Transformers

Shape-changing Space Systems Built with Robotic Textiles

(*ro-textiles/ro-fabrics/ro-skins*)

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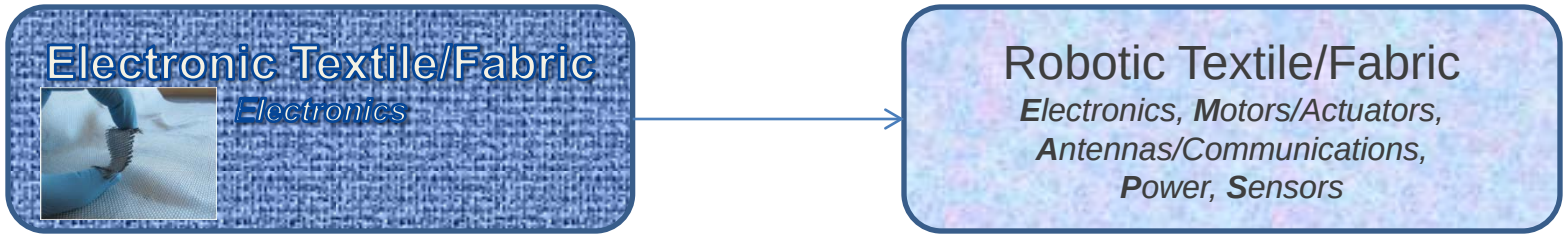
Transformer concept

This paper proposes *transformers*,
a new kind of robotic space system,
dramatically different from current systems
in at least two ways:

1. The entire transformer is built from a thin flexible sheet, of “robotic textile”, *ro-textile*
2. The ro-textile sheet folds to small volume, and self-unfolds to adapt shape and function to mission needs.

Ro-textiles

- An extension of electronic textiles (e-textiles, e-fabrics)



- Gossamer-thin (~100 μm) and light flexible layer
- Survivable to extreme environments
- Cellular (~ cm square?, cells may be in patches)
- Each cell includes cells of all robotic sub-systems, from sensing to actuation, power, comms/antennas, control/computing
- Modular, distributed architecture

All sub-components demonstrated

All subsystems have been demonstrated on flexible substrate

- E: electronics (foldable in a radius less than 100 µm.),
- M: motor/mobility - actuators
- A: antennas/communications
- P: Power (e.g. solar)/batteries
- S: Sensors

