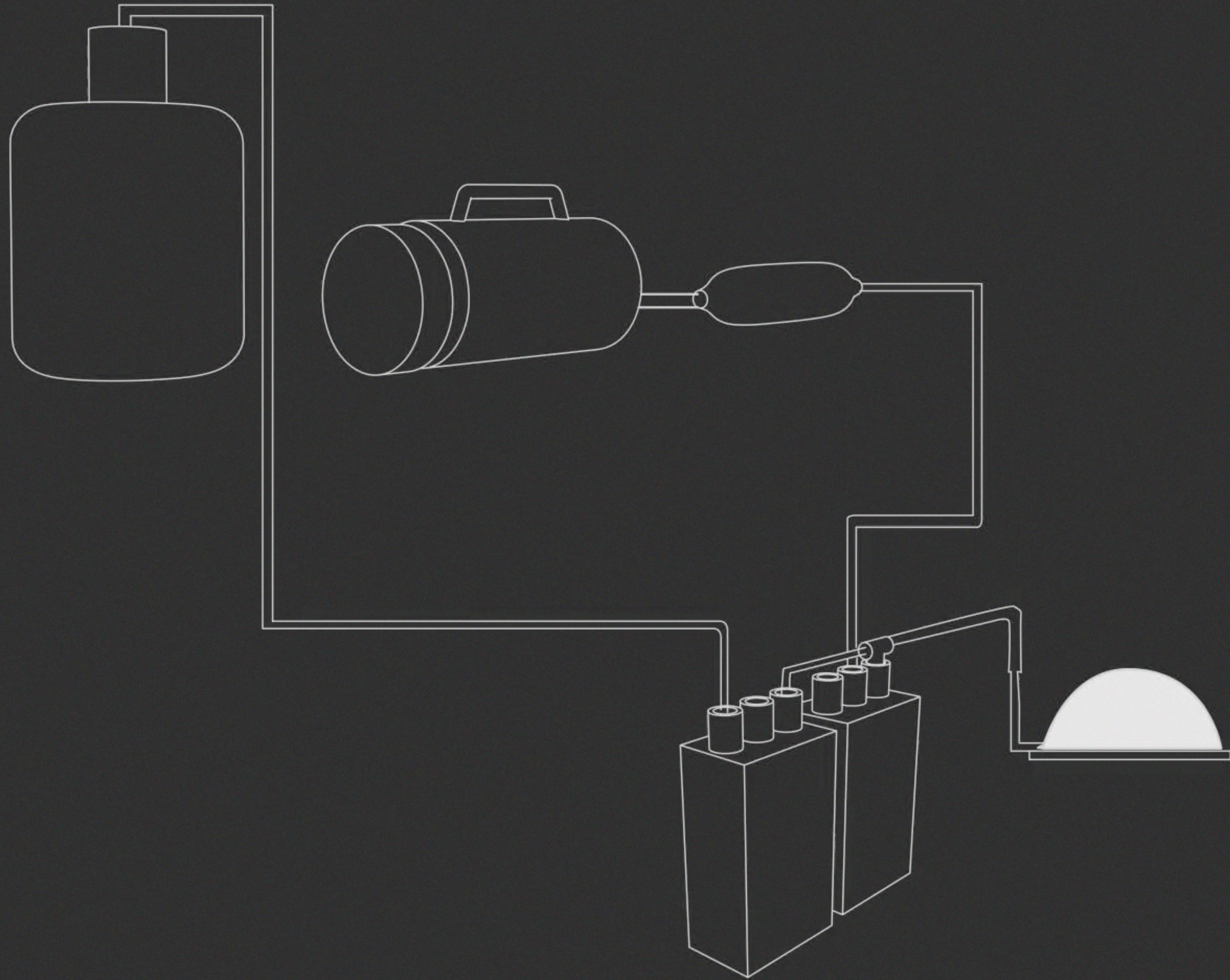




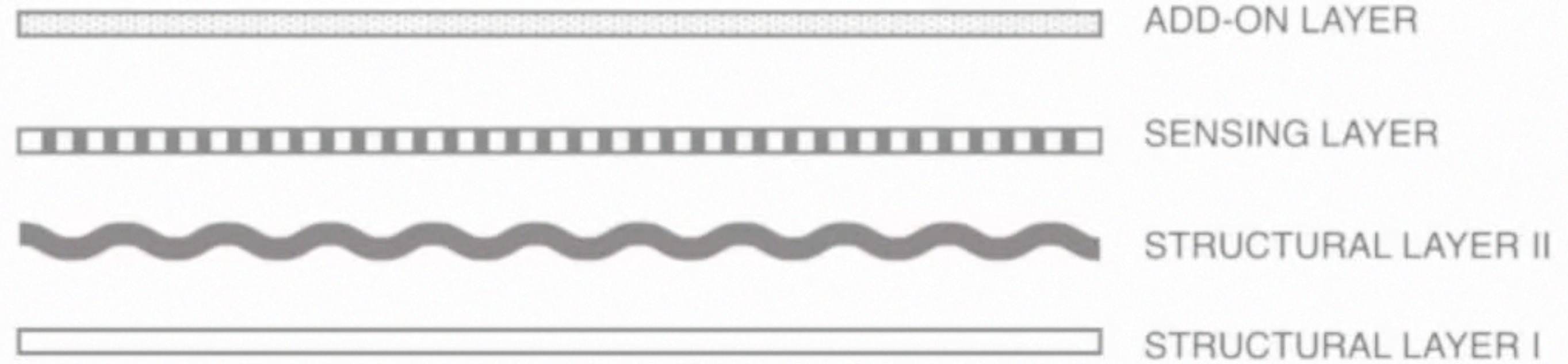
Multigait Soft Robots. Harvard Whitesides Group. 2011

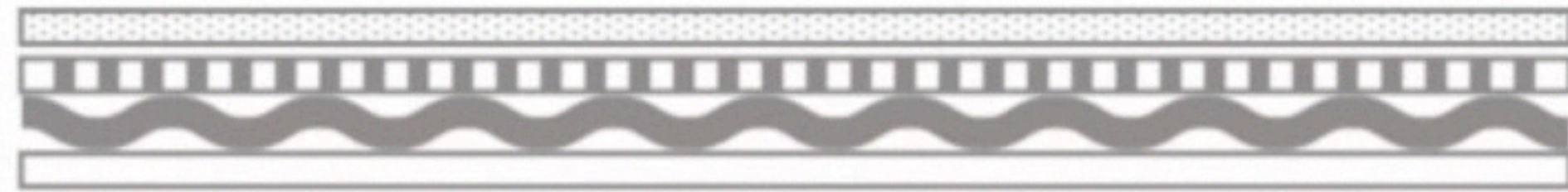






Three Types of Shape Changing Primitives



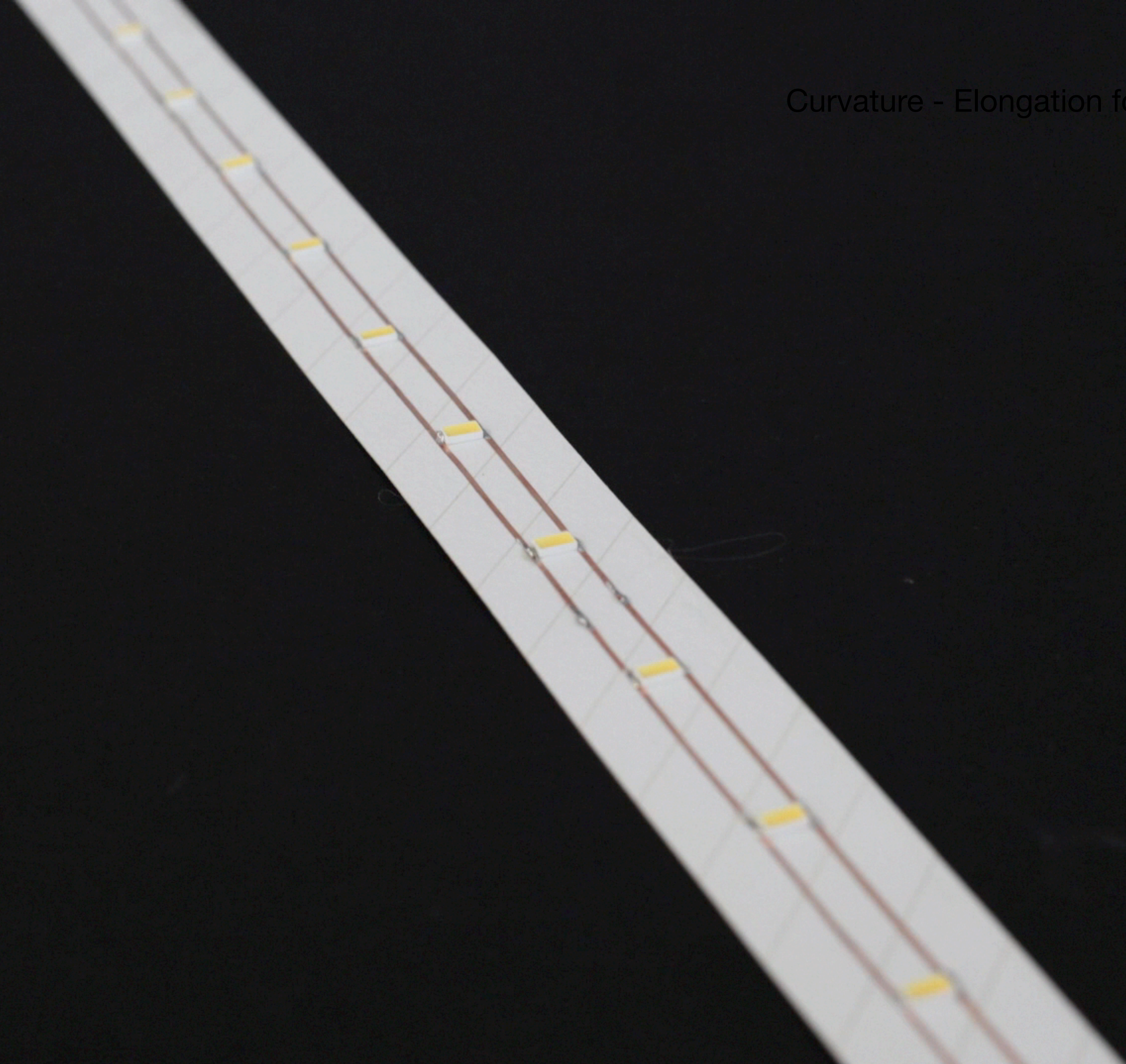


CURVATURE

VOLUME

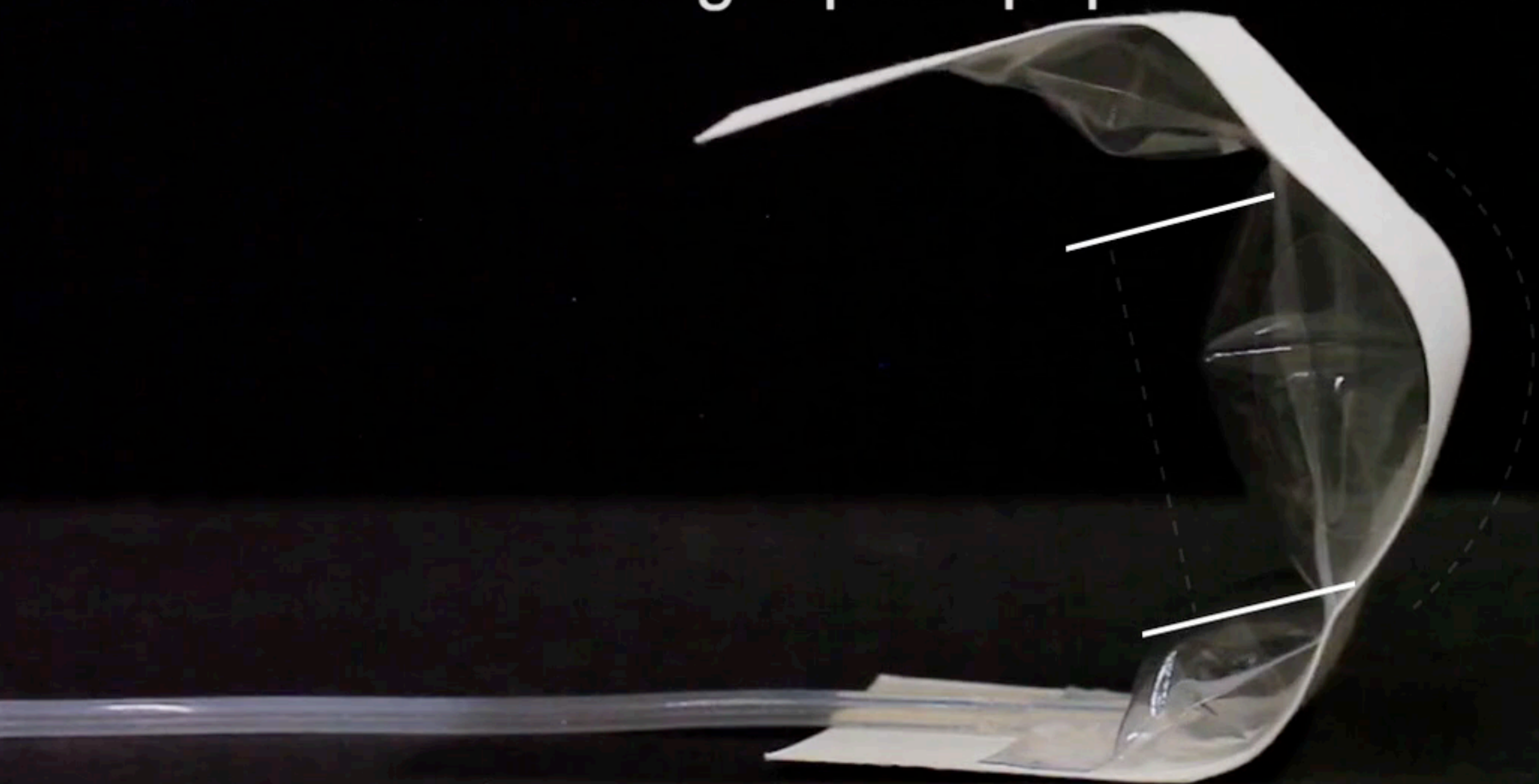
TEXTURE

Curvature - Elongation for Bending



Compression for Bending

non-elastic airbag + plain paper



Constant Length

CURVATURE

VOLUME

TEXTURE

Volume



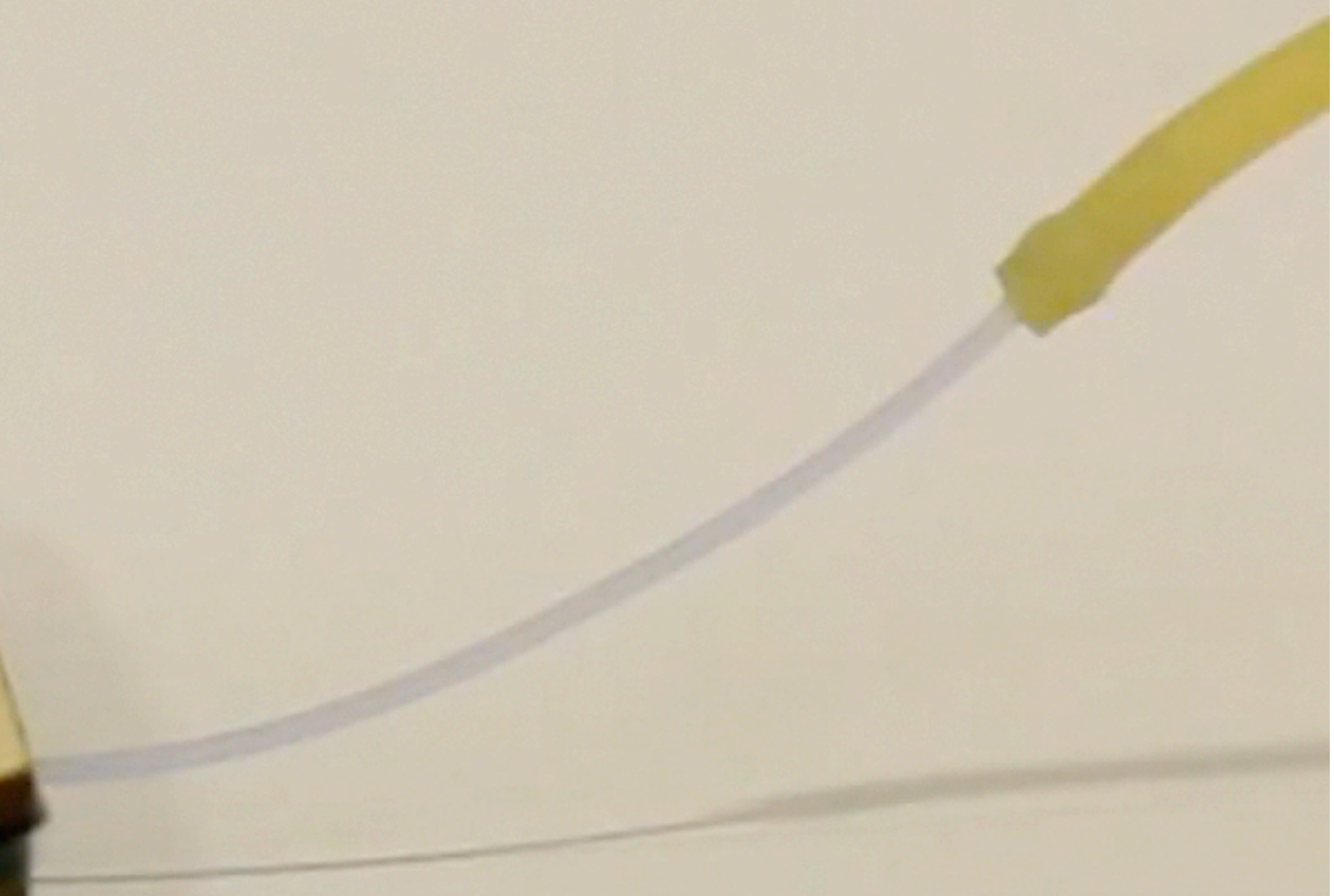
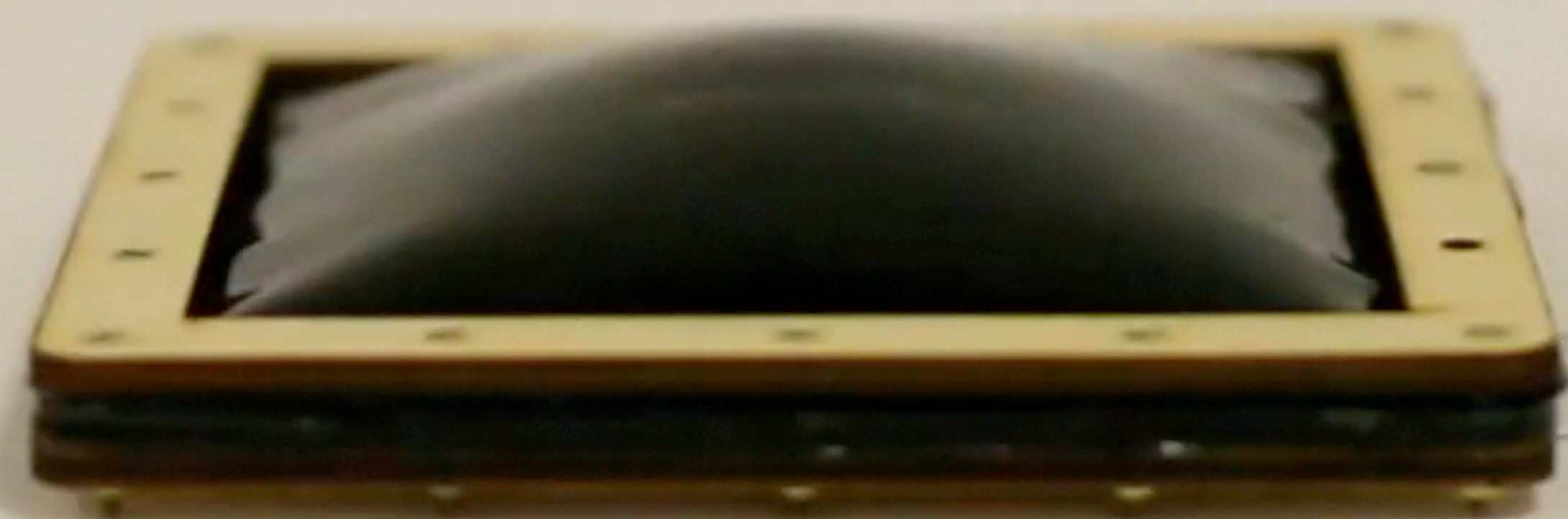
Linear elongation

CURVATURE

VOLUME

TEXTURE

Texture - Two-stage Texture

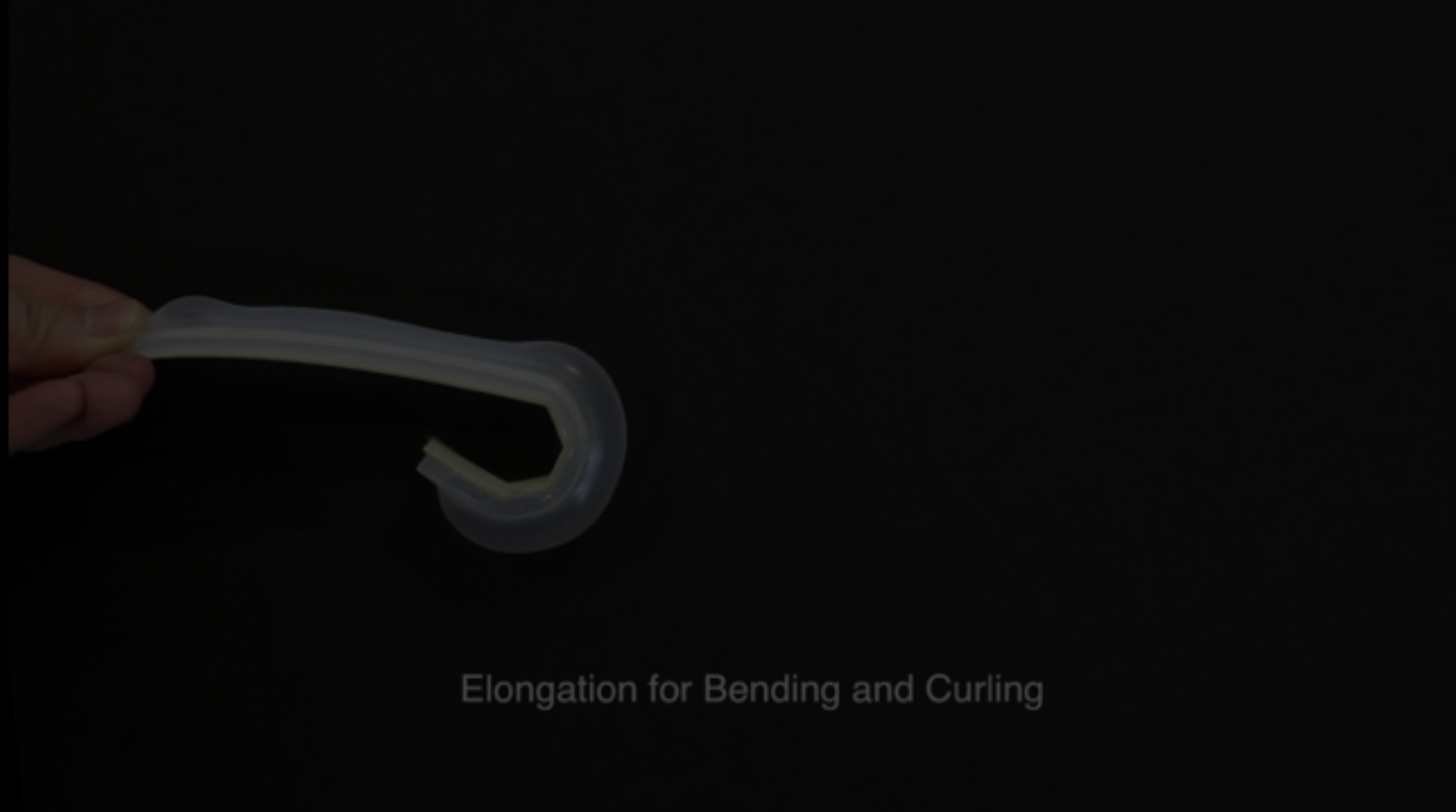


texture - Multilayer Texture

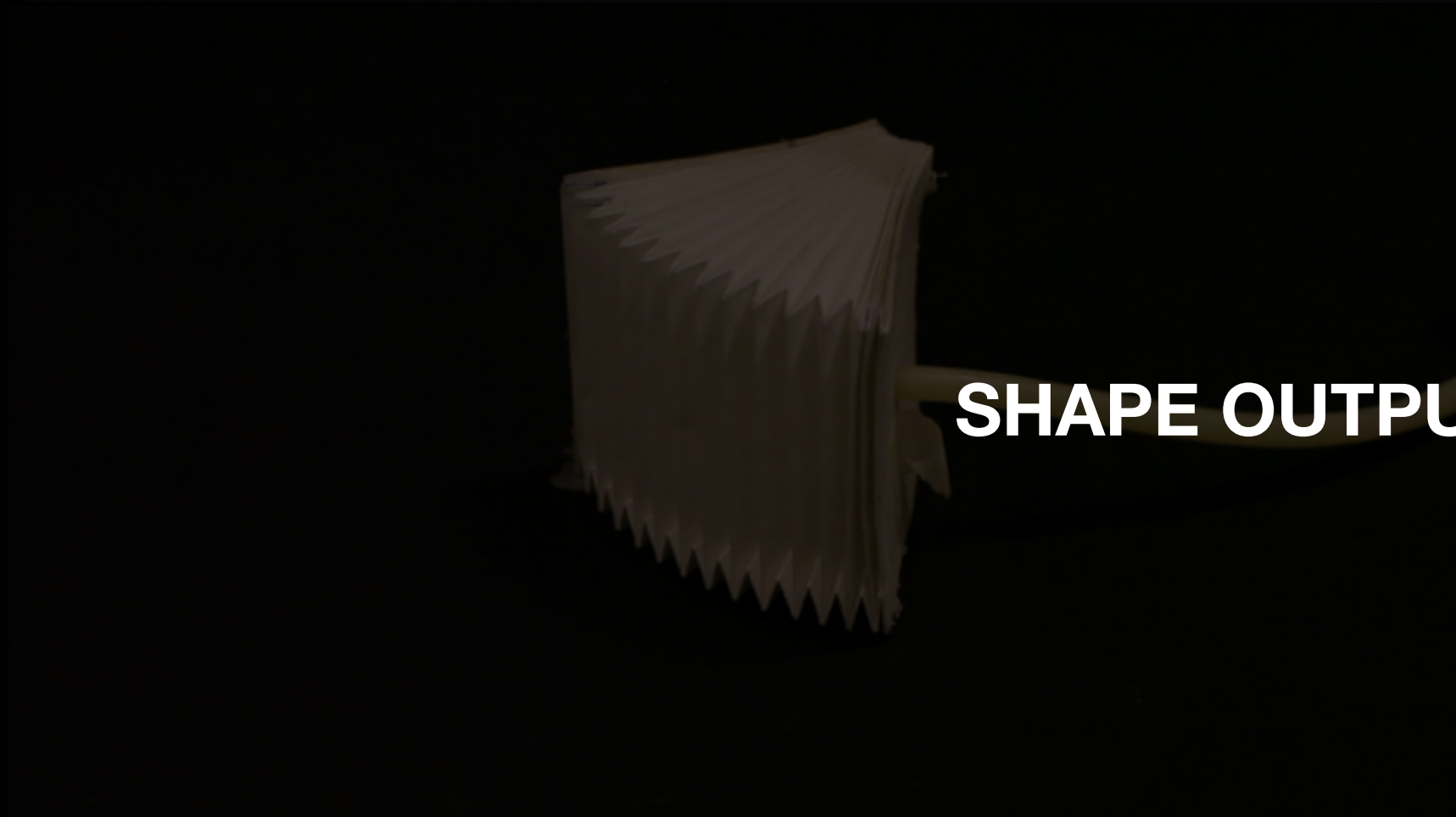
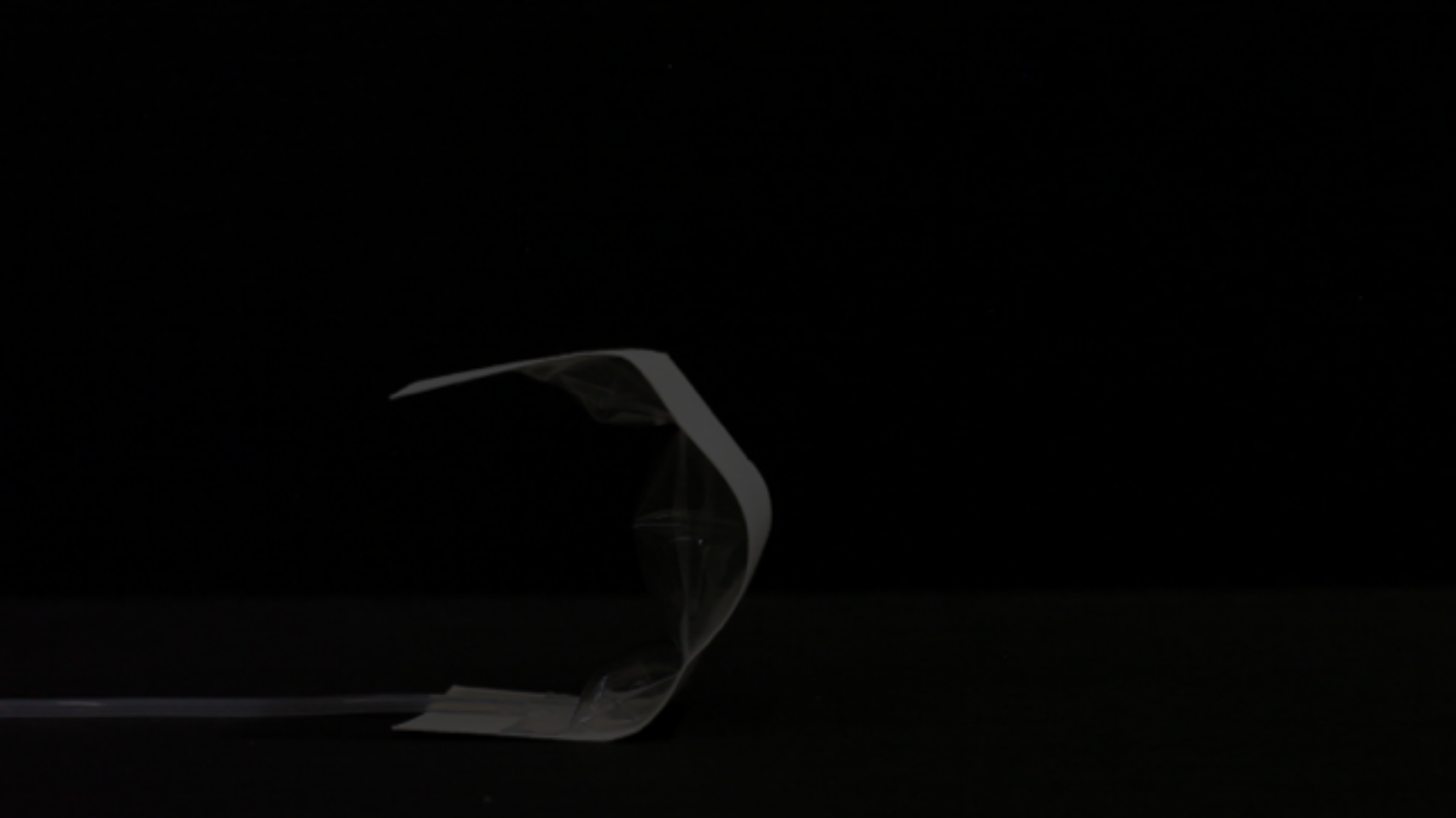
macro + micro airbags in elastomer



