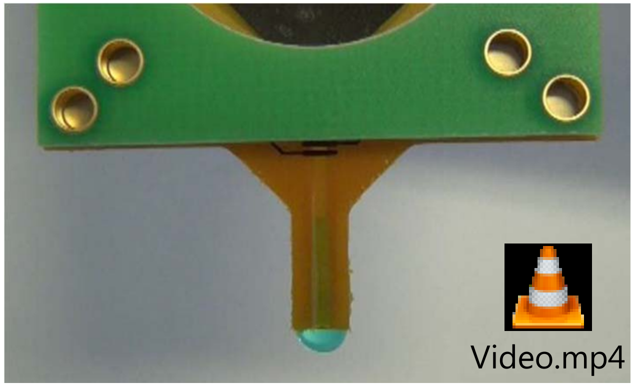
Integration of CNT-based actuators for bio-medical applications

Example printed circuit board CNT actuator pipette



Fraunhofer IPA, Germany
AIST Kansai, Japan

Besoncons,France
11.07.2014

Raphael Addinall
Raphael Neuhaus

Fraunhofer IPA as part of the Fraunhofer-Gesellschaft

Europe's largest applied research organization

Fraunhofer

IPA

Fraunhofer Institute for Manufacturing Engineering and Automation IPA

- One of the largest single institutes of the Fraunhofer-Gesellschaft
- More than 50 years of experience
- Competent at implementing innovations into industry

AIST NEDO PtJ Projektträger Jülich Forschungszentrum Jülich — Projektträger für das Bundesministerium für Bildung und Forschung — Fraunhofer IPA

German-Japanese Cooperation

Fraunhofer Institute for Manufacturing Engineering and Automation (IPA)

Department Functional Materials

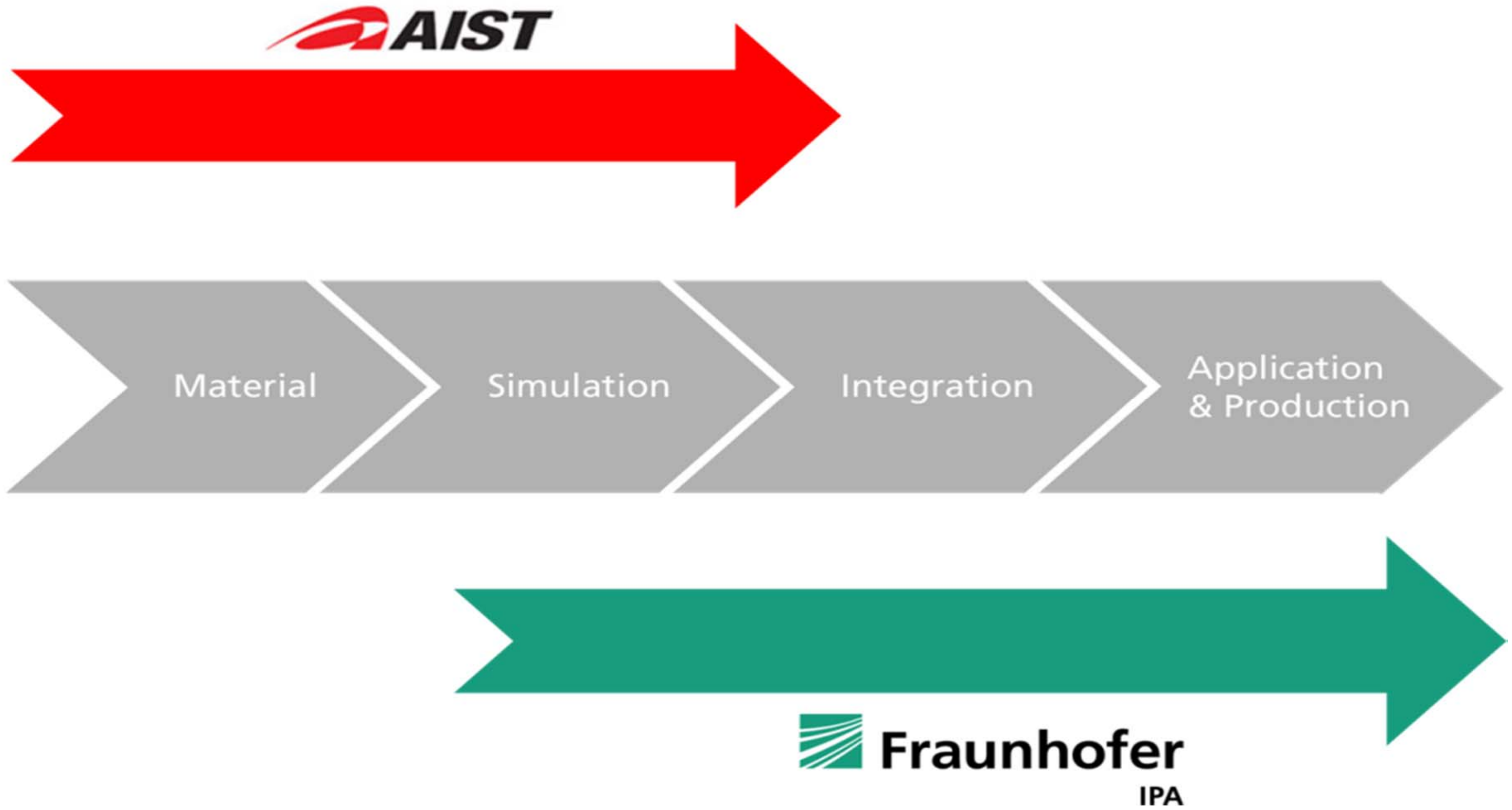
AIST Kansai National Institute of Advanced Industrial Science and Technology (AIST)

Research Institute for Cell Engineering

Picture source: http://cio-perspectives.com

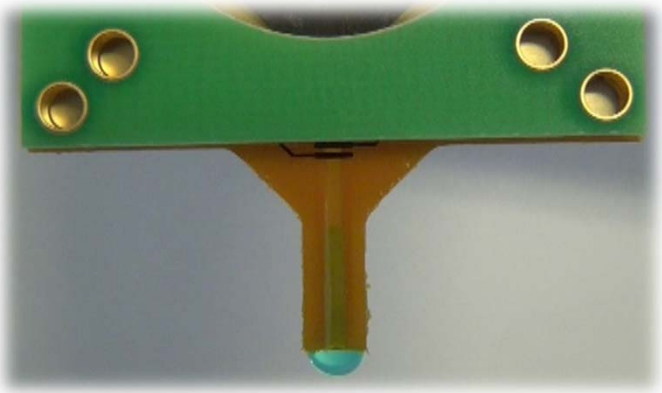
Complementary Workflow of AIST and Fraunhofer IPA