E → R

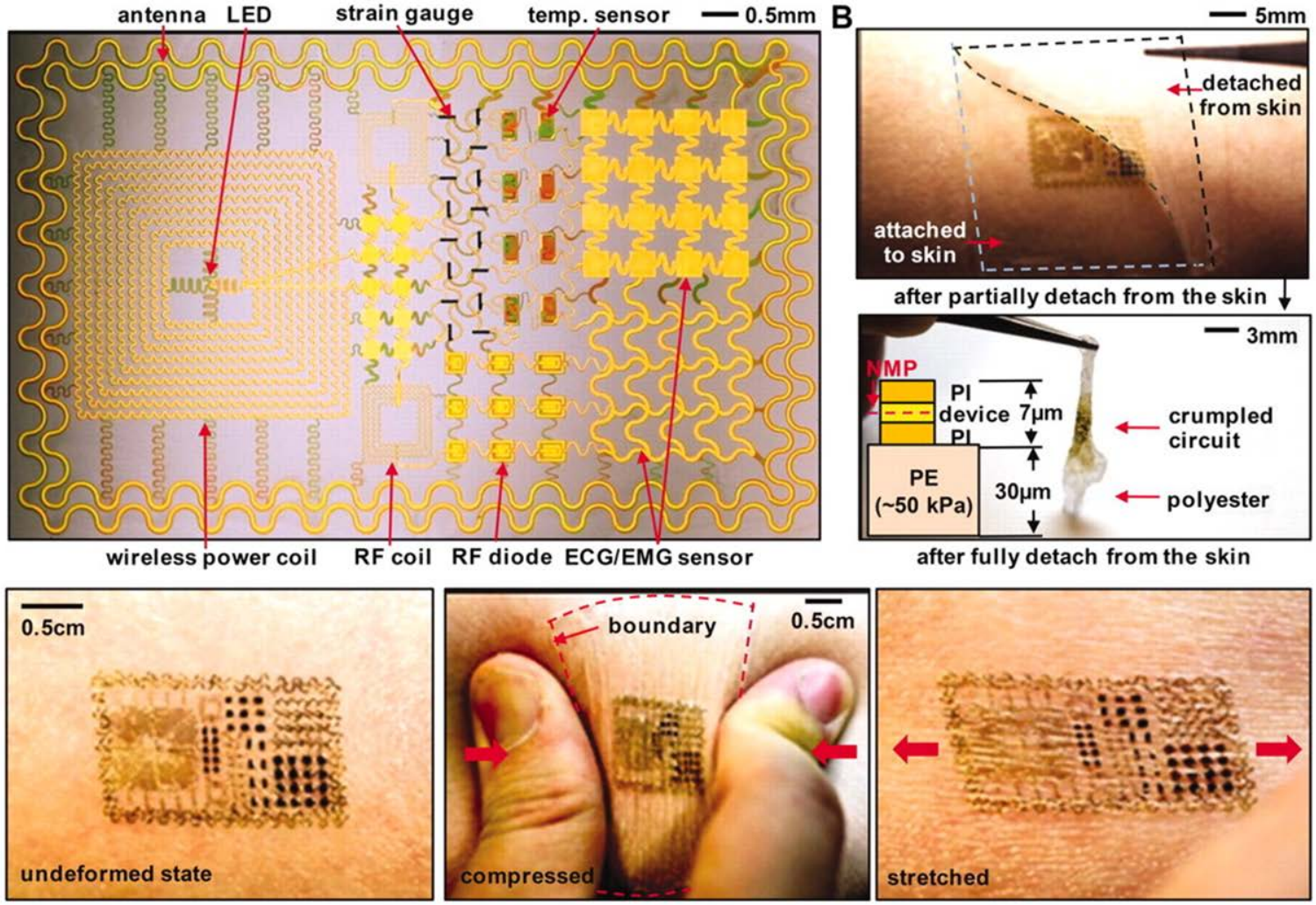
R = E+M+A+P+S

R layer or EMAPS layer

Spatial and functional integration is the next challenge

Epidermal electronic skin (EES)

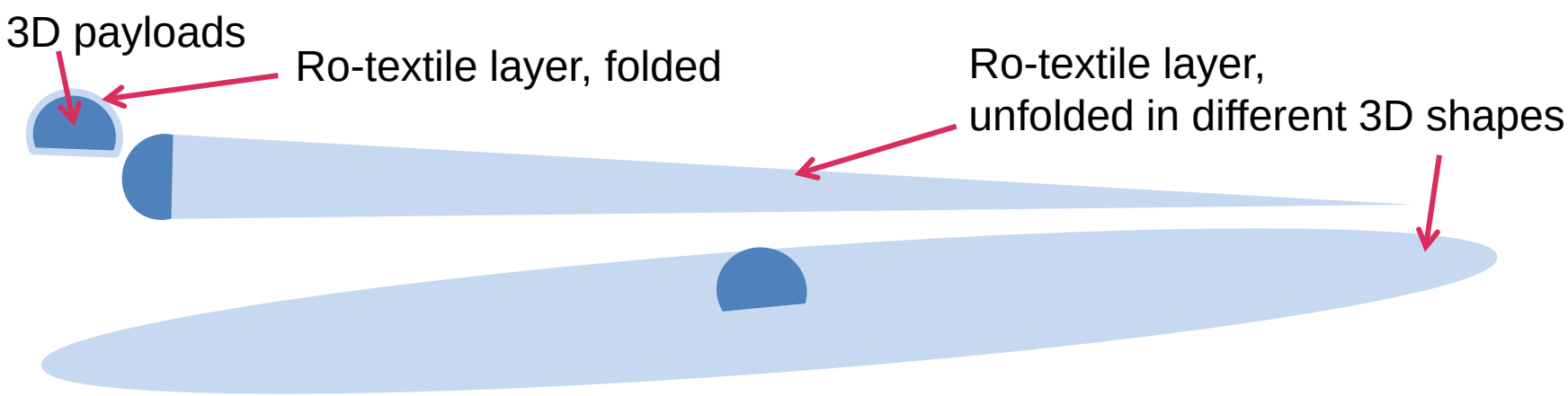
D.H. Kim, et al., “Epidermal electronics,” Science, ID: 1206157, 2011 (August 12)