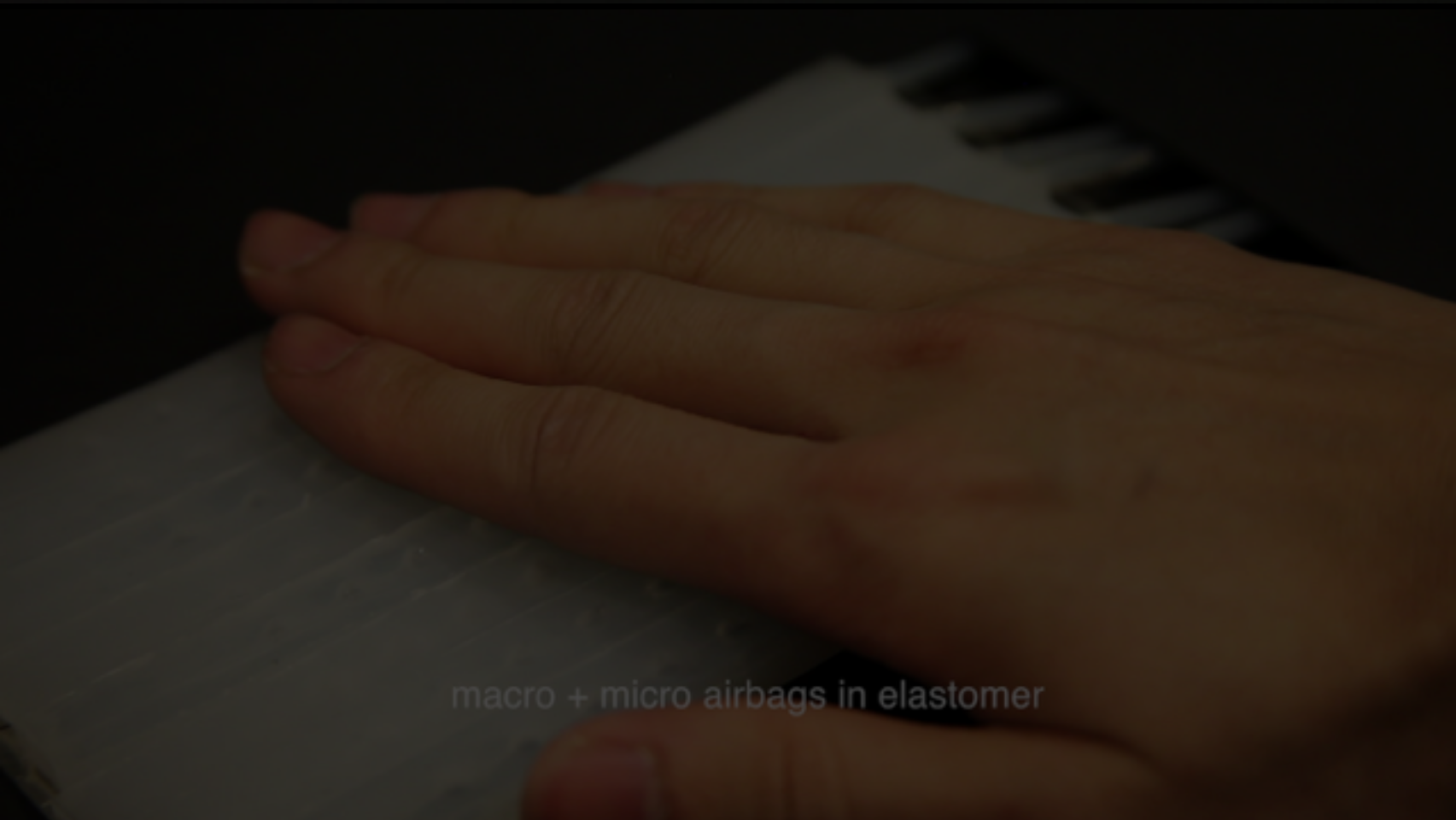
SHAPE OUTPUT PRIMITIVES



Elongation for Bending and Curling



SHAPE OUTPUT PRIMITIVES

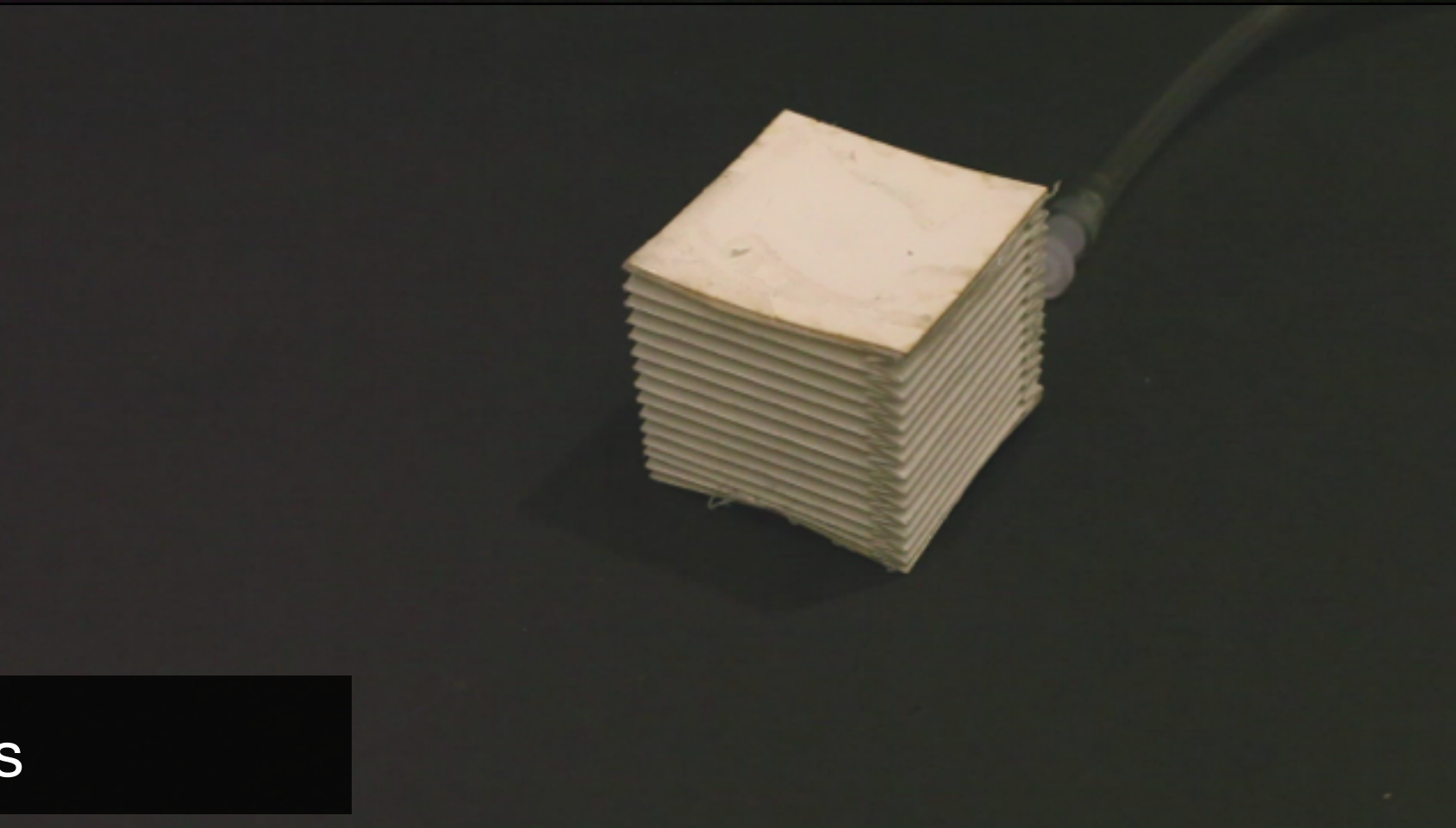
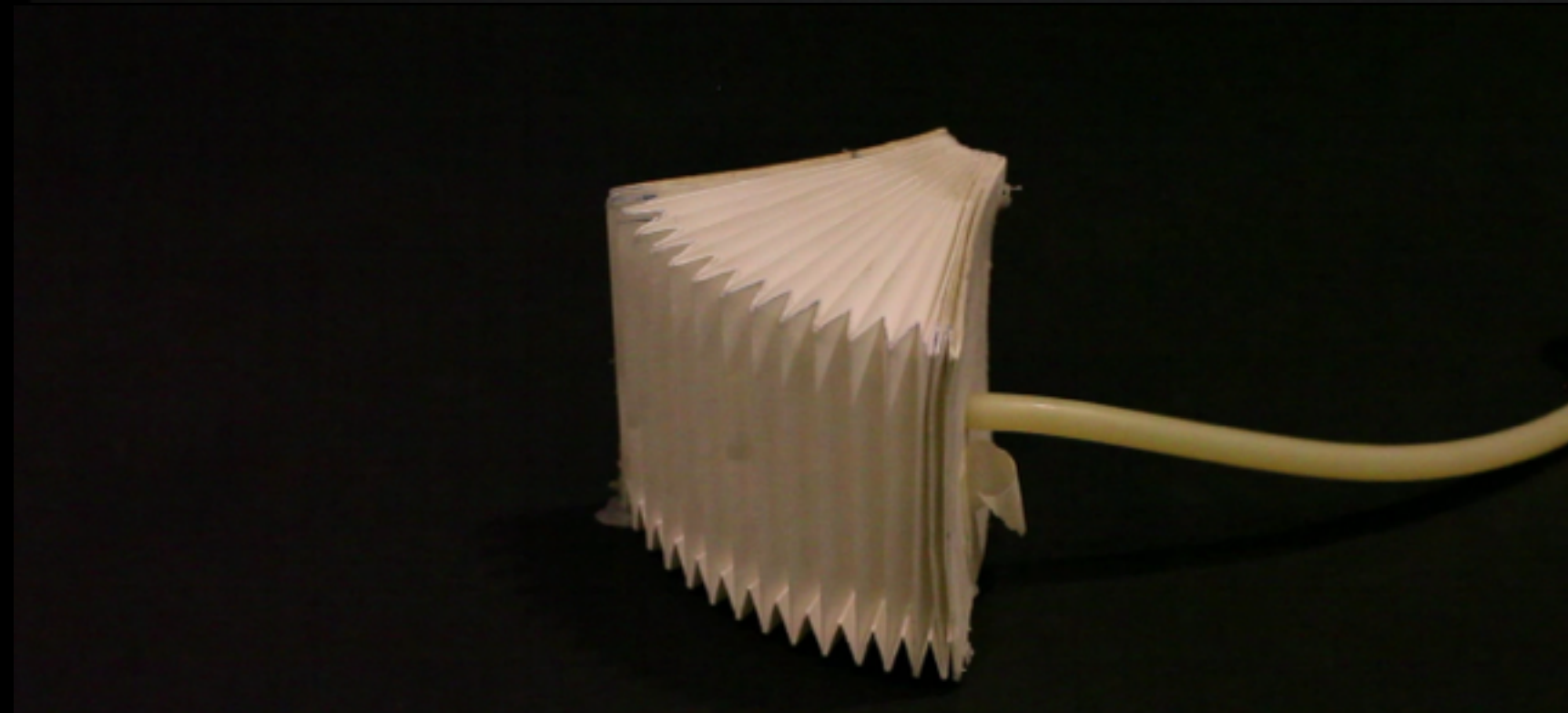
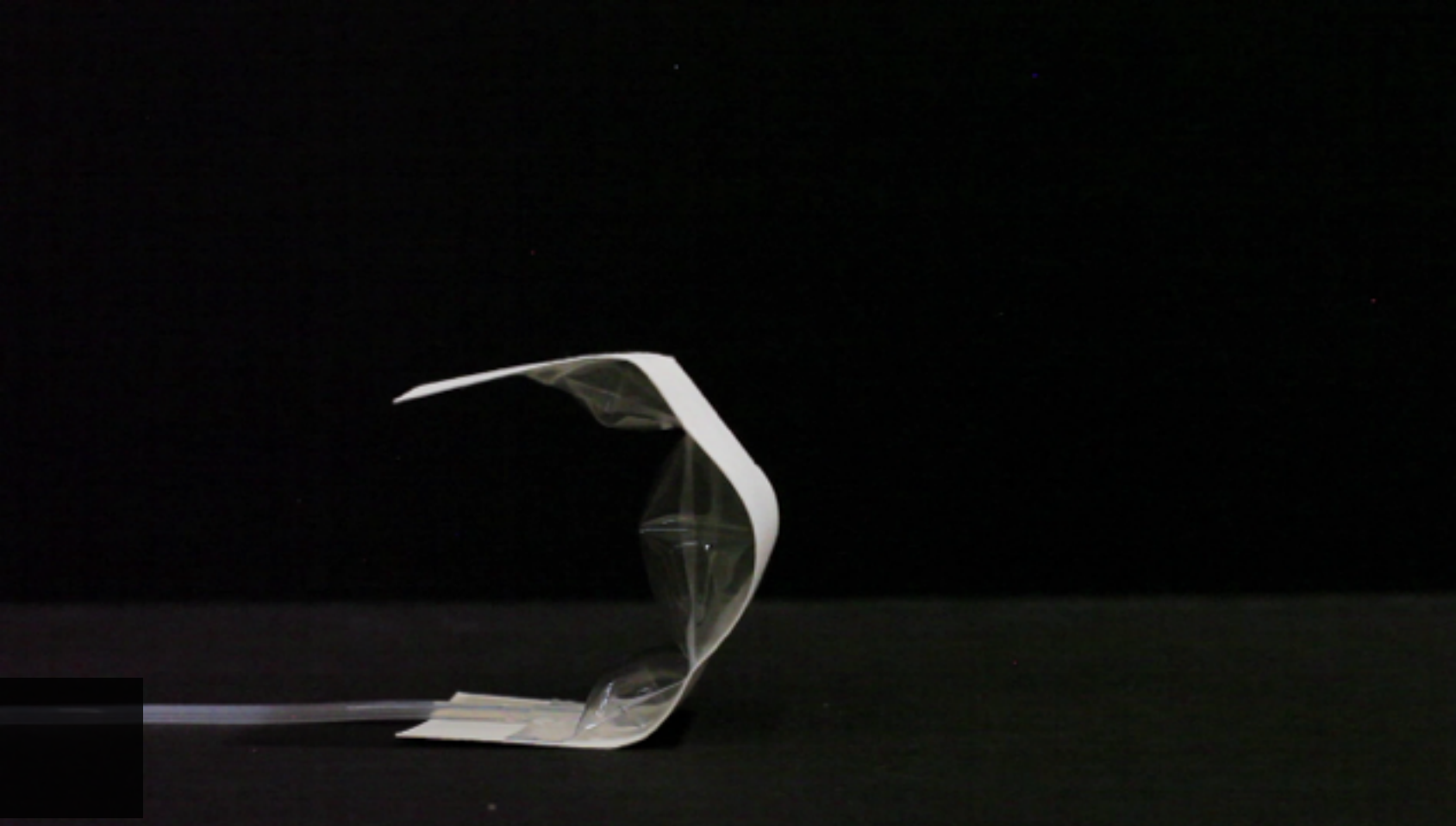


macro + micro airbags in elastomer



Elongation for Bending and Curling

Curvature on Surfaces: Bending and Curling



Unidirectional Volume Change of Solid Geometries

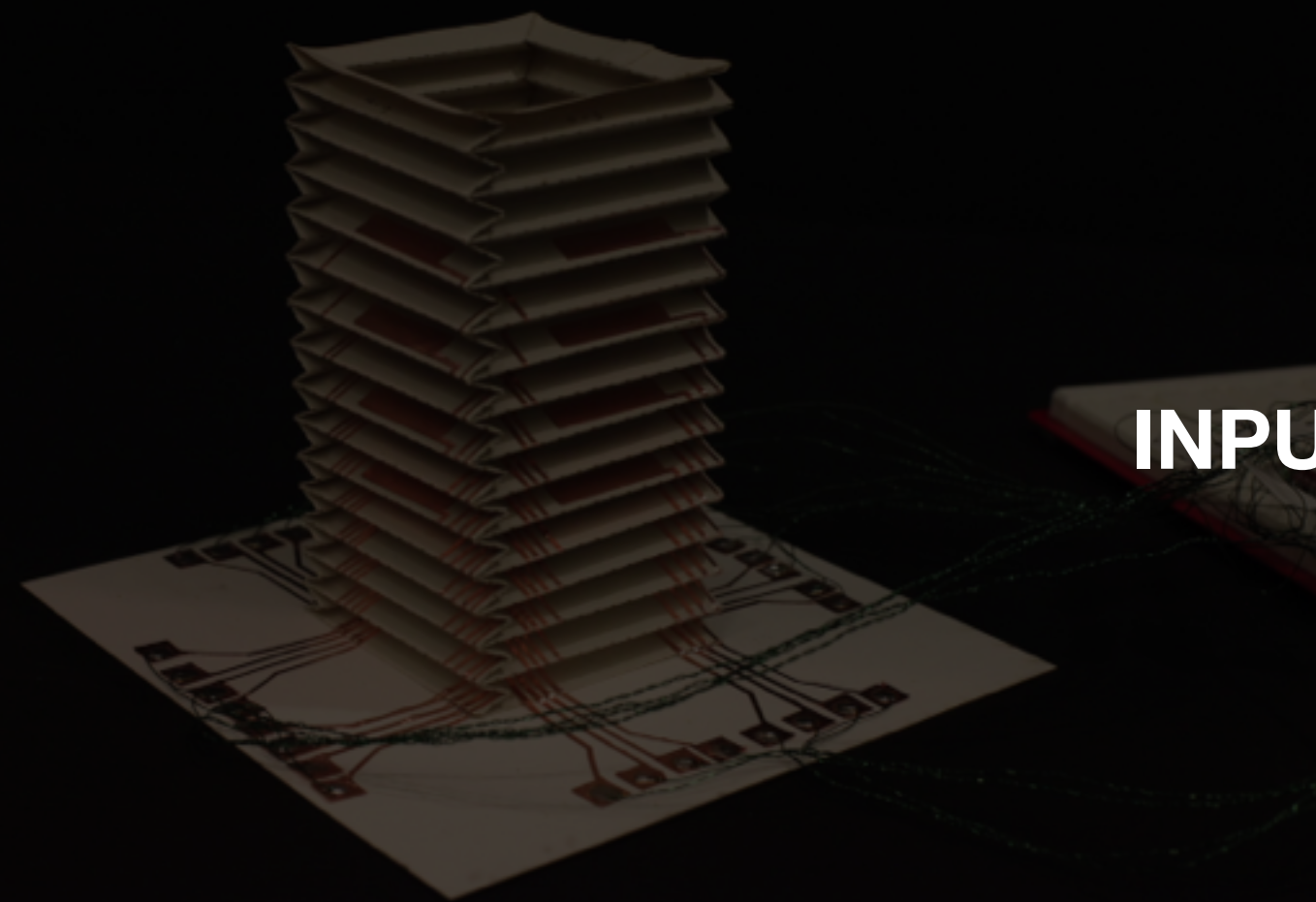


Dynamic Texture Change

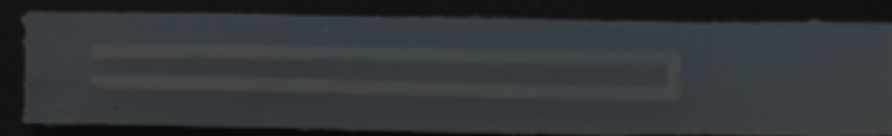


macro + micro airbags in elastomer

INPUT SENSING



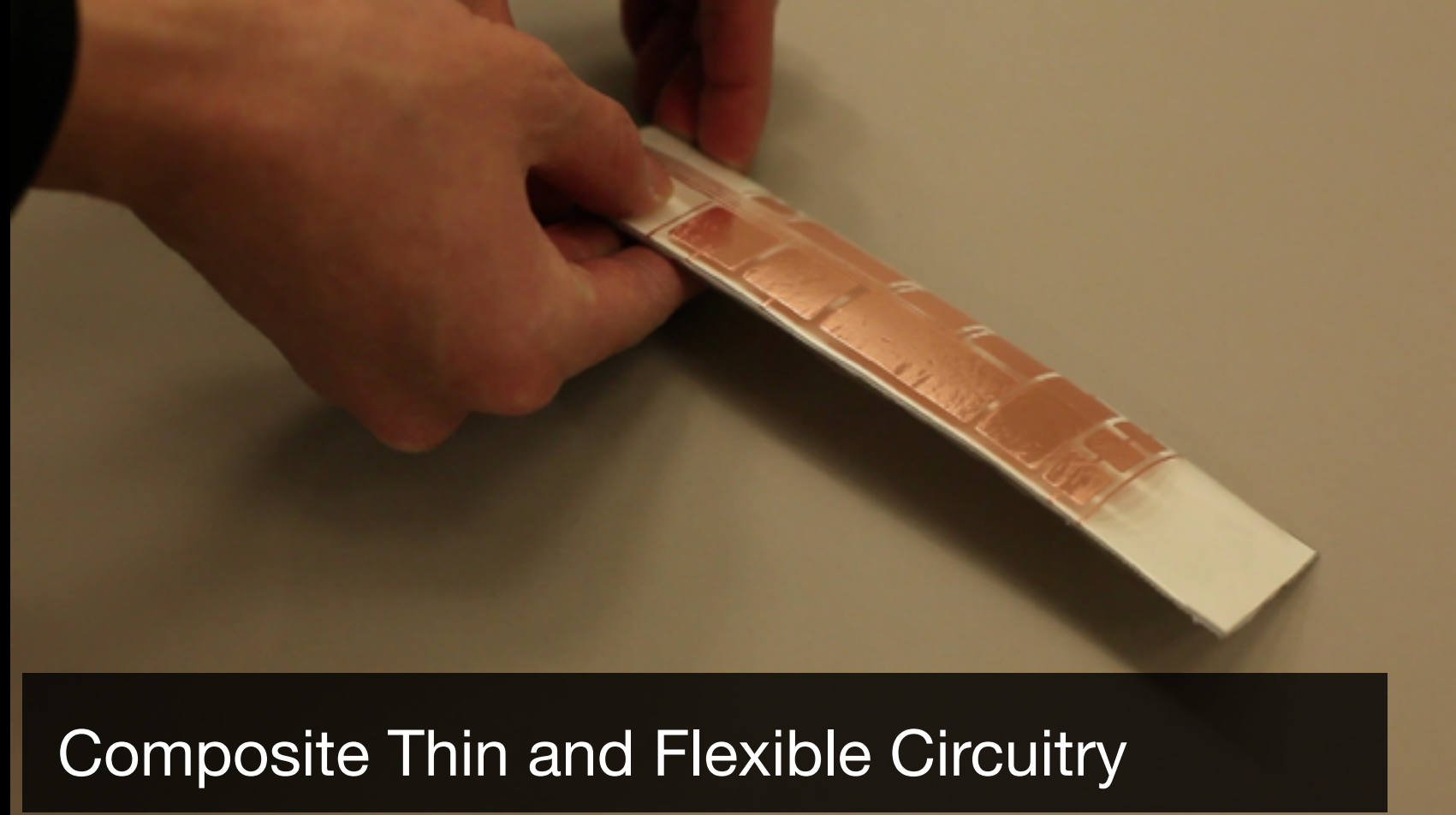
INPUT SENSING



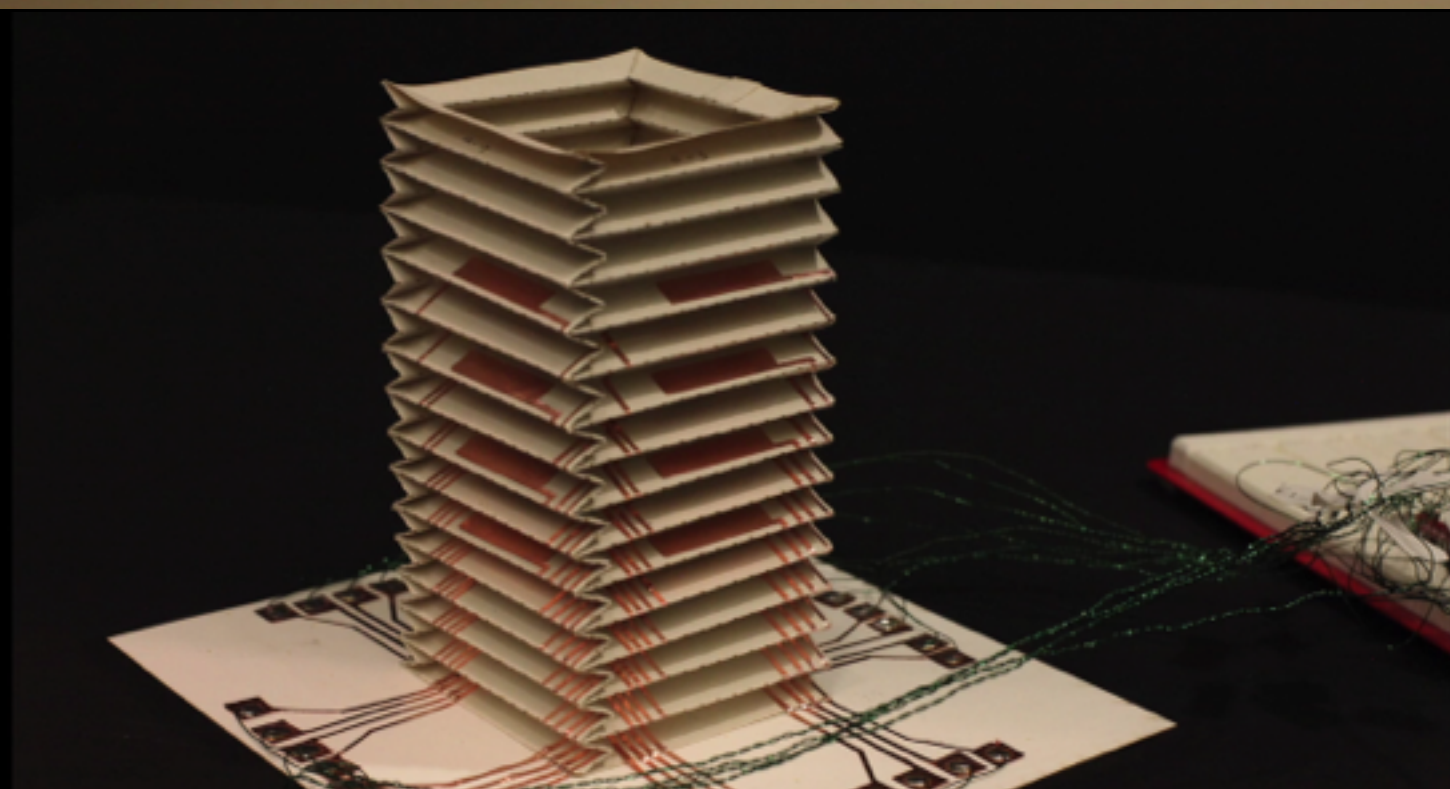
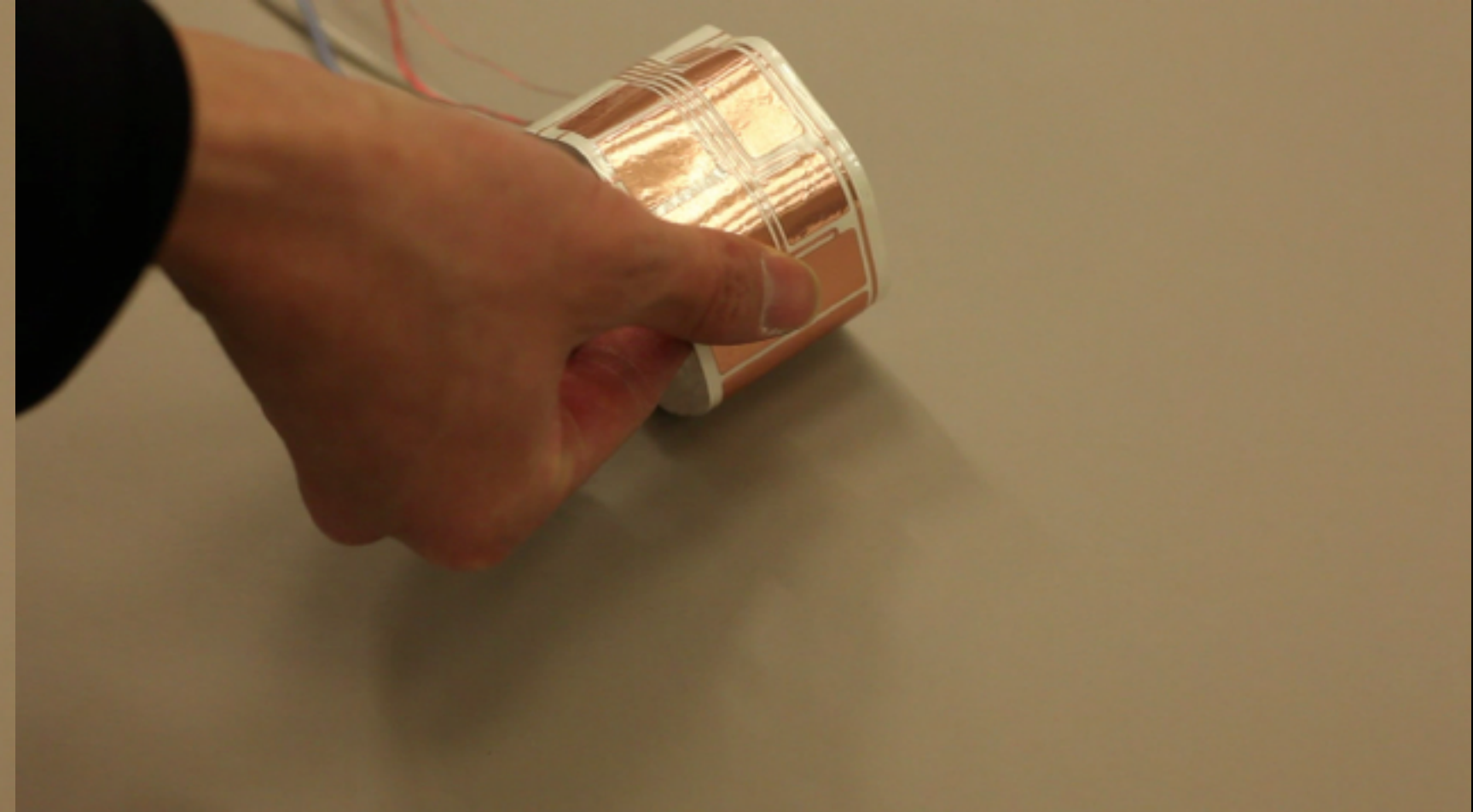
injected liquid metal
for stretching sensing



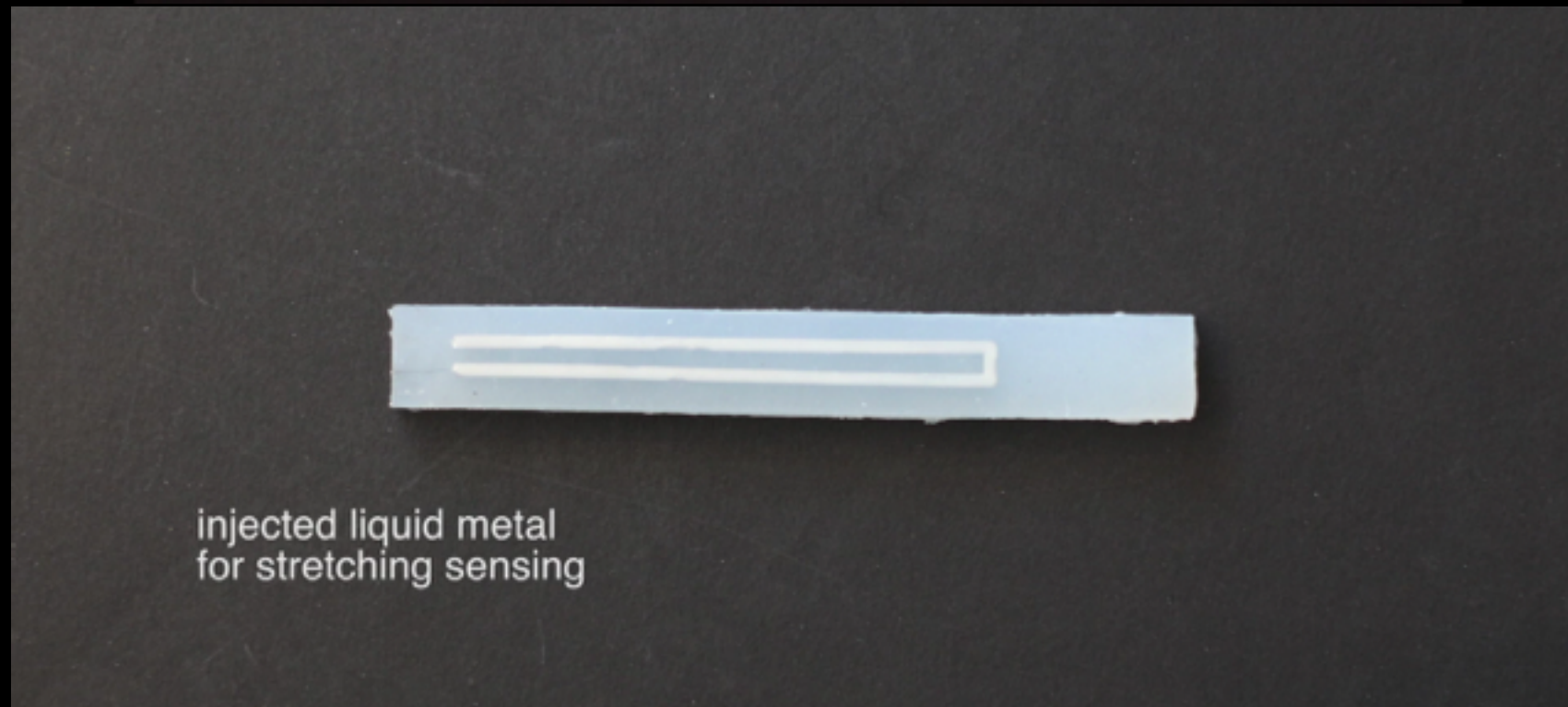
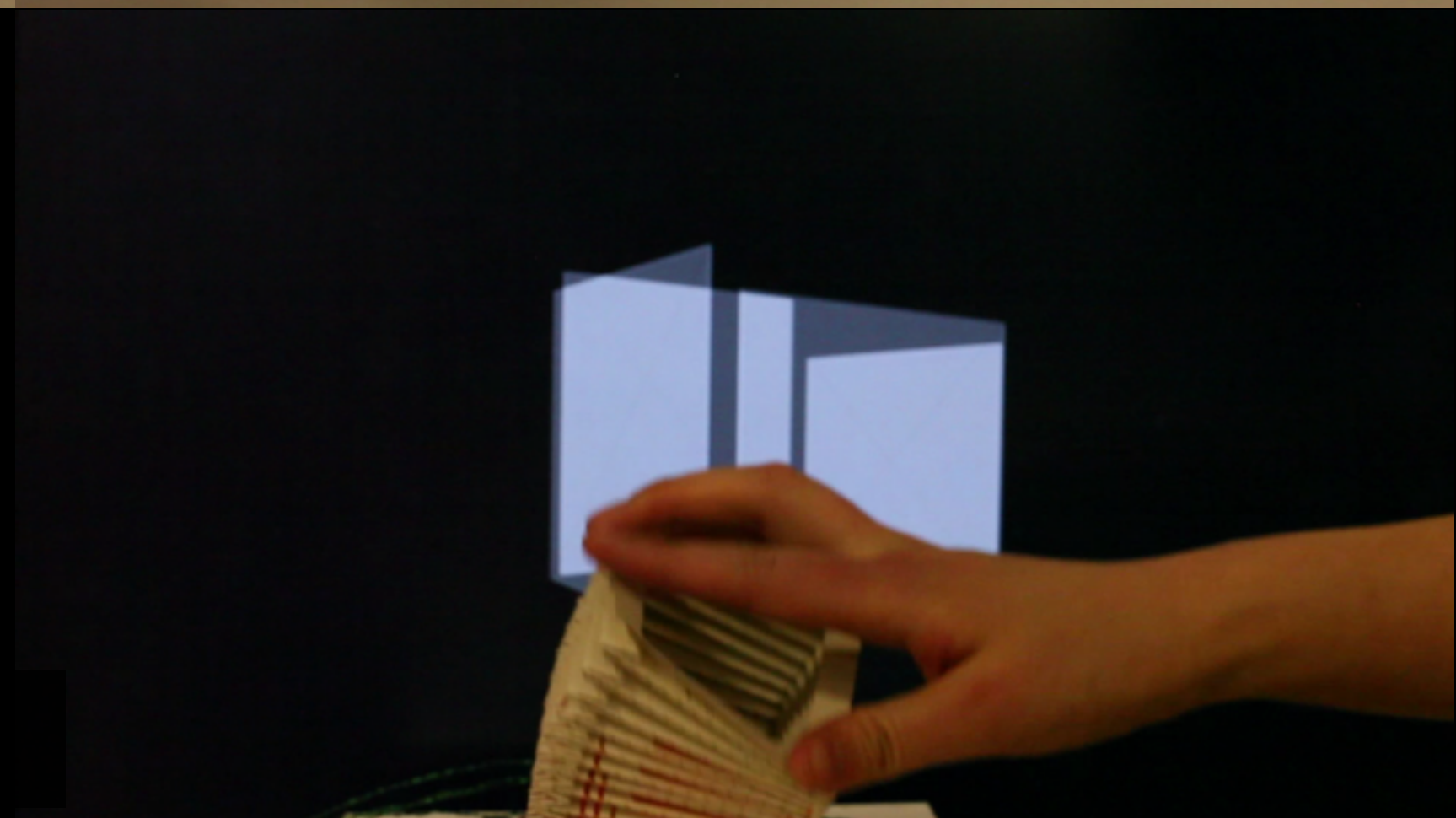
Sensing inflation