Sharing and complementing Expertise

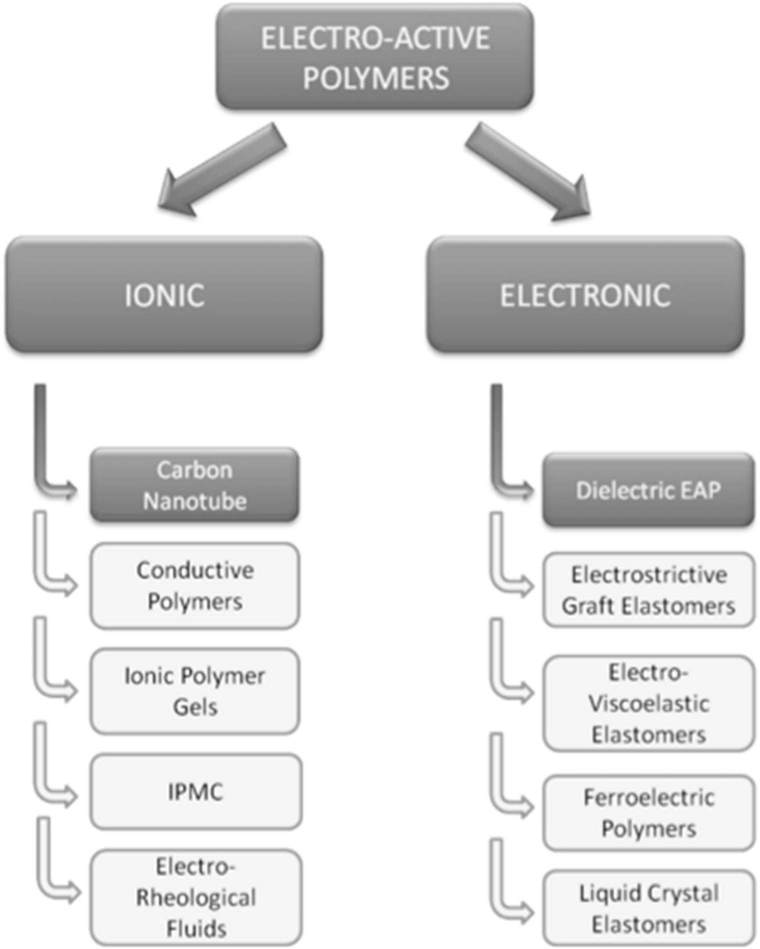


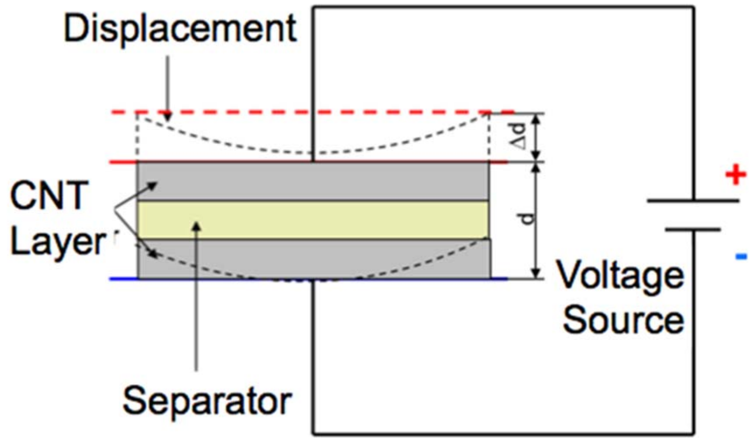
Overall aim of our collaboration

- **The need for integration:**
  - use actuator technology in a specific application
- **Exploring the design space and optimization:**
  - Finite element simulation of actuators – compare and predict actuator behaviour
- **Production technology:**
  - Both printed circuit boards and actuators



Actuators





Application of voltage on the CNT electrode layer

↓

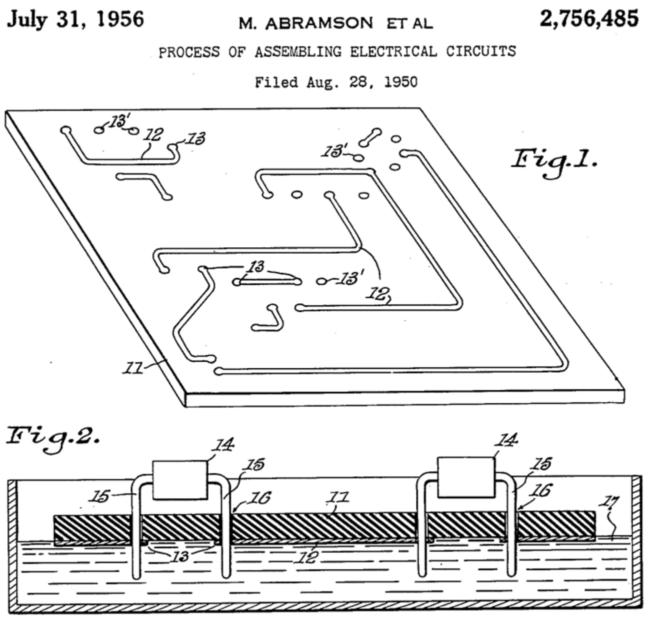
Change in the charge density in the electrochemical double layer

Quantum-mechanical effects "Swelling" of one electrode layer

↓

Actuation

Printed Circuit Board (PCB) Technology

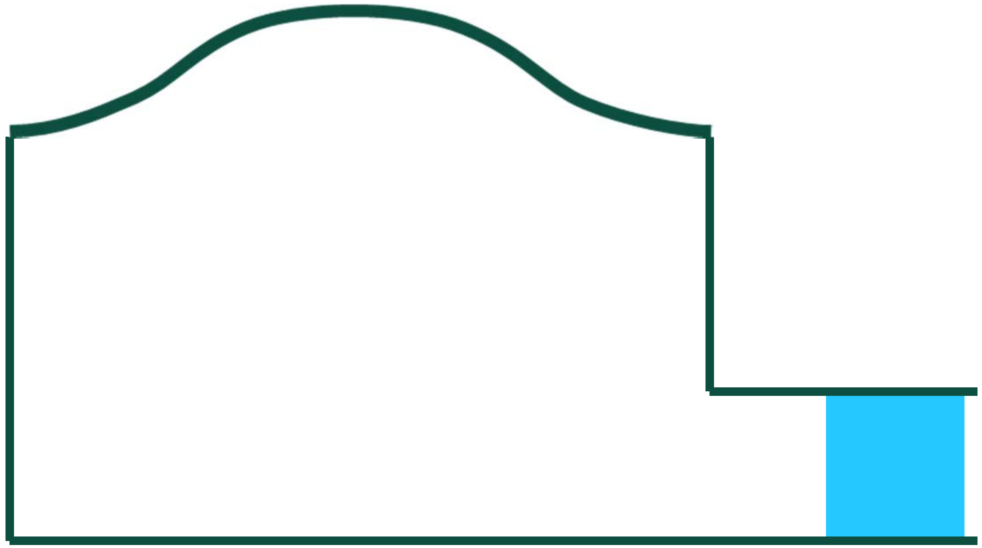


First patent-1956, M. Abramson et AL

- Standardized interfaces (mechanical/electrical)
- Standardized production
- Easy handling
- Easy integration of driver electronics
- Integrated electrodes and connection leads