…systems incorporating electrophysiological, temperature, and strain sensors, as well as transistors, light-emitting diodes, photodetectors, radio frequency inductors, capacitors, oscillators, and rectifying diodes. Solar cells and wireless coils provide options for power supply.

Non-integrated instruments

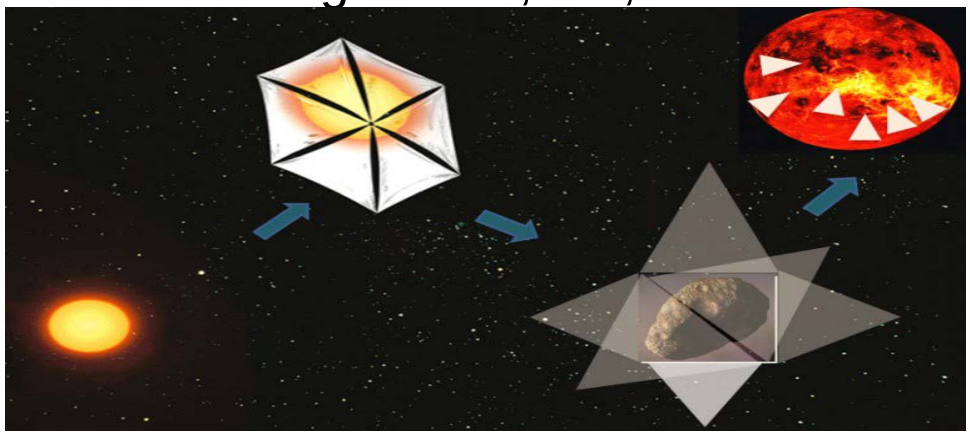
- Some 3D payloads may still be needed,
  - e.g. some special instruments that cannot be integrated as 2D structures;
  - these would be carried as payloads in kernels around which the 2D layer would fold.
  - Ro-textile layer would unfold to needed 3D shapes



Foldable, self-unfolding

- The ro-textile layer is
  - foldable to small volume (tightly folded at launch)
  - self-unfolding to adapt shape and function to mission phases.

An Ares V would have had ~1000m^3 divided by depth of 100micron gives 10,000,000m2 ~ 3km/3km sail/dish



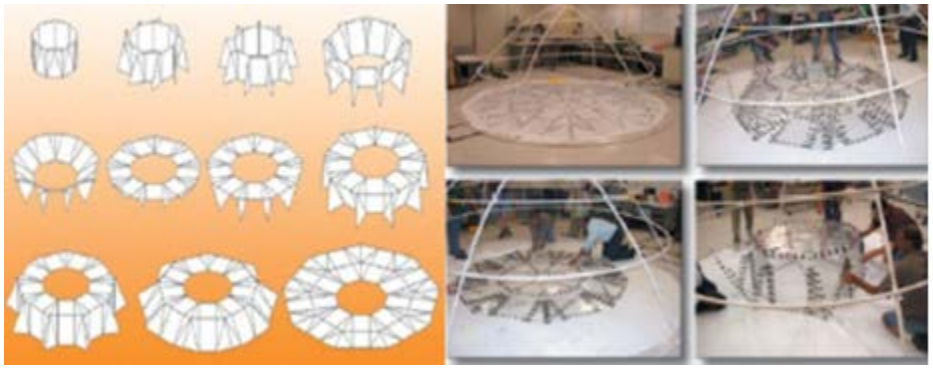
large solar sail for interplanetary/ interstellar travel

component patches separate in swarms of winged flyers in atmosphere

limbed robot capable of surface mobility and sample manipulation

3D from 2D

MC Escher – Bond of Union. Reflects the idea of using a band to shape 3D things.



