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Results of Modeling the Mechanical Behavior of an Ionic Polymer-Metal-Composite for Assembling as an Actuation System

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Teflon™ is a rather inert material, chemically and thermally resistant, hydrophobic and a good electrical isolator. In the 1960´s, Dr. W. Groth found a way to coupling *sulphonic groups* onto the molecular fluor-carbone chain. Due to its hydrophilic surface properties and *proton permeability* the resulting material *Nafion*™ is of high interest in several fields of technology. If Nafion™ is covered with a metallic layer on both sides and a voltage is applied, actuatoric effects can be observed. This 'side-effect' chemically is studied at TITK Rudolstadt in detail. Electroless-reductive plating is used to fabricate Nafion™- platinum or gold multilayers ('IPMC').

Depending on the direction of the electric field between the metal electrodes, the hydrated cations (H_3O^+) move to their corresponding electrode. The resulting volume gradient increase in that particular area of cross section leads to a significant deformation (see fig. 1). In the case of a strap shaped element, bending can be observed.

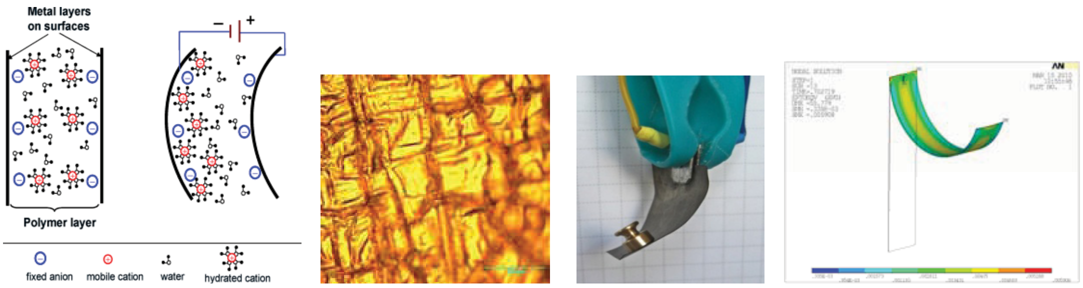

Fig. 1: Actuation principle [1], Surface morphology after sputtering gold, Nafion-straps (Membrane N117, 175 µm; DuPont Inc., 30 x 10 mm², actuation voltage ca. 3 V at a Kelvin-clamp), FEM-simulation shows an in-equally dispersed mechanical stresses.
Ref.: [1] Chen Z., Tan X.: A Control-Oriented and Physics-Based Model for Ionic Polymer–Metal Composite Actuators) IEEE/ASME. 13/5, 2008.

In the Center of Micro- and Nanotechnologies several metallization processes were evaluated. Plasma deposition of gold onto the chemically deposited metal, as well as a single gold layer (100 – 300 nm) on the uncoated Nafion™, have been tested. The ductile mechanical behavior of gold and its excellent adhesion on the surfaces had a positive effect on the overall characteristics of the Nafion-Actuators.

The department of Biomechatronics (IMN MacroNano®) currently is working on the implementation of biomimetic principles into actuatoric Nafion™ elements. One source of inspiration is the human muscle. Polymer based muscle-like drives are under intense research worldwide, mostly operated by ion absorption from an electrolyte with a resulting volume increase. In contrast, Nafion™ can be operated in air with no need for any additional liquids. The requested water already is inside the material due to its hygroscopic behavior. Our approach to an *artificial muscle* at first is based on bending beams, collaborating in a mechanical cascade.

However, the general handling of metal coated Nafion™ pieces is still the main technological challenge. The compliance of solvated foils, the key property for the actuator-effect, also is a major drawback. Standard electric interconnecting technologies such as soldering or gluing cannot be used. In addition, each motion cycle strains the metal layers to their limits and beyond. A conductive *polysiloxane* elastomer seems to be a promising future solution for both problems.

The first attempt in design of motion systems is the transformation of the bending into *linear* motions. Two principles are taking to consideration: a *knitted network* of slender stripes or a structure, called the "*lampion*". FEM-models indicate that both of them are rather in-effective (fig. 2).

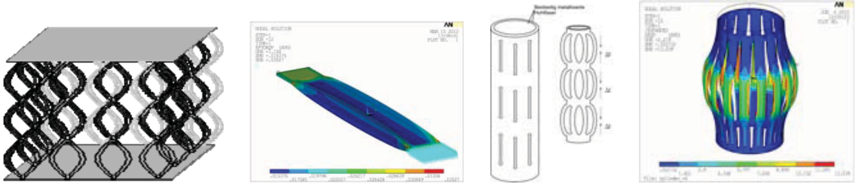

Fig. 2: (left) with serial and parallel cascaded double bowing stripes; (right) by a contraction of a longitudinal splitted tube wall in comparison with their calculated behavior.

One further phenomenon also is a constructive challenge: because the ions are crossing the volume between the metal sheets the bending does not only occur in the preferred direction, but in both directions of the whole area of the polymer foil. This *spherical* deflection causes a "loss" of the generated mechanical force which can be coupled out. FEM models visualize the dispersion of stresses in a square membrane. The suggested geometry to extinct such sectors of compression is for example to split the foil radially, like a *malthesian* cross. Now the motion is usable for the assembly of a linear actuator (fig. 3).

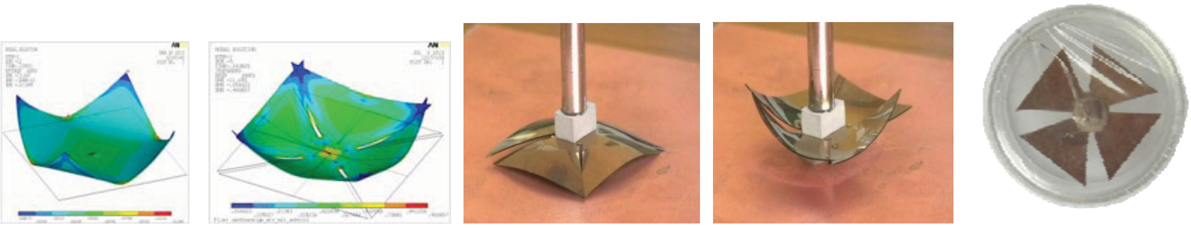

Fig. 3 (left): simulation the ubiquitary spherical deformation, if the membrane is splitted; (middle) the convex deformation will be enhanced; (right) by central conducting with silver-doted siloxane gum, this flat actuator is flapping up- and downward by changing polarity and finally the encapsulated "*malthesian cross*" in a very tensible membrane of polysiloxane elastomer.

For this geometry we can conclude one first advantage - such membranes with cyclic deformation are able to change a volume in a cavity beyond them. This assemblage can be used as a piston for pumping of a fluid. If three of those pistons are added in serial, a *peristaltic* module in analogy of the gut is realizable.

Further applications seem possible if the actuatoric substrate IPMC will be maintainable in different environments and capable for precise control of the motion parameters by electrical signals.

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