Principle: Displaced Volume

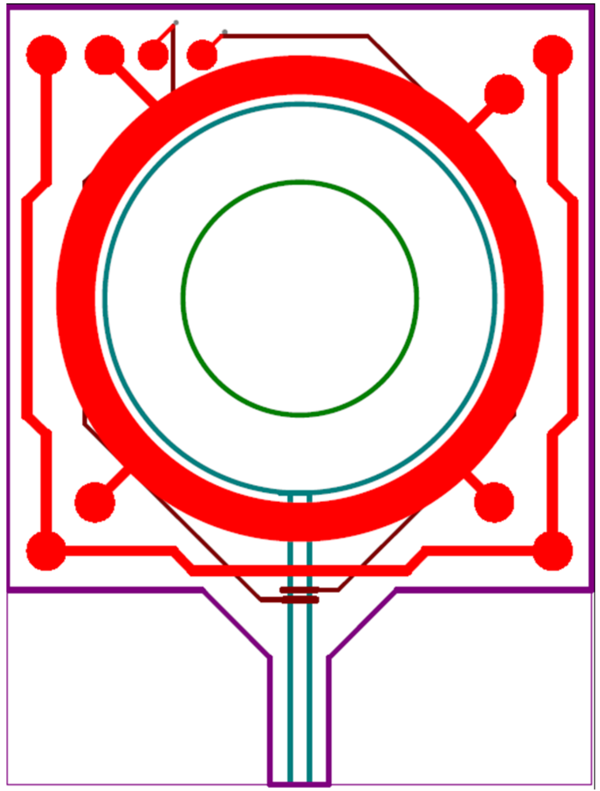
Overall aim



Design aim for actuation: > 100 µm in center, > 10 µl displacement

CAD PCB Design

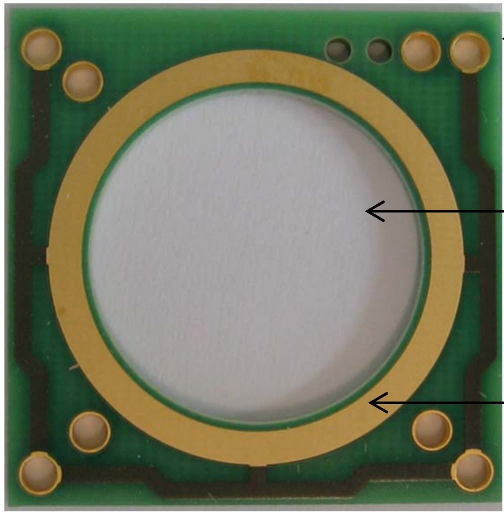
- 2D CAD design on several layers
- Layer stack:
- PCB boards made of standard FR4 material
- 50 µm polyimide foil or PTFE

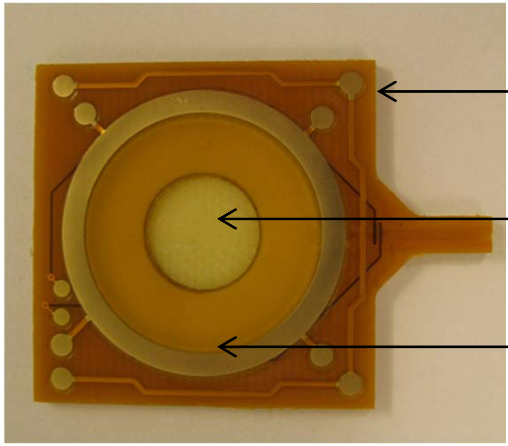


	Verpressen	Material	Position / Film	
		Deckfolie		63
T DKS	↑	Cu: 18µ -> 35µ		35
Polyimid	1.1	Polyimid: AP8525		50
B	↓	Cu: 18µ -> 35µ		35
		Noflowprepreg		50
		FR4 Kern 1,5mm		1500
Arbeitsablauf:			Kürzel:	1733

Source of layer stack: Contag AG, Berlin

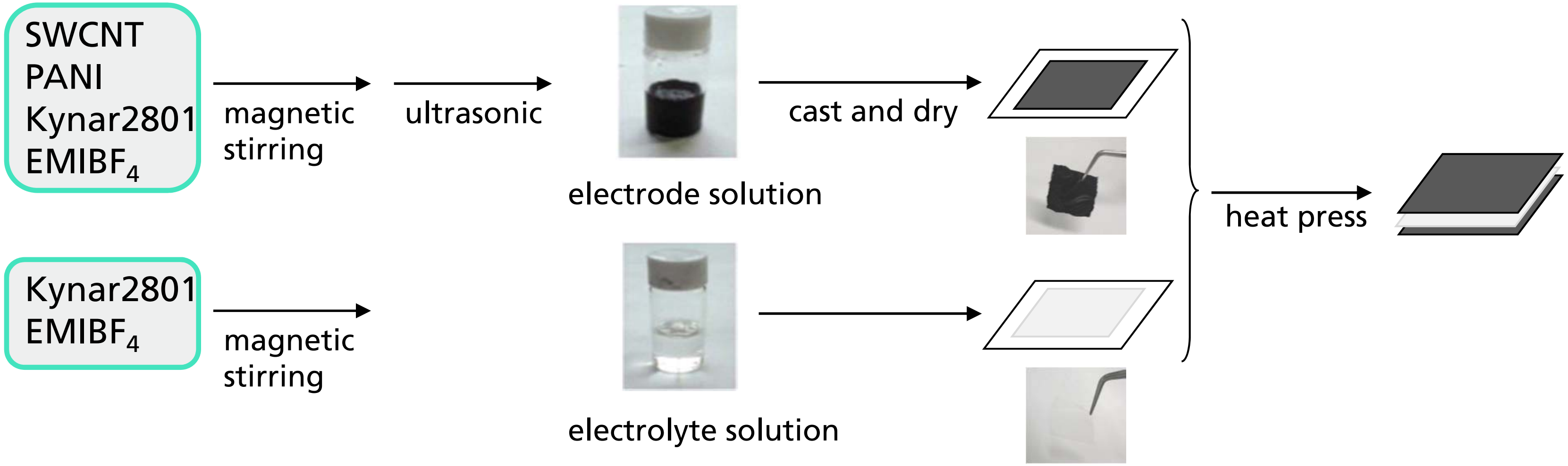
Printed circuit board (PCB) Design





- Holes/vias with and without metallisation
- Mill any inner geometry
- Etch any electrical trace geometry into copper
- Nickel/gold plating
- Lower stiff layer
- Flexible Membrane ring

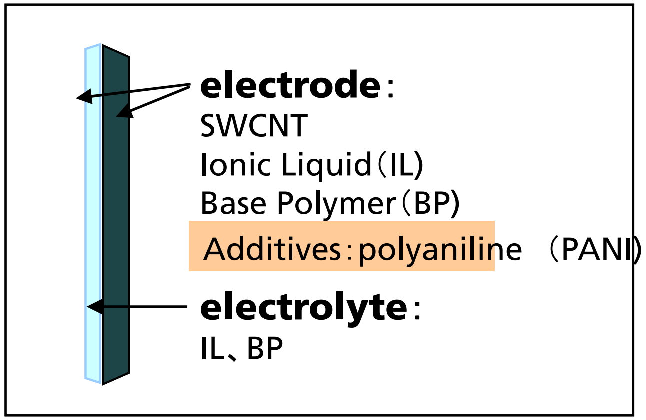
Fabrication process of the three-layered actuator



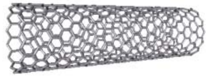
【Characteristic data of PANI】

20 wt% polyaniline on carbon black
particle size：ca. 40 nm
conductivity：40 S/cm
BET surface area= 690 m^2/g

