Institute for Electron Microscopy and Nanoanalysis
Graz Centre for Electron Microscopy

Micromechanics

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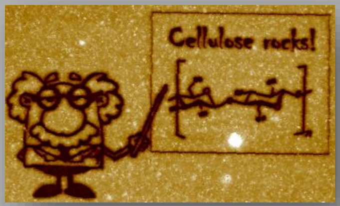
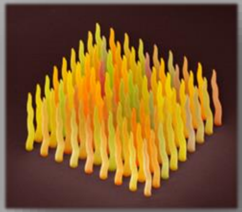
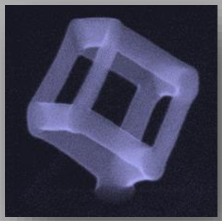
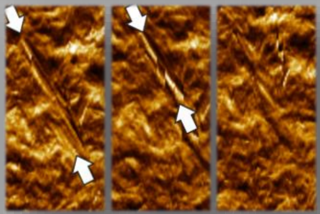




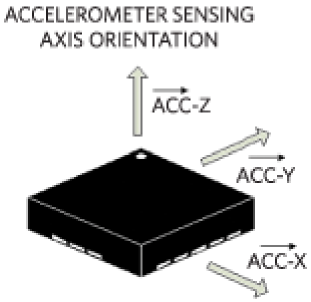



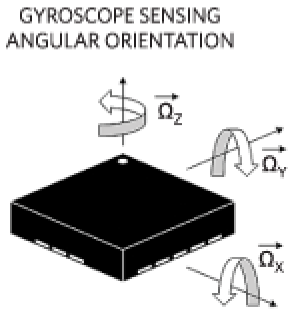
16 May 2017

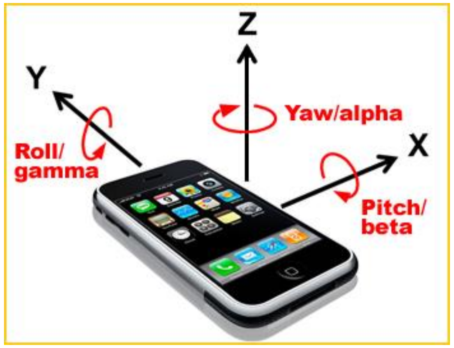
APPLICATIONS – PART II

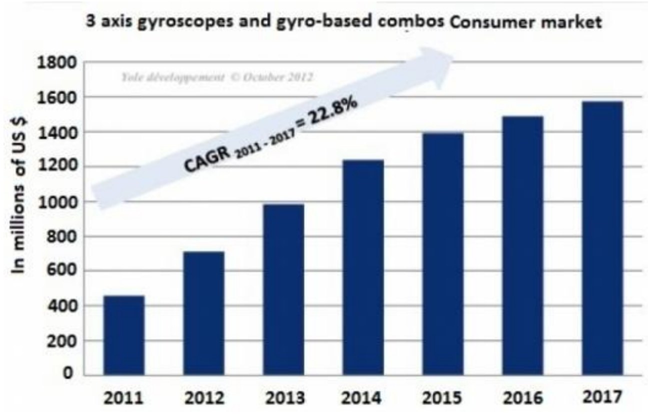
Gyroscopes - Purpose

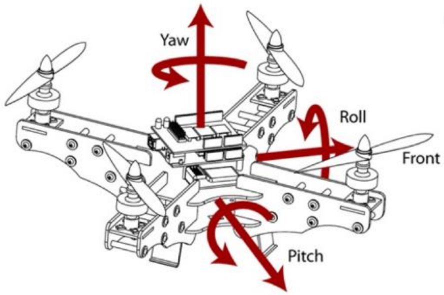
- So far, we have discussed accelerometers which gives information about the spatial movements
- A gyroscope is a device which gives information about the spatial inclination of a system
- By that it complements classical accelerometers to give complete information about spatial inclination and movements











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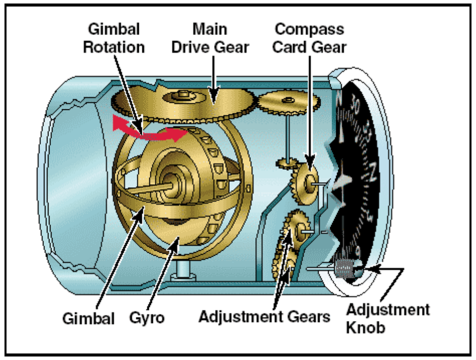
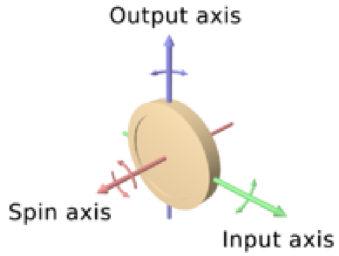
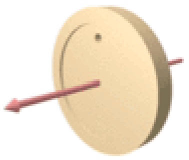
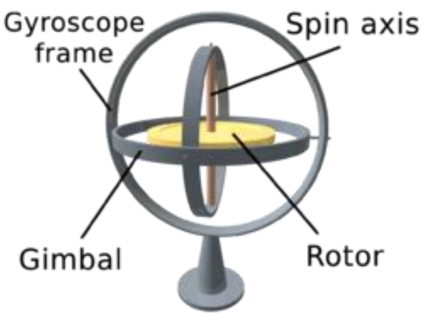
Gyroscopes – Function (Rotationally)

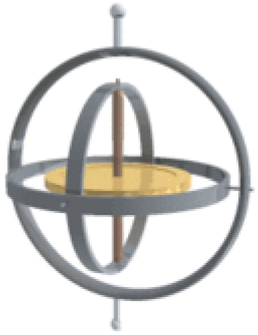


- In the past, gyroscopes used a rotational approach
- It bases on the conservation of the angular momentum
  - We start with a central spin axis which defines the angular momentum to be maintained
  - This is placed in a detection and a frame gimbal
  - Once a force is applied there is a response perpendicular to the gimbal and spin axis
  - By smart integration the outer frame can be used as mechanical transducer









- State of the art rotation gyroscopes were about 2.5 cm large, about 85 g light and reached rotation speeds of about 24.000 rpm
- However, they need to be highly balanced, had high demands on the bearings and were shock sensitive → they were replaced by simpler approaches → MEMS resonant gyroscopes!