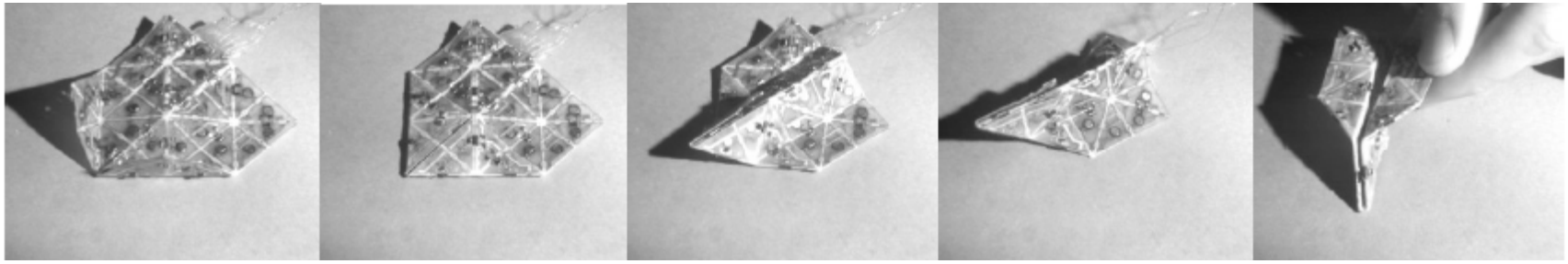
Right: Origami for folding lenses, at Livermore (LLNL)

Printable electronics

SULSA is the world's first 'printed' aircraft

Project SULSA UAV printed on an EOS EOSINT P730 nylon laser sintering machine, which fabricates plastic or metal objects, building up the item layer by layer.

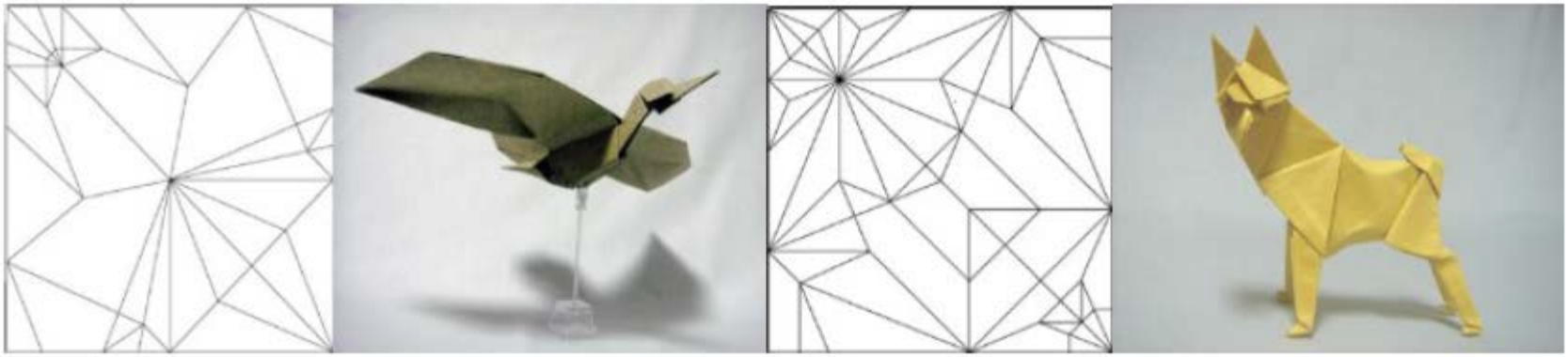
Simple self-folding surface (an origami ‘robot’)



Controlled 2D robotic origami that self-reconfigures, with shape-memory alloy actuators (Harvard-MIT).