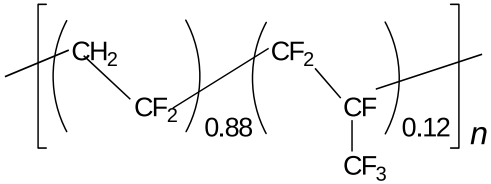
【Structure of nanocarbon polymer actuators (three-layered) and components】



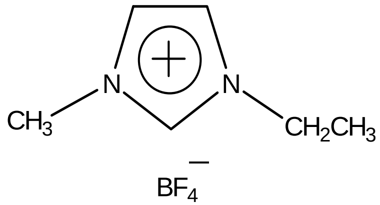
SWNTs: Single-walled carbon nanotubes by HiPco method



BP: PVDF-HFP(kynar2801)



IL: $EMIBF_4$



- stable and long-life actuation in air
- low voltage drive (within ±3V)
- easy fabrication by a casting method

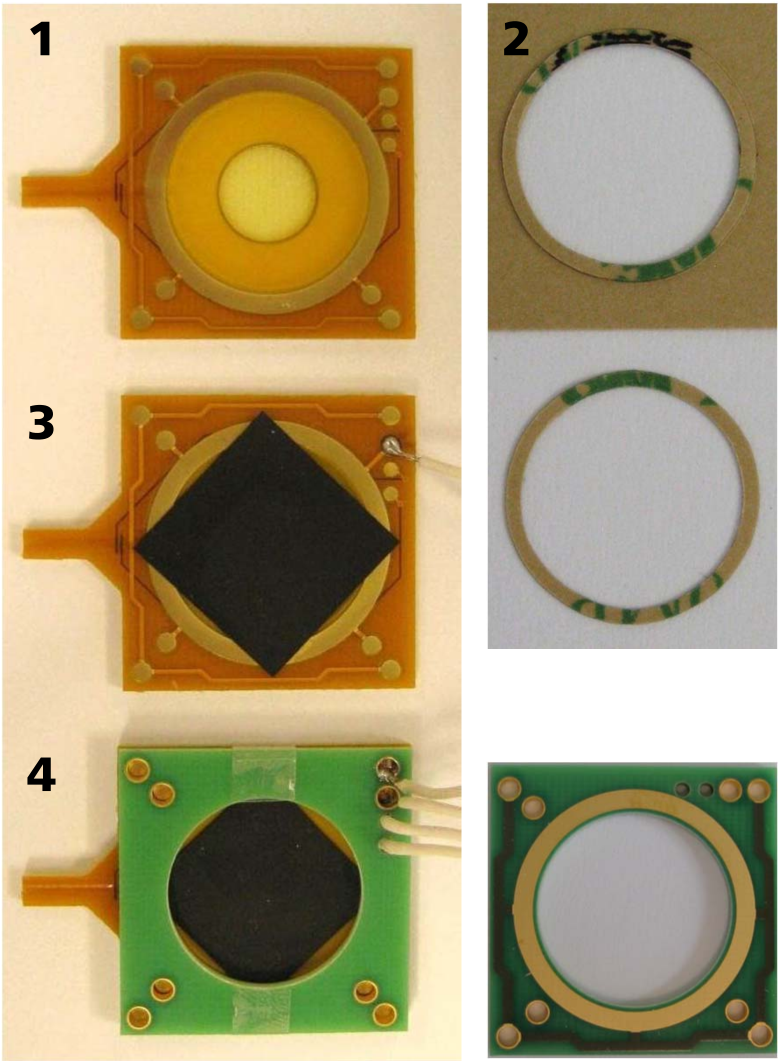
Electrode:SWCNT/PANI(50/50)-2IL

components: **SWCNT**/**PANI**/kynar2801/$EMIBF_4$=**50.7 mg**/**50.6 mg**/80.6 mg/240.9 mg
(**11.99 wt%**/**11.97 wt%**/19.06 wt%/56.98 wt%)

Electrolyte: kynar2801/$EMIBF_4$

components: kynar2801/$EMIBF_4$=200.4 mg/200.1 mg
(50.04 wt%/49.96 wt%)

Integration & connection methods



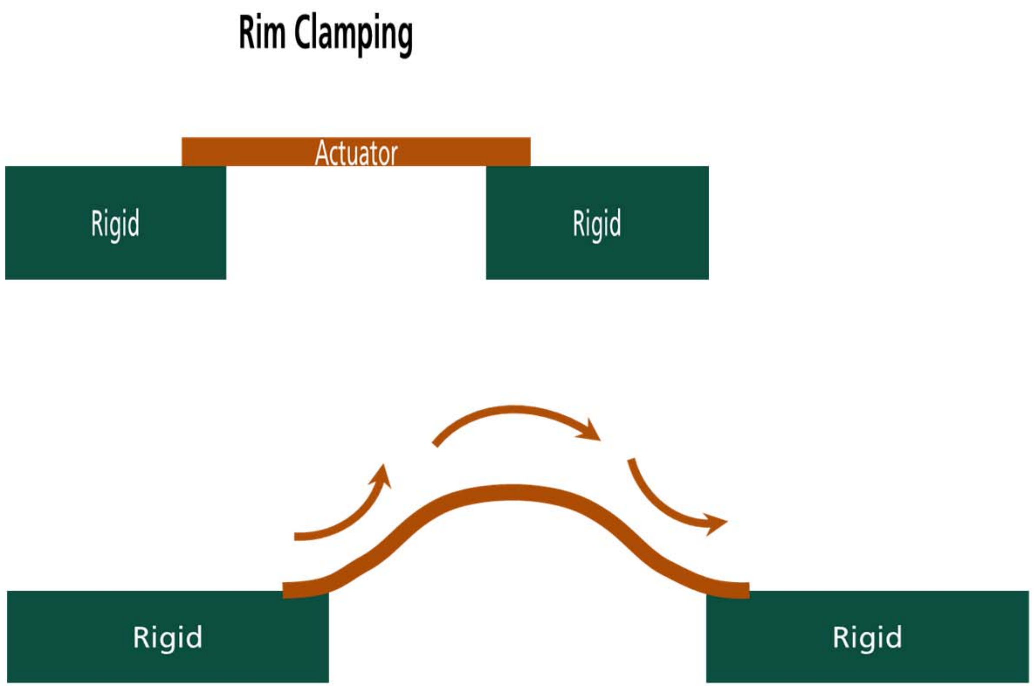
Mechanical:

- Gluing (Epoxy, „super glue“, etc.)
- Tape (3M Double sided) laser cut

Electrical:

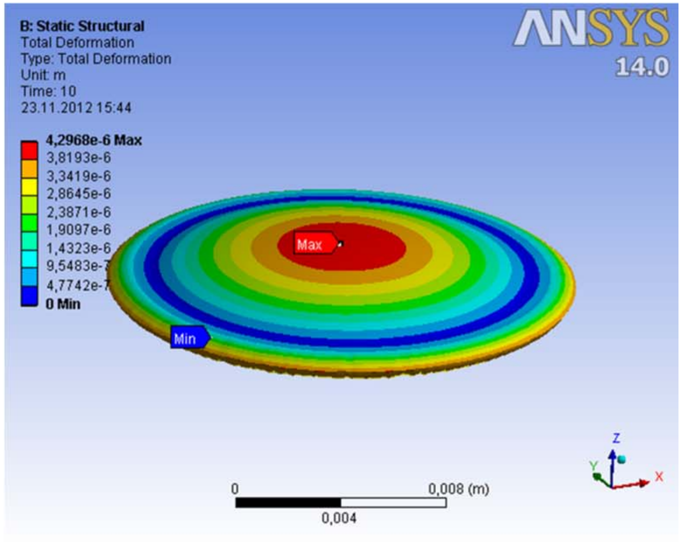
- Soldering, Reflow soldering
- Conductive glues or glue tapes
- Non-standard: Low temperature solders
- Clamping with top electrode (PCB)