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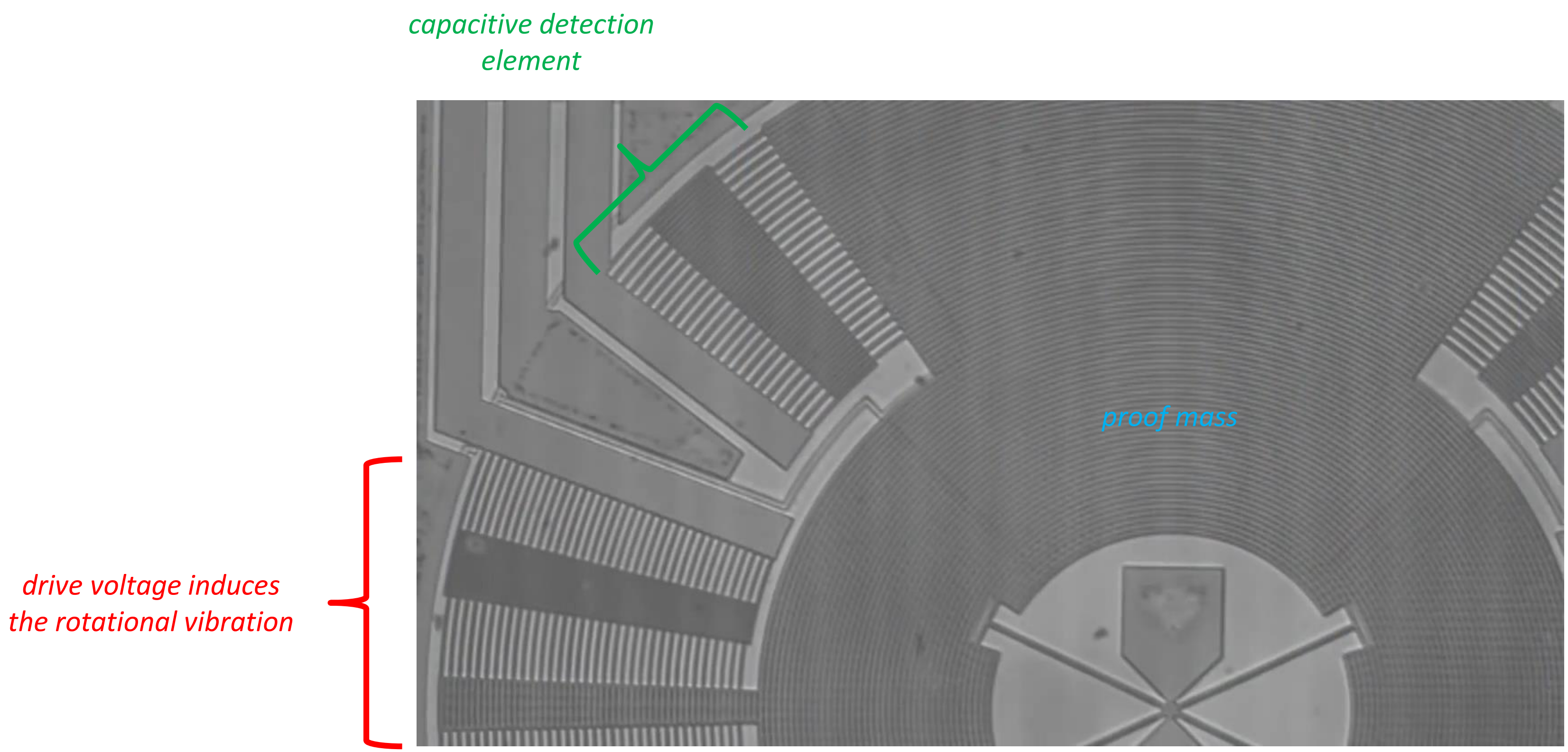
Gyroscopes – Function (Vibratory)

- In MEMS gyroscopes, most concepts base on the high-frequency oscillation of the proof mass
- This represents the angular momentum to be maintained caused by a drive voltage
- When a spatial tilting event takes place, the Coriolis force induces a perpendicular movement
- This, in turn, induces a capacitor change which can be detected



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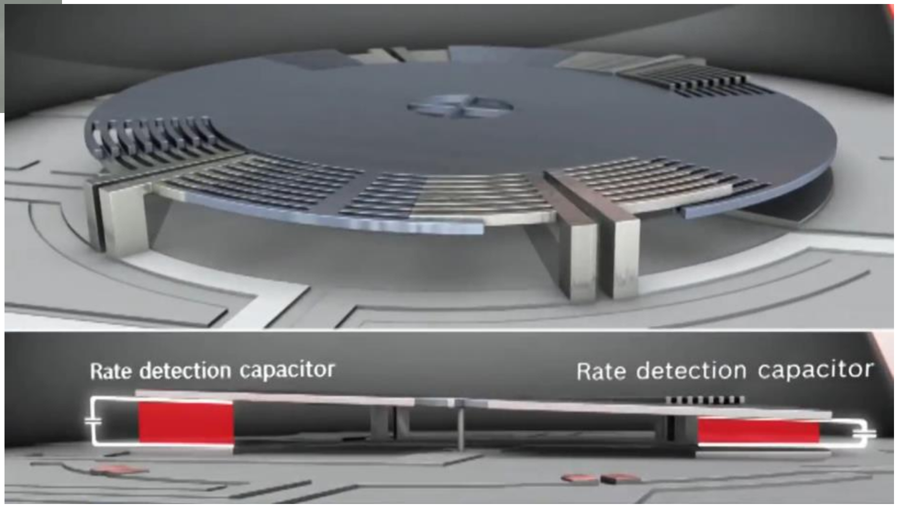
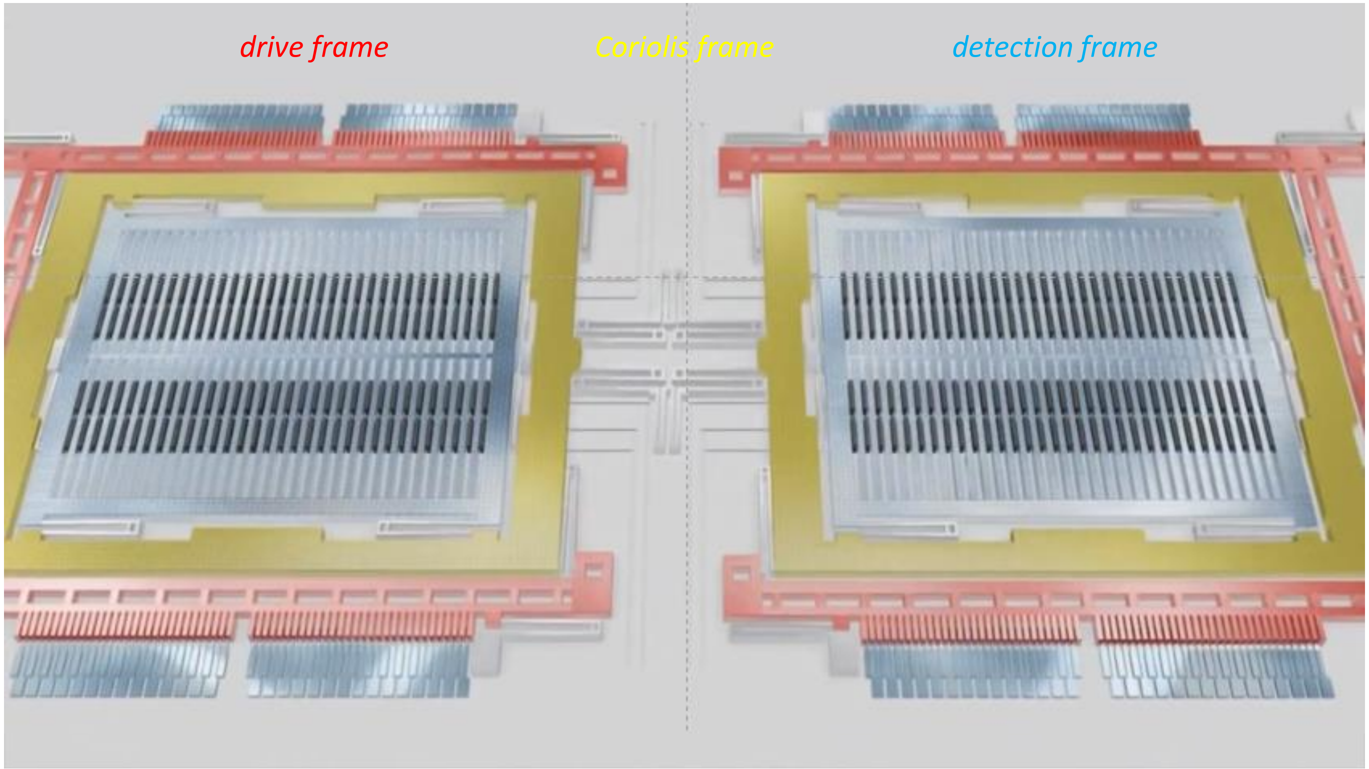