Composite Thin and Flexible Circuitry

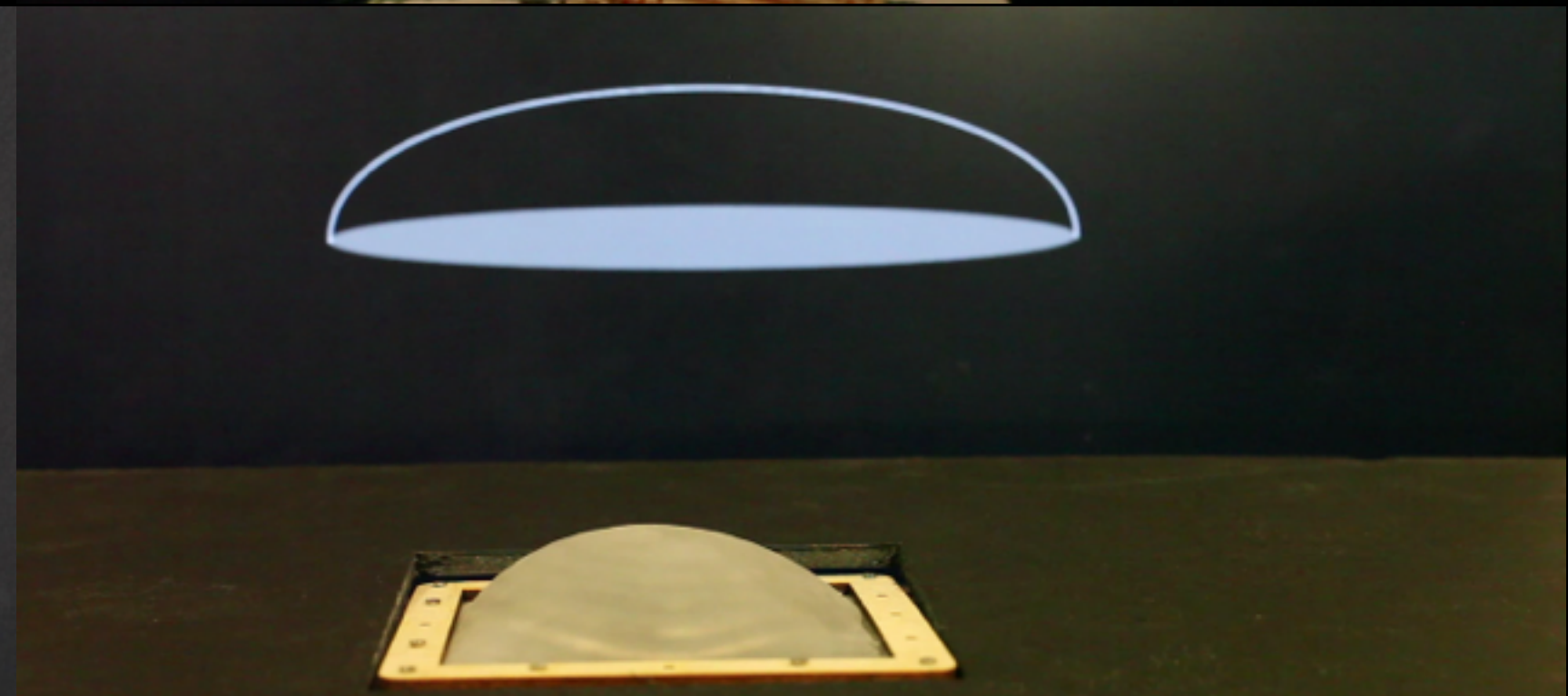


Composite Sensors on Folding Structures



injected liquid metal
for stretching sensing

Composite Liquid Metal in Elastomeric Channels



Sensing inflation

Soft Shape Change in HCI and Design - Case Studies and Reflection

Overview on history and applications in HCI

Case study 1: PneuUI, by Lining Yao from TMG

Case study 2: JamSheets, by Jifei Ou from TMG

Reflection: Unique contribution of soft shape change in HCI and design

Soft Shape Change in HCI and Design - Case Studies and Reflection

Overview on history and applications in HCI

Case study 1: PneuUI, by Lining Yao from TMG

Case study 2: JamSheets, by Jifei Ou from TMG

Reflection: Unique contribution of soft shape change in HCI and design

Reflection: Unique Opportunity of Soft Shape Change in HCI and Design

Mechanical Property

Opportunity for HCI and Design

elastically deformable

lifelike form and motion

mechanical compliance matching with the human skin

friendly for onbody/wearable applications

potential for multi-functionality

integrate both input sensing and shape output

potential for utilizing material anisotropy

complex transformation behaviors

unique actuation mechanism
(pneumatic, smart materials)

silent/soft change

Reflection: Unique Opportunity of Soft Shape Change in HCI and Design

Mechanical Property

elastically deformable

mechanical compliance matching with the human skin

potential for multi-functionality

potential for utilizing material anisotropy

unique actuation mechanism
(pneumatic, smart materials)

Opportunity for HCI and Design

lifelike form and motion

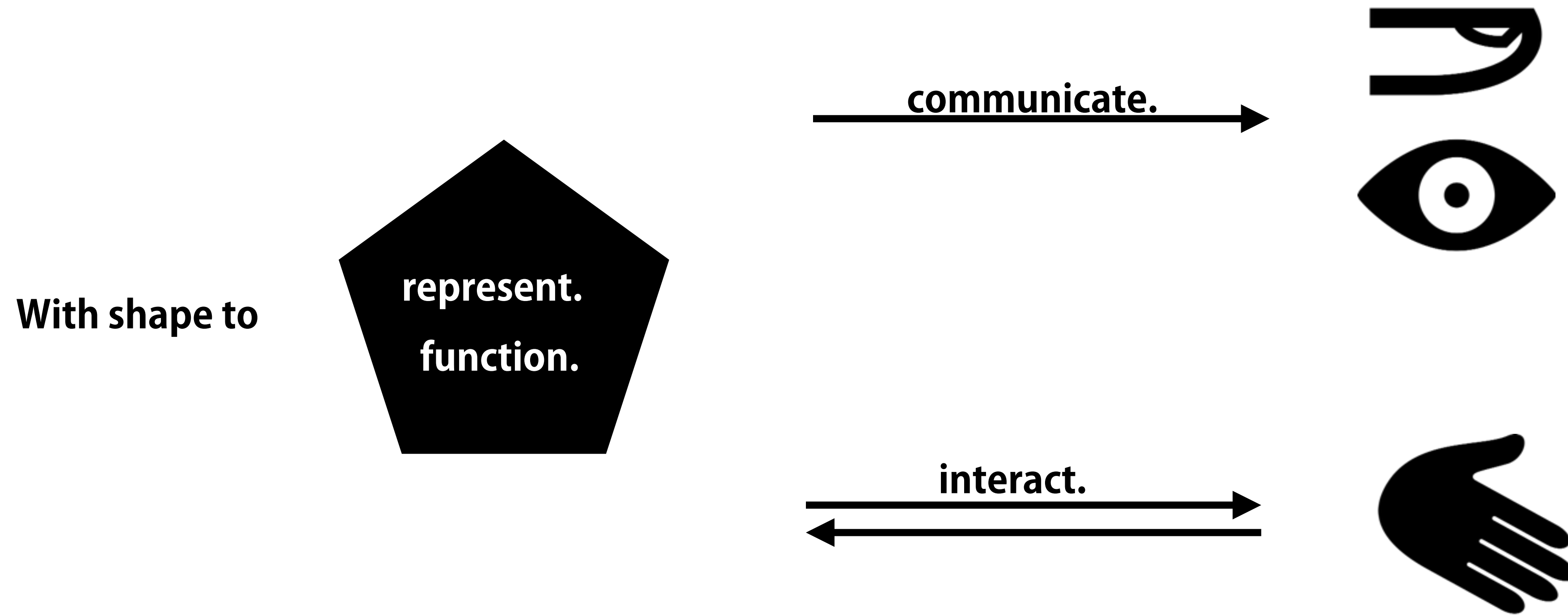
friendly for onbody/wearable applications

integrate both input sensing and shape output

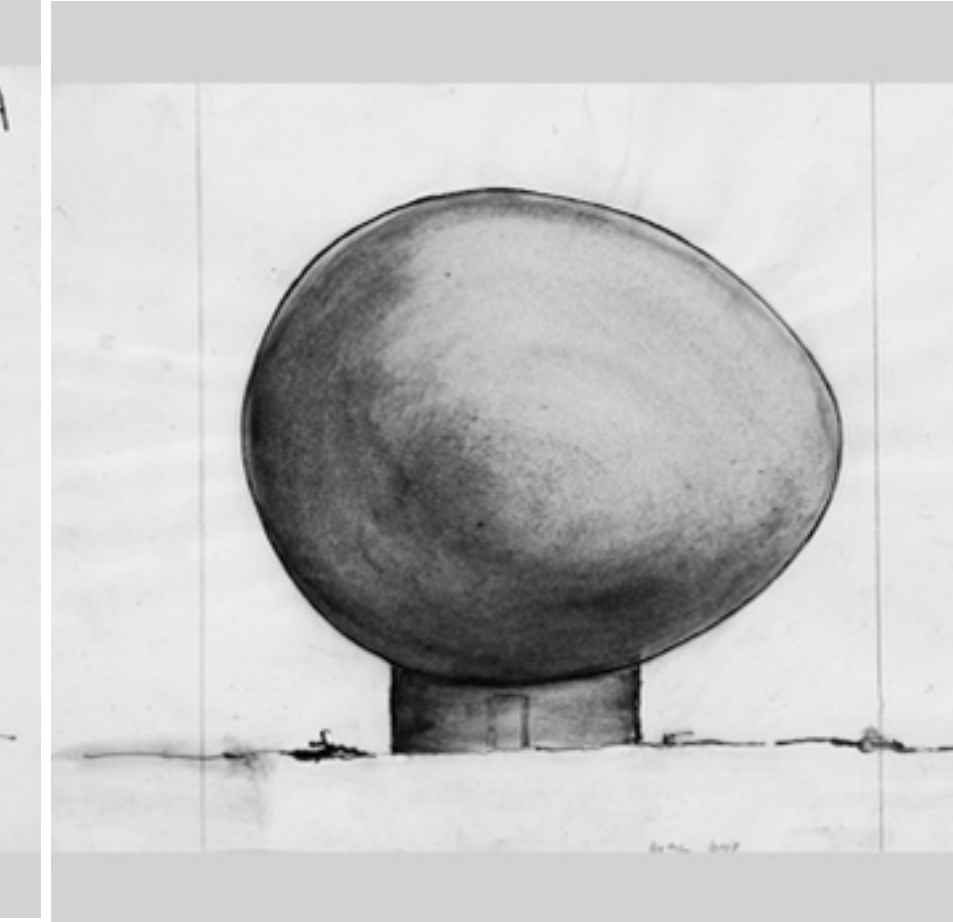
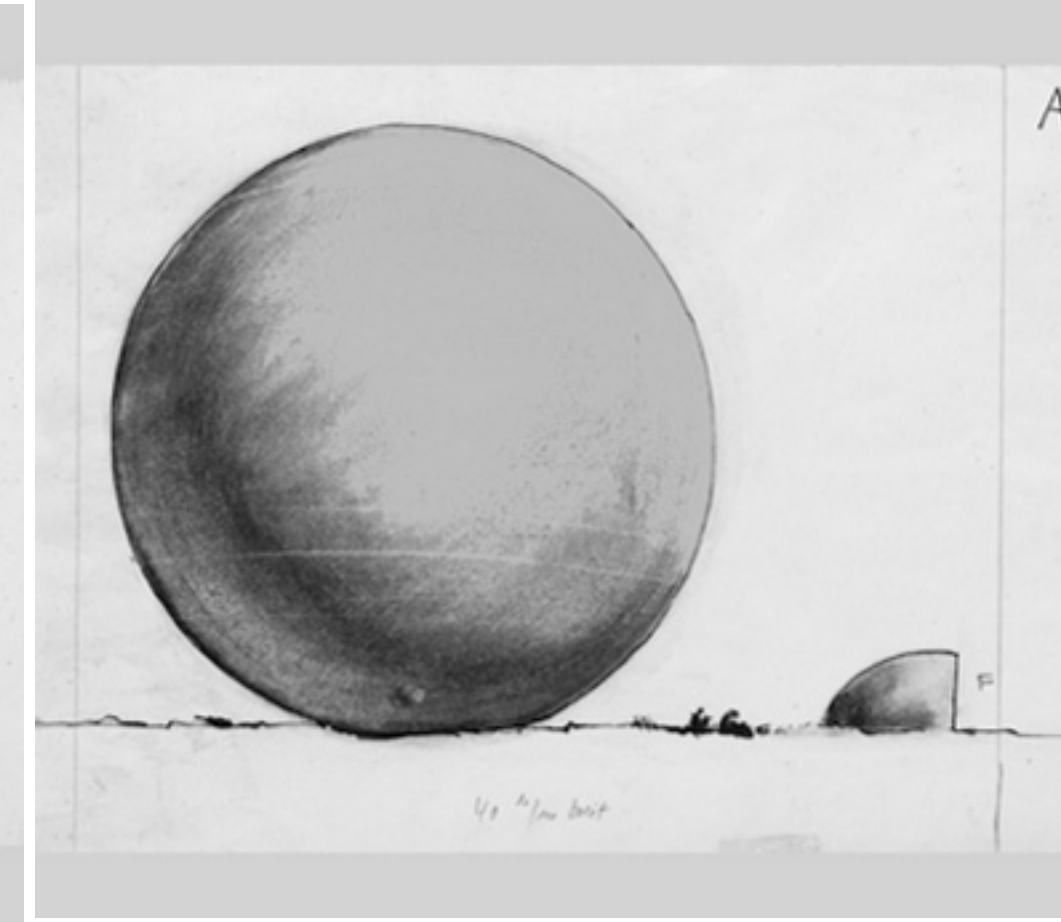
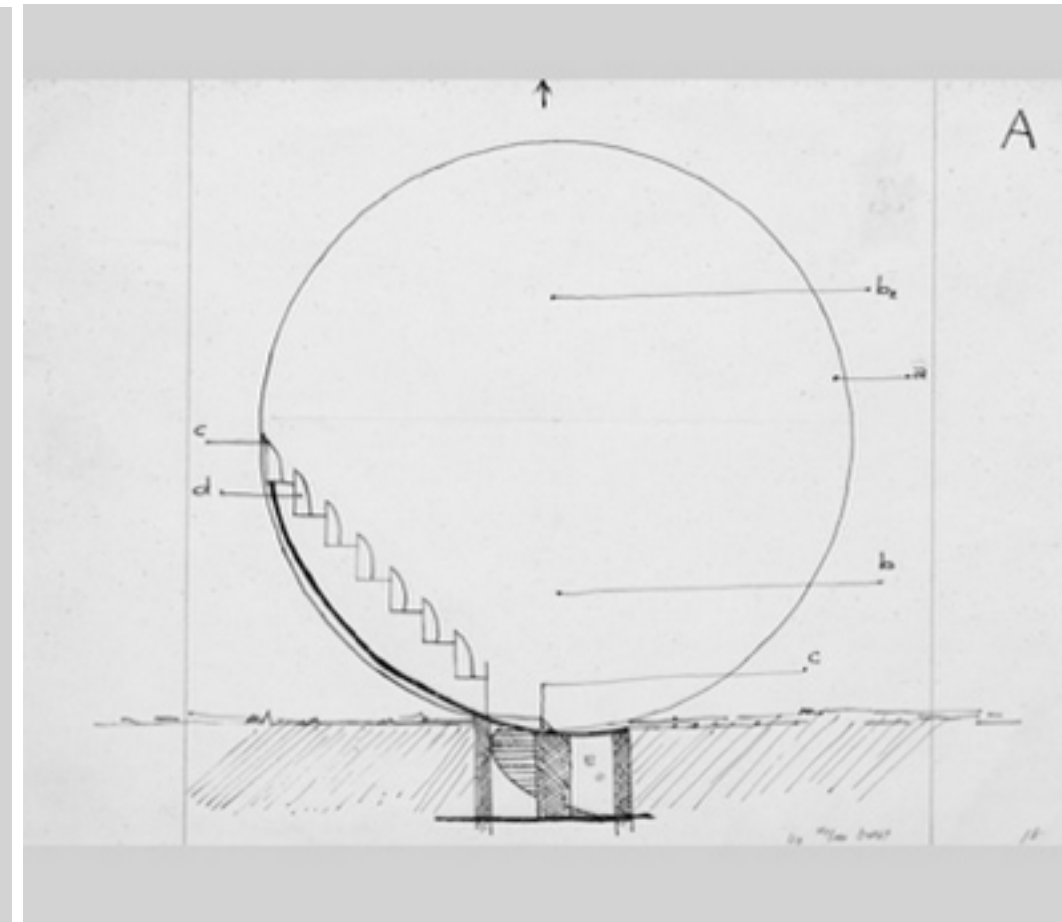
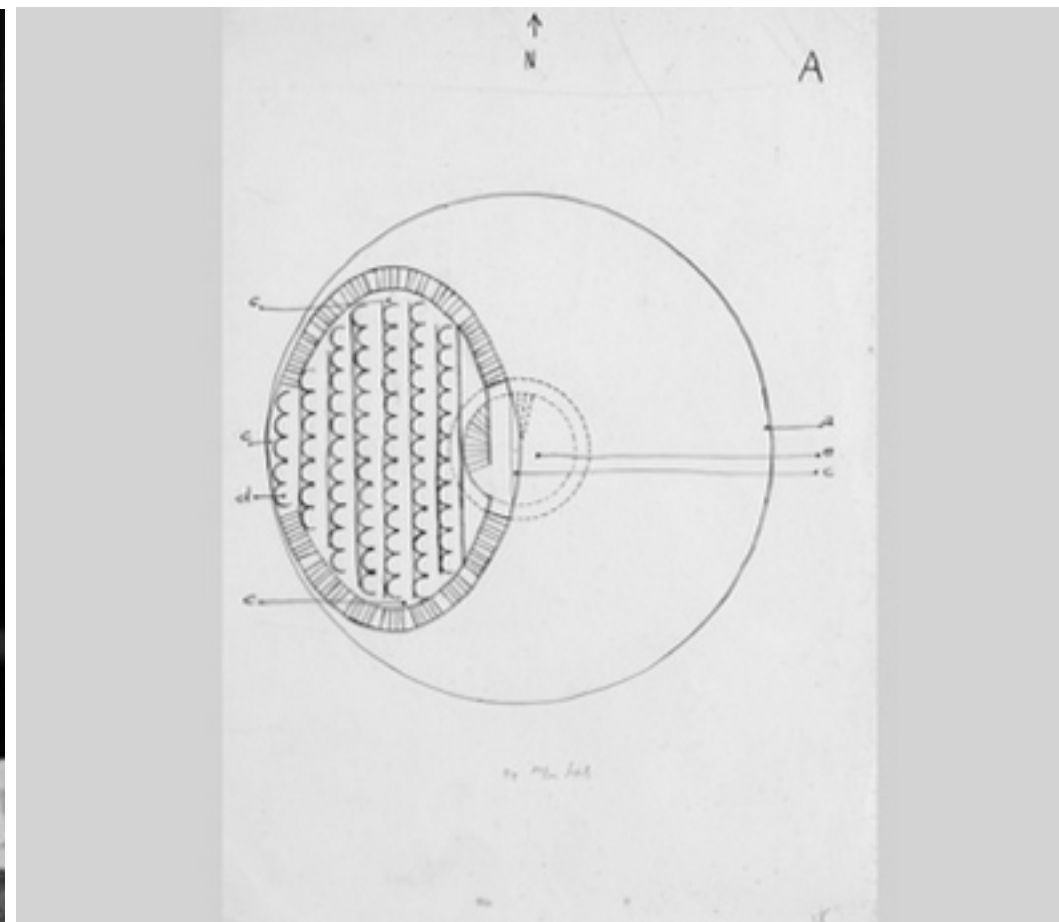
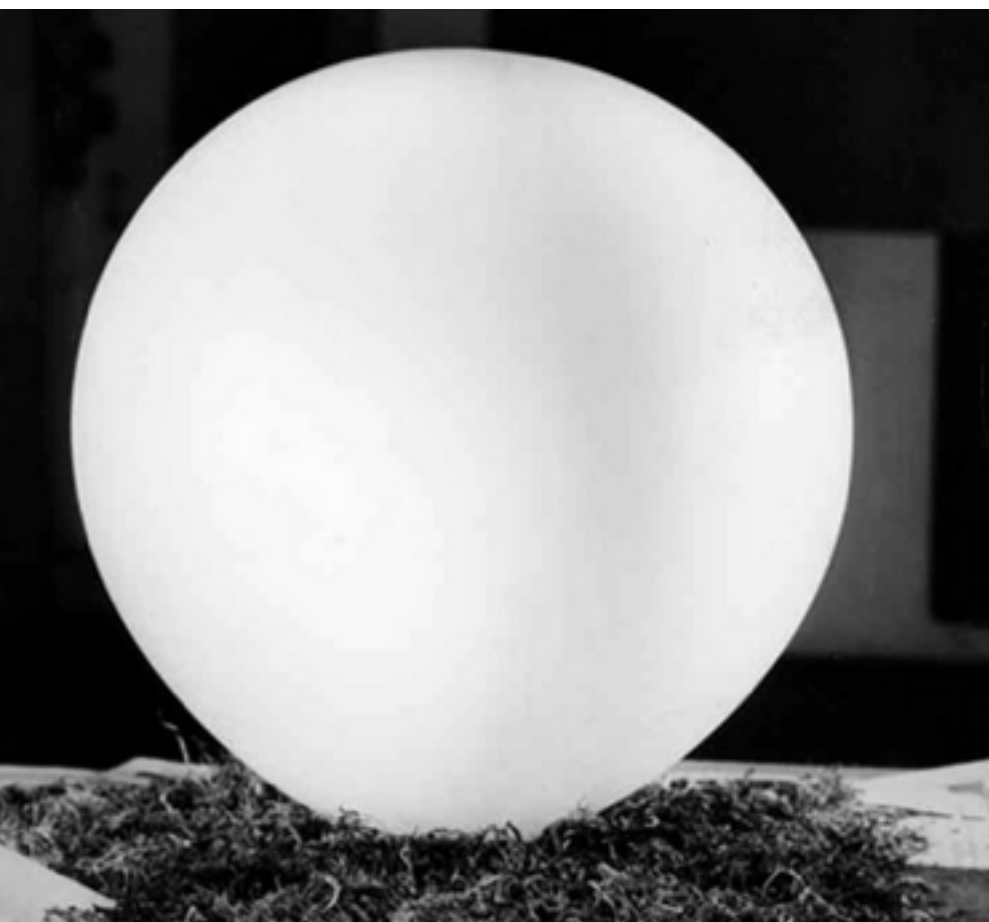
conditional transformation without machine computing

silent/soft change

Dynamic shape can be perceived as media with which to function, represent, communicate and interact.

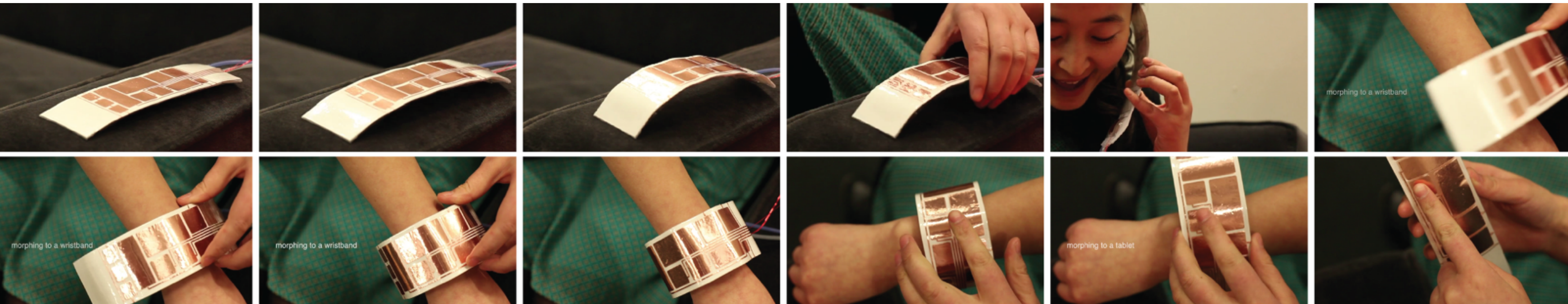


To represent and communicate through lifelike motion. [Design]



Piero Manzoni, Pneumatic for Light and Gas Ballets, 1960

To represent and communicate through lifelike motion. [HCI]



To communicate lifelike form and haptic sensation. [Design]



Tokyo Fiber '07, Senseware. Panasonic.

To function. [Design]



To function. [HCI]



To Interact with the environment. [Design]



WIPING CLEANER "FUKITORIMUSHI", Panasonic Corporation

Reflection: Unique Opportunity of Soft Shape Change in HCI and Design

Mechanical Property

Opportunity for HCI and Design

elastically deformable

lifelike form and motion

mechanical compliance matching with the human skin

friendly for onbody/wearable applications

potential for multi-functionality

integrate both input sensing and shape output

potential for utilizing material anisotropy

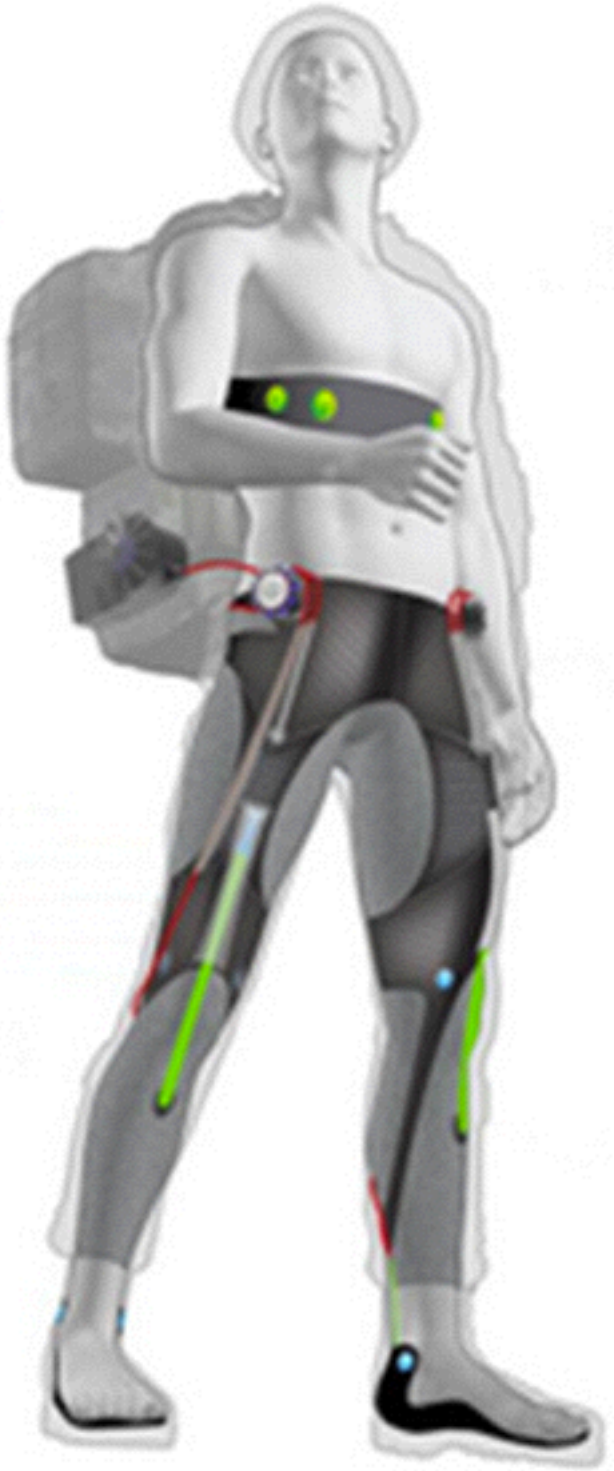
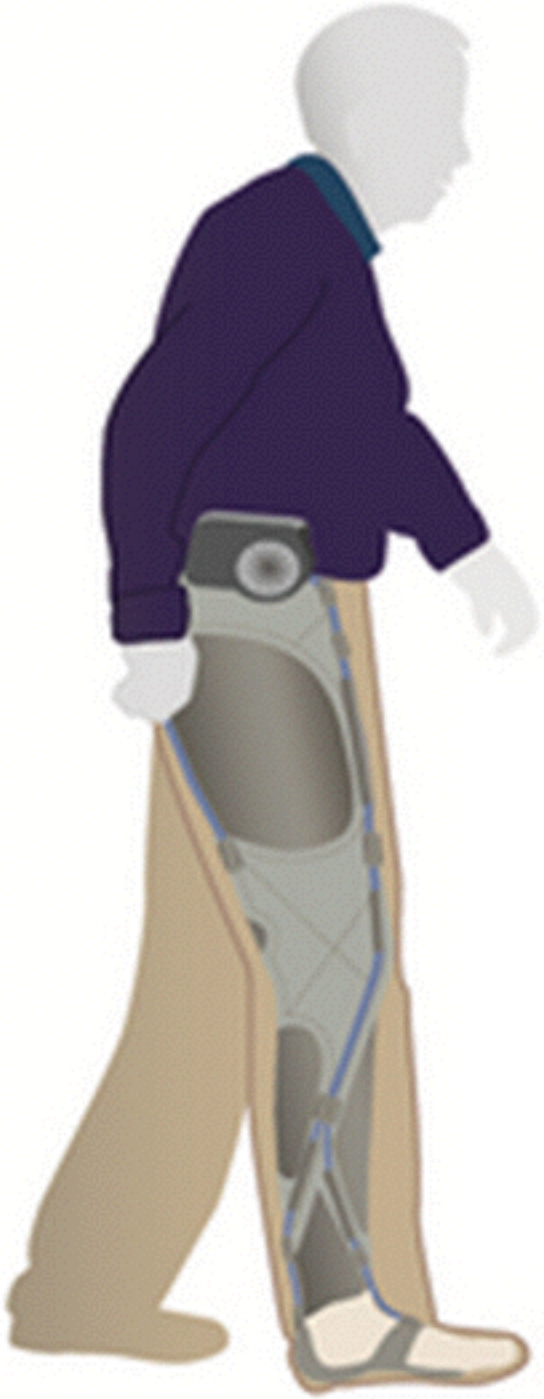
conditional transformation without machine computing

unique actuation mechanism
(pneumatic, smart materials)

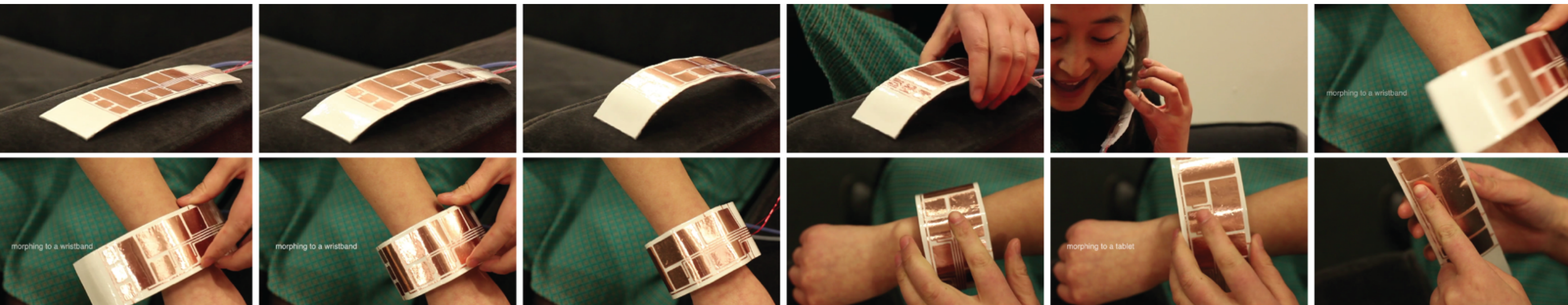
silent/soft change

Harvard Biodesign Lab

Augmenting and restoring human performance



Wearable sensors, structural functional textiles, translation applications



Reflection: Unique Opportunity of Soft Shape Change in HCI and Design

Mechanical Property

Opportunity for HCI and Design

elastically deformable

lifelike form and motion

mechanical compliance matching with the human skin

friendly for onbody/wearable applications

potential for multi-functionality

integrate both input sensing and shape output

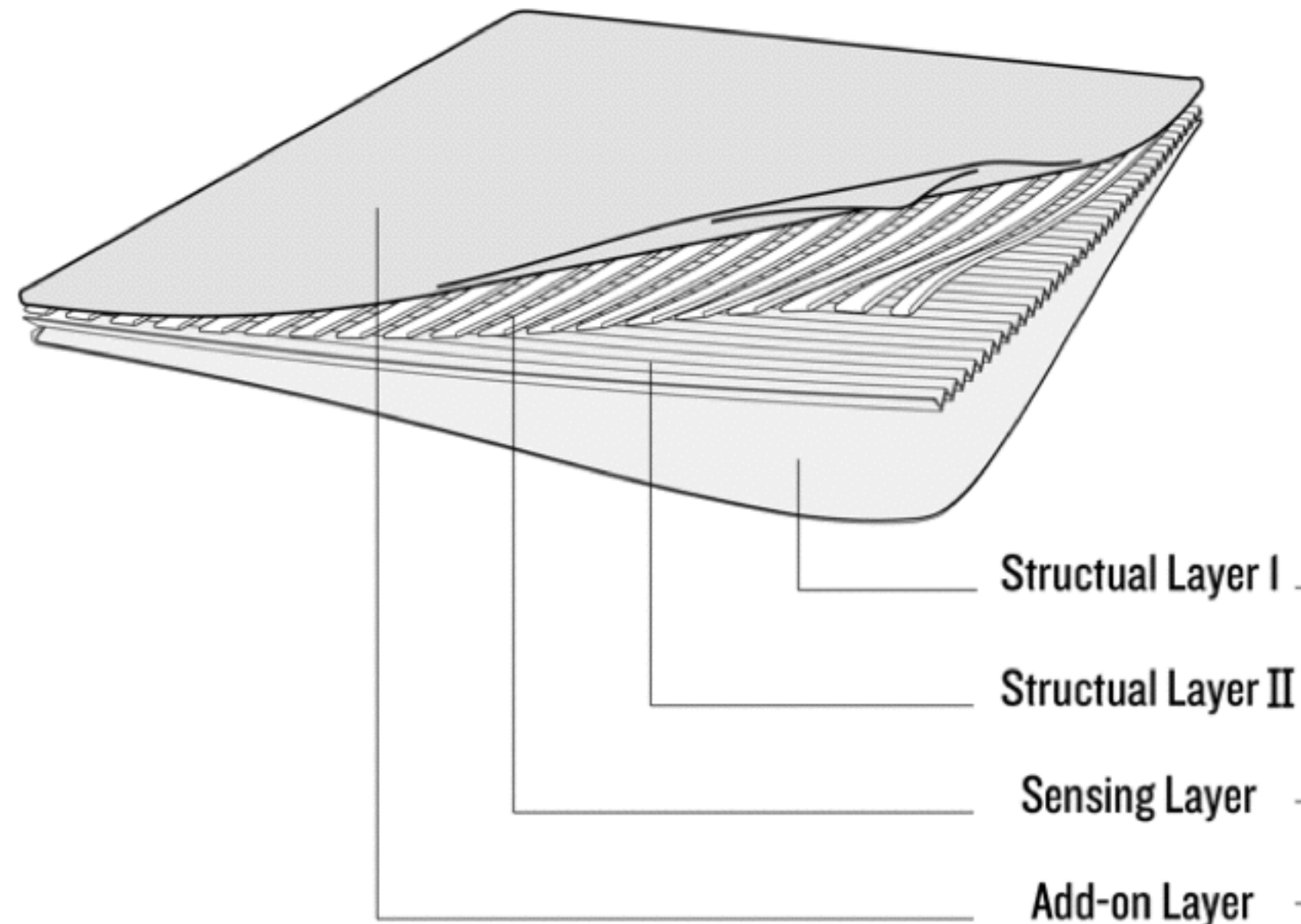
potential for utilizing material anisotropy

conditional transformation without machine computing

unique actuation mechanism
(pneumatic, smart materials)

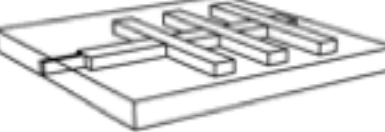
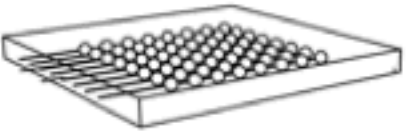