Positioning of actuator to PCB (no soft intemedeate layer)



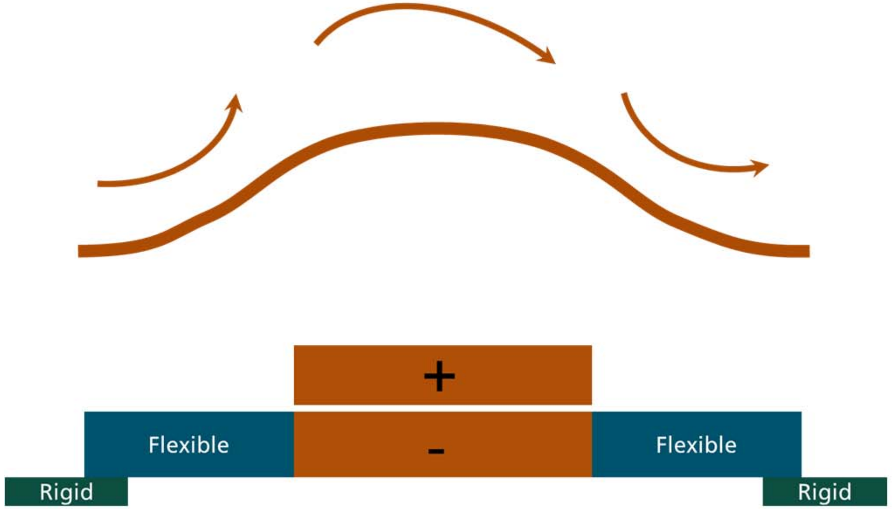
Rim Clamping: Non-constant Curvature

Soft to hard - rim clamped actuator

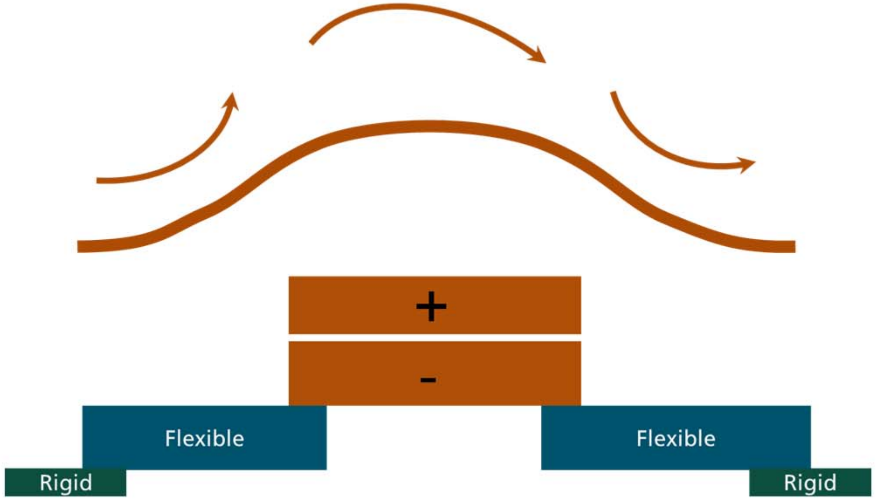


Positioning of actuator to PCB (with soft intemedeate layer)