Gyroscopes - Function

- As such "twisting" gyroscopes can be tricky in fabrication and operation due to very high precision demands, different more planar architectures have been developed



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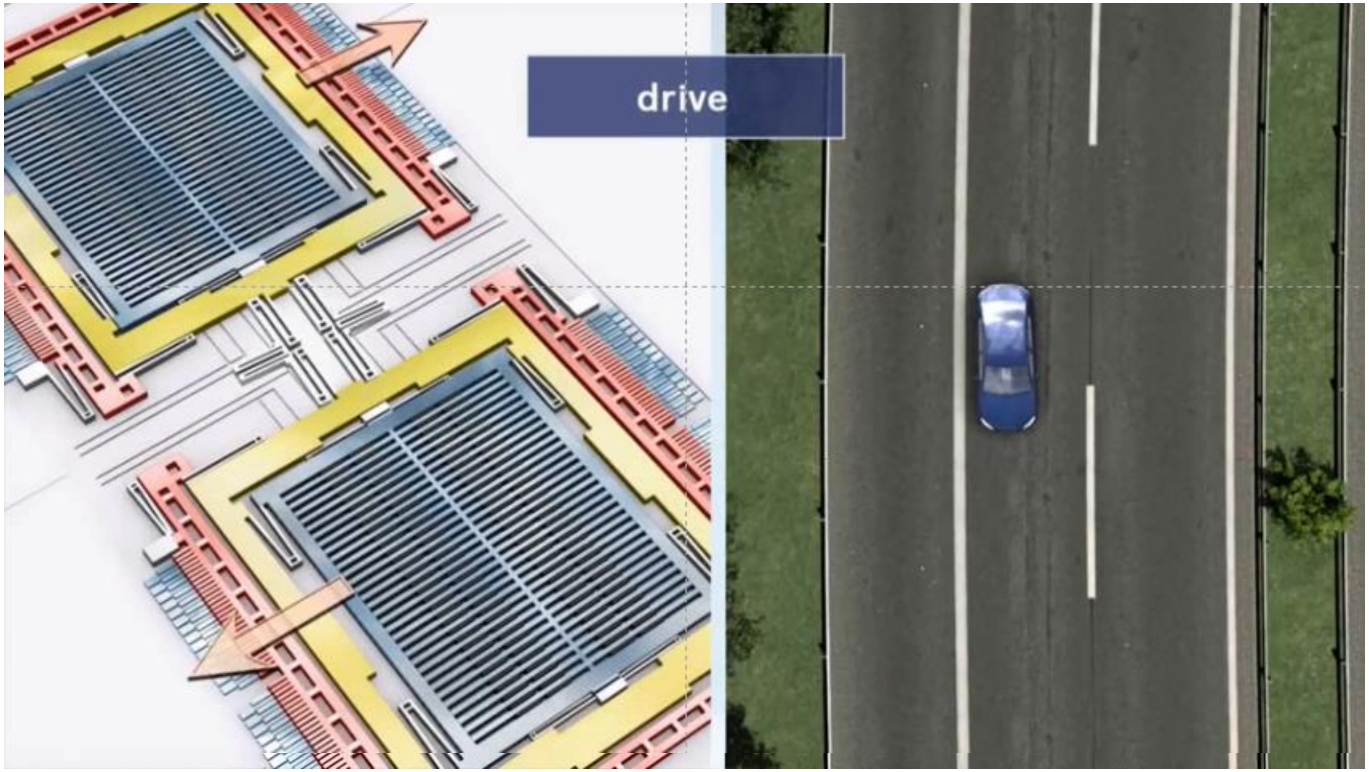
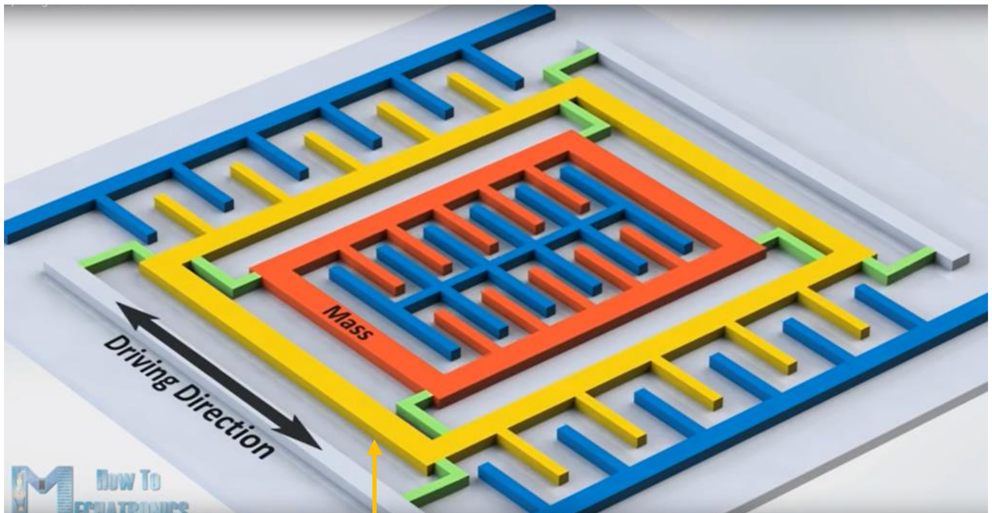


drive frame *Coriolis frame* *detection frame*

Gyroscopes - Function

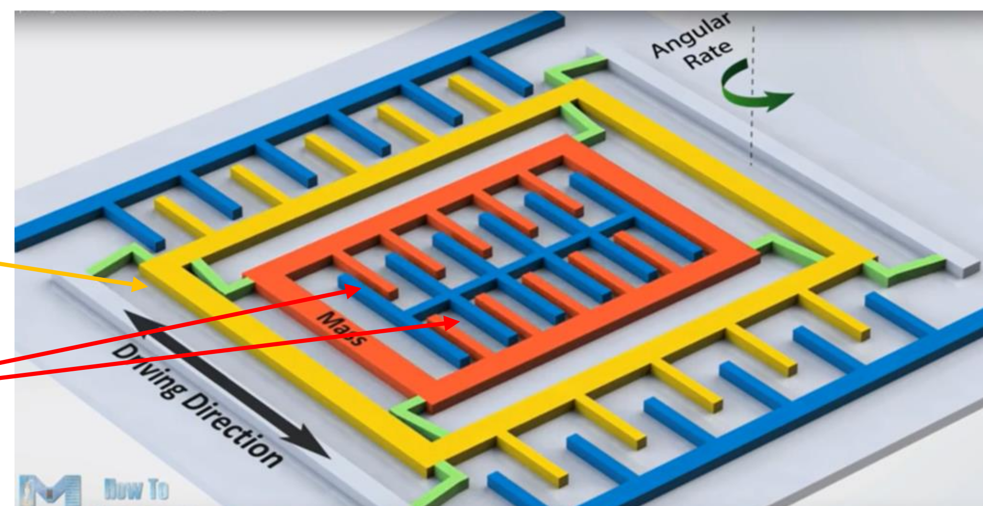
- The basic detection element is again capacitive as for the accelerometer