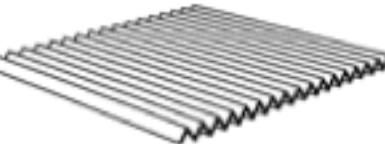
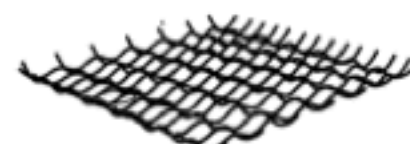




silent/soft change

Ideal Model of Soft Composite Interface



Materials

Structures

<p><u>Elastomer</u> (Rubber as the most typical one)</p>	 <u>Air Channels</u>	 <u>Air Bubbles</u>	 <u>Thin Film</u>
<p><u>Paper</u> <u>Fabric</u> <u>Wood</u> Yarn and String Plastic Metal Sheet and Wire</p>	 <u>Origami Structure</u>	 Woven Structure	 <u>Air Bags</u>
<p><u>Liquid Metal</u> <u>Conductive Thread</u> <u>Metal Wire/ Foil/ Tape</u> Conductive Fabrics Conductive Ink</p>	 <u>Layout on Substrates</u>	 <u>Channels</u>	 <u>Printed Pattern</u>
<p><u>Jamming Particles</u> Thermochromatic Pigment / Liquid Crystal Photochromics</p>			

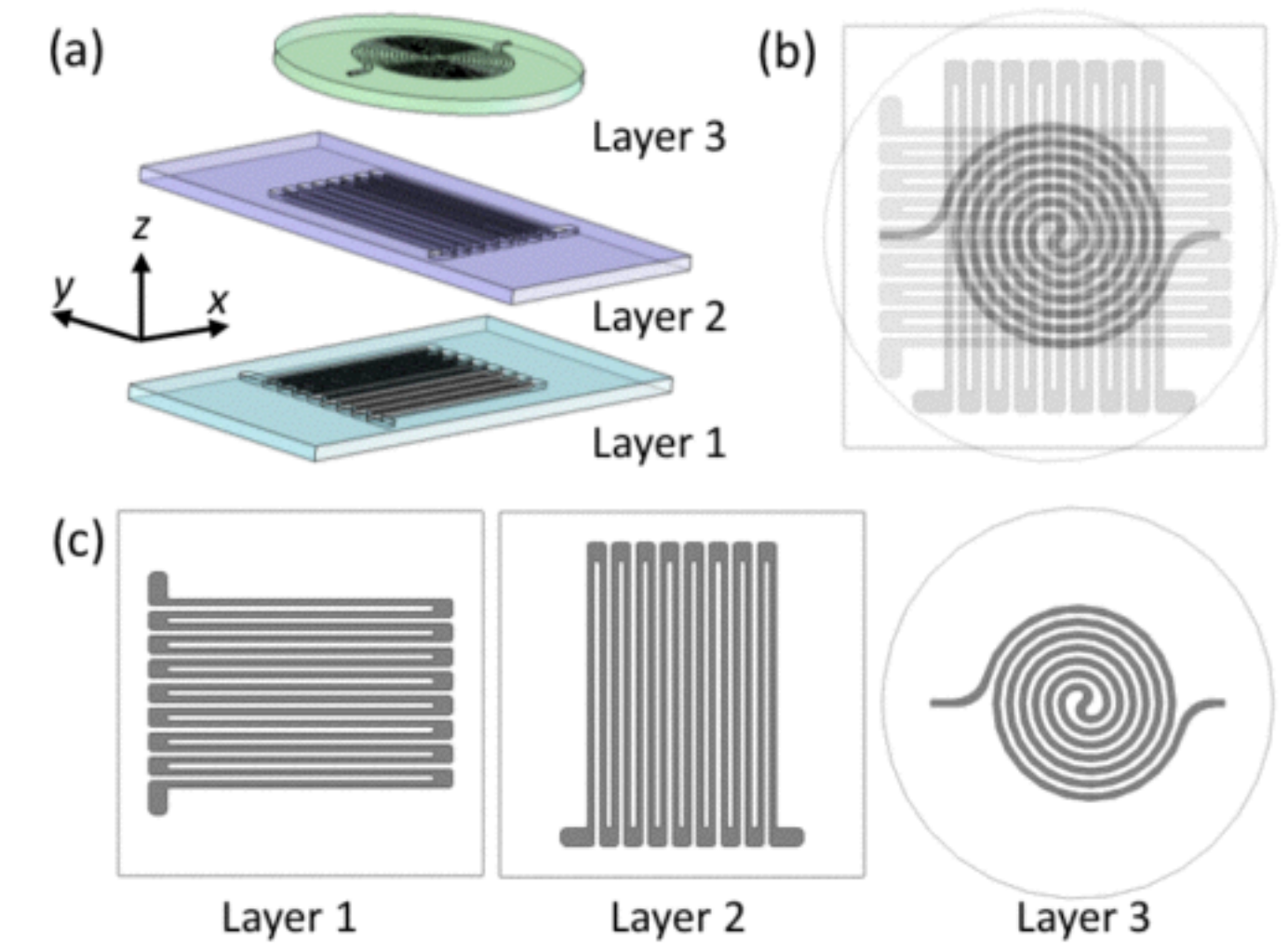
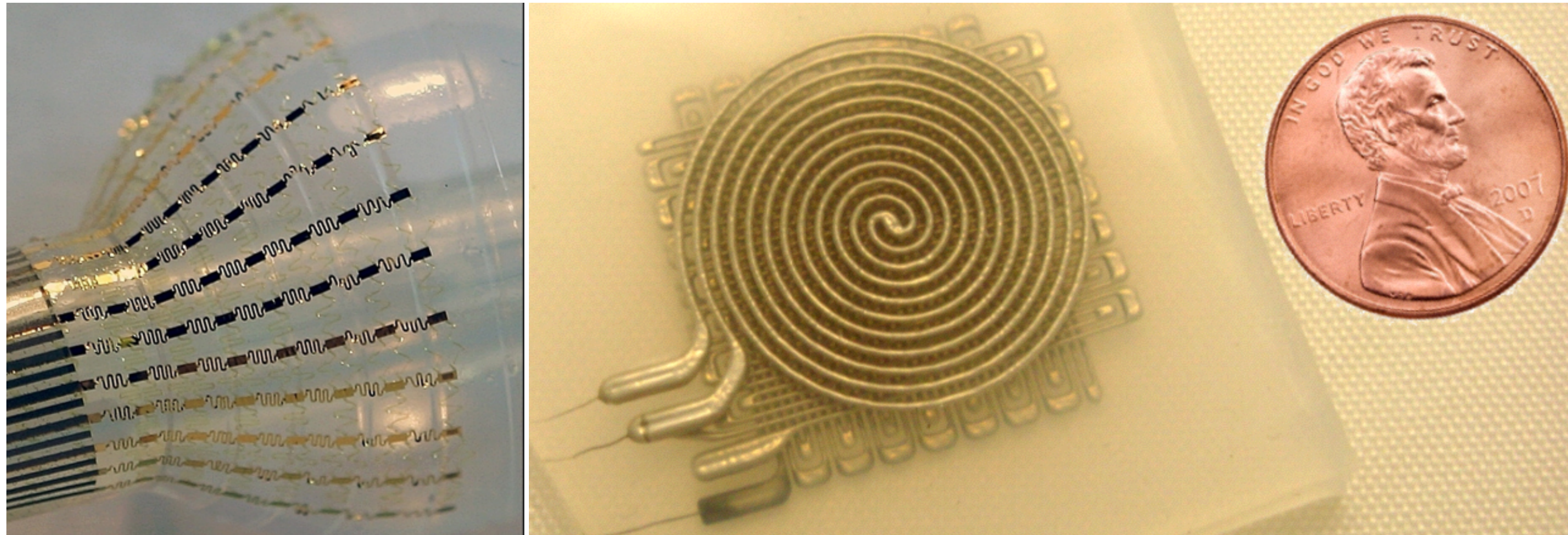
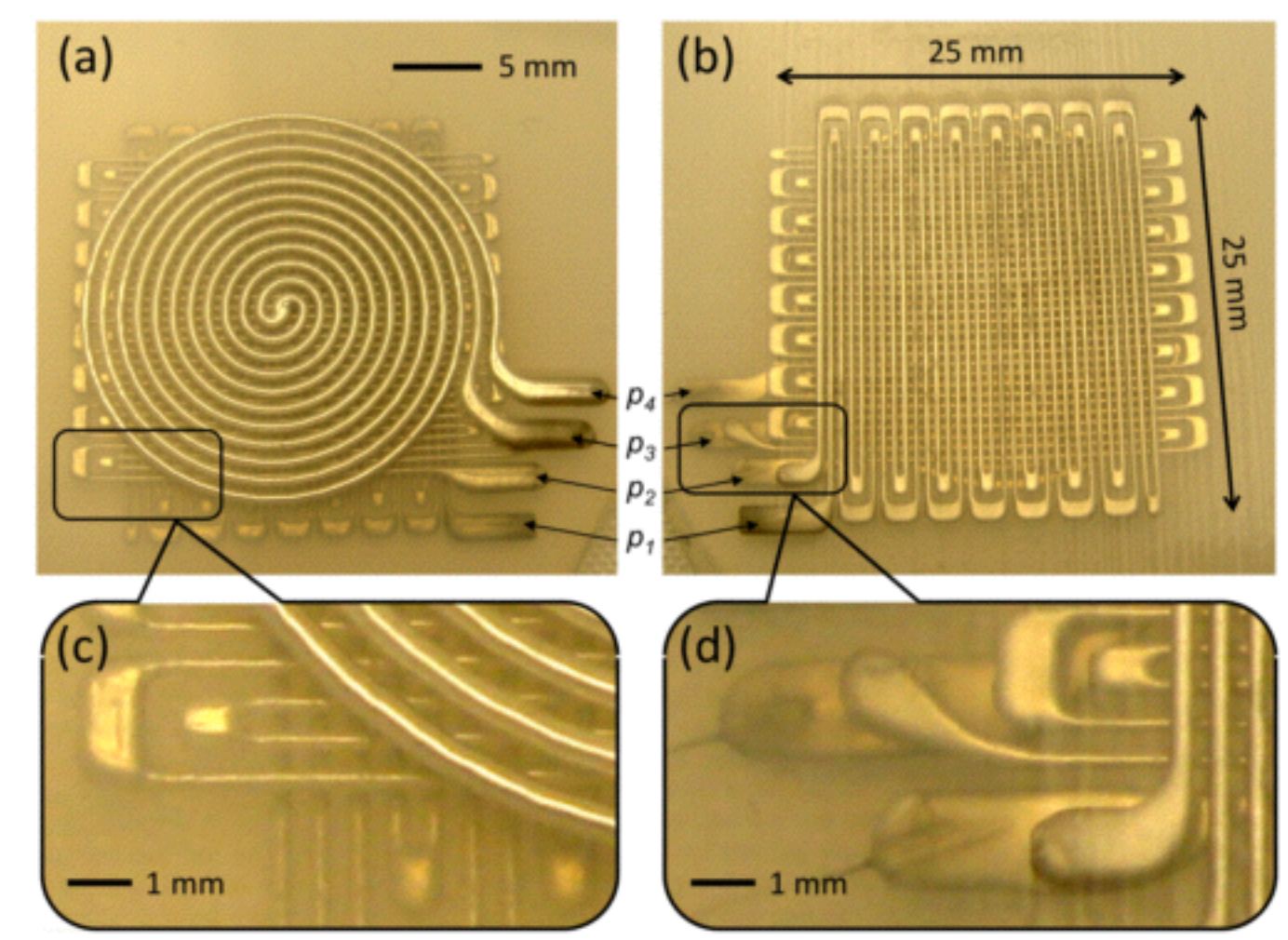
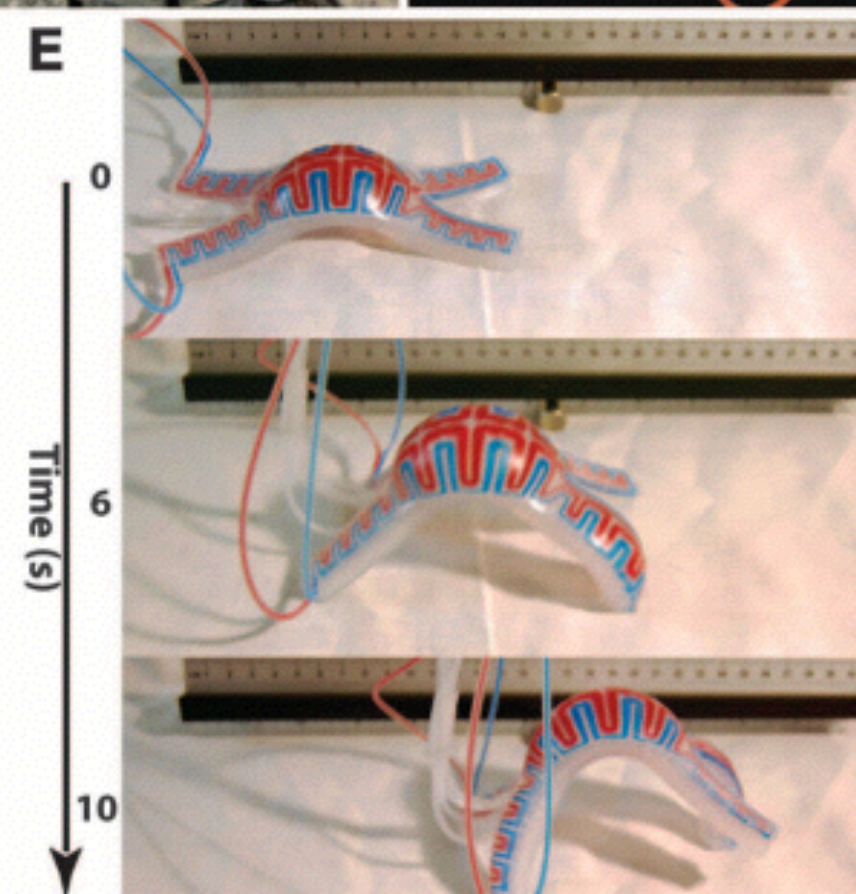
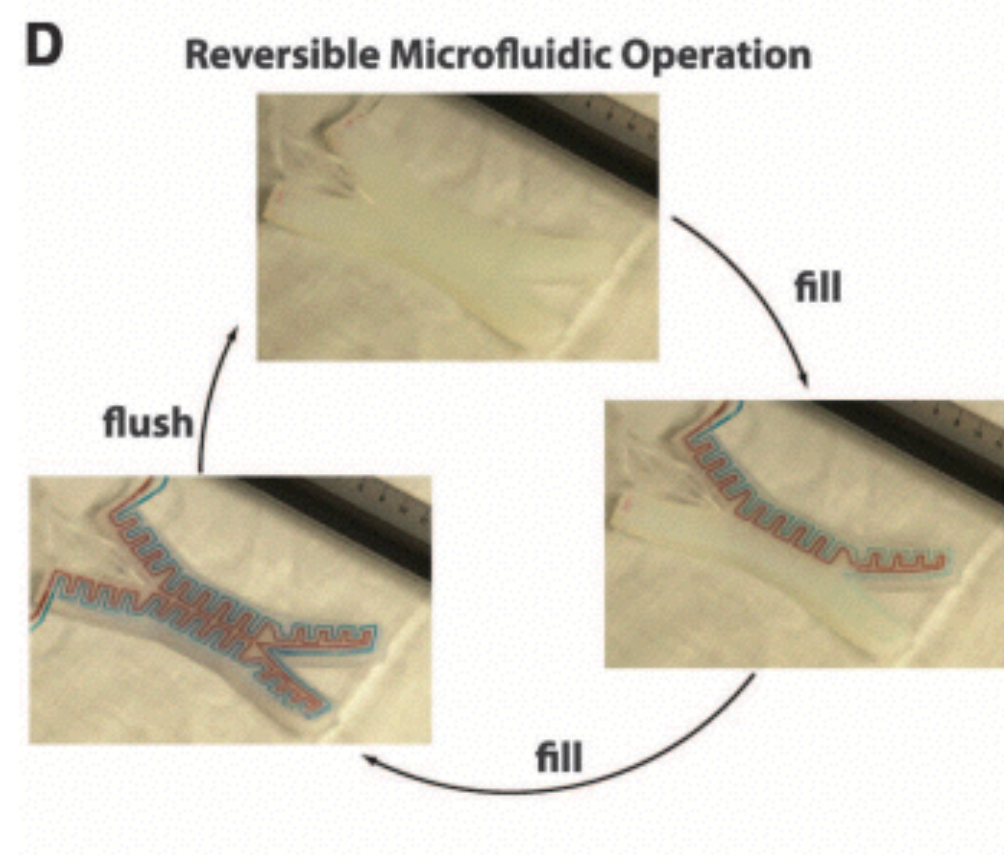
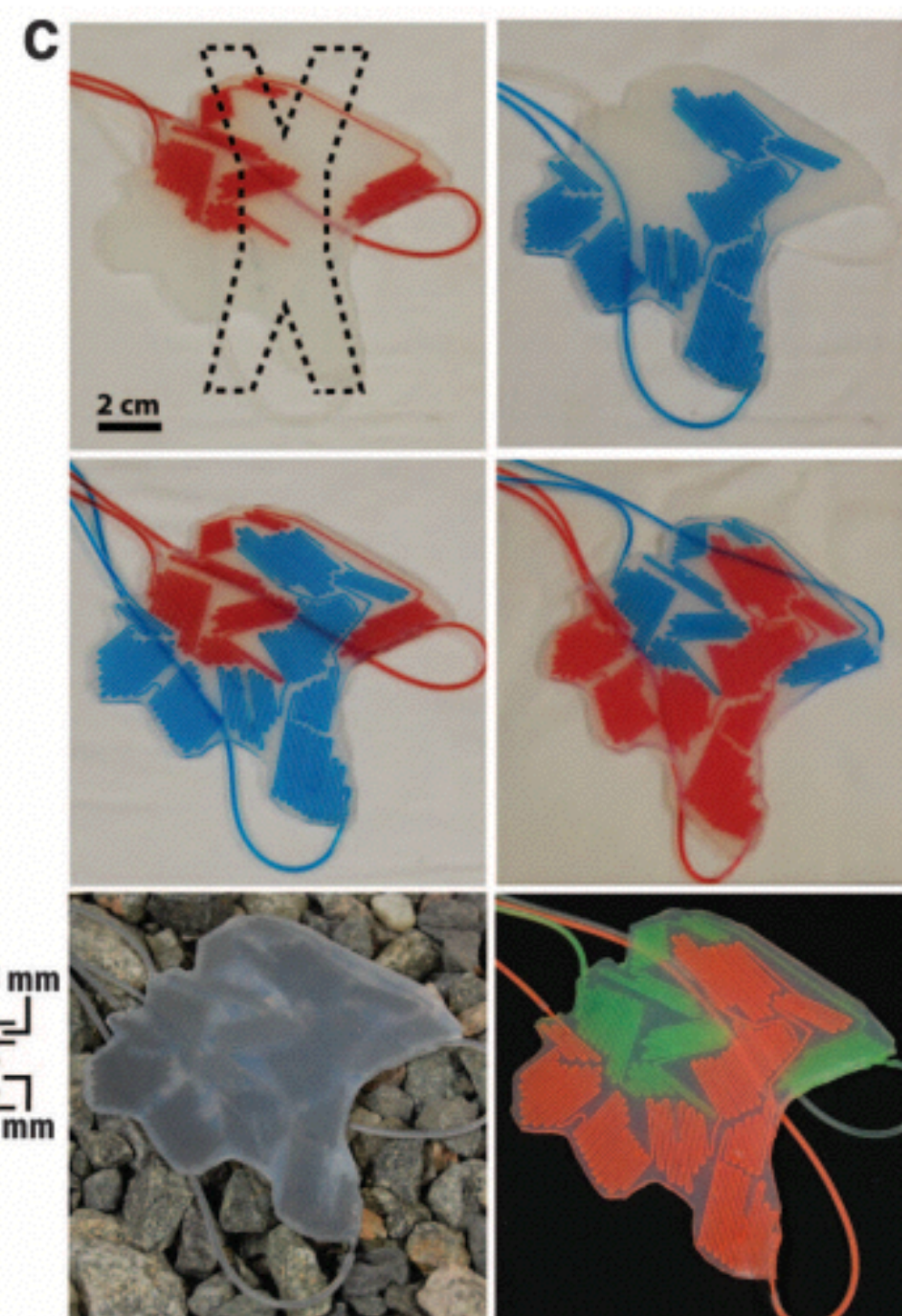
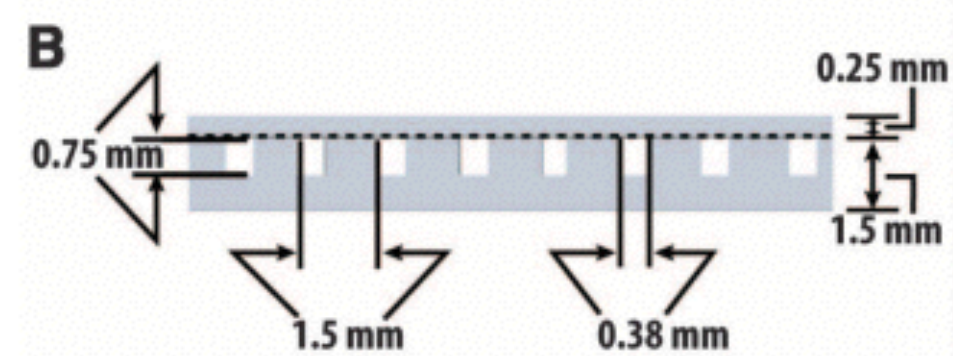
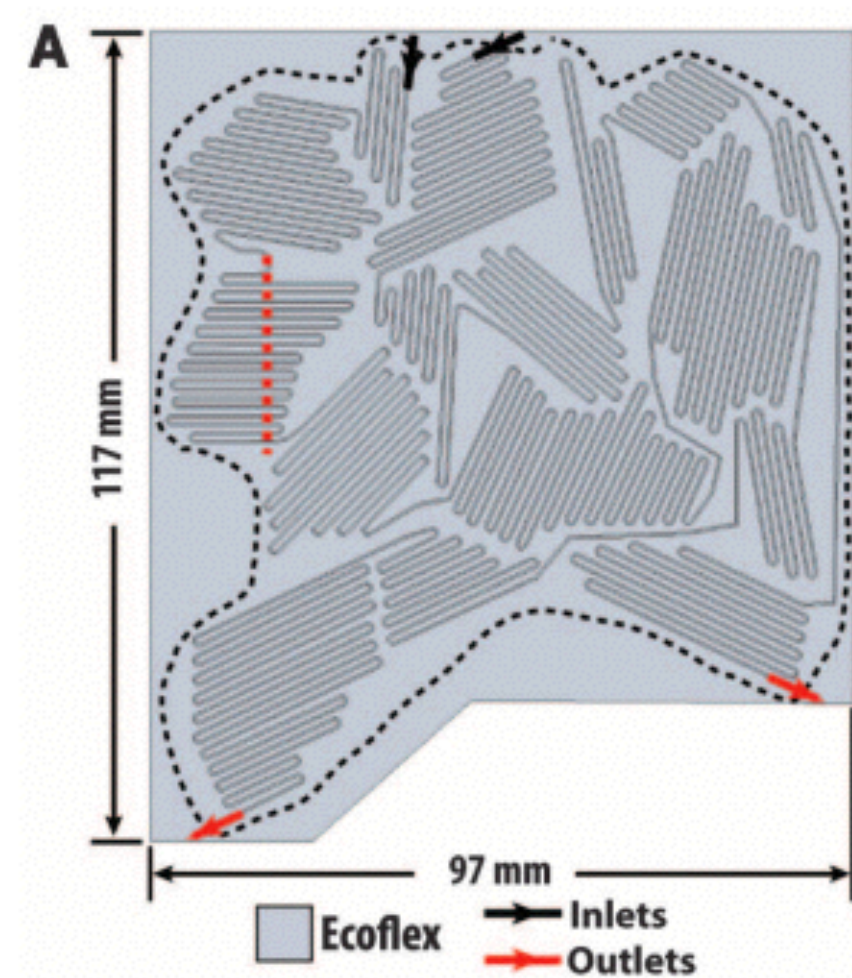
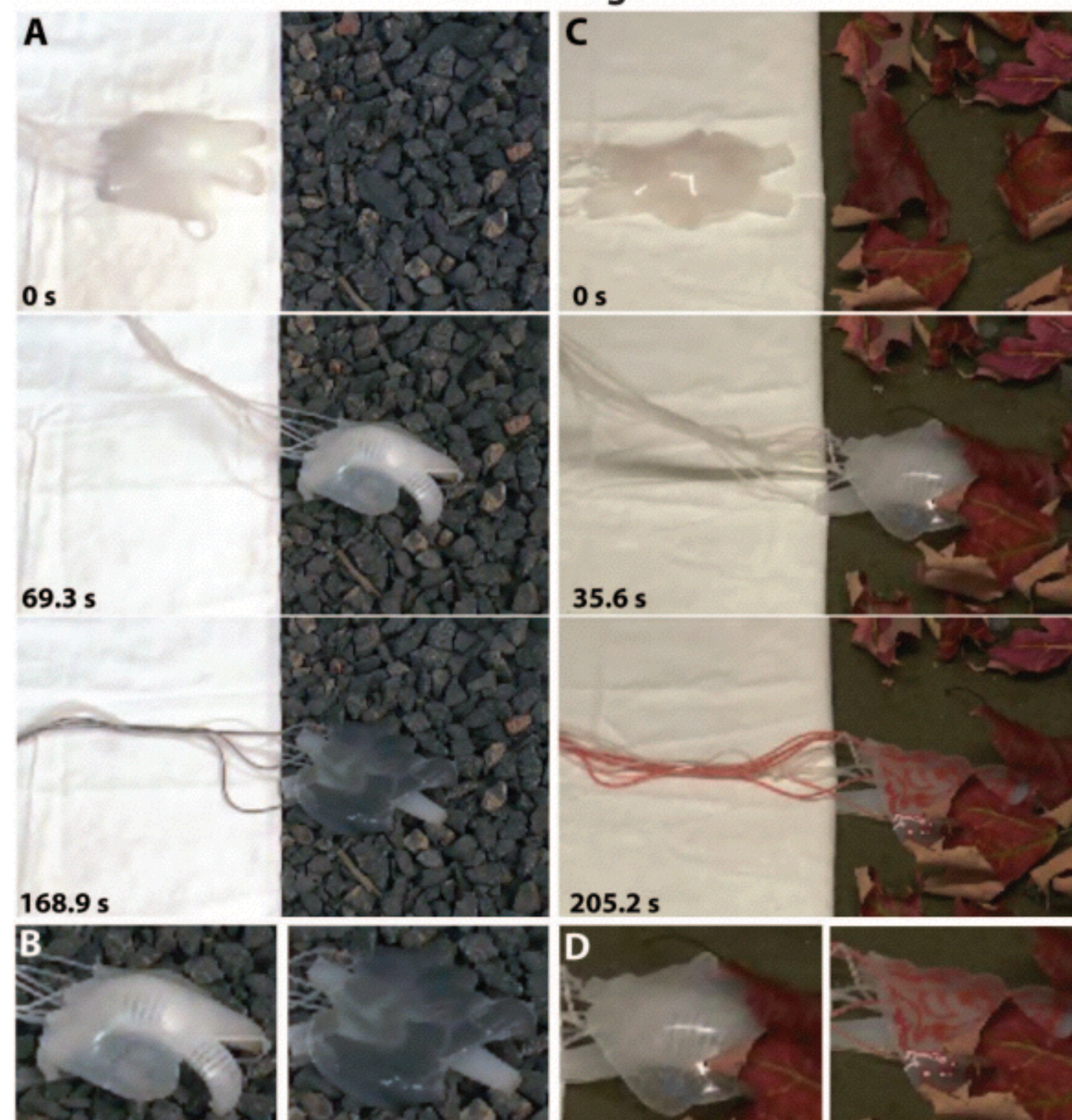


Fig. 2. Design of three sensor layers with embedded microchannels: (a) Exploded view. (b) Assembled view. (c) Each sensor layer design.

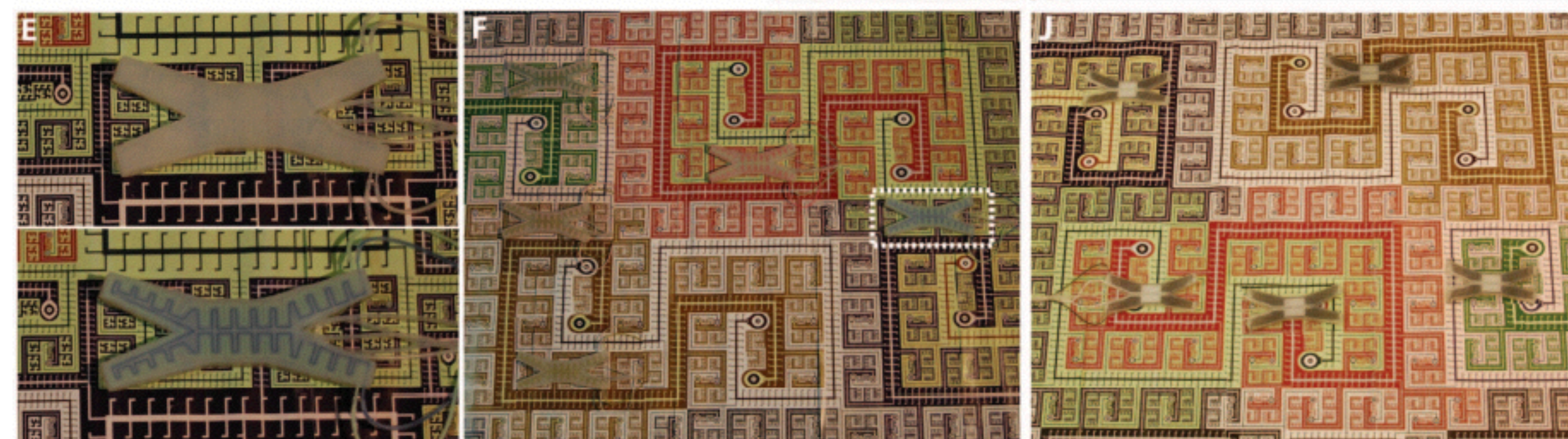
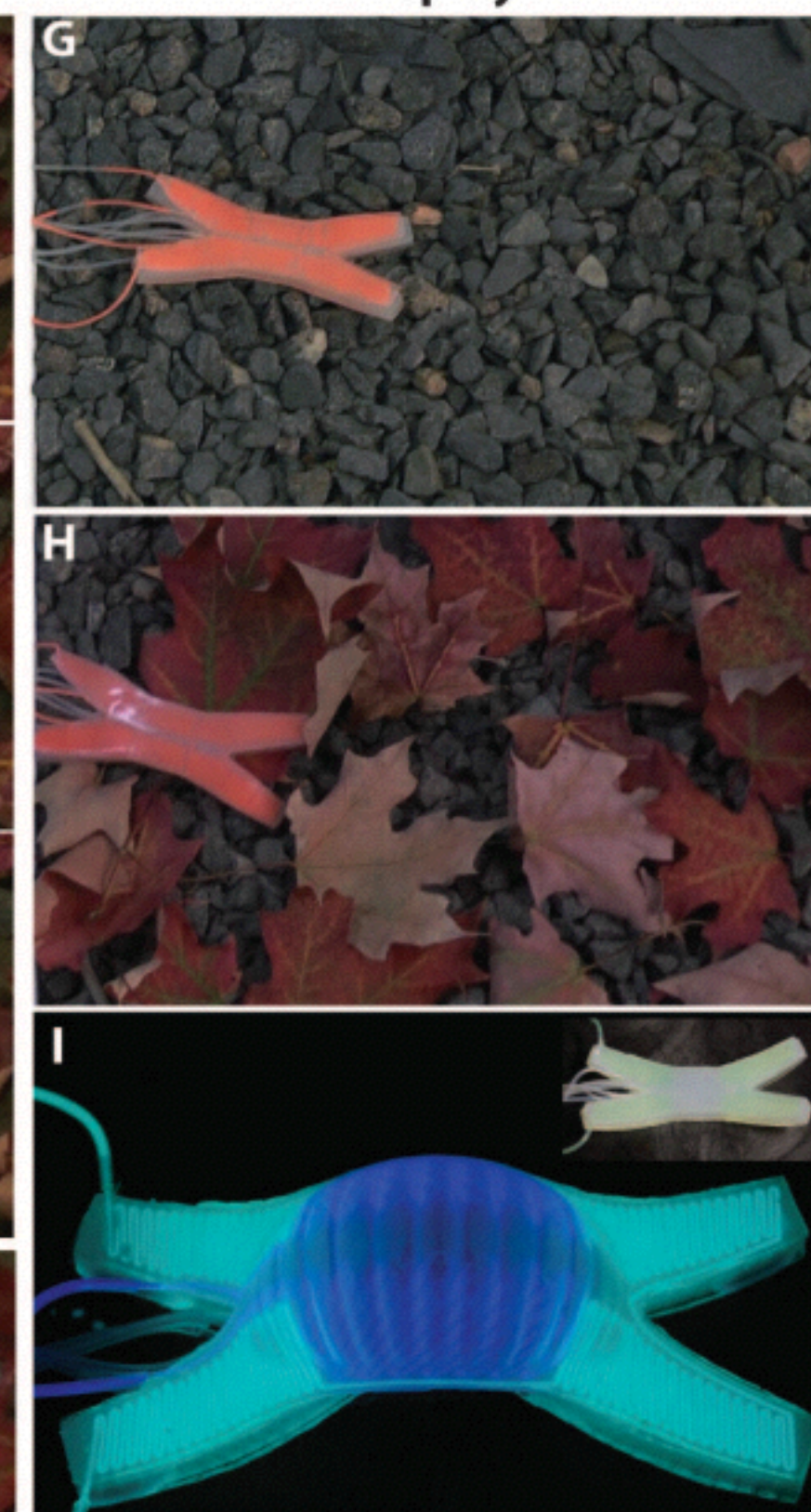