- So far it only includes actuators (M-layer)
  - power brought to the surface by cables
  - controls also being computed/induced from outside

Folding



Diagrams, folding designs on 2D thin layer, and shaped 3D, dog and bird

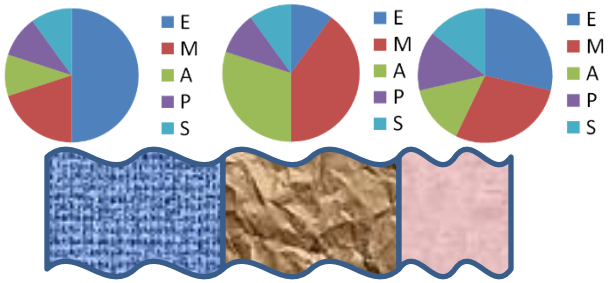
- Proper partitioning (sufficient resolution and choice of lines) would allow shaping of practically any 3D shape, as insured by various mathematical proofs.
- Common lines for multiple shapes (multi-function design) ensure ability to transform from one shape to another.
- *Flexible layers would provide further freedom for modification of shape at sub-cell resolution.*

Ro-fabric patches

- The surface is composed of connected ('zipped') multi-cell patches that can separate to operate in formations
- these may be all the same or specialized (e.g one with more sensing circuitry)

homogeneous mixture of functions along a single sheet.

homogeneous mixture of functions separated in multiple sheets, which can become a formation/swarm



heterogeneous single-sheet s/c (a 2D mechanical collapse of current s/c solutions) illustrating specialized functionality in each module

multi part, heterogeneous

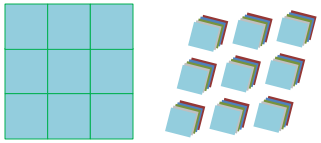
Ro-fabrics cells

- Cell embeds circuits of all s/c sub-systems (EMAPS)

- A cell-based architecture is used in

  Distributed computing

  Sensor array, etc



- Reconfigurable electronics
  - Field Programmable Arrays type architecture
  - Electronic/computing/function change/optimization
  - Sensor/antenna/ reconfiguration
- Should survive extreme environments without any protective layer

Transformer platforms

A revolutionary way to conceive

- Building of space platforms
- Exploration missions

- Low cost *design* paradigm
  - with reusable design, standard production of many similar platforms,
  - the built-in multi-functionality, with EMAPS
- Low cost *manufacturing* paradigm
  - In 2D, for example by printing methods, homogeneous.
- Low cost *deployment* method,
  - Thin, highly folded, low volume,
  - Light, low mass
- Cost-effective *operation*
  - a single space craft adaptive to multiple missions/targets.

Cheaper, fast response time

- *Faster and cheaper space systems,*

  reducing the launch and redesign cost for new missions:

  - *can launch more of them, and at shorter intervals,*
  - *can send them to many more places after launch.*