drive voltage induces the horizontal oscillation

resonant frame

Proof mass induces a ΔC



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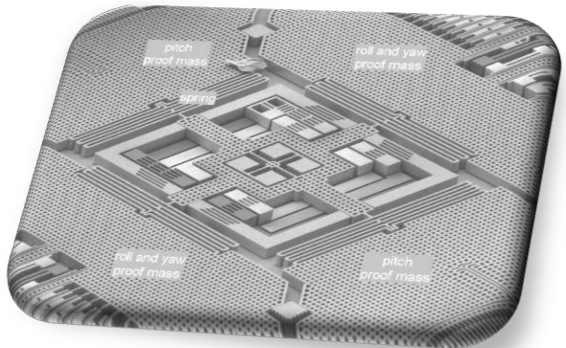
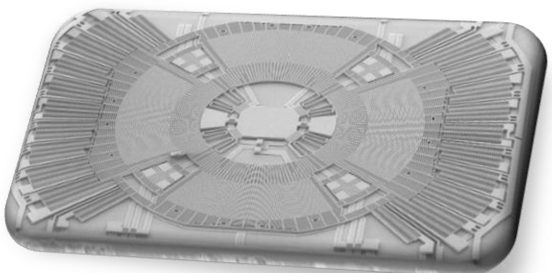
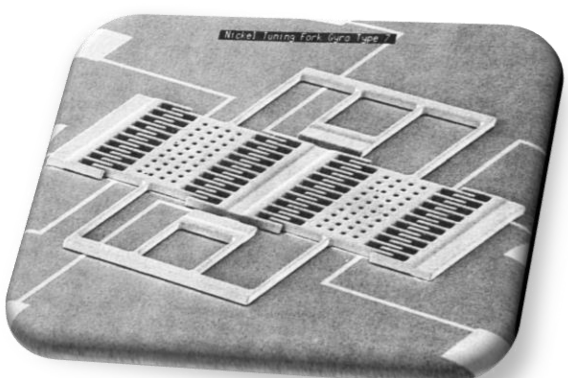
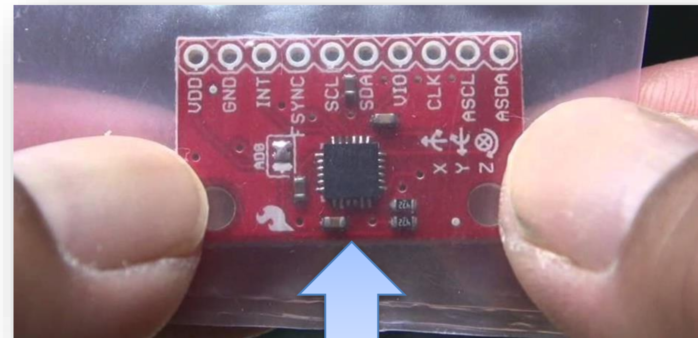
Gyroscopes – Many Different Types & Small Scale

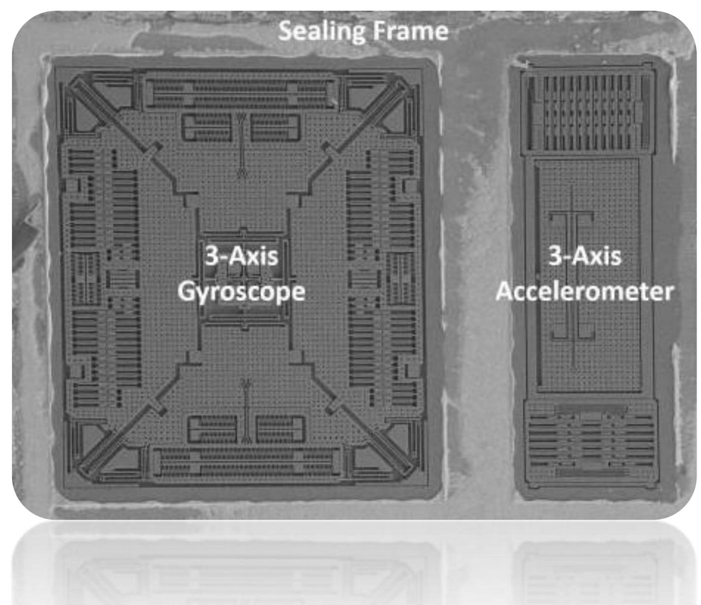






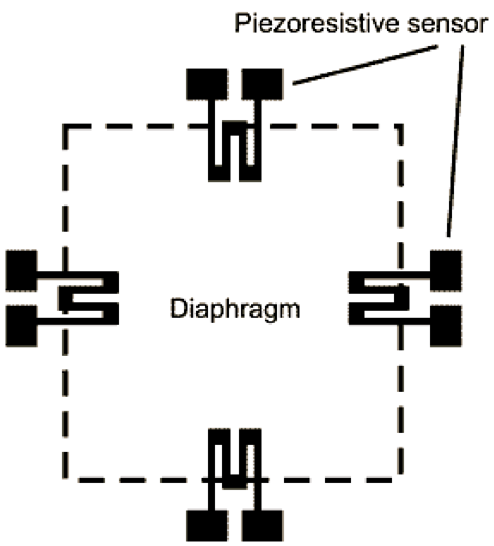
fully operational 6 axes system including the required electronics