Camouflage



Display

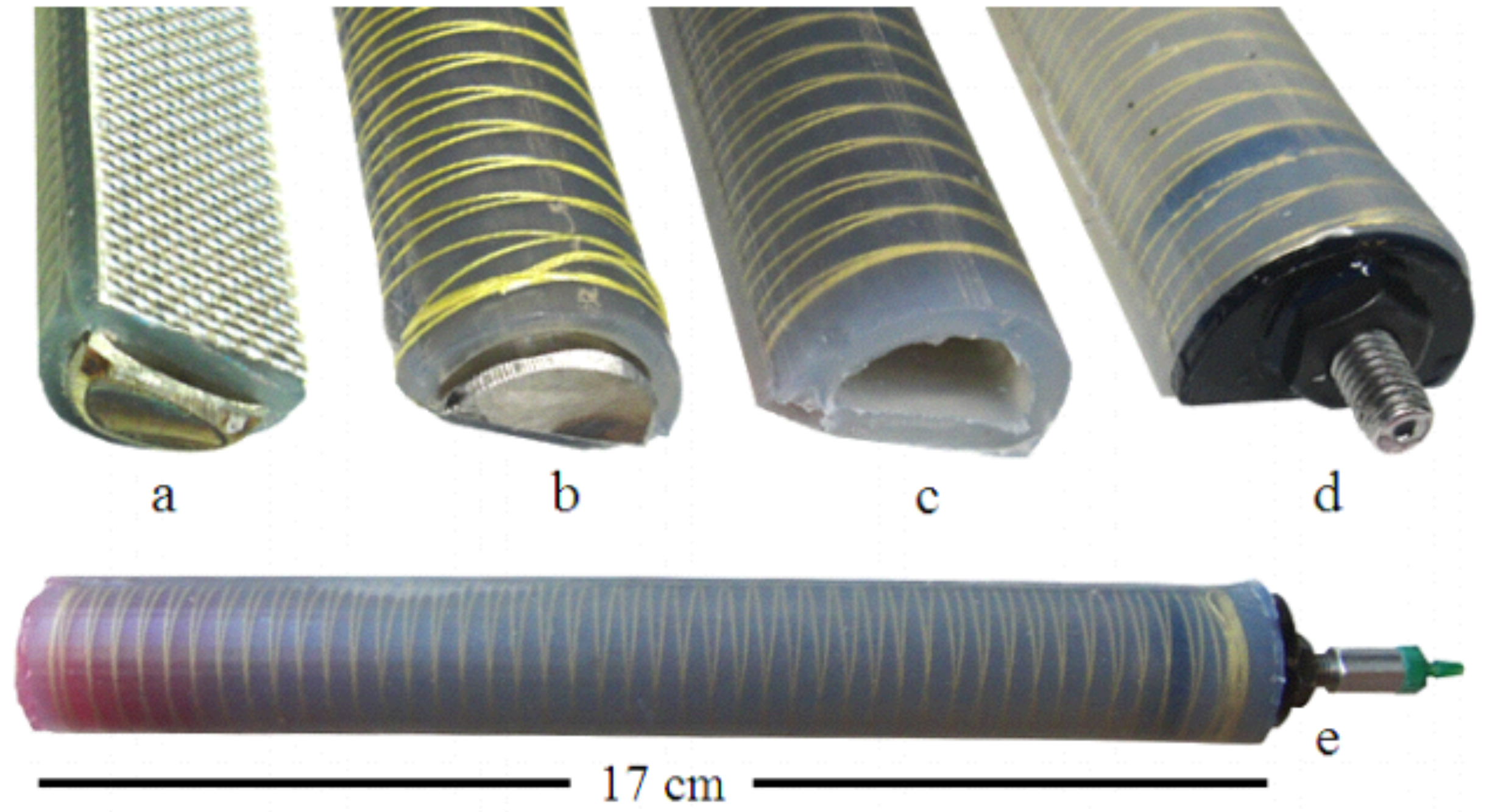
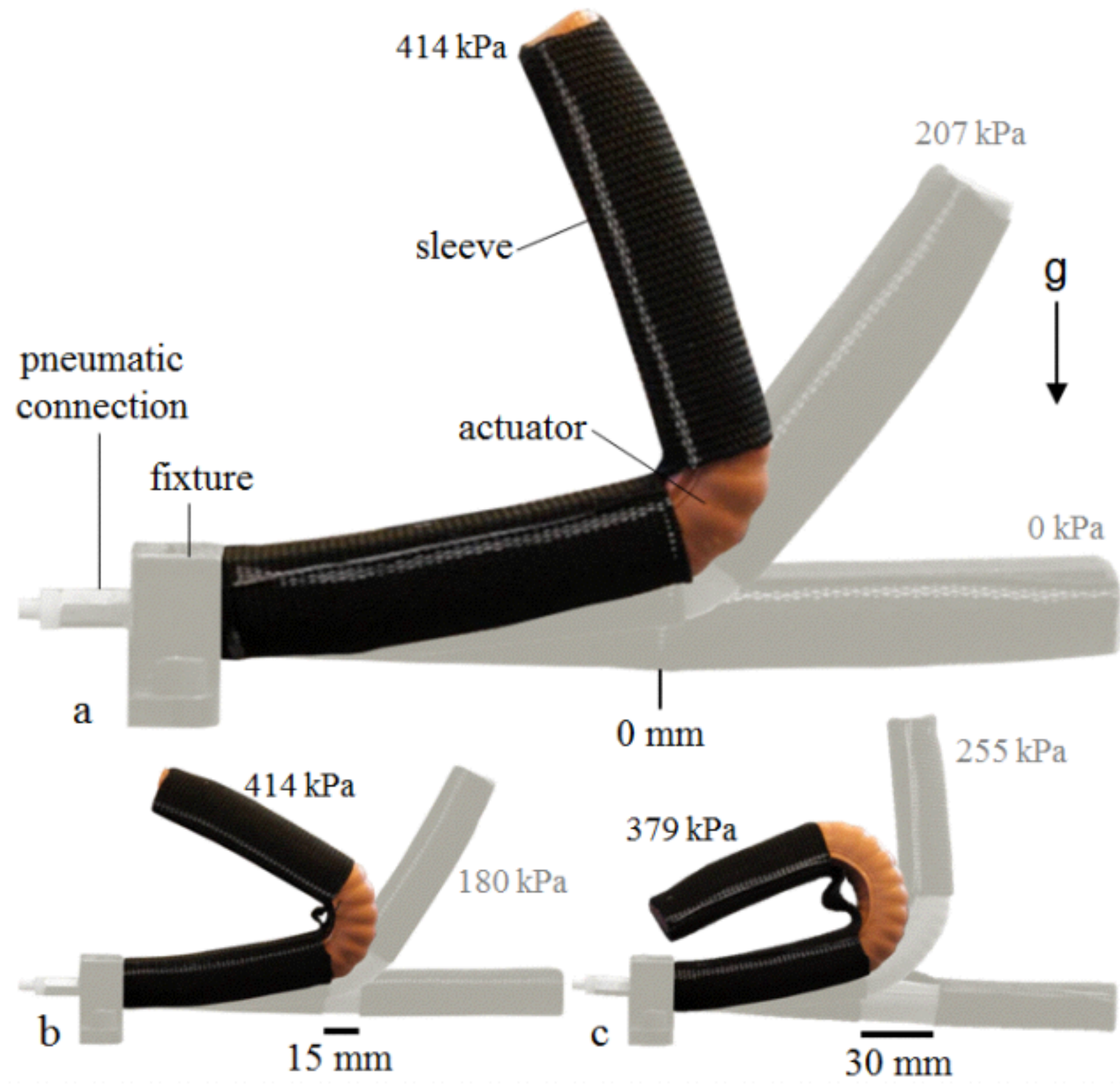


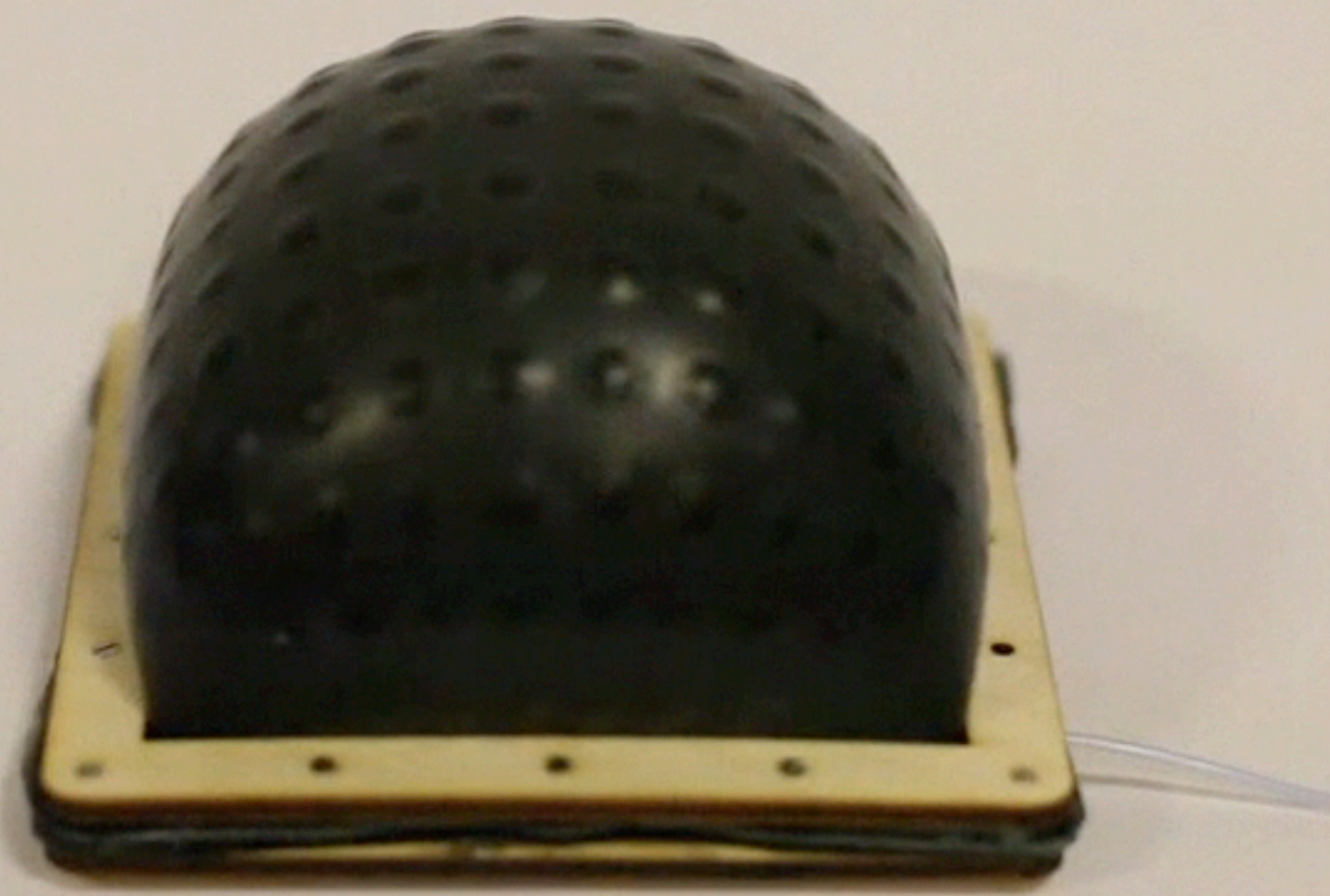
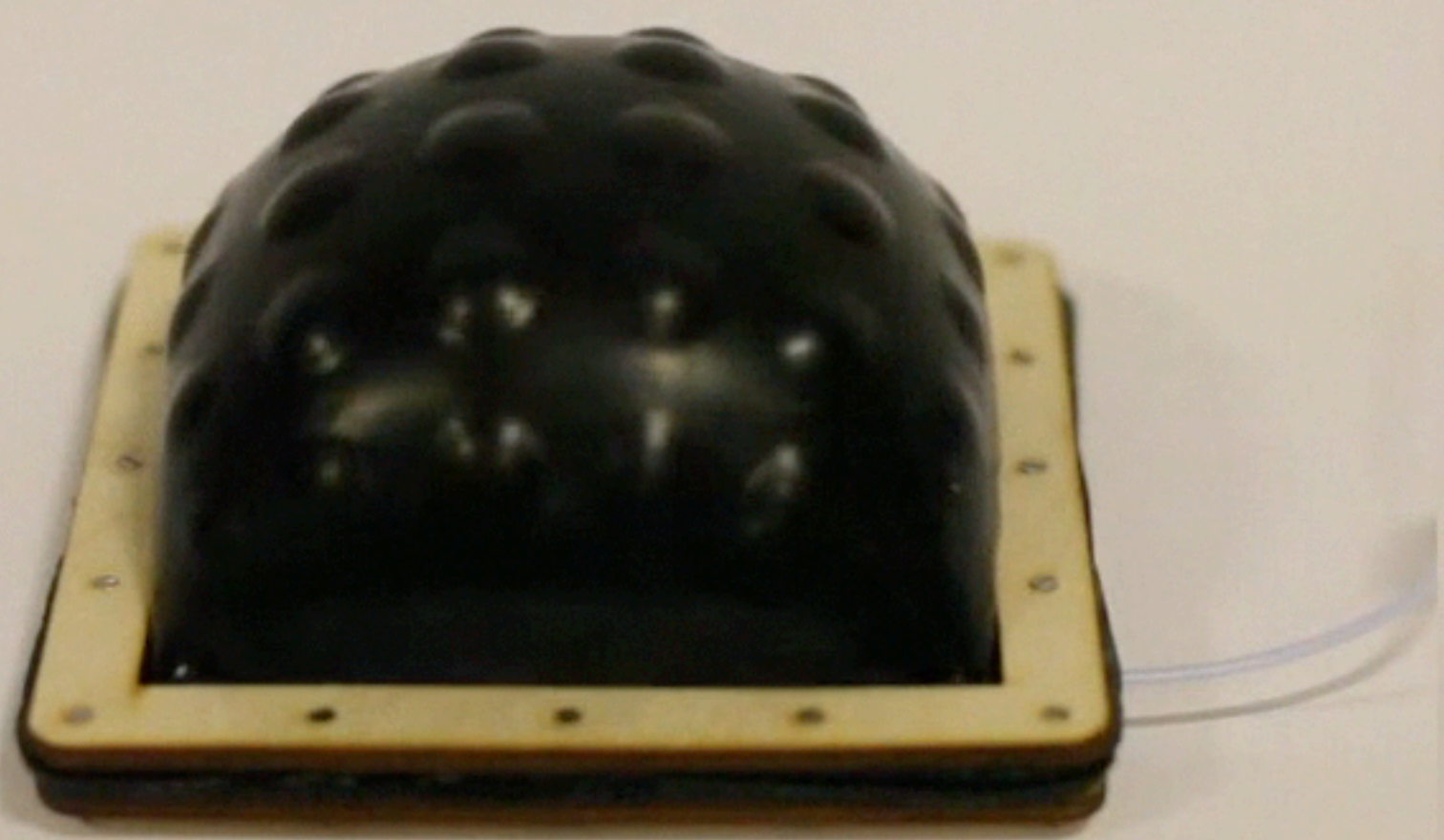
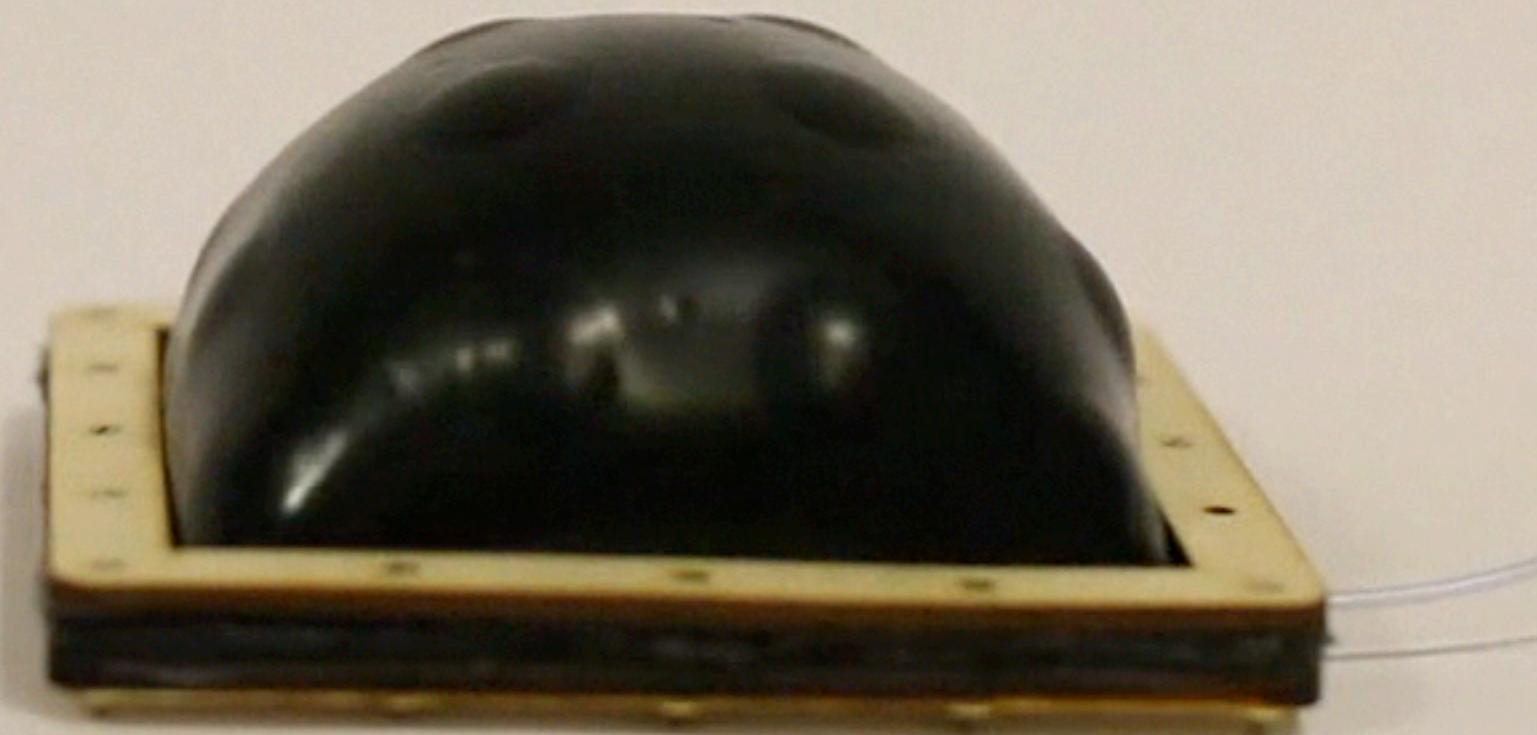
Reflection: Unique Opportunity of Soft Shape Change in HCI and Design

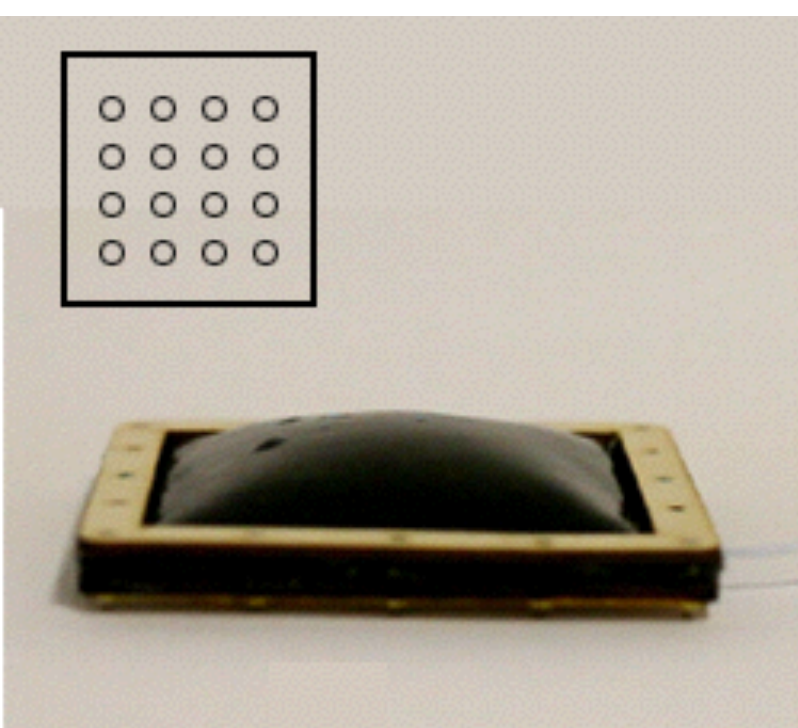
Mechanical Property	Opportunity for HCI and Design
elastically deformable	lifelike form and motion
mechanical compliance matching with the human skin	friendly for onbody/wearable applications
potential for multi-functionality	integrate both input sensing and shape output
potential for utilizing material anisotropy	complex transformation behaviors
unique actuation mechanism (pneumatic, smart materials)	silent/soft change

Mechanical Design through Computation

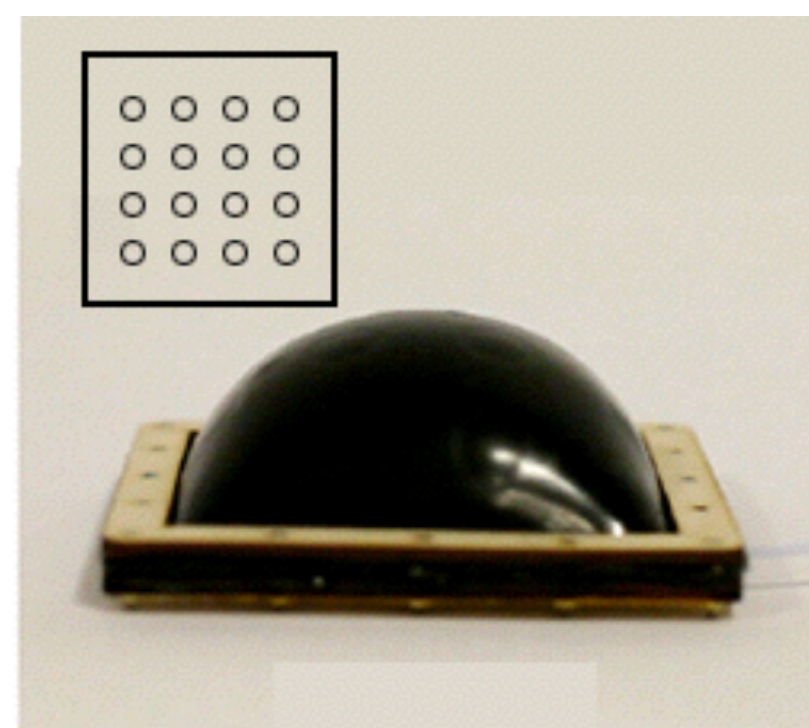
Shape matching, string reinforcement



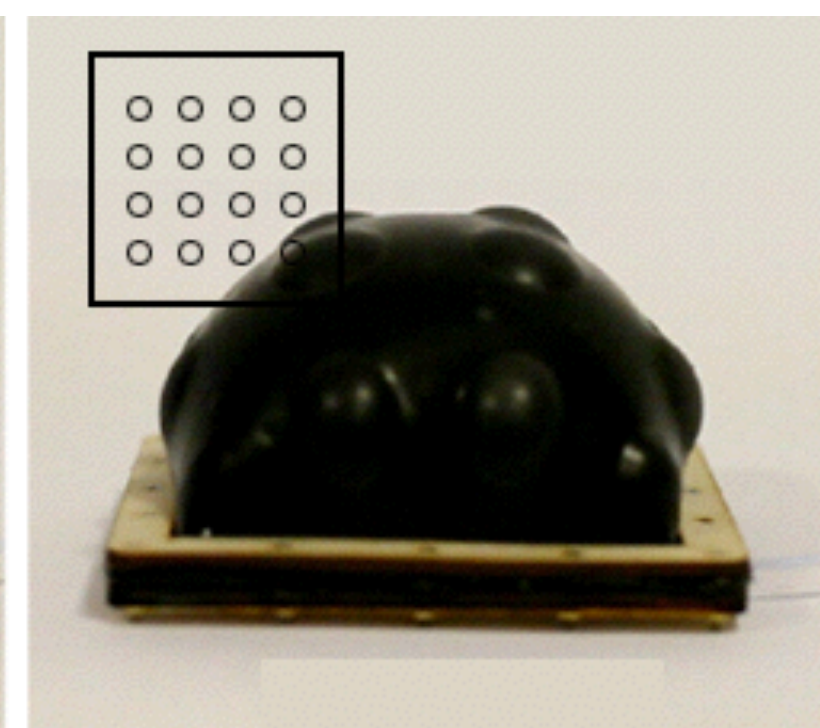




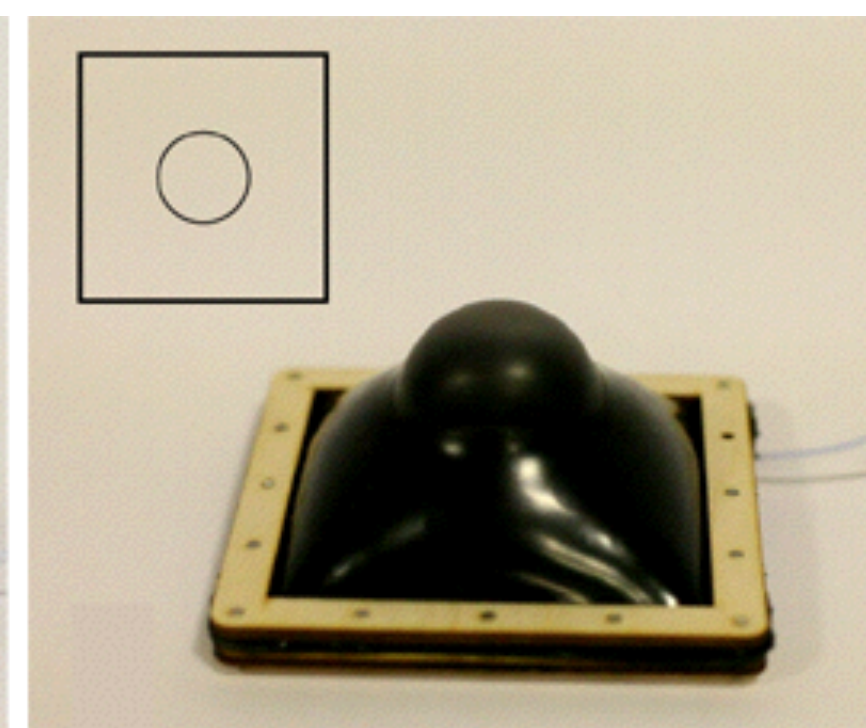
P_{atm}



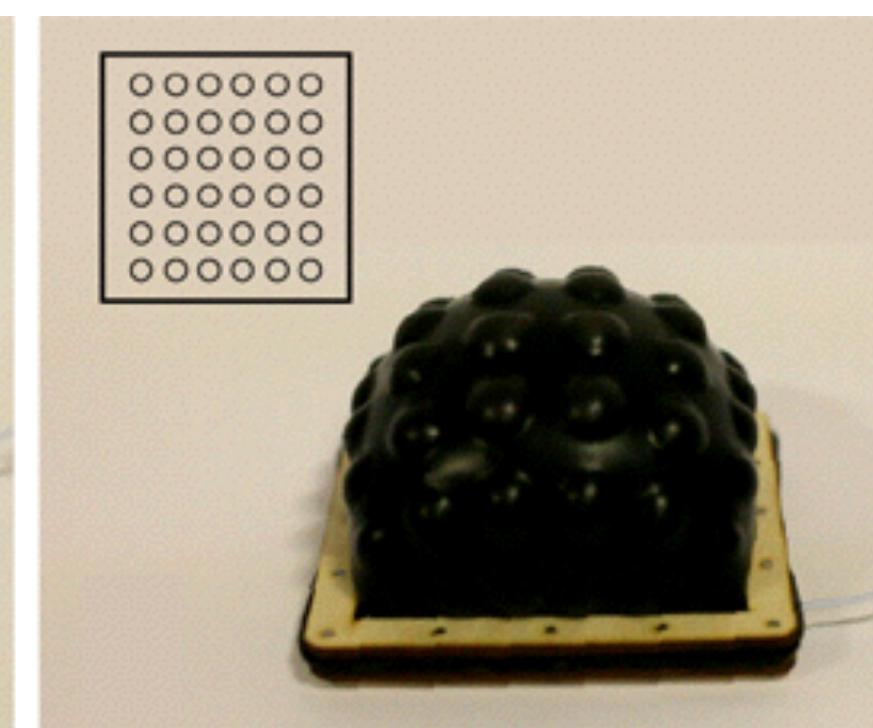
$P_1 = 80 \text{ mbar}$



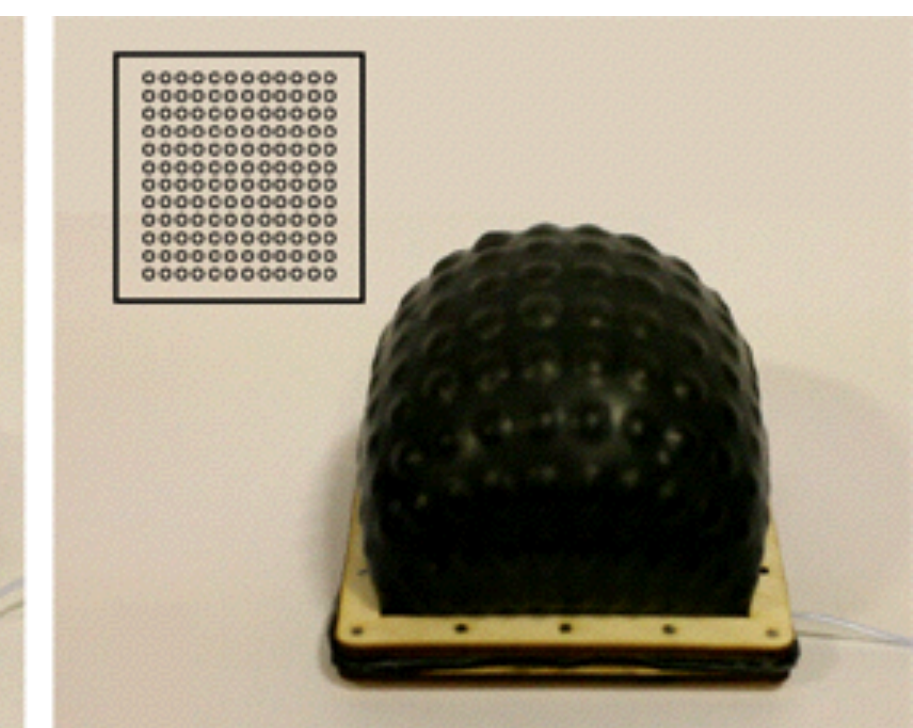
$P_2 = 120 \text{ mbar}$



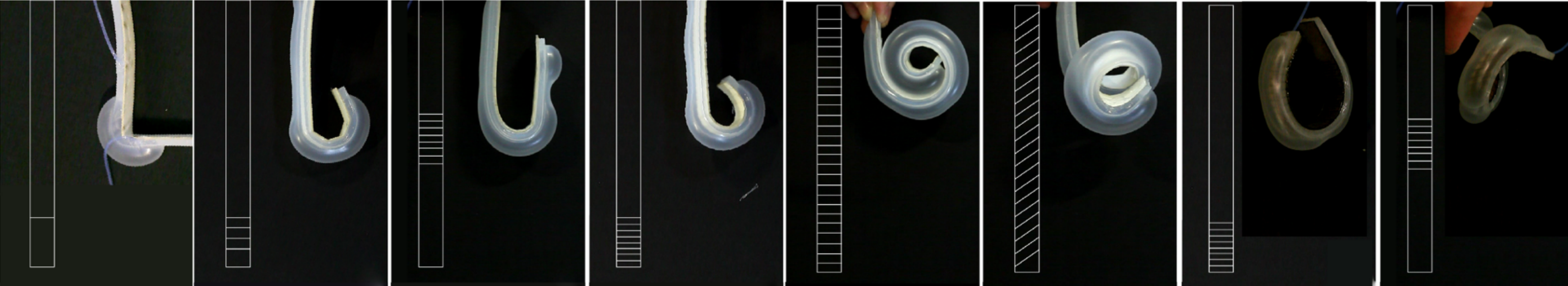
$P_2 = 120 \text{ mbar}$



$P_2 = 120 \text{ mbar}$



$P_2 = 120 \text{ mbar}$



Reflection: Unique Opportunity of Soft Shape Change in HCI and Design

Mechanical Property

Opportunity for HCI and Design

elastically deformable

lifelike form and motion

mechanical compliance matching with the human skin

friendly for onbody/wearable applications

potential for multi-functionality

integrate both input sensing and shape output

potential for utilizing material anisotropy

complex transformation behaviors

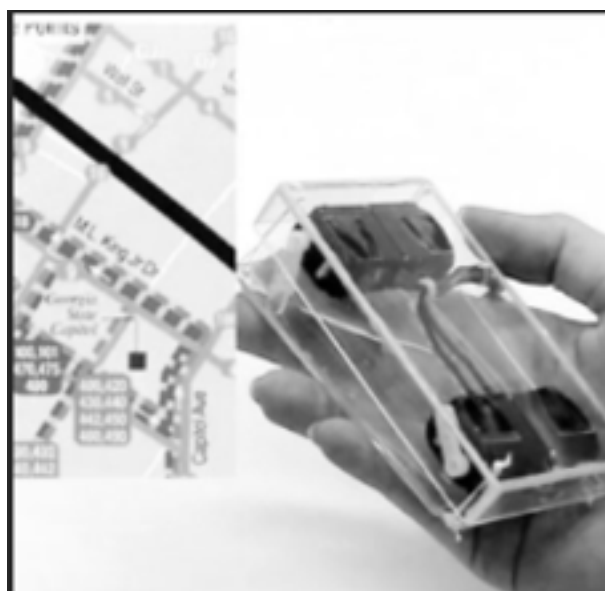
unique actuation mechanism
(pneumatic, smart materials)

silent change with large force

GEARED MOTOR /SOLENOID



Relief/Recompose. Daniel.L. et,al



Shape Changing Phone.

Rigid;
Constrained by its
own size/weight;
Controllability.