It would enable

an intense and persistent exploration program

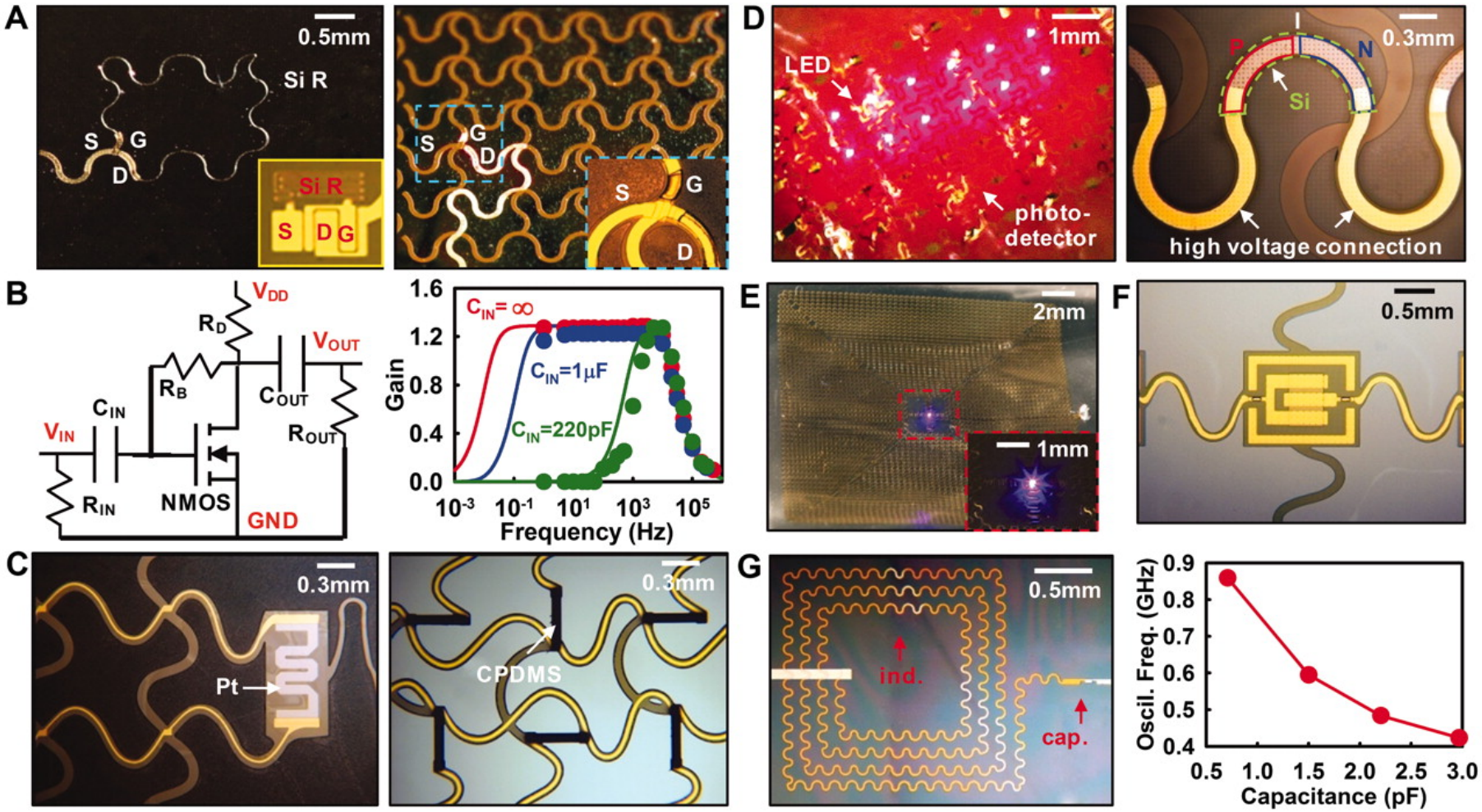
with a fleet of low cost,

shape/function changing robotic spacecraft,

adaptive to mission/phase needs.