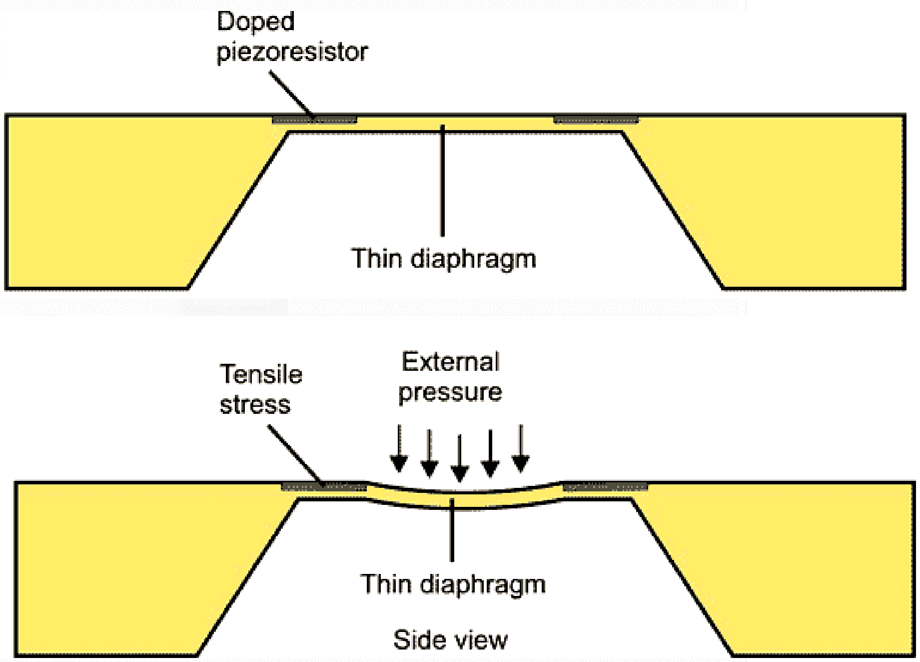




Further Applications – Pressure MEMS

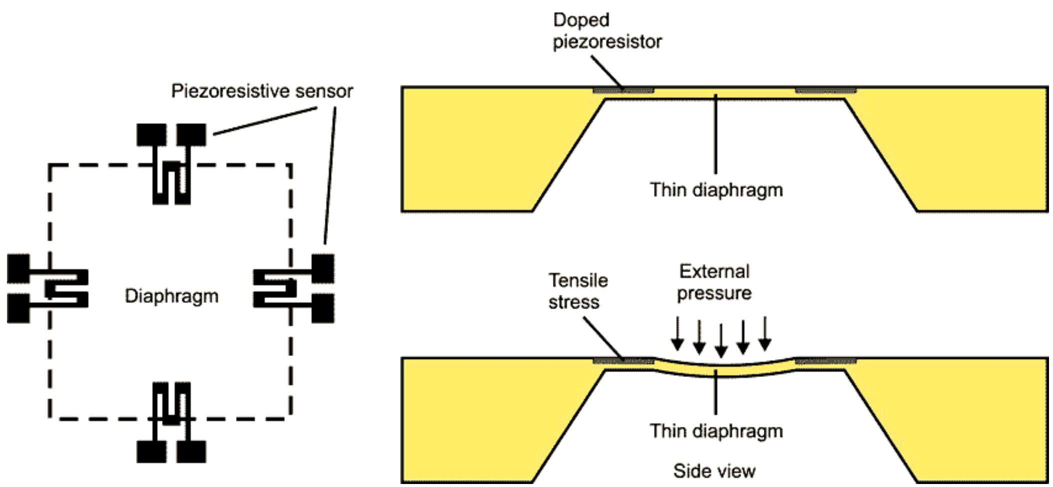
- To detect pressure differences, a thin but flexible membrane is used
- For this piezoelectric (active) OR piezo-resistive (passive) elements are strategically integrated in the membrane
- The electric readout gives then information about the bending strength and by that about the quantitative pressure difference between the upper and lower membrane face

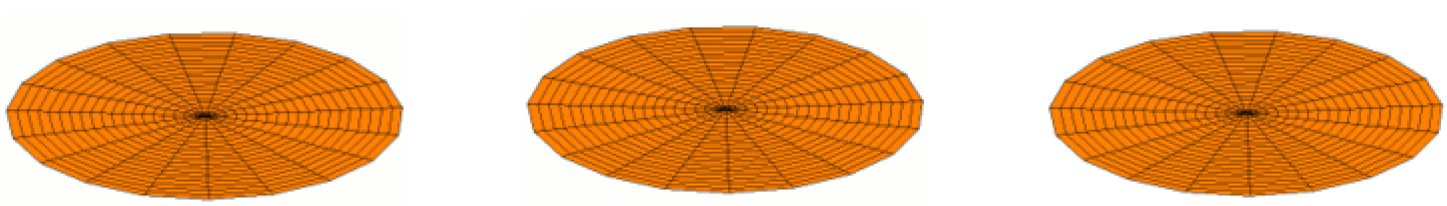




Further Applications – MEMS Microphones

- This basic principle can also be used for microphone applications
- However, the full frequency band can induce different membrane movements and / or higher harmonics excitations
- For silent noises the membrane amplitude might be too small for proper piezo based detection



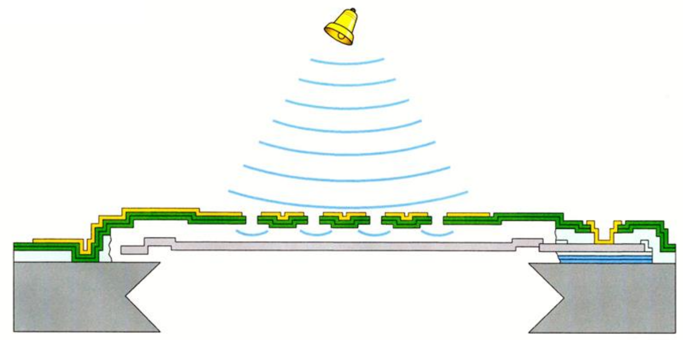


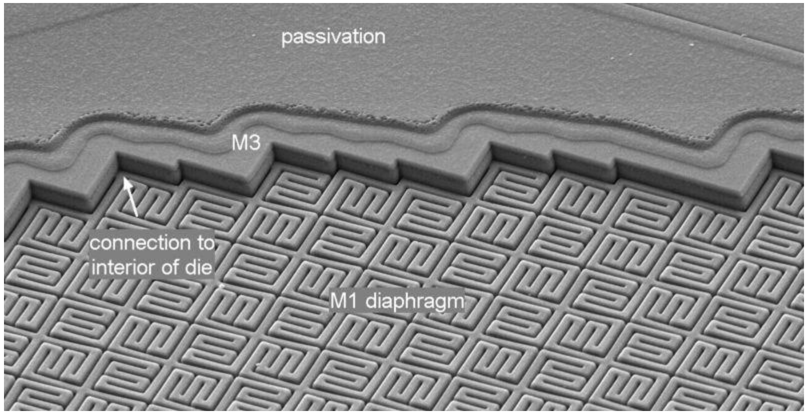
basic frequency
detection OK

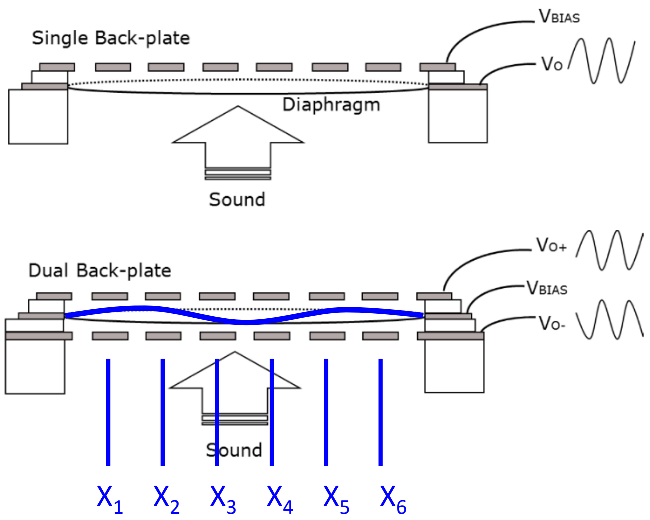
higher frequencies can induce different membrane oscillations
detection, however, says it is the basic frequency!