SHAPE MEMORY ALLOY



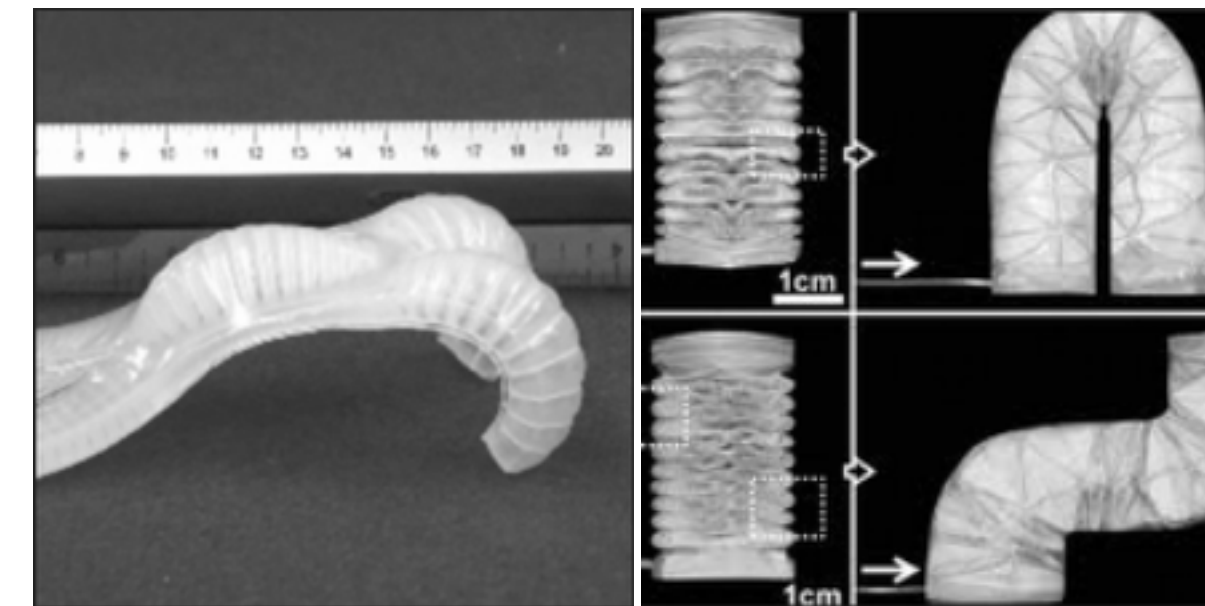
Surflex. Marcelo, C. et,al



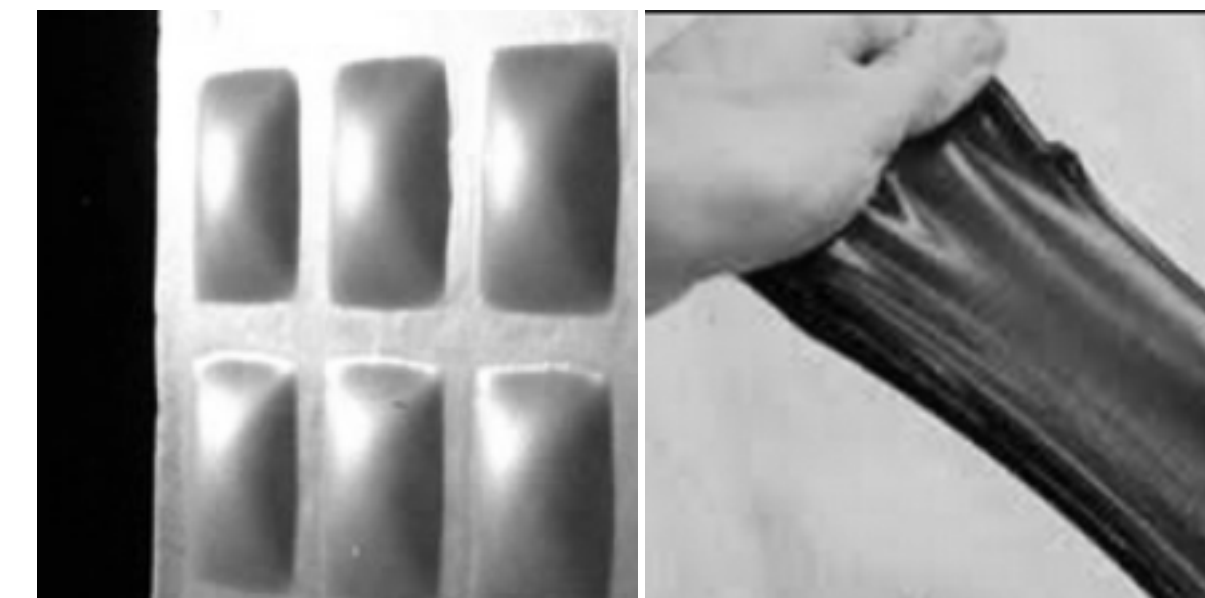
Morephone. Antonio.G.et,al

Flexible
Light weight
controllability
small force output

PNEUMATIC/HYDRAULIC



Soft Robots. Whitesides Group. Harvard



Dynamic Buttons. Harrison C. et.al
Jamming UI. Sean, F. et.al

light weight
controllability
compliance (soft, flexible)
water proof
large force output (compare to SMA)
volumetric deformation

Other alternative approaches to actuate soft matter

Review



Soft robotics: a bioinspired evolution in robotics

Sangbae Kim¹, Cecilia Laschi², and Barry Trimmer³

¹Massachusetts Institute of Technology, Cambridge, MA, USA
²The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa, Italy
³Tufts University, Medford, MA, USA

Animals exploit soft structures to move effectively in complex natural environments. These capabilities have inspired robotic engineers to incorporate soft technologies into their designs. The goal is to endow robots with new, bioinspired capabilities that permit adaptive, flexible interactions with unpredictable environments. Here, we review emerging soft-bodied robotic systems, and in particular recent developments inspired by soft-bodied animals. Incorporating soft technologies can potentially reduce the mechanical and algorithmic complexity involved in robot design. Incorporating soft technologies will also expedite the evolution of robots that can safely interact with humans and natural environments. Finally, soft robotics technology can be combined with tissue engineering to create hybrid systems for medical applications.

Soft biological materials inspire a new wave of robotics

Human-made manufacturing robots are mostly designed to be stiff so that they can perform fast, precise, strong, and repetitive position control tasks in assembly lines. Common actuators in such robotic systems are composed of rigid electromagnetic components (e.g., magnets, copper, and steel bearings) or internal combustion engines made of steel and aluminum alloys. By contrast, in the animal world soft materials prevail. The vast majority of animals are soft bodied, and even animals with stiff exoskeletons such as insects have long-lived life stages wherein they are almost entirely soft (maggots, grubs, and caterpillars). Even animals with stiff endoskeletons are mainly composed of soft tissues and liquids. For example, the human skeleton typically contributes only 11% of the body mass of an adult male, whereas skeletal muscle contributes an average 42% of body mass. In addition, parts of animal bodies that play supportive roles in locomotion (e.g., digestion, gas and heat exchange, and motor control) are highly deformable as well.

Studying how animals use soft materials to move in complex, unpredictable environments can provide invaluable insights for emerging robotic applications in medicine, search and rescue, disaster response, and human assistance. All these situations require robots to handle

unexpected interactions with unstructured environments or humans. Soft robotics aims to equip robots for the unpredictable needs of such situations by endowing them with capabilities that are based not in control systems but in the material properties and morphology of their bodies (Figure 1) [1]. Soft robotics is a growing, new field that focuses on these mechanical qualities and on the integration of materials, structures, and software. In the same way that animal movements are based on the tight integration of neural and mechanical controls, soft robotics aims to achieve better and simpler mechanisms by exploiting the 'mechanical intelligence' of soft materials.

In this article we introduce robotic systems that are fundamentally soft and highly deformable [2]. These robots are differentiated from other approaches in which the machines are built using hard materials and compliance is achieved using variable-stiffness actuators and compliant control [3]. We discuss the key biomechanical features of three soft animals that are used as inspiration for different soft robotic systems and suggest future directions where soft robotics can be integrated with tissue engineering for medical applications.

Lessons from biology

Soft materials are essential to the mechanical design of animals, and their body structures have coevolved with the central nervous system to form a completely integrated neuromechanical control system. These soft components provide numerous advantages, helping animals negotiate and adapt to changing, complex environments. They conform to surfaces, distribute stress over a larger volume, and increase contact time, thereby lowering the maximum impact force. Soft materials also lend themselves to highly flexible and deformable structures, providing additional functional advantages to animals, such as enabling entrance into small apertures for shelter or hunting. Simple examples include the soft paws of mammalian runners that damp the force of impact when their legs strike the ground, and the soft finger pads and skin of arboreal animals that assist climbing by conforming to surfaces for better grip or adhesion.

Ultimately it is probably the ecological niche that determines the evolutionary tendency to be stiff or soft. Animals that do not need to travel quickly or exert high-impact forces do not need a permanently stiff skeleton and can instead develop highly deformable bodies that allow them to exploit behaviors and environments unavailable to

Review

Trends in Biotechnology May 2013, Vol. 31, No. 5

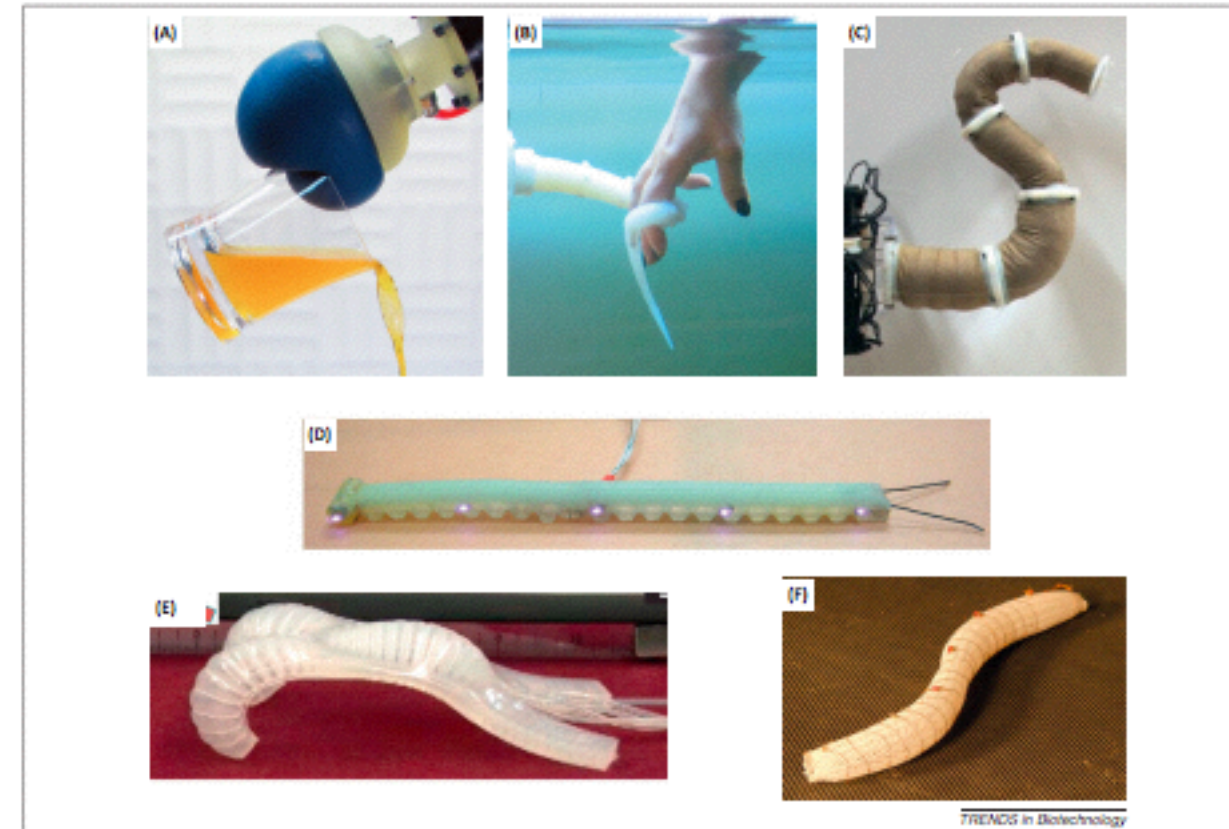


Figure 1. Recent development of robots that incorporate soft materials. (A) A soft gripper composed of a flexible sac filled with granular materials that can grasp a wide range of objects by vacuum pressure control [56]. (B) A soft manipulator modeled on the characteristic muscle structure of the octopus [7]. (C) The GoQBot, capable of the ballistic rolling motion observed in caterpillars [8]. (D) A multi-leg soft walker powered by compressed air [38]. (E) The Meshworm, which attains peristaltic locomotion by contracting its body, made of compliance mesh [6].

skeletal animals. The octopus can mimic its surroundings, caterpillars can conform to their host plants to be cryptic, and all of them can squeeze through gaps smaller than their unconstrained body. These are important lessons for building soft robots.

For all of their advantages, soft biological structures have some important limitations. Soft animals tend to be small because it is difficult for them to support their own body weight without a skeleton. All of the extremely large soft invertebrates are found either in water (squid and jellyfish) or underground (giant earthworms), where their body is supported by the surrounding medium. Similar limitations would apply to soft robots and necessitate careful selection of materials to match size as well as function. Additionally, the high deformability and energy-absorbing properties of soft tissues prevent them from exerting large inertial forces and limit how fast soft animals can move from place to place. This does not prevent different parts of the body from moving quickly under low loads. Octopuses can extend their limbs quickly by exploiting the fixed volume, low-aspect ratio geometry of their arms [4], and carnivorous caterpillars can strike their prey within a few hundred milliseconds [5]. However, these considerations make it likely that terrestrial soft robots bigger than a mouse or rat will incorporate stiff components for better performance, taking advantage of high flexibility.

Soft-bodied animals and soft-bodied robots

One problem with developing robots that use soft materials is that we currently have no general theory of how to control such unconstrained structures. Robotics engineers have begun to develop this knowledge by building robot models based on the neuromechanical strategies that soft-bodied animals use to locomote, chiefly annelids (earthworms and leeches)[6], molluscs (primarily the octopus)[7], and insect larvae (caterpillars) [8].

Worms and worm-like robots

From a biomechanical perspective, worms are fixed-volume hydrostats. They mimic the mechanical actions of a lever by transforming force and displacement through Pascal's principle. Contraction of longitudinal muscles shortens the body and increases its diameter, whereas contraction of circumferential muscles decreases the diameter and elongates the body [9,10] (Figure 2). Worms achieve locomotion by creating traveling waves of contraction and expansion using their cylindrical segments, a process that is analogous to intestinal peristalsis. The directions of the locomotion and the traveling wave can be the same or opposite, depending on the timing of contact with the terrain [11].

Many worm-like robots have been developed based on hydrostatic structures, with a range of hard and soft

Review

Trends in Biotechnology May 2013, Vol. 31, No. 5

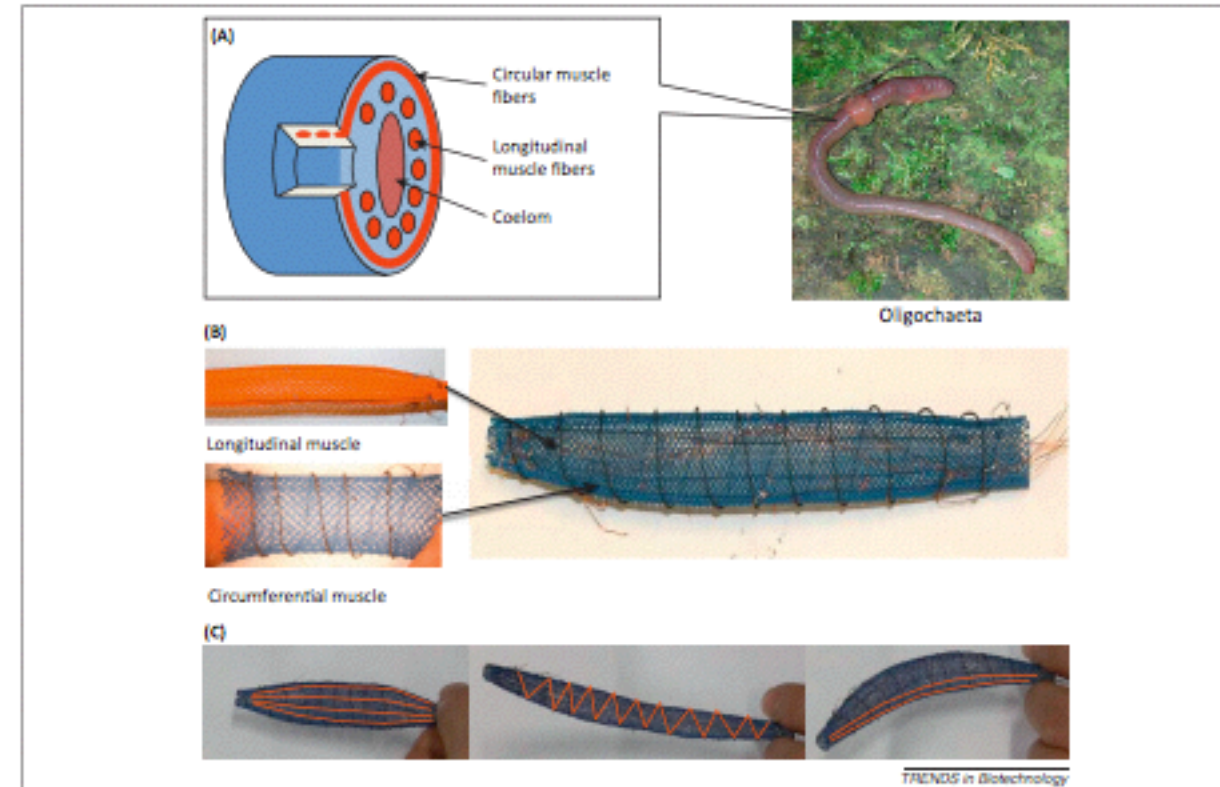


Figure 2. Earth worm-inspired robot. (A) Muscular structure of Oligochaeta, which forms antagonistic pairs without skeleton or joint. (B) A mesh structure that contains longitudinal and circumferential artificial muscles, creating an antagonistic pairing similar to the pairing in Oligochaeta. (C) Demonstration of various actuation modes.

actuators. One example uses pressure actuators with air valves, metal springs, and thermoplastic bearings [12], and an annelid robot uses a stack of dielectric elastomers mounted on a printed circuit board inside a silicone skin to generate worm-like movement [13]. Many worm-like robots have used shape-memory alloy (SMA) actuators, pioneered in the worm-like crawler [14] and later in a jointed, segmented worm robot that mimics how nematodes swim [15]. The Meshworm is the most recent device to use the SMA technology (Figure 1E) [6]. The Meshworm is based on a constant-length design rather than the constant-volume design that worms use. Radial SMA contraction in one segment causes radial expansion of an adjacent segment, and propulsion is derived from peristaltic waves of ground contacts. Linear potentiometers that detect the length of each segment provide feedback. Using iterative learning, the duration of each SMA actuation is adjusted to maximize either the speed of the Meshworm or its traveling distance and energy consumption. Steering is achieved by replacing two of the passive tendons with longitudinal SMA coils. Activation of one coil shortens one side of the robot and biases its movements in that direction. This robot demonstrates a key feature of soft technology: it can be hit repeatedly with a hammer and still function reliably.

Caterpillars and caterpillar-like robots

Although sometimes confused with worms, the larval stages of insects have a completely different anatomy

and locomotion strategy. Burrowing species such as fly larvae (maggots) and sedentary *Hymenoptera* larvae (e.g., wasps) generally lack limbs, but butterfly and moth larvae are highly active climbing animals with well-developed gripping appendages called prolegs. Although their bodies appear to be segmented, there are no internal divisions between these segments, just a single continuous body cavity called the hemocoel. Caterpillar musculature is surprisingly complex, with as many as 2000 motor units distributed throughout. There are no circumferential muscles, only longitudinal muscles, oblique muscles, and many small muscles attached to the limbs and other body parts (Figure 3A). Caterpillars can adjust pressure to increase body stiffness so that they can cantilever their body across a gap, but they do not appear to use pressure as a major control variable for most other movements [16–18].

Caterpillars crawl and climb by exerting compressive forces on the substrate (the so-called 'environmental skeleton hypothesis') [19,20] and controlling the release of body tension. Waves of muscular contraction do not appear to be tightly coordinated [21,22] but serve primarily to redistribute mechanical energy stored in elastic tissues [23]. The coordination of movement is determined by controlling the timing and location of substrate attachment by means of hooks at the tip of the prolegs [24,25]. The hooks grip in a purely passive way, but release is actively accomplished by a single pair of retractor muscles controlled by three motoneurons [26,27]. This is remarkable because a single proleg can produce sufficient grip to prevent any forward

Review

Trends

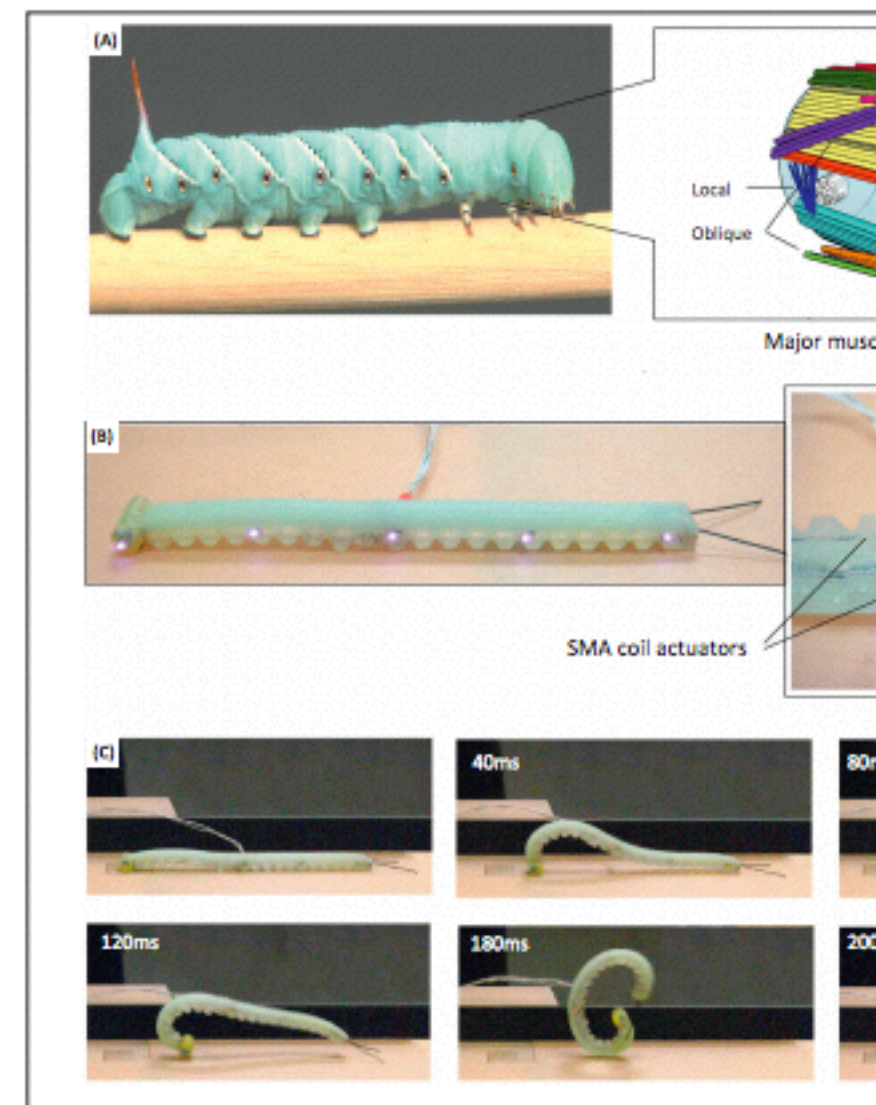


Figure 3. Caterpillar-inspired robot. (A) The caterpillar as a model organism for studying the control of soft-bodied movement. Each segment contains many longitudinal and oblique muscles. (B) A soft silicone-elastomer robot (GoQBot) with longitudinal shape-memory alloy (SMA) coil actuators. (C) Rapid ballistic rolling that exploits the morphology and elastic contraction of SMAs.

locomotion. Grip release must therefore be completely reliable regardless of the shape or texture of the substrate. It is unlikely that the retractor muscles are controlled with great precision or adjusted with every step to compensate for changes in attachment. It is more likely that very soft parts of the proleg are deformed to redirect automatically muscle forces to ensure hook release from the substrate. The system appears to be an excellent example of morphological computation and illustrates how important the embodiment process will be in the design of soft robots [1].

These caterpillar-like robots demonstrate an important attribute of highly deformable devices: they can morph to exploit other body shapes. As an example, the GoQBot (Figure 3B) has an elongated narrow body that can be deformed into a circle. When done quickly, this change releases enough stored elastic energy to produce ballistic

rolling locomotion (H. conformation within 1 G acceleration at 10-cm-long robot at

Octopus and octopus. Some of the most elegant movements are accomplished by cephalopods and other bodies to fill complex environments or other remarkable physical manipulate objects, model [28].

Each octopus arm distinct anatomical

Corresponding author: Kim, S. (sangbae@mit.edu)
 Keywords: bioinspired robot, soft robotics.
 0167-7396/\$ - see front matter
 © 2013 Elsevier Ltd. All rights reserved. http://dx.doi.org/10.1016/j.tbi.2013.05.002



Dielectric elastomer actuators (DEAs), SMAs, compressed fluid, combing with electromagnetic actuators.

Soft robotics: a bioinspired evolution in robotics. Sangbae Kim, Cecilia Laschi, Barry Trimmer.

Soft Shape Change - Toolkits

Make it : Fabrication

Control it : Electronic and Pneumatic Circuit

Make it: Fabrication

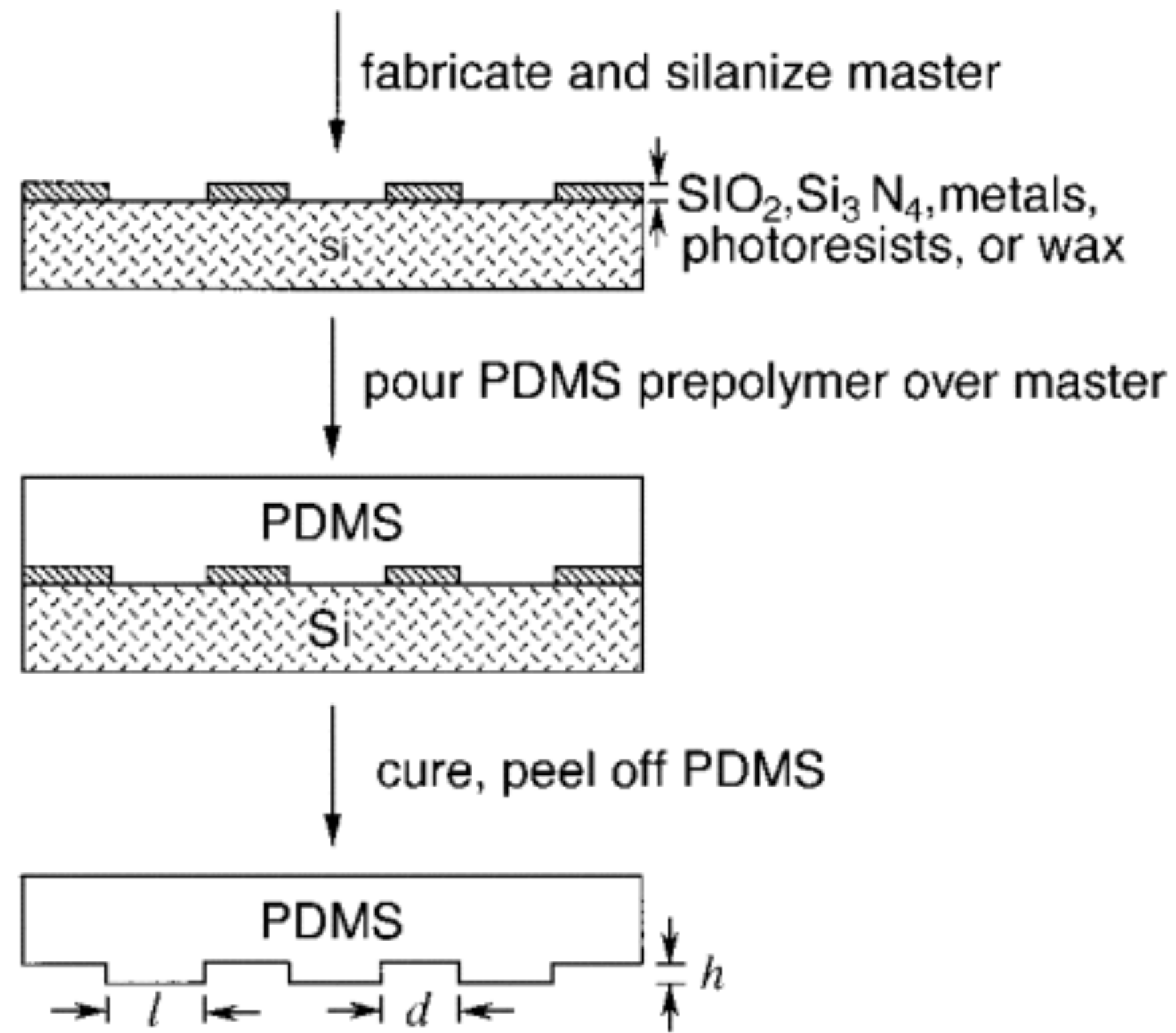
Soft lithography

Modular Assembly

3D printing

Your own way

Soft Lithography



Soft Lithography. Younan Xia and George Whitesides. Elastomer stamp and molding.

Modified Soft Lithography

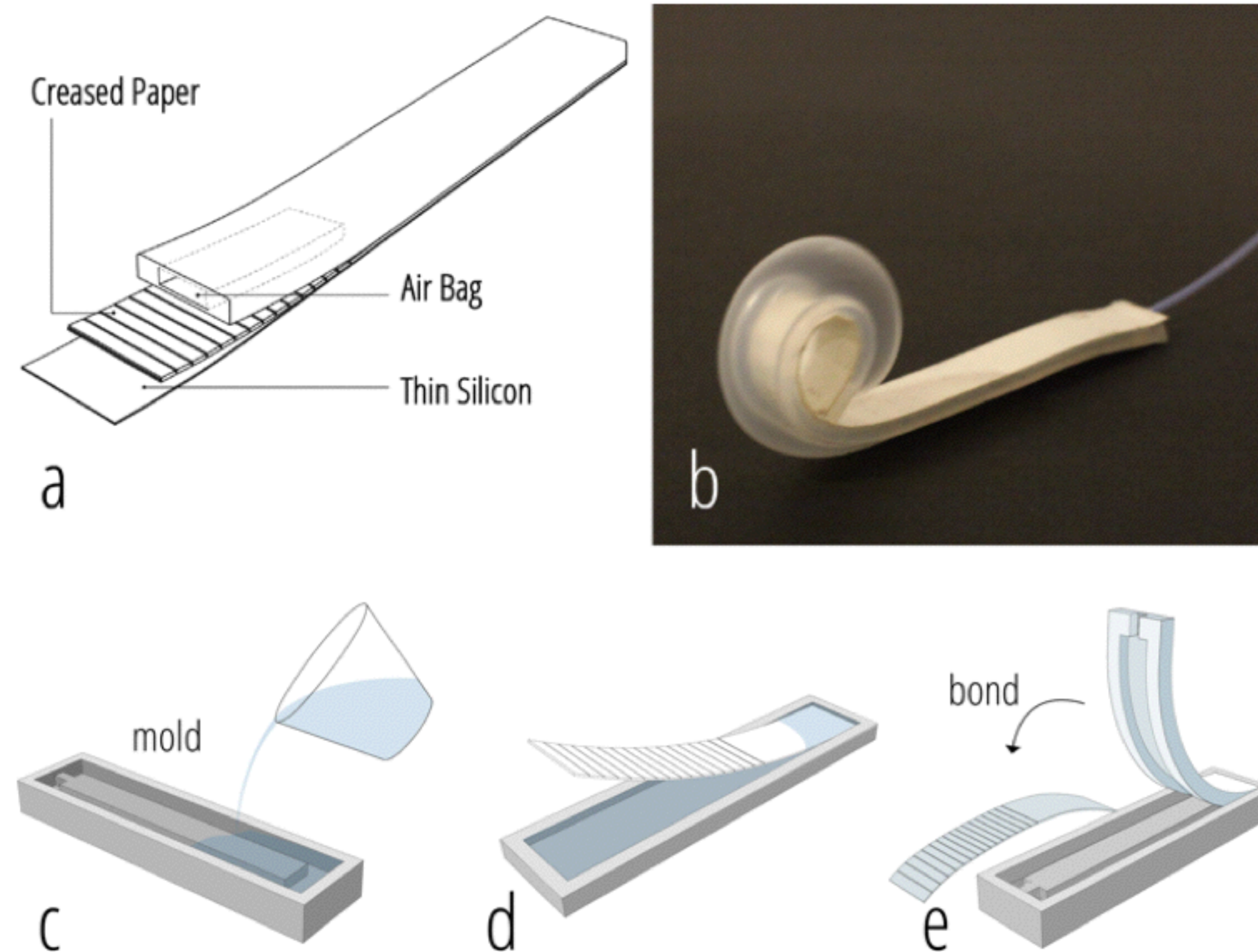


Figure 5: (a, b) Structure of the composite. (c, d, e) Fabrication process. (c) Pre-mixture of silicon (EcoFlex 00-30, Smooth-on, Inc) is poured into a 3D printed mold designed to form a shape with air channels. (d) Creased paper is soaked into the same silicon mixture. (e) Silicon and paper layer are peeled off molds separately once thermally cured. Two layers are then bonded with uncured silicon.

Specs
Materials: silicone rubber, paper, spandex, acrylic sheets
Tools: air compressor, vacuum, laser cutter, 3D printer

PneUI

An elastic pneumatic interface takes its cues from living things.

Describe what you made.

Our project is called PneUI. It includes a series of pneumatic (inflatable) artifacts and interfaces. They are transformable and responsive objects, such as a lamp that can wrap its own body when pulled, a transformable iPad cover that inflates bubbles when players of racing games need to turn left or right, and a cellphone that turns into a wrist band. Technically, we

envision a future material with an embedded grammar that can sense and transform, either through geometrical or structural computation.

Briefly describe the process of how this was made. We see the fabrication process as not only a labor procedure, but also a process to embed computation inside materials. Soft lithography has been used by soft roboticists, biologists, and

other scientists to fabricate elastomers with micro-scale air channels. We have adapted this process, enlarged the scale, and combined it with traditional molding and casting methods to fabricate our pneumatic artifacts.

What for you is the most interesting thing about what you made? We started with making new actuators, but it turned out

that we wanted to create the feeling of artificial life. We think the elastomeric pneumatic actuators go far beyond generating bending curvature. The unique physicality of translucent silicone rubber and the natural transformability of inflatable structures convey a type of motion and form factor that resembles or reminds us of life.

What was the biggest

surprise in making this? Surprisingly, and a bit strangely, we feel like we are developing a unique relationship with the materials we are working with. They are like your pets. They have their personalities and unexpected behaviors. In order to let them achieve the performance you hoped for, you need to really invest

time, patience, and passion into interacting with them, trying everything you can think of to play with them.

What is the one thing about making this that you would like to share with other makers? Try to minimize errors from the very beginning. You thought you just wanted to try out something quick, so instead

of milling or 3D printing a proper mold, you just laser cut and glued a mold with a thin, heat-distorted acrylic. And of course you will fail in this experiment. Then you realize the quick failure has prevented you from going down this route and spending more time on it. But the possible truth is the failure might be only in the accuracy of your fabrication, and you

have just missed a chance to create a great invention.

As told by Lining Yao, Tangible Media Group, MIT Media Lab

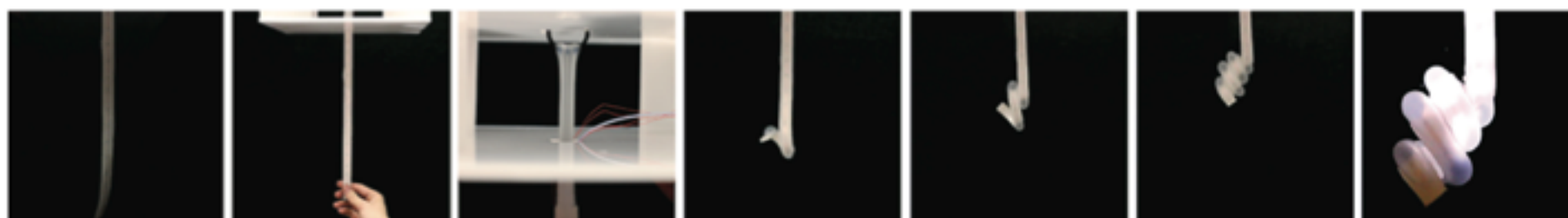
Project Members: Lining Yao, Ryuma Niiyama, Jifei Ou, Sean Follmer, and Hiroshi Ishii, Tangible Media Group, MIT Media Lab

<http://tangible.media.mit.edu/project/pneui-pneumatically-driven-soft-composite-material/>

DOI: 10.1145/2626273 COPYRIGHT HELD BY AUTHOR



→ Lining Yao is fabricating the PneuUI lamp, a shape-changing object that can morph from a single strip into an energy-saving bulb shape.



→ The PneuUI lamp.