Appendix

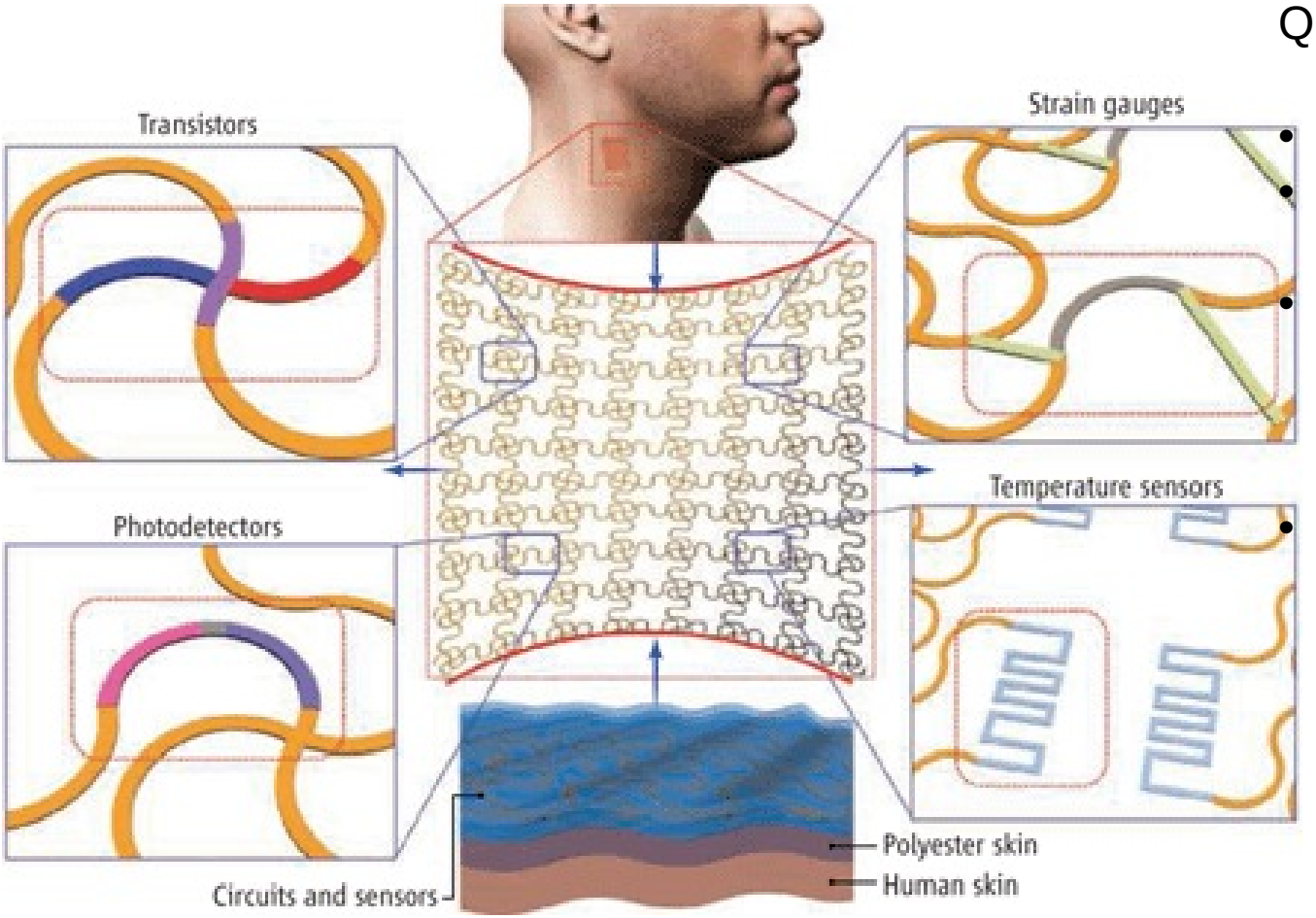
Optical micrographs of an active electrophysiological (EP) sensor with local amplification, as part of an FS-EES.



D Kim et al. Science 2011;333:838-843

Z Ma Science 2011;333:830-831

Information caught by film



Piezoelectric Polymers Actuators for Precise Shape Control of Large Scale Space Antennas
Qin Chen et al

- Electroactive polymers
- Flexible PVDF Film actuator technology,
- control of a 0.2-meter diameter membrane (2x25um thick) reflector engineering model,
- high-precision adaptive reflector surface contour control system for ultra-large deployable thin-material antenna reflectors