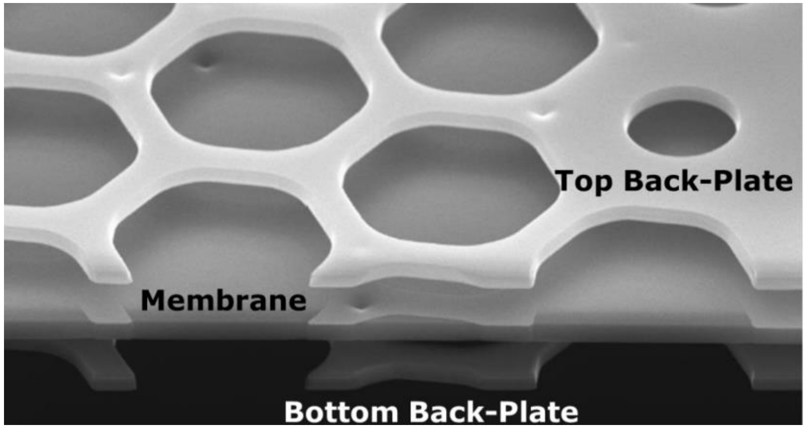
Further Applications – MEMS Microphones

- Therefore, the membrane is used as capacitive element together with perforated electrodes
- This can be improved by double face electrodes and / or by a smart electrode design
- Highly sophisticated systems are also double sided and position sensitive to distinguish between basic frequencies and higher harmonics









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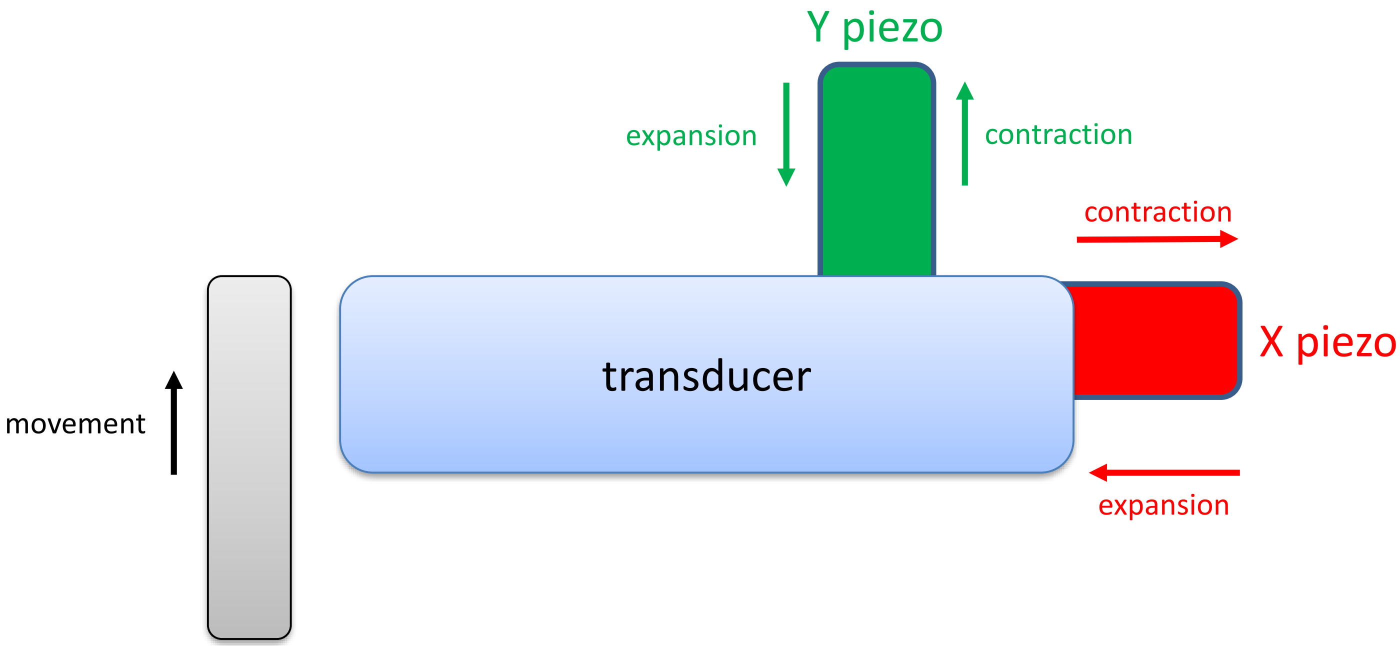
Further Applications - Gears

- We have discussed the surface micromachining of gear elements
- The movement bases on cyclic piezo control



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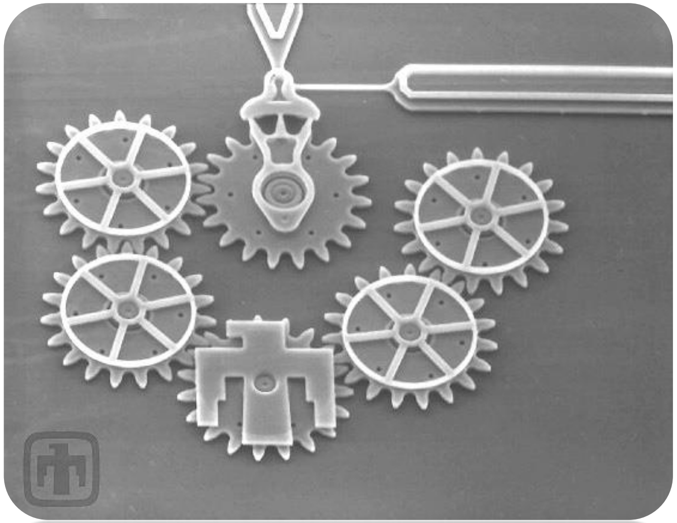
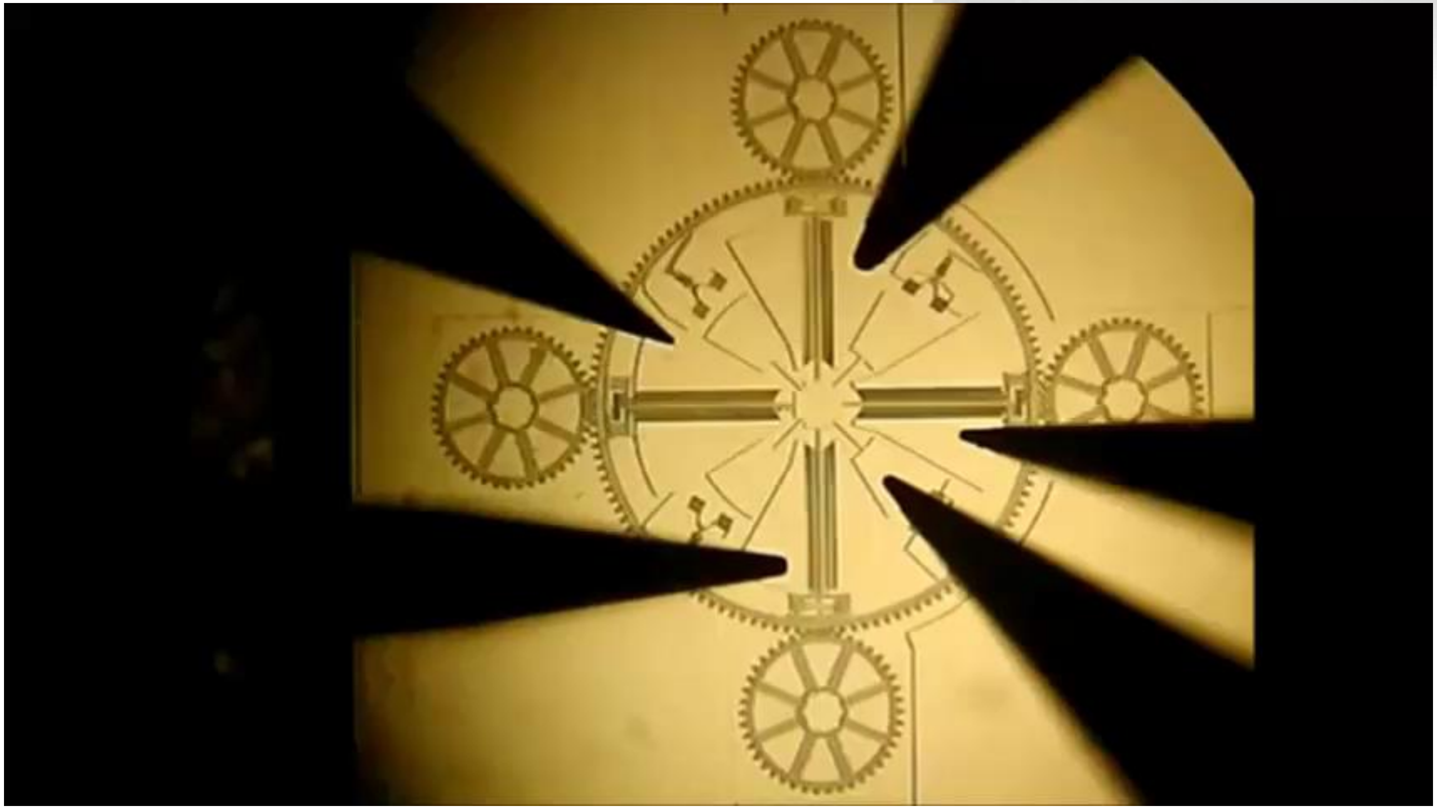
- Speeds of more than 200.000 rpm (!) are possible!