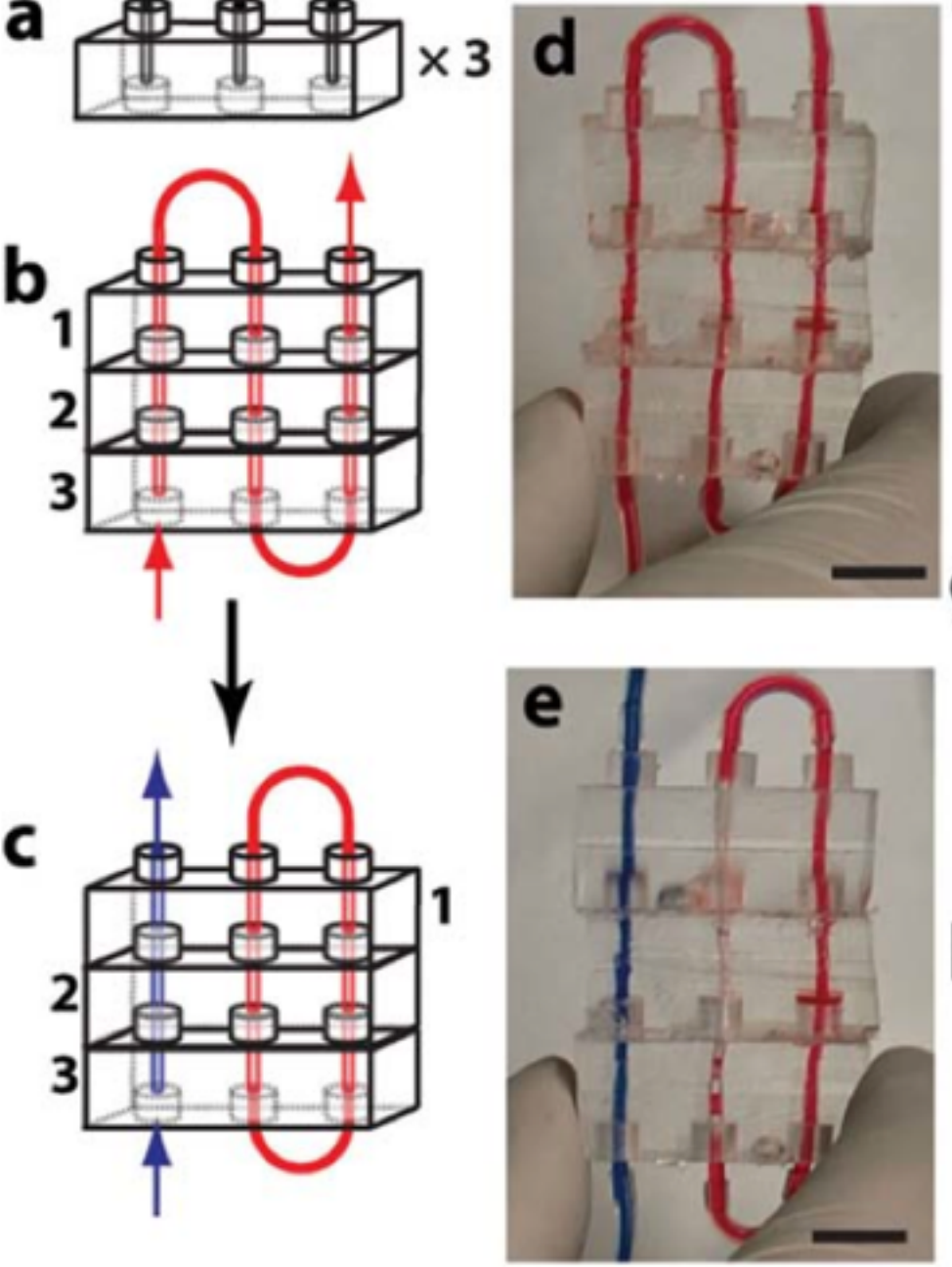
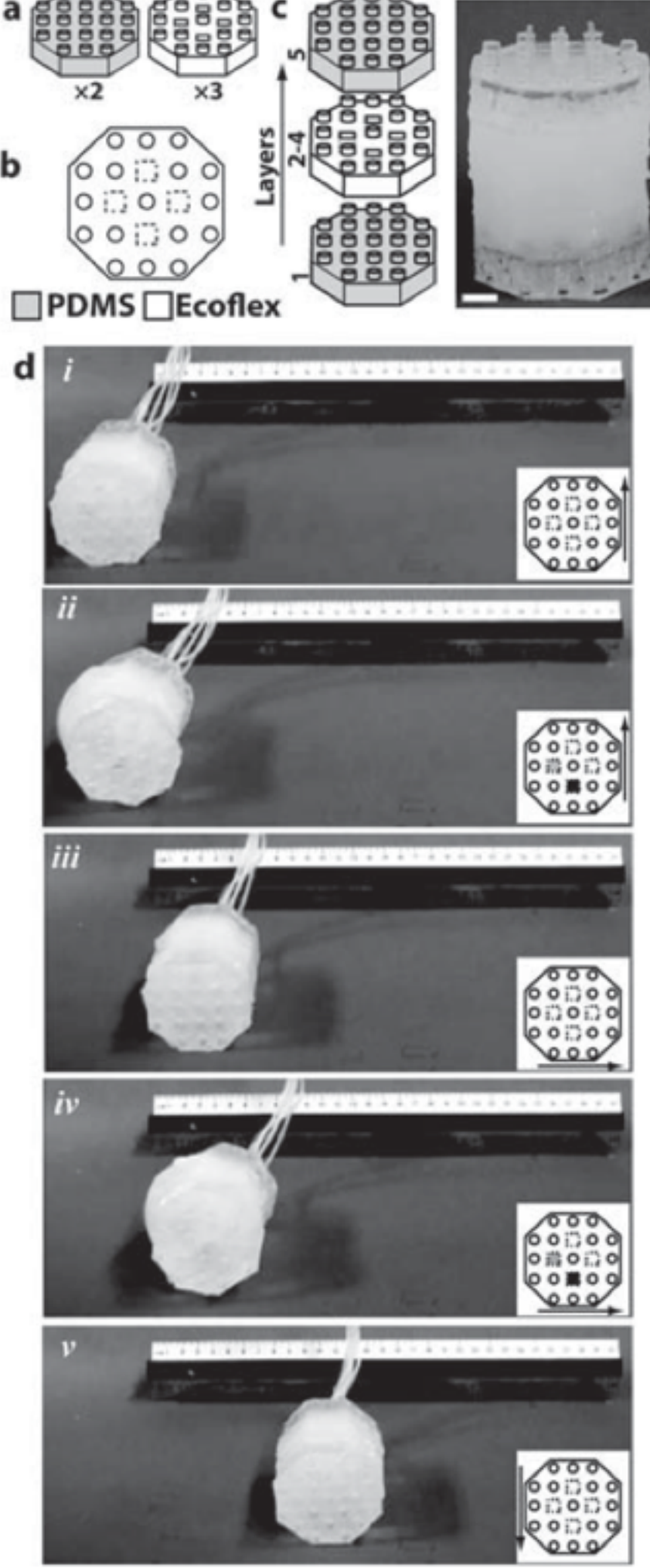
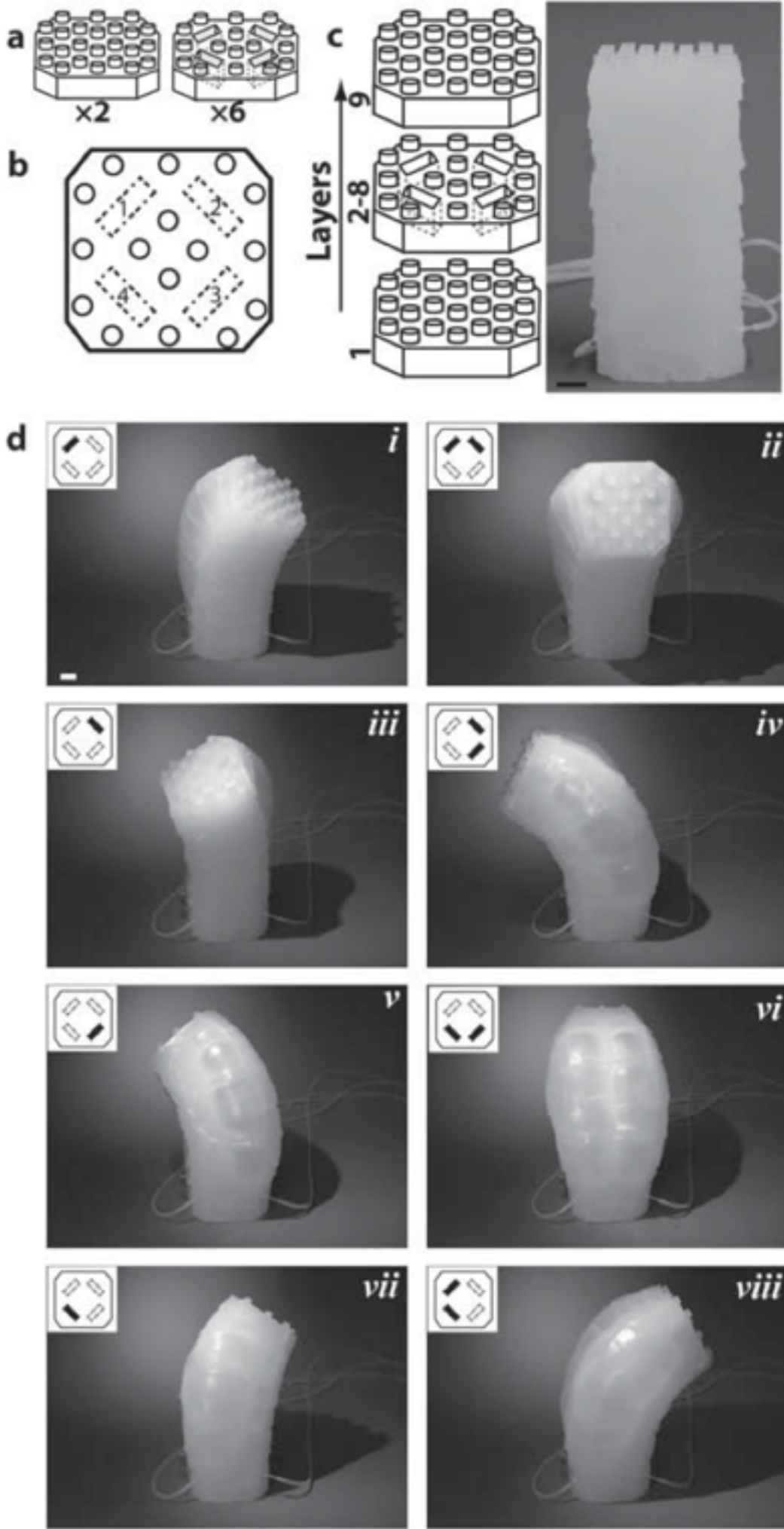
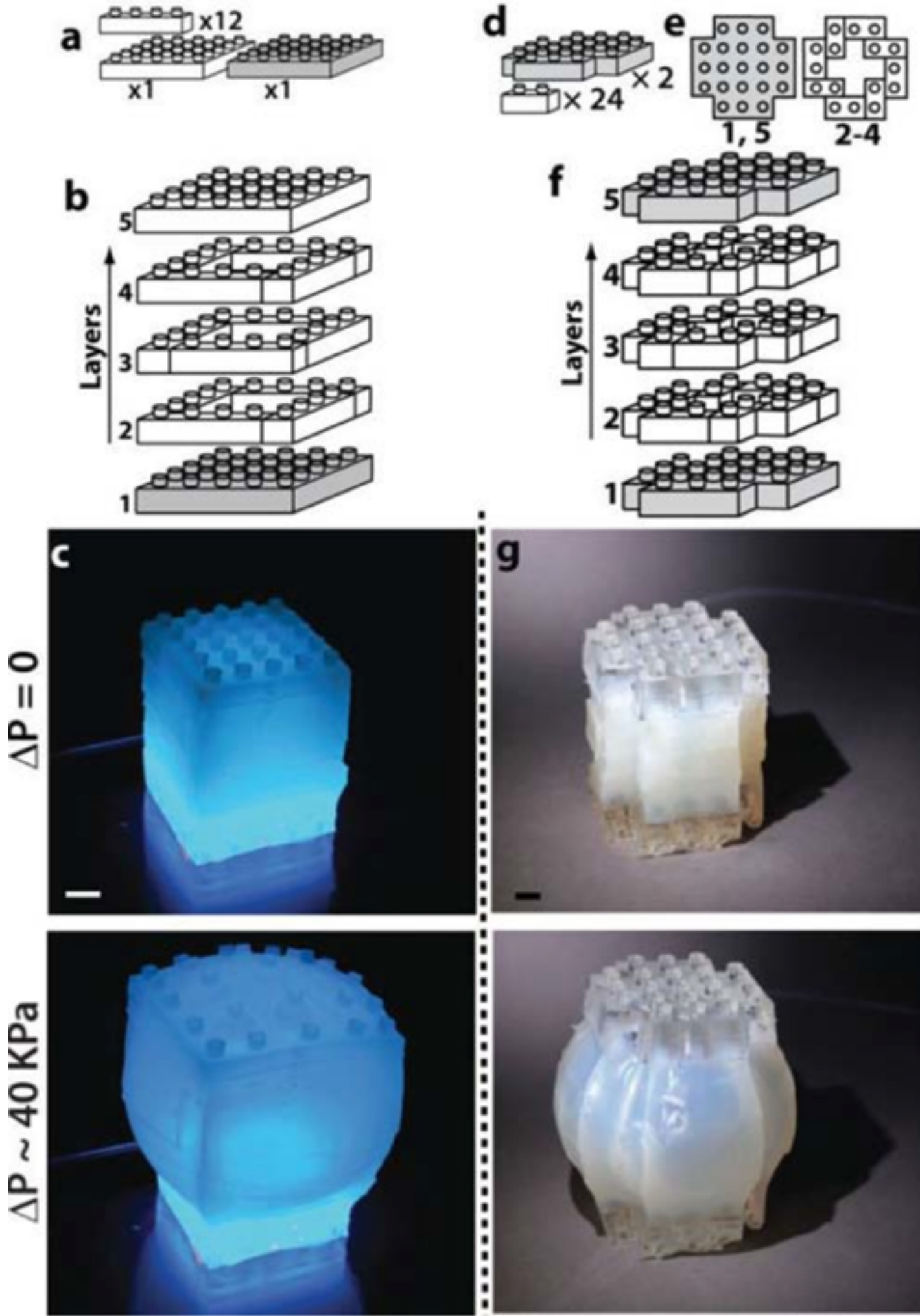


→ Jifei Ou is fabricating the multi-state air bladder. Bubbles can grow on bubbles; balloons can grow on balloons.

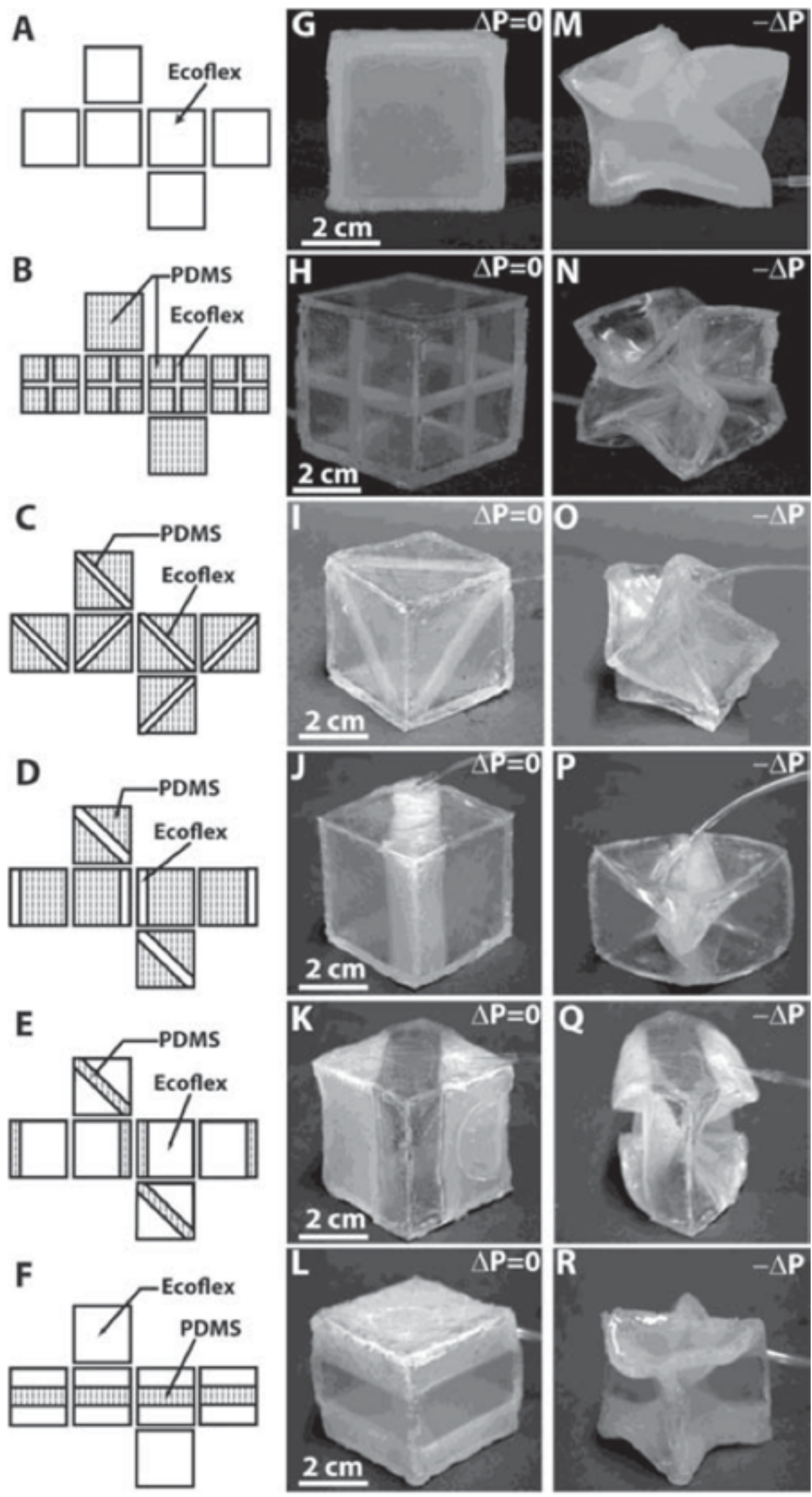
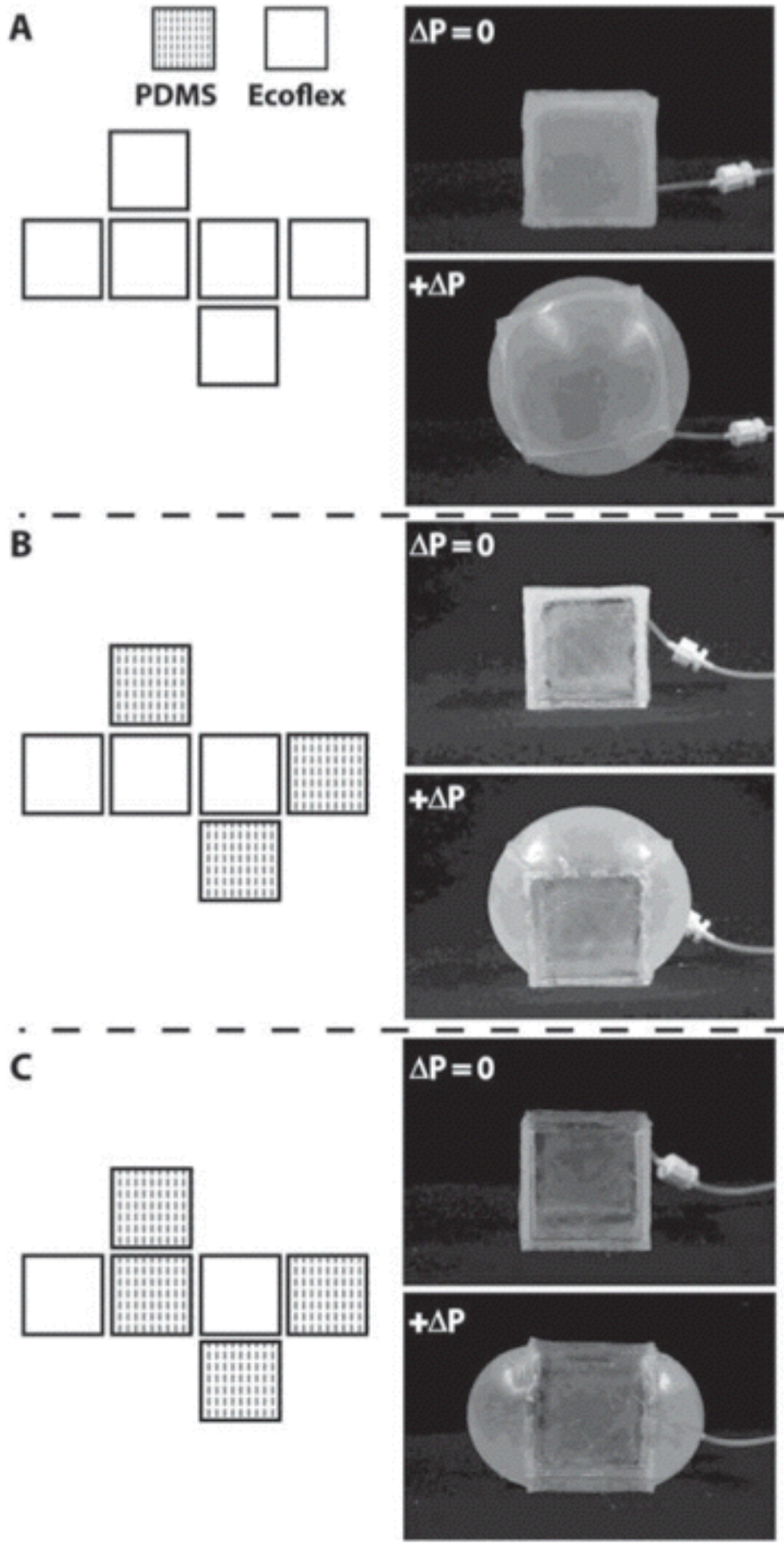
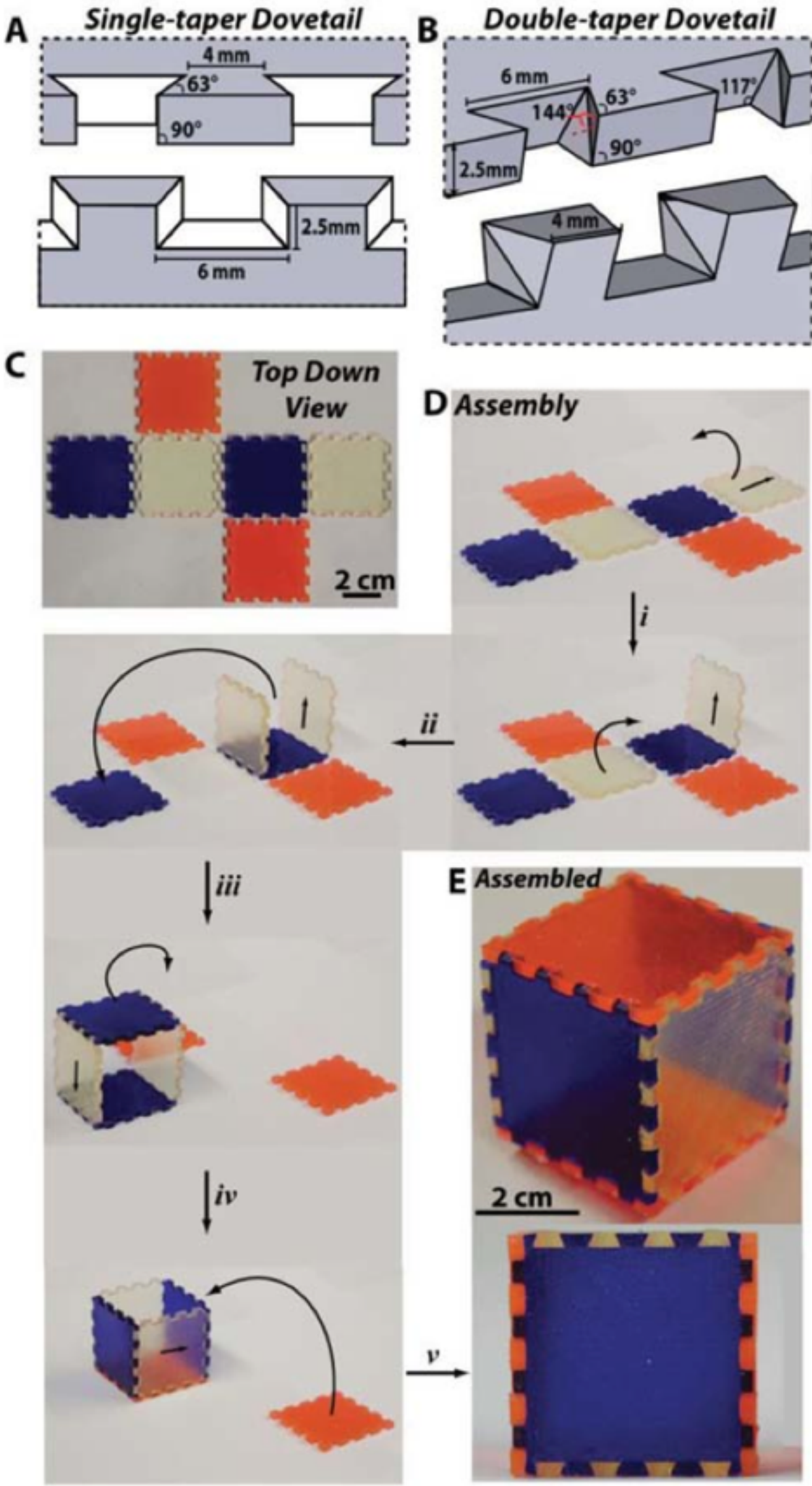


→ Multi-state texture samples with different cut patterns.

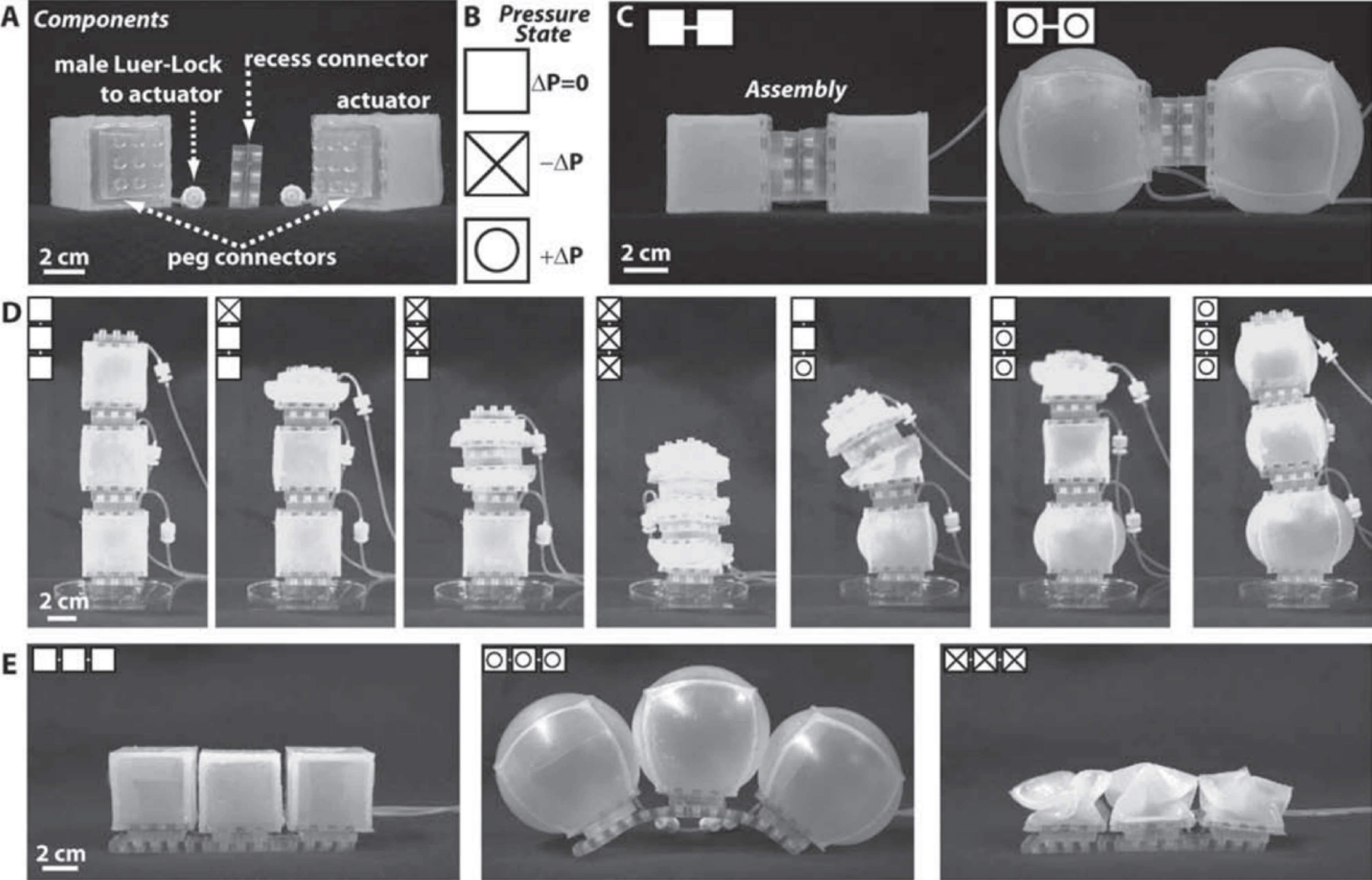
Modular Assembly - Lego Assembly



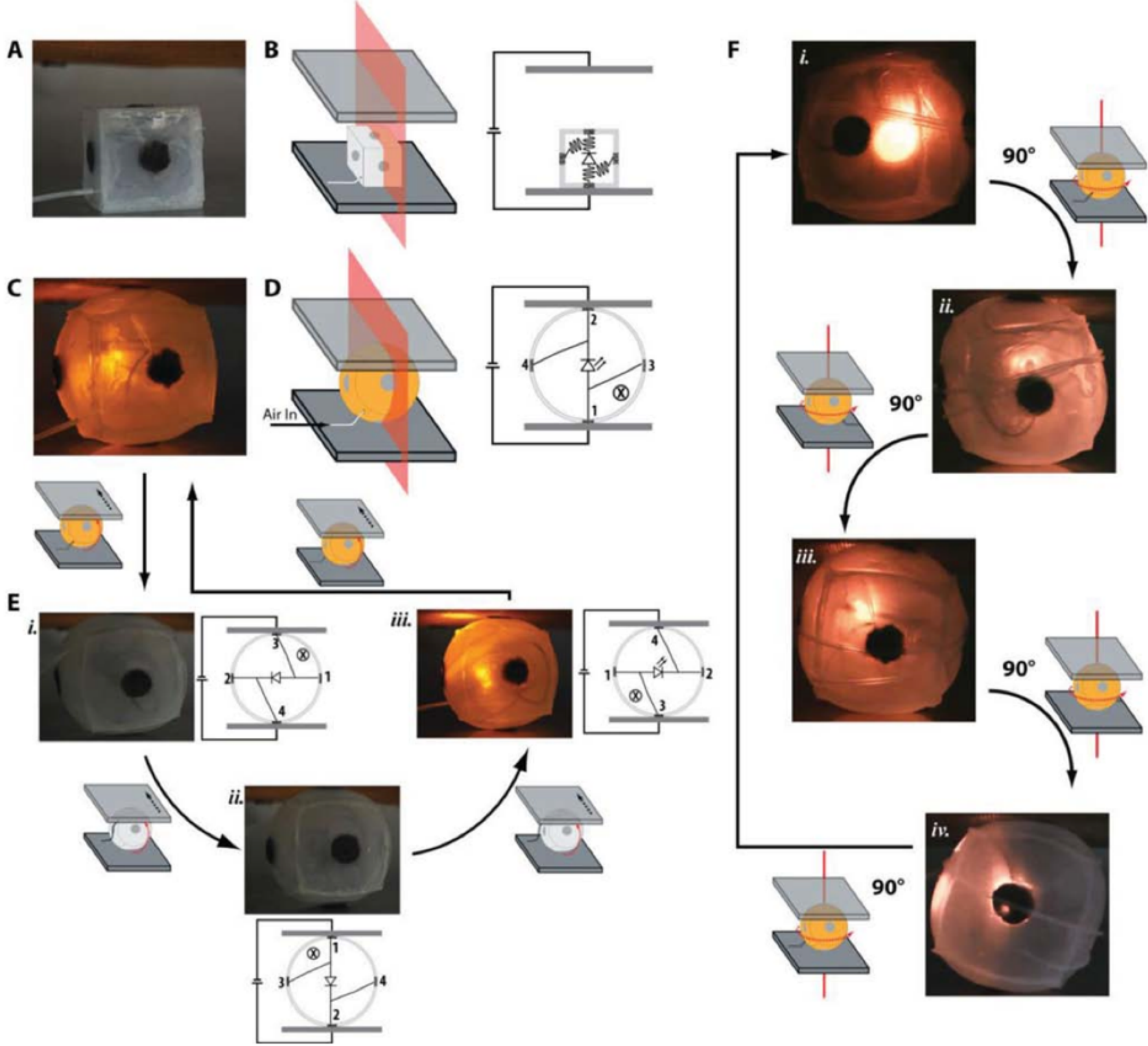
Modular Assembly - Soft Joinery



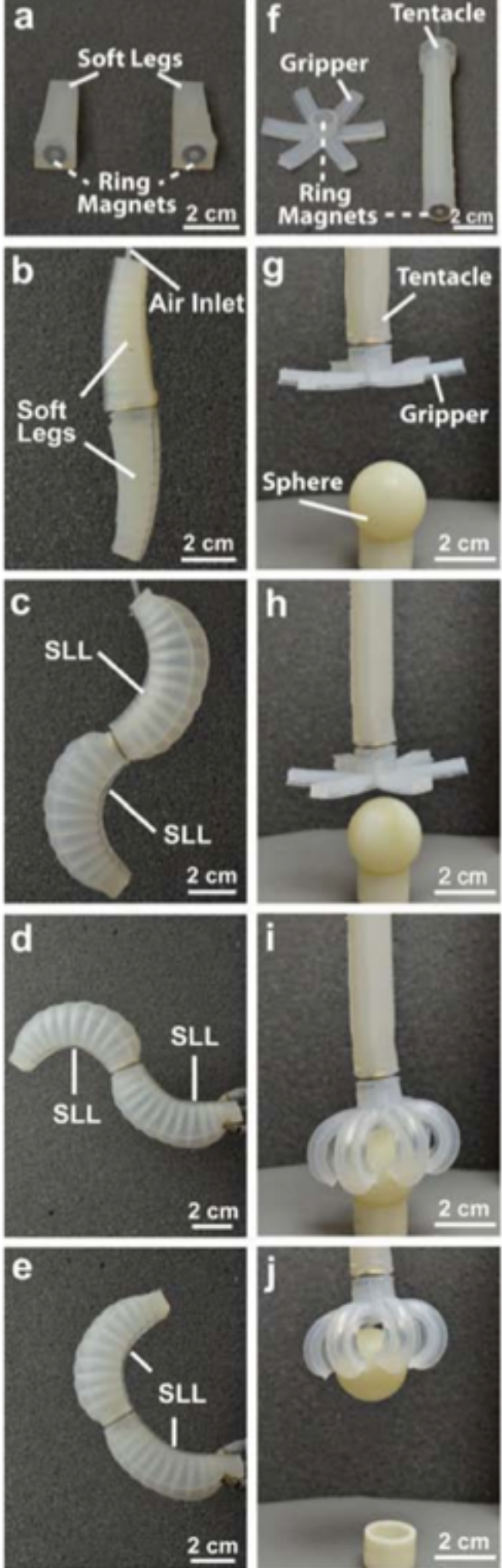
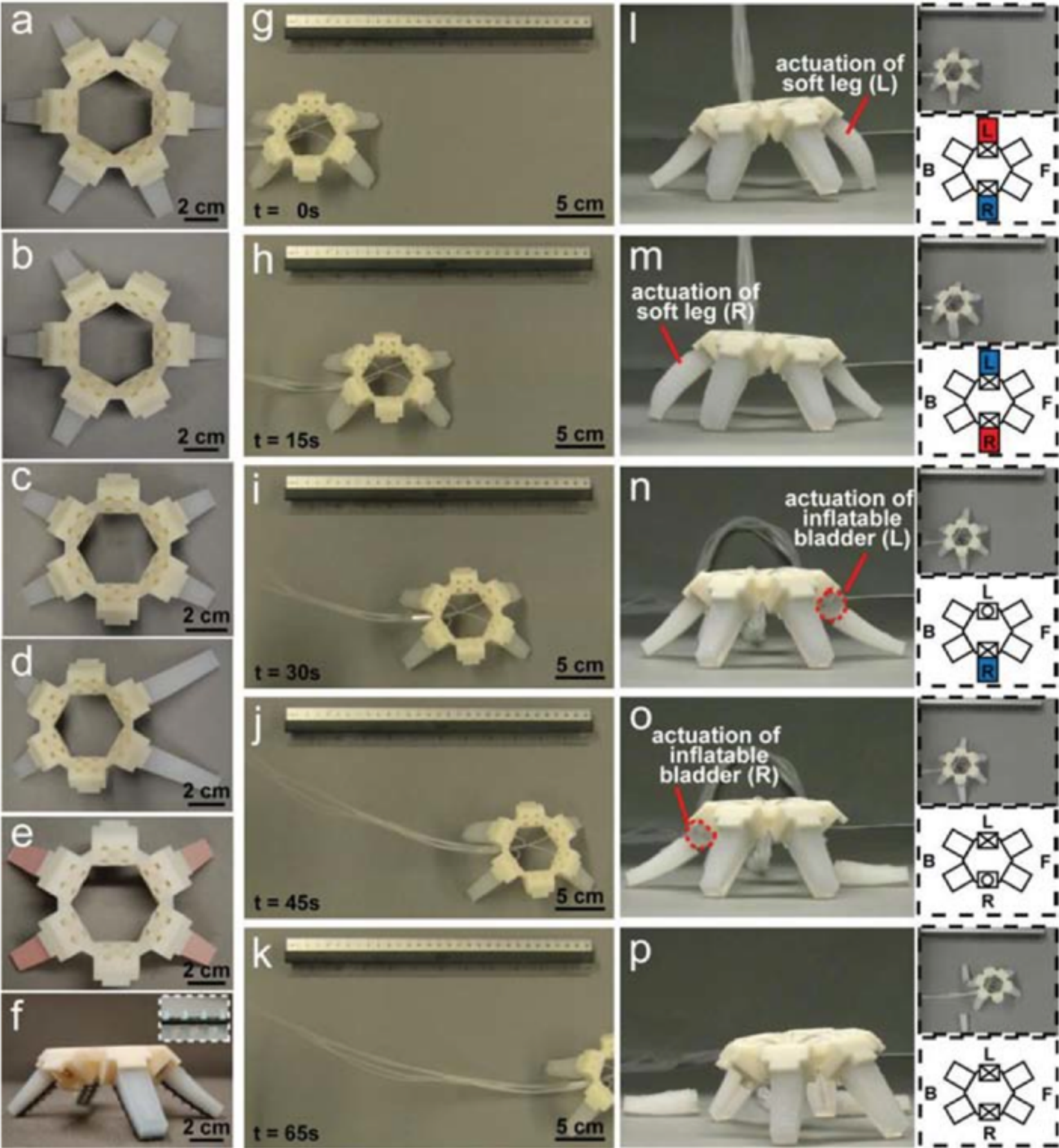
Modular Assembly - Soft Joinery



Modular Assembly - Soft Joinery



Modular Assembly - Magnetic Assembly



3D Printing



3D Printing

[3D Printers](#)[Materials](#)[Solutions & Applications](#)[Industries](#)[Resources](#)[Customer Support](#)[Home](#) ▶ [Materials](#) ▶ [PolyJet](#) ▶ [Rubber-like](#)

Rubber-like

3D print flexible, soft-touch models

With Rubber-like PolyJet photopolymers, you can simulate rubber with different levels of hardness, elongation and tear resistance. Gray, black, white and translucent, Rubber-like material enables you to simulate a very wide variety of finished products, from soft-grip handles to footwear. With Connex3 systems, you can add color to the mix for exceptional final-product realism.