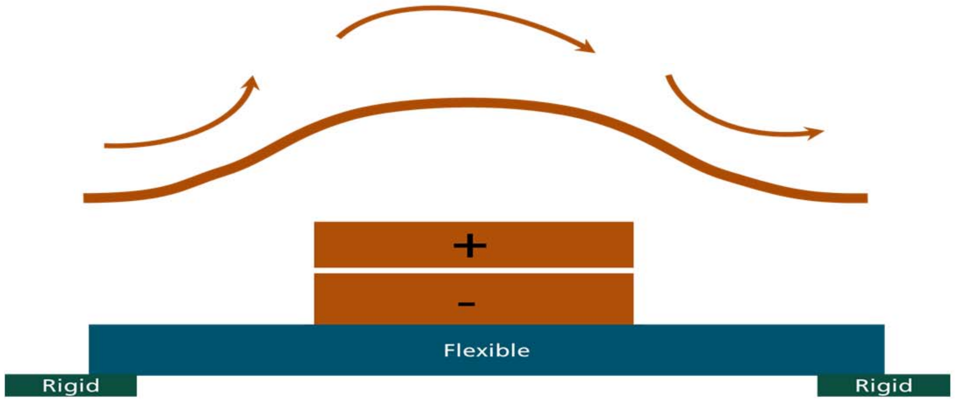
Setup with Passive Flexible Layer



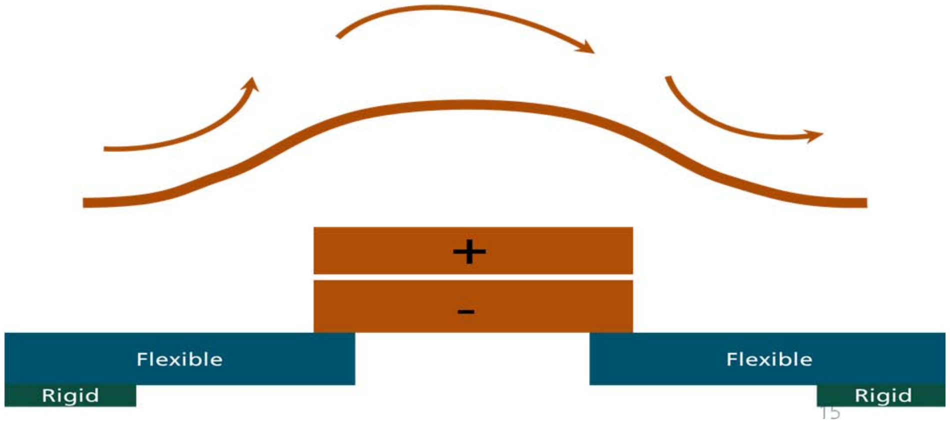
Setup with Passive Flexible Layer 2



Closed Membrane Setup



Open Membrane Setup



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PROJEKTTRÄGER FÜR DAS Bundesministerium für Bildung und Forschung
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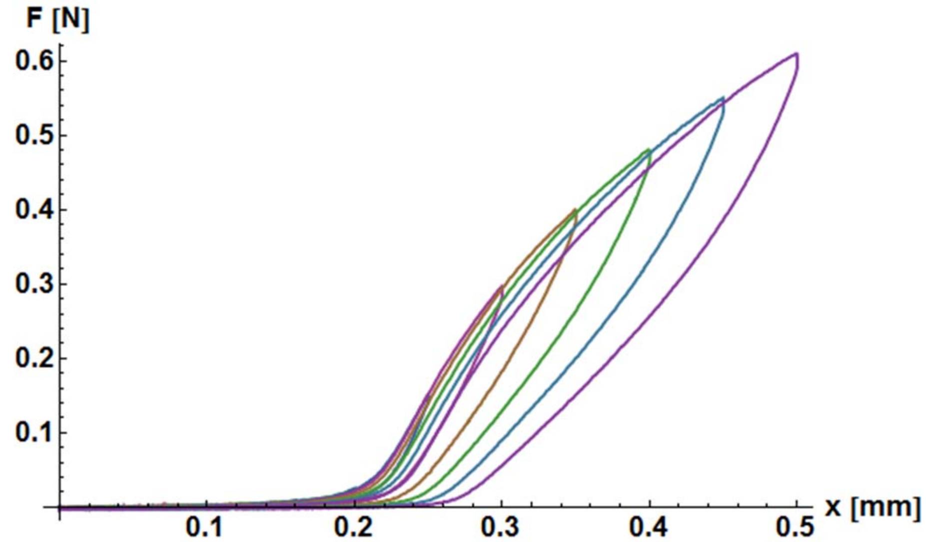
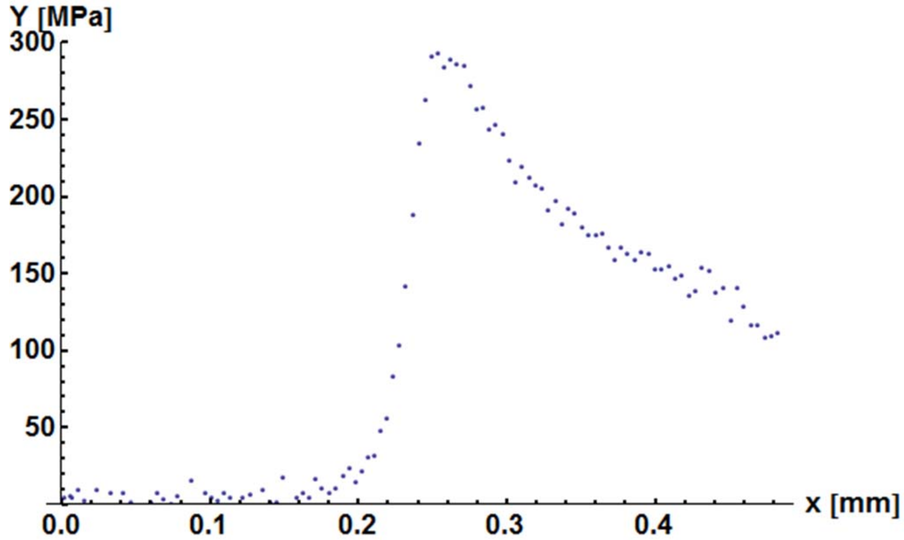
Tensile Test Data and Digital Material Models





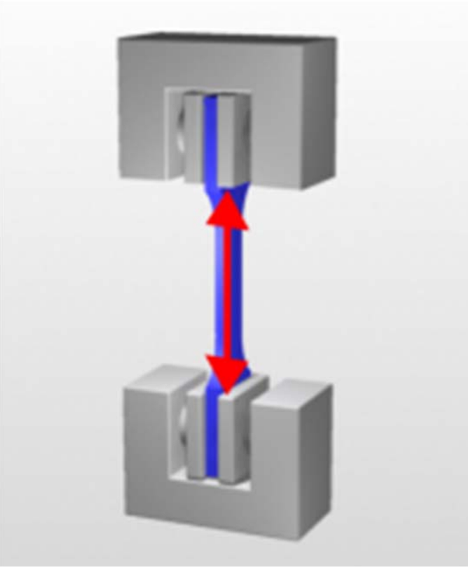
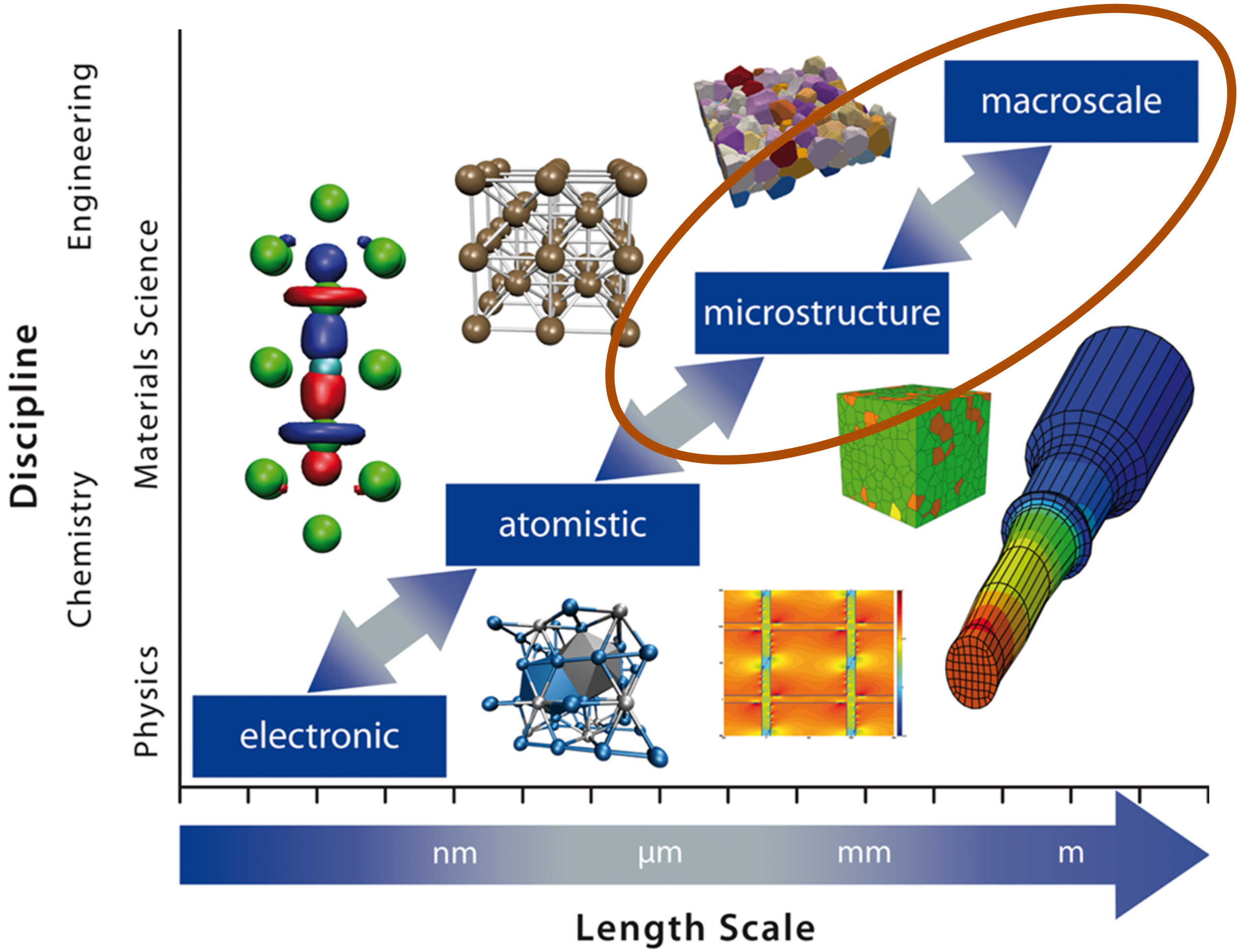


Image source: Zwick (Software)

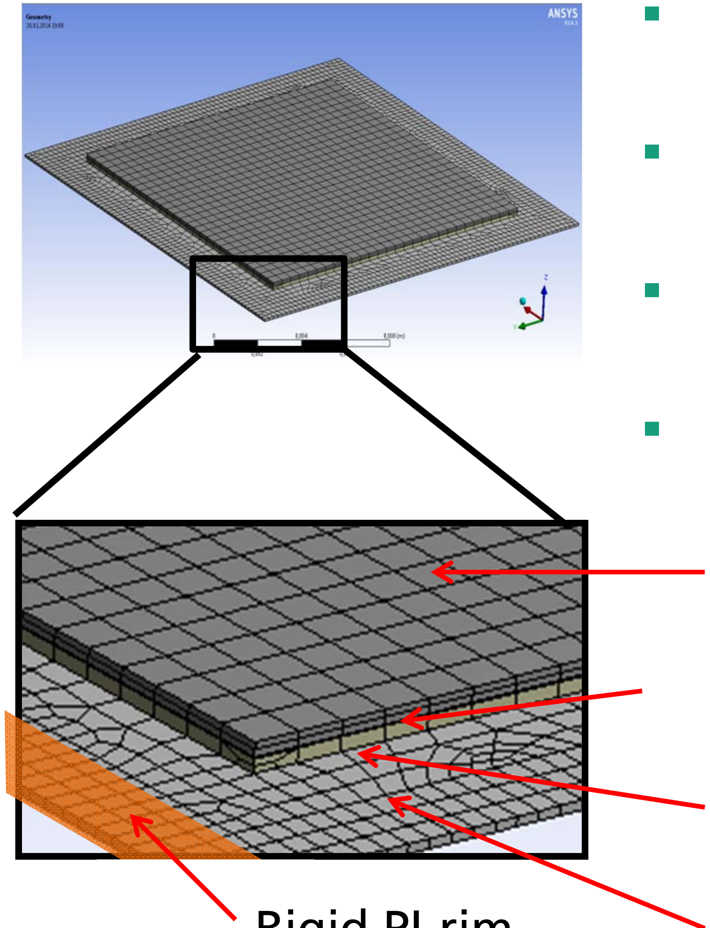
Simulation
Multi-scale simulation



Macro-scale simulation
- Static Analysis - FEM
- Dynamic processes / vibrations
- Heat transfer
- Flow processes
- Electromagnetism

Microstructure Simulation
- Friction processes
- Heat conversion
- Dynamic stiffness
- Composite modeling
- New Materials
- Nano / micro-reinforced plastics
- Functionalization

Meshing of electrode, seperator and polyimide layers



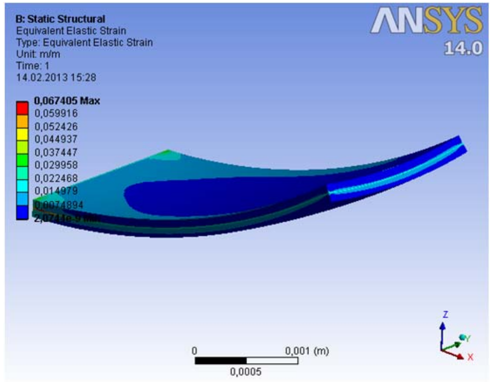
- Using material parrameters depending on strain
- Estimation of Young's Modulus
- Fitted E modulus found to be 42MPa
- To match the measured actuation force

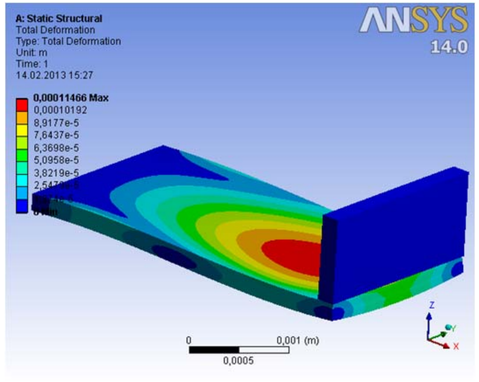
Matching Experimental Data and Linear Elastic Theoretical Model

1) Match effective strain 0.9 % by displacement

2) Match Young's Modulus with force

(Poisson's Ratio 0.35; fixed 70 MPa for electrolyte layer)

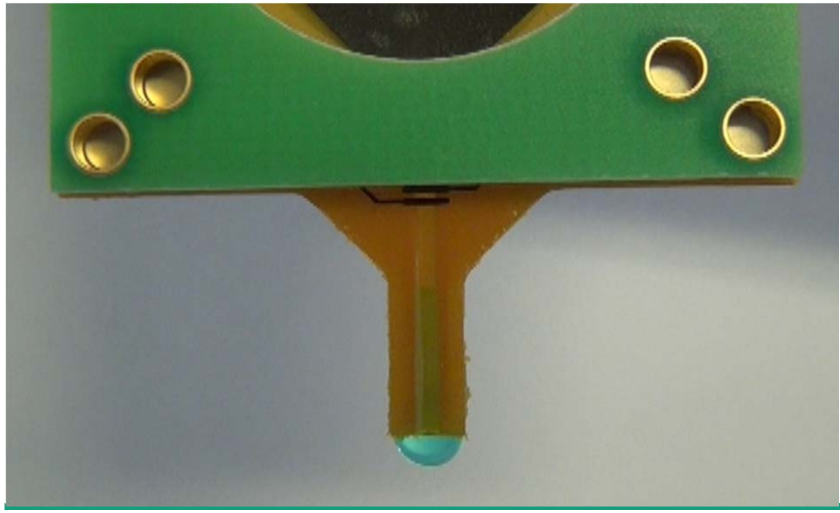




P2 Electrode Thickness	P6 Actuator Width	P3 Electrolyte Layer Thickness	P4 Young's Modulus	P7 Deformation Probe Z Axis	Corresponding AIST actuator measurement	P1 Force Reaction Z Axis	Corresponding AIST actuator measurement
µm	mm	µm	MPa	mm	mm	mN	mN
90	2	7.5	350	1.21		22.5	
90	2	7.5	100	1.21		6.5	
105	2	7.5	42	**1.06**	**1.15**	**3.7**	**3.87**
173	2	7.5	42	**0.66**	**0.53**	**10.0**	**9.43**

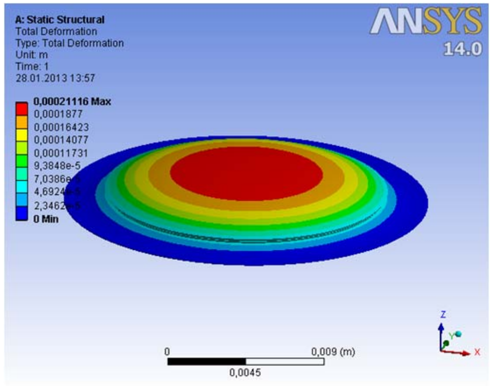
Actuation Test of Pipette

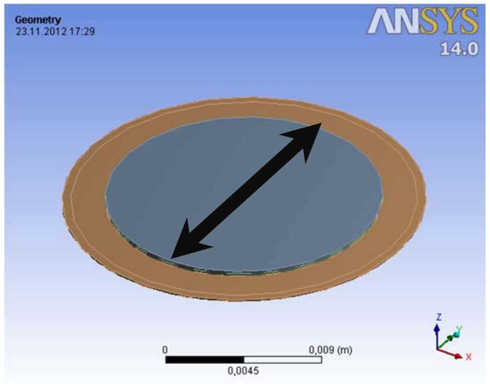
Pipette number	Actuator number	Actuator thickness	Membrane inner radius	Cut to shape	Top electrode connection	Glue	Actuation	Comment
P5	X	323 µm	6 mm	no	Counter PCB	Epoxy	70 µm	Large droplet
P9	VII	323 µm	6 mm	no	Counter PCB	Epoxy	50-70µm	V fast current discharge 0.03A reached in <10sec
P11	V	271 µm	7 mm	no	Counter PCB	3M ring type laser cut		Operation tested for fluid level change, small droplet



