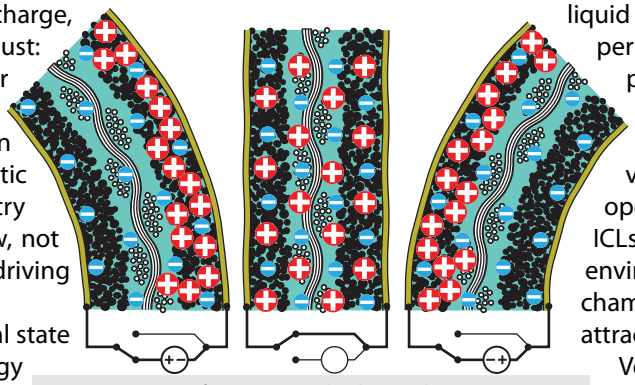
Compliant electroactive micromanipulators for scanning electron microscope

In situ micromanipulation and -probing of soft, especially biological, samples with real-time imaging using a scanning electron microscope (SEM) demands congruent actuators that are vacuum-compatible and do not interfere with electron optics. The novel class of micromanipulators that fulfils all the prerequisites uses a novel soft shape-morphing actuator made of a material called **ionic and Capacitive Laminate (ICL)**.

» ICLs have bipolar symmetric continous actuation
» ICLs can reversibly store electric charge, whereas the actuation is proportional to the applied charge, which makes its control very robust: merely an integral controller for input current can suffice
» ICL stress and strain behavior can be tuned by changing the elastic modulus and the actuator's geometry
» The operating voltage is very low, not exceeding 2.7 V, which makes its driving very straightforward
» An ICL actuator returns to its initial state passively, without additional energy input
» ICL can be fabricated completely metal-free, metals can be used as optional current collectors for an increased performance
» The charge stored into an ICL can be re-extracted at a high yield



Cross-section of an ICL in a discharged state (center) and charged to the opposite polarities (left and right)

Ionic liquid–polymer gel · Supporting fibers · Electrode active material · Current collector

ICL's actuation involves displacement of an electrolyte within the material in response to an electrical stimulus. ICLs with ionic liquid electrolyte demonstrate excellent performance both in air and in reduced pressure environments. Water sorption by ICL from ambient air results in a slight performance variation and in a decrease in its operating voltage range; therefore, ICLs are especially suitable for dry environments such as space and SEM chambers. ICL actuators are especially attractive for environmental-SEM.

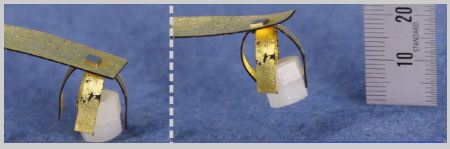
Very small size of an individual ICL actuator allows massively parallel probing of biological samples.

Owing to their intrinsic soft and compliant structure, ICLs offer an additional safety margin against damaging the samples.

ICL-based manipulators combined with SEM are attractive for:
» Manipulation and electrical probing of soft objects
» Probing of soft gels and liquid droplets

Applications for soft ICLs

» **Manipulators for vacuum environment**
» Grippers for small and fragile objects[a]



» Bio-inspired micro-robots[b]

» Safer micro-medical and -surgical devices
» Flexible ultracapacitors for energy storage

[a] www.youtube.com/watch?v=SBObUisncvk
[b] www.youtube.com/watch?v=1mSMsIQMTnU

Key characteristics

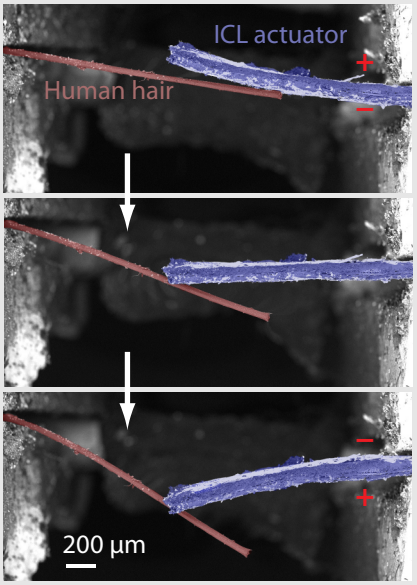
Actuation type	Bending cantilever
Operating voltage	±2.7 V (in vacuum)
Strain level	0.5% V^{-1} typ
Thickness	50—500 µm
Capacitance	50—150 mF cm^{-2}
Current density	0—50 mA cm^{-2}
Elastic modulus	100—400 MPa

Case study: **Manipulation of human hair in-situ under SEM using an ICL**[a]

» Free length of ICL 1.6 mm
» Tip deflection >0.5 mm
» Chamber pressure ~50 Pa
» No interference with electron beam due to low voltage and no magnetic components
» No evaporation of ionic liquid electrolyte
» Soft ICL actuator provides extra compliance

Possible configurations:
» Actuator for a stand-alone manipulator
» An end-effector

[a] www.youtube.com/watch?v=XzREDblOta8



Effector technologies for SEM manipulators

	ICL	Electro-thermal[a]	Electro-static[a]	Piezo-electric[a]	Electro-magnetic
Voltage	Low	Low	High	High	Low
Thermal drift	Low	High	Low	Low	Low
Actuation range	High	Low	Low	High	High
Magnetic interf.	No	No	No	No	High
Compliance	Yes	No	Yes	No (PZC)	Yes

[a] Shi, Chaoyang, et al. Microsystems & Nanoengineering 2 (2016)

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