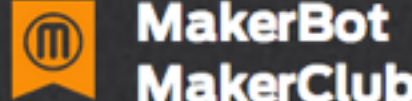
GET A SAMPLE PART U.S. ONLY





MAKERBOT
FLEXIBLE
FILAMENT

COMPATIBLE WITH
MAKERBOT REPLICATOR 2
DESKTOP 3D PRINTER

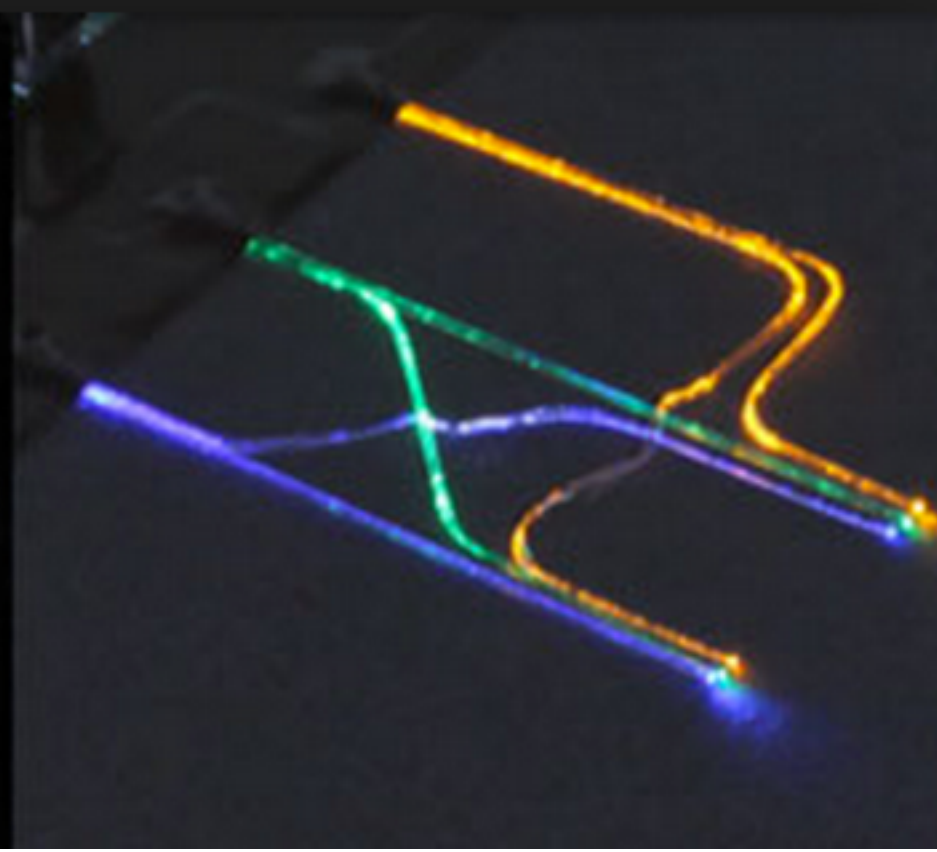
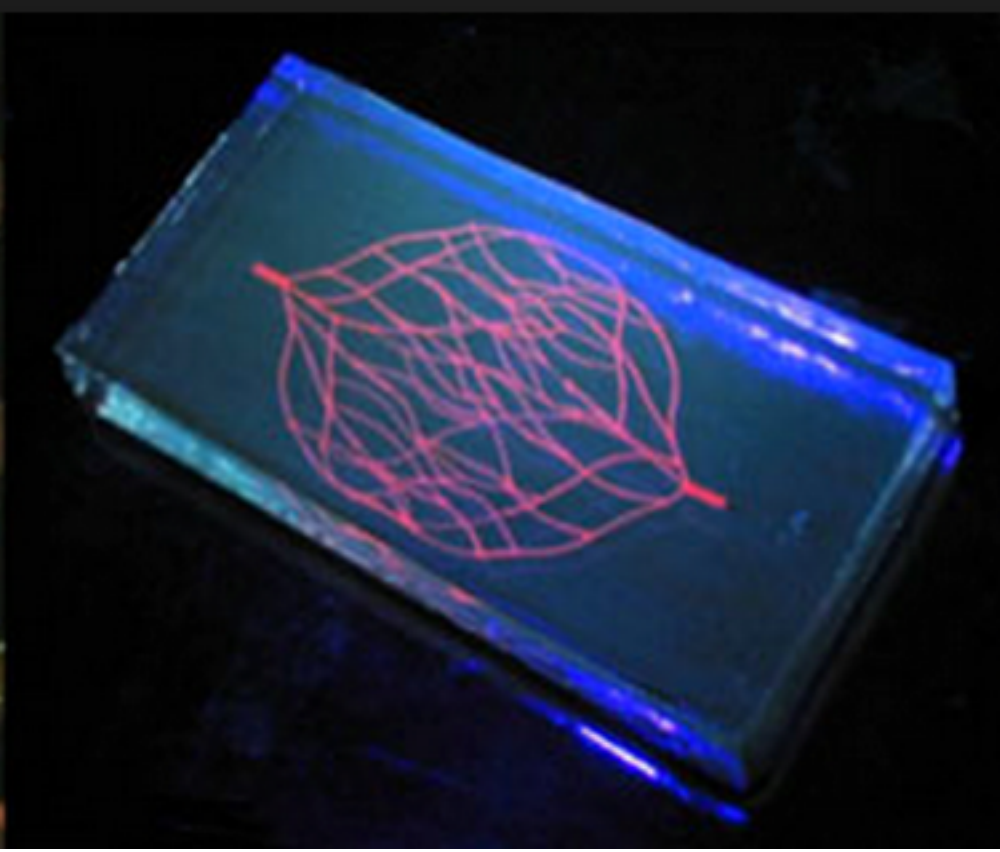
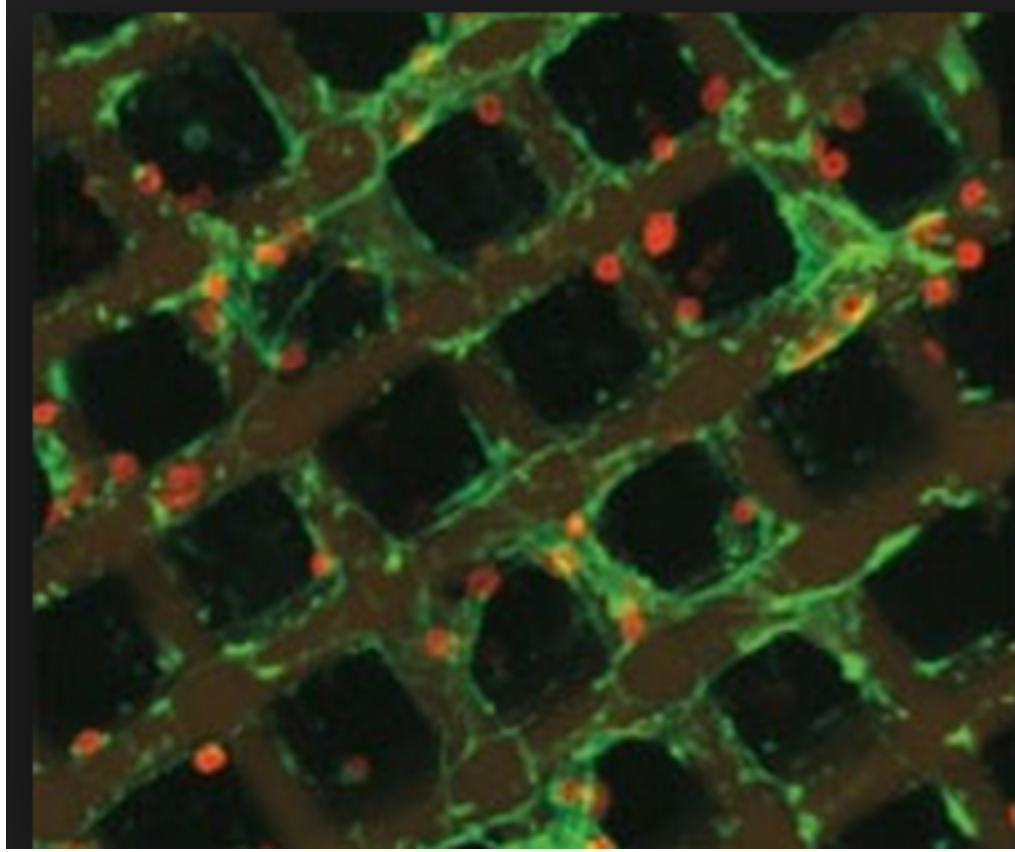


Save 10% on filament. [Join Now](#)

Chat



Formlabs Flexible Resin



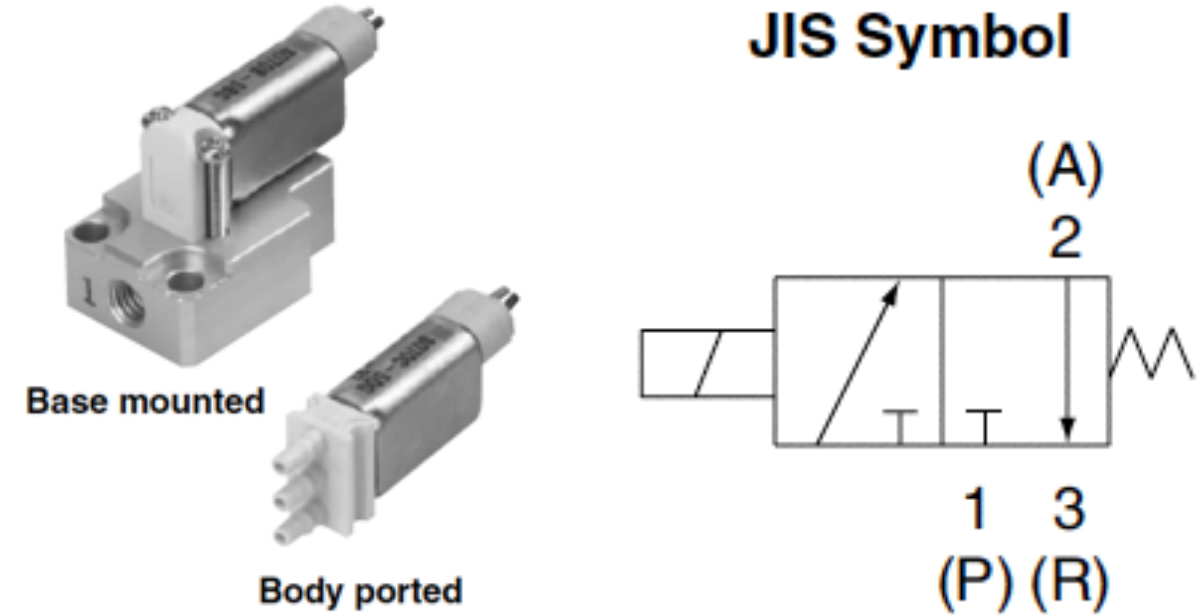
Your Own Way

Texture - Fabrication Process

Control

Control Toolkits

Pneumatic Valves



3 port S070, SMC

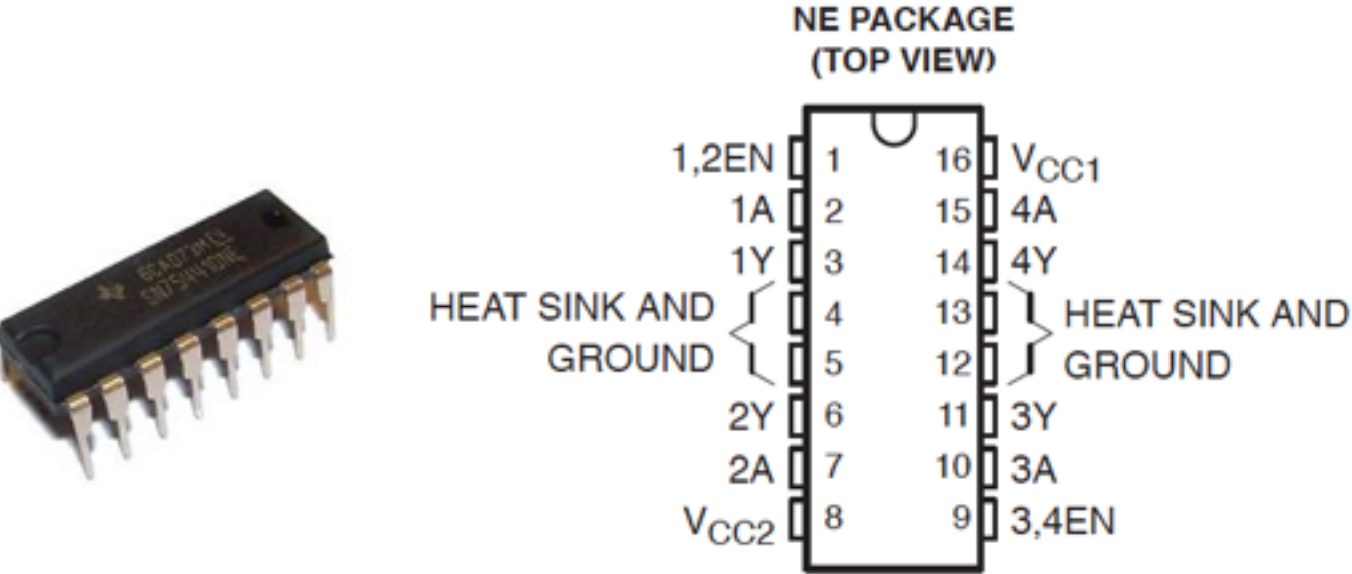
Pumps



0-32PSI Pressure,
0-16''Hg Vac,
Sparkfun

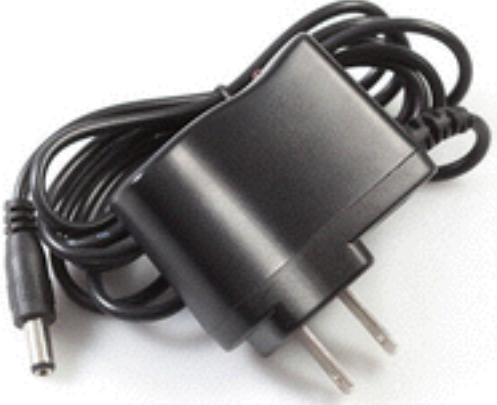
6 PSI Pressure
Koge KPM12A

Motor Drivers (H-bridge)



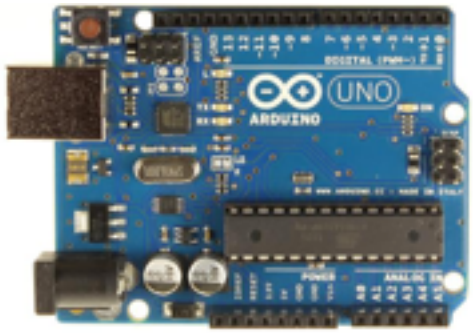
SN754410 Half-H driver

Power Supply



12V, wall adaptor power supply

Micro-controller

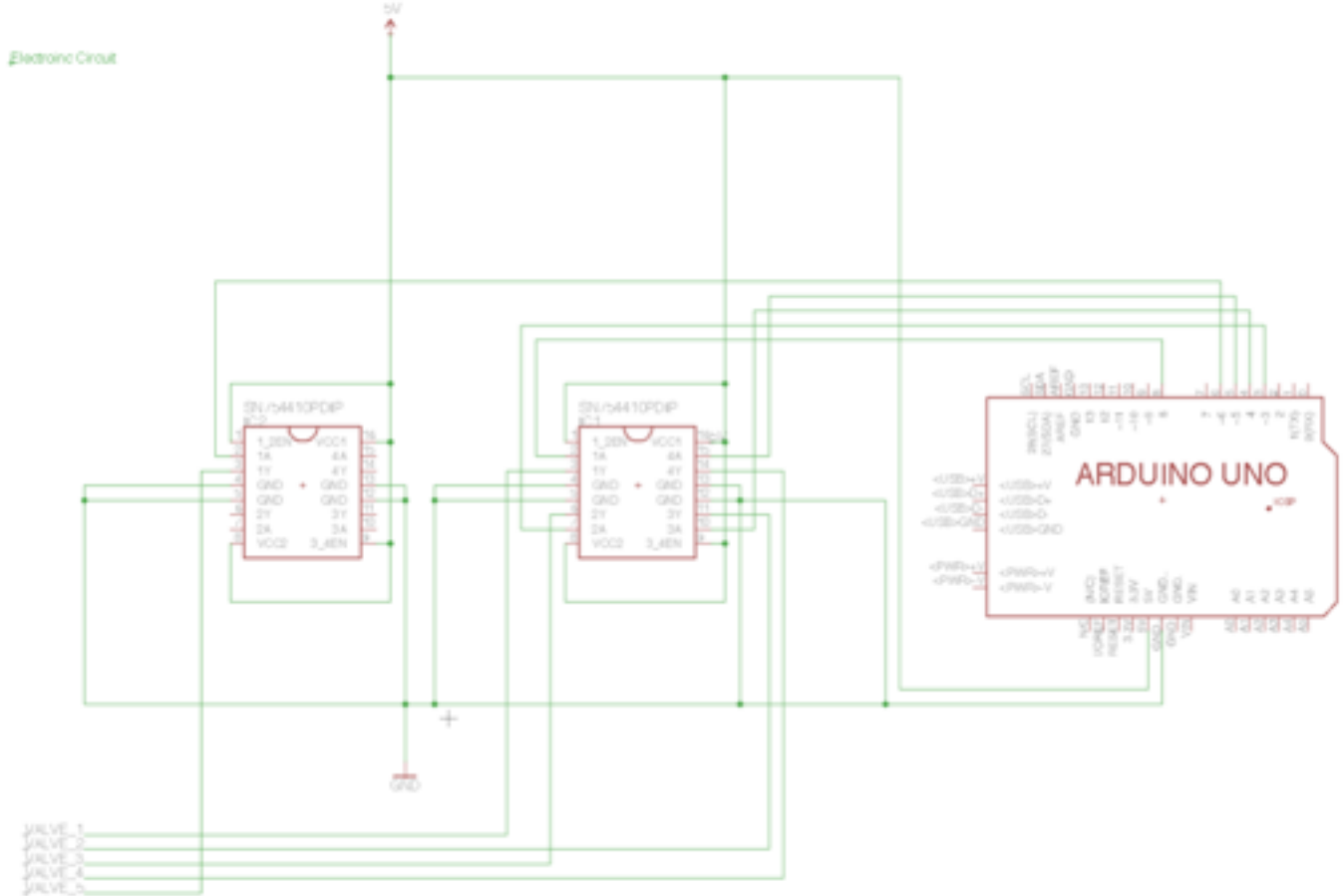


arduino.cc

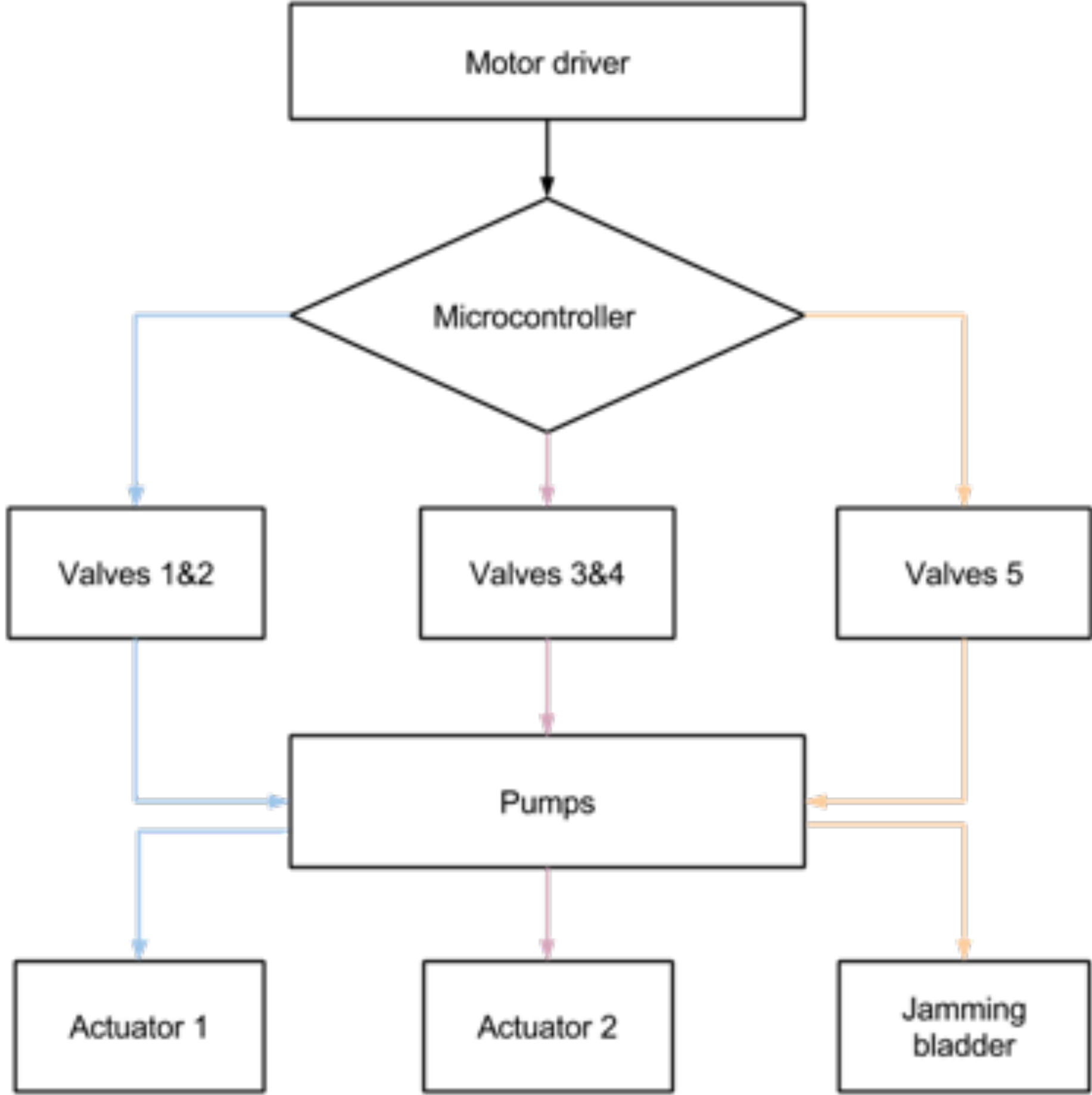
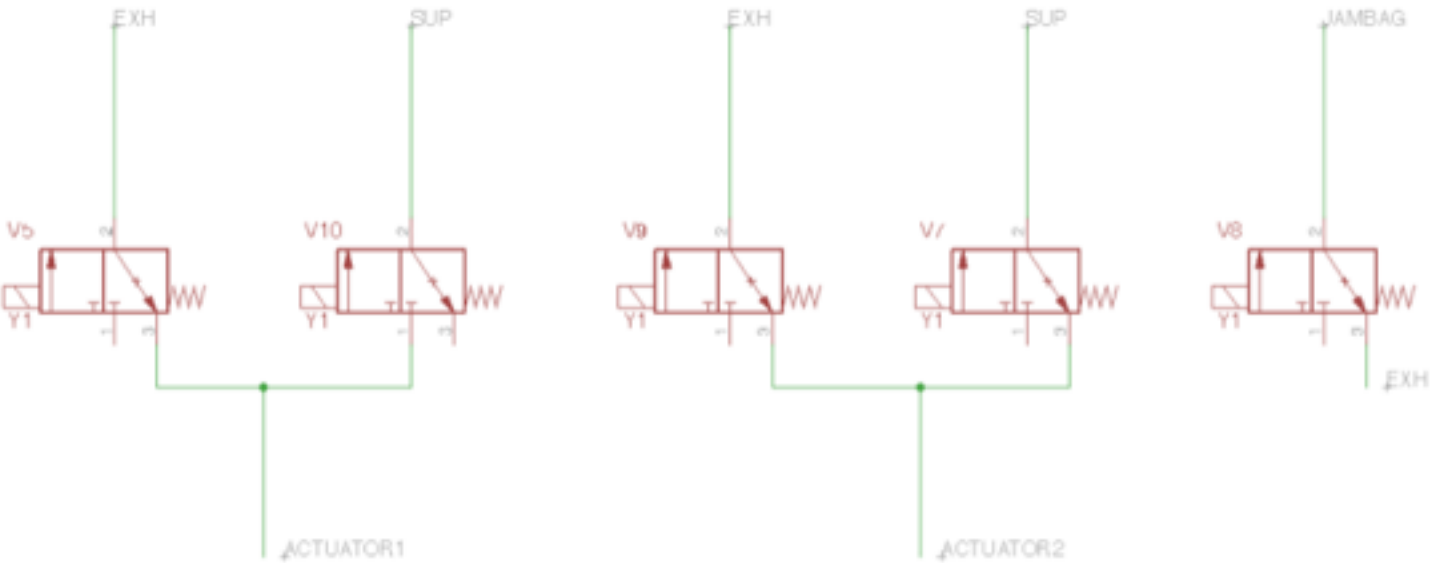
Control

Control Toolkits

Electronic Example Circuit



Pneumatic Example Circuit



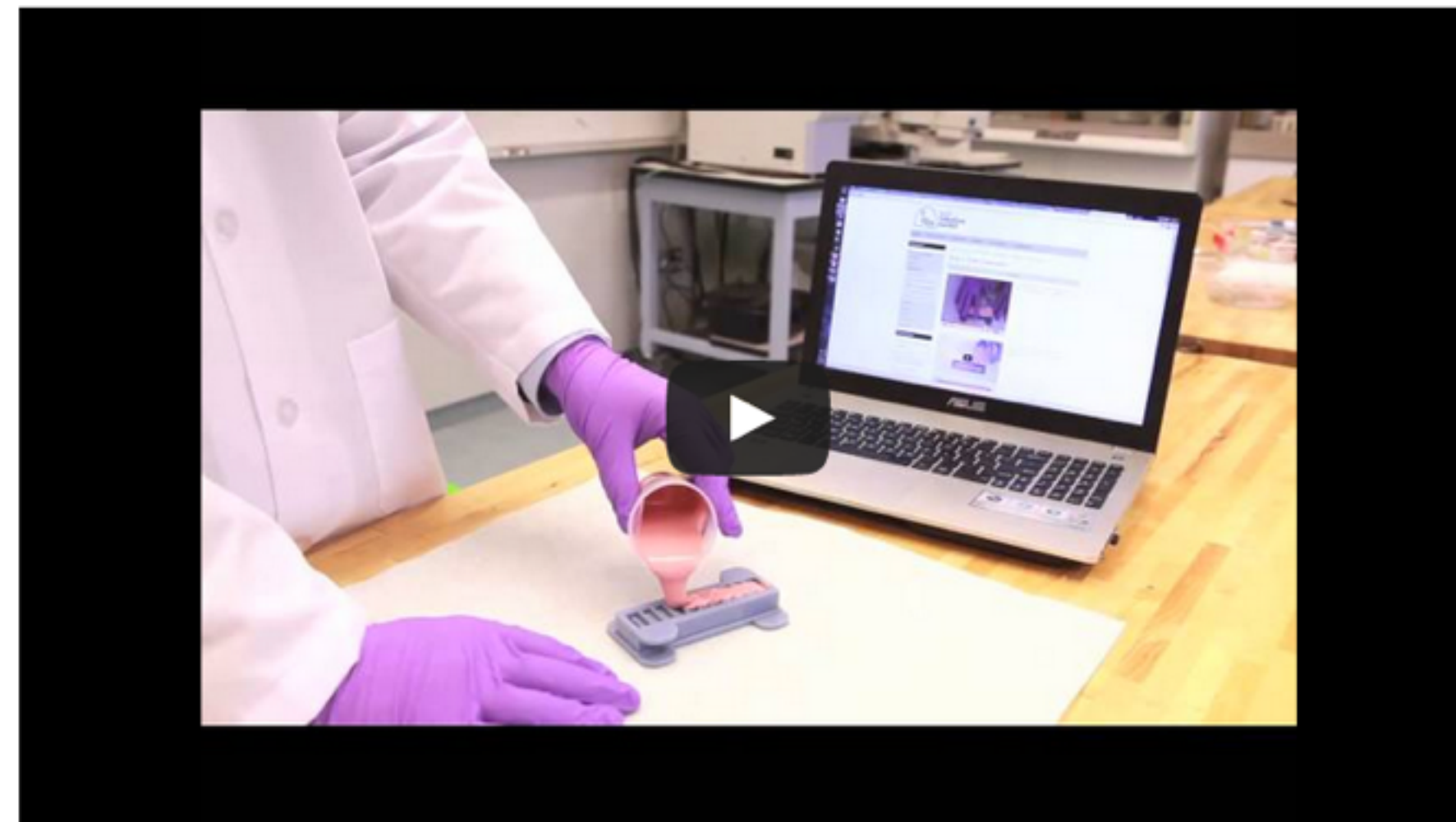
<http://softroboticstoolkit.com/>



Home About ▾ Actuators ▾ Sensors ▾ Control ▾ Case Studies Get Involved ▾

What is soft robotics?

Soft robotics is a growing field that takes inspiration from biological systems to combine classical principles of robot design with the study of soft, flexible materials. Many animals and plants are composed primarily of soft, elastic structures which are capable of complex movement as well as adaptation to their environment. These natural systems have inspired the development of soft robotic systems, in which the careful design of component geometry allows complex motions to be "pre-programmed" into flexible and elastomeric materials. The use of compliant materials to embed intelligence in the mechanics of the body enables designers to simplify the more complex mechanisms and software control systems used in traditional, rigid robotics. The inherent compliance of soft robots makes them highly adaptable to a wide range of tasks and environments. In particular, they are ideally suited for interactions with humans, from assisting with daily activities to performing minimally invasive surgery.



Live Demo

Supplementary Material: More Relevant Work

How are human beings using it? (except breathing)

Soft Robotics

Technical Properties

Mechanical compliance matching, elastically deformable,

- large contact area to transfer force between the robot and the surface
- Maneuvering through confined spaces
- friendly, not harmful to the skin

Multi-functionality

Elastic Versatility

(compliance matching: the principle that contacting materials should share similar mechanical rigidity in order to evenly distribute internal load and minimize interfacial stress concentrations.)

Biomimetic: octopus squeeze through a small hole

Applications

Locomotion and manipulation

“Versatile, lifelike, compatible for human interaction

Medical robots that interact with soft materials such as skin muscle tissue

Field Robots encountering deformable surfaces like sand, mud, and soft soil

Cooperative Human assistance

Wearables