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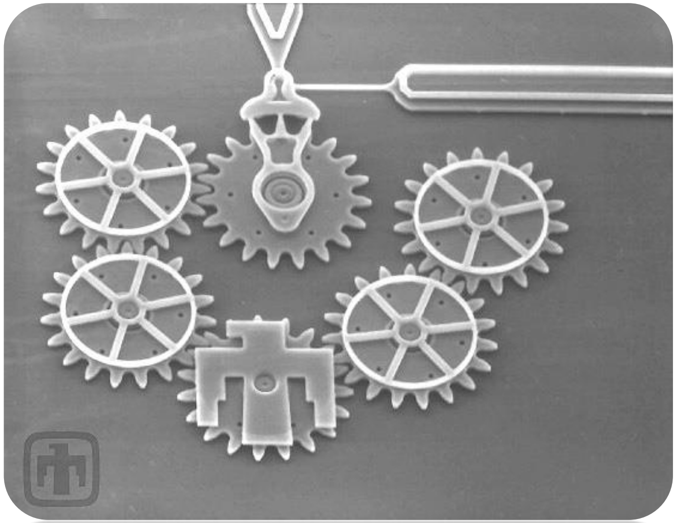

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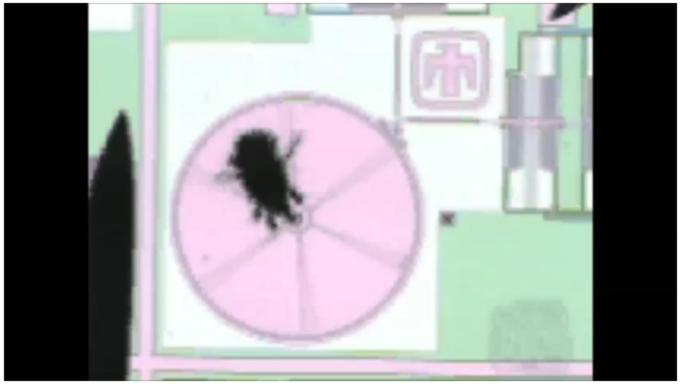
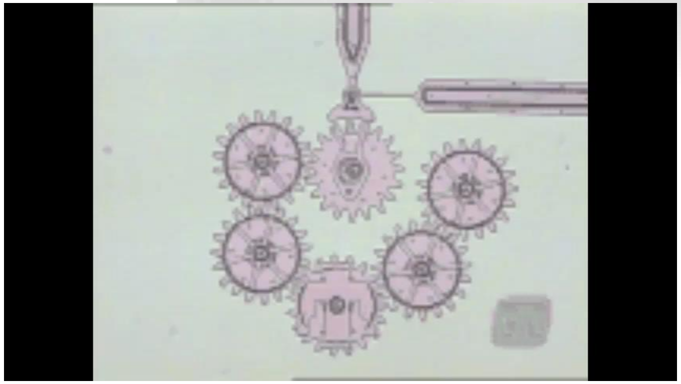
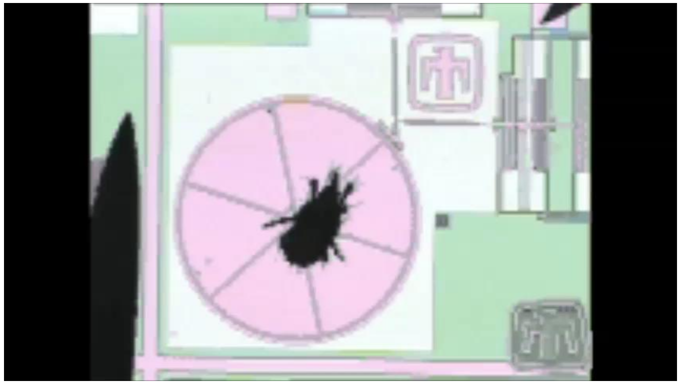
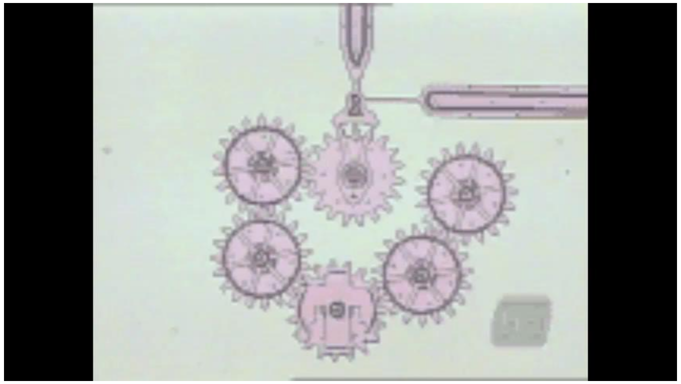