Design Space and Parameter Tuning: Open Membrane

Young's modulus for electrode layer	42 MPa
Young's modulus for electrolyte layer	70 MPa
Flexible layer thickness (passive layer)	0.05 mm
Flexible outer radius	20 mm
Thickness of actuator electrode	150 µm
Thickness of electrolyte layer	15 µm



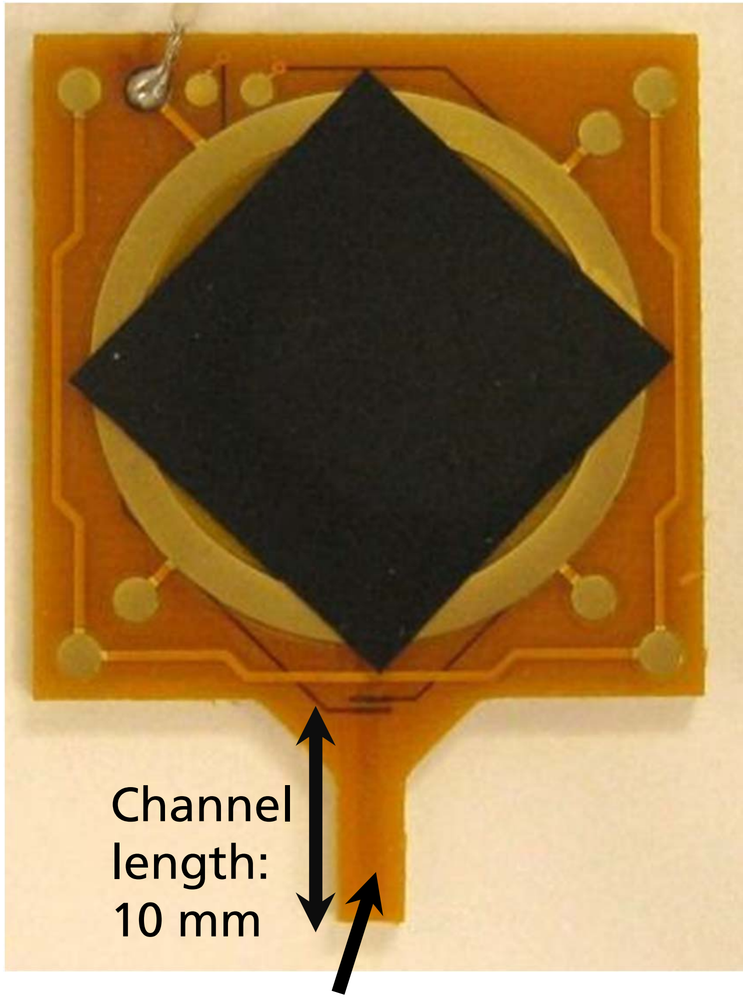


Actuator diameter (with 1 mm glue ring)	P7 Deformation Probe Z Axis
mm	µm
10	167
12	190
14	208
16	211
18	199

End result - Pipette Features

- **Fluidic**
  - Nominal fluid and actuation volume 10 µl (up to 20 µl - single droplet)
  - Resistive upper fluid level detection.

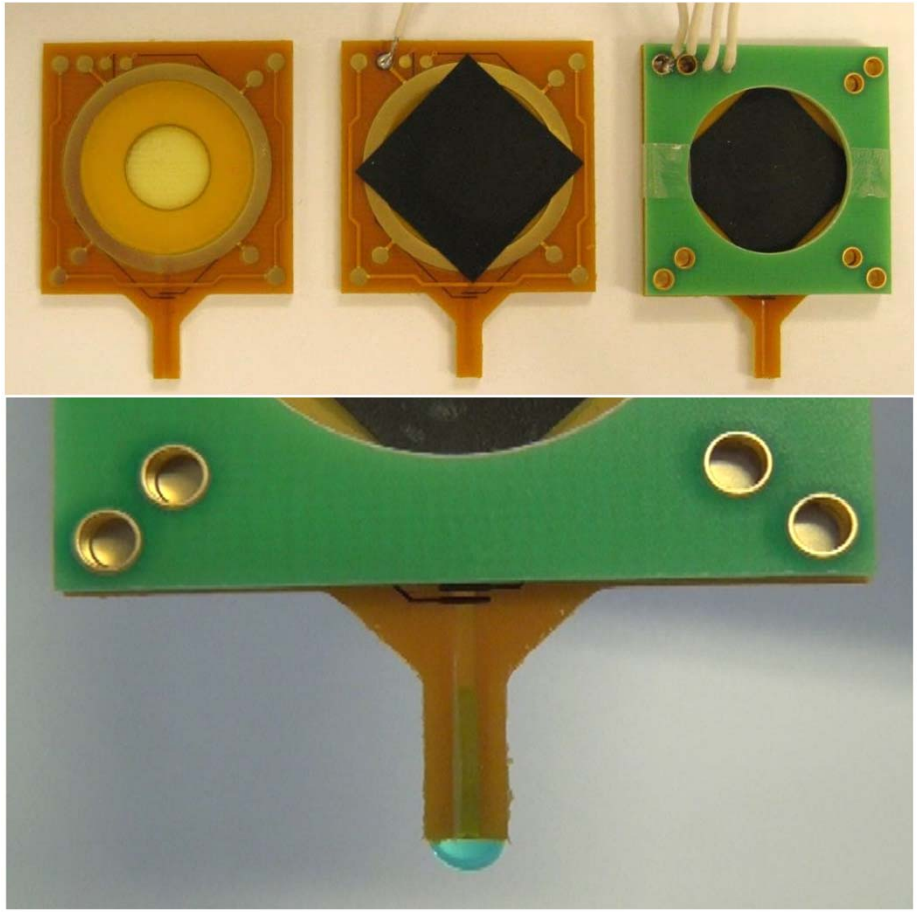
- **Electrical specifications**
  - Driving voltage 2 V
  - Capacity 0.23 F
  - Peak current 0.21 A
  - Charging time (10 % to 90 %): 4.1 s



German-Japanese Cooperation – First Joint Development 2012 –Pipette with CNT actuator

- Simulation of actuation and geometry
- Material development and processing
- Electrical contacting and system integration
- Construction and engineering of Pipette based on PCB board
- Showed at Nanotech 2013

The 12th International Nanotechnology Exhibition & Conference
nano tech 2013



Team Kick-Off Meeting Osaka – March 2013

AIST

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Thank you very much for your attention

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