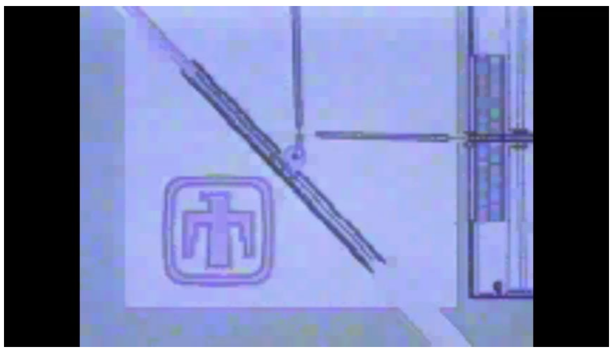


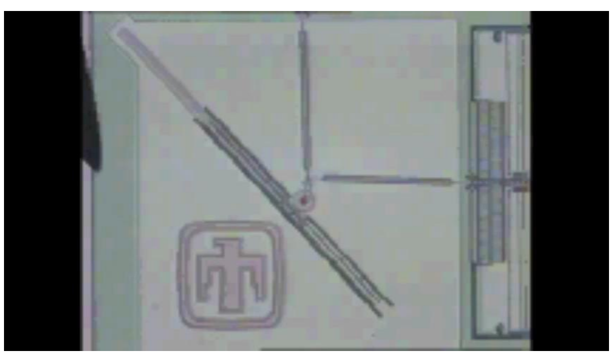


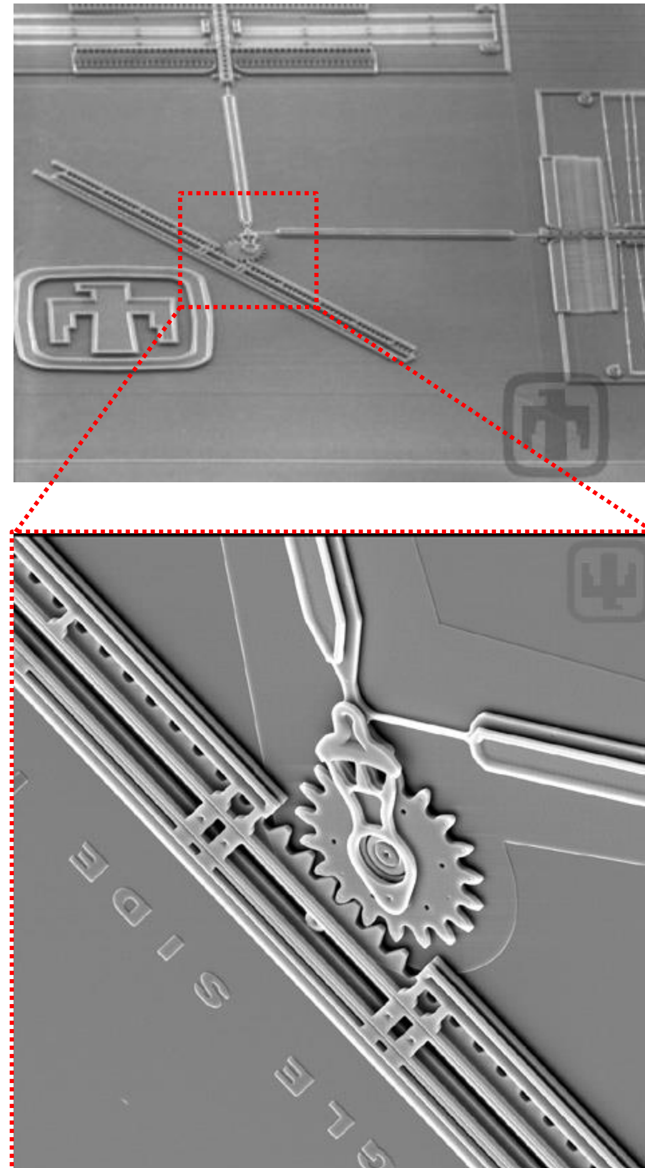


Further Applications – Linear Motors

- Using the same drive principle, linear motors can be done up to 5 m.s^{-1}!

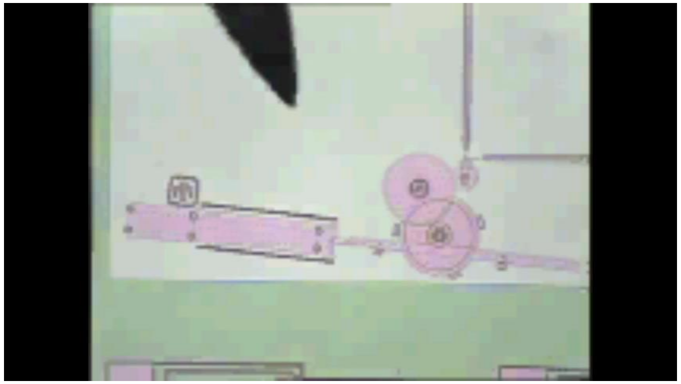


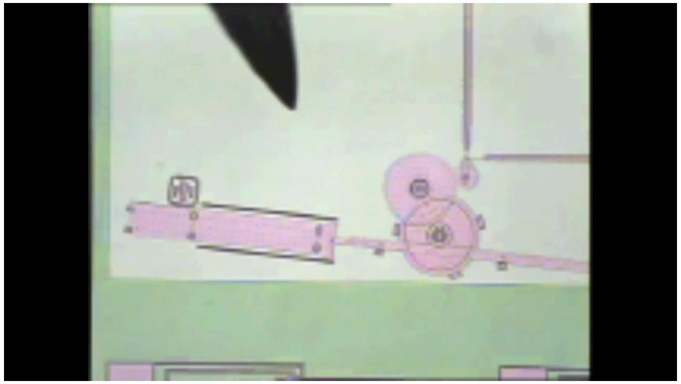


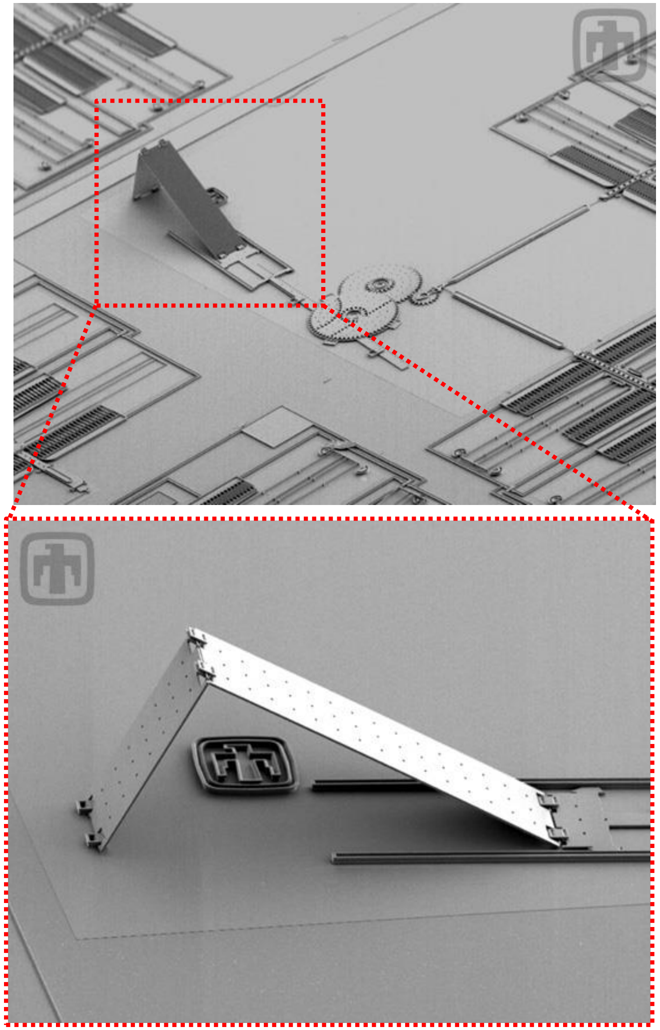


Further Applications – Light Guidance / Manipulation

- Both concepts together can then be combined for the manipulation / guidance of light
- This is huge market in consumer applications such as projectors … but how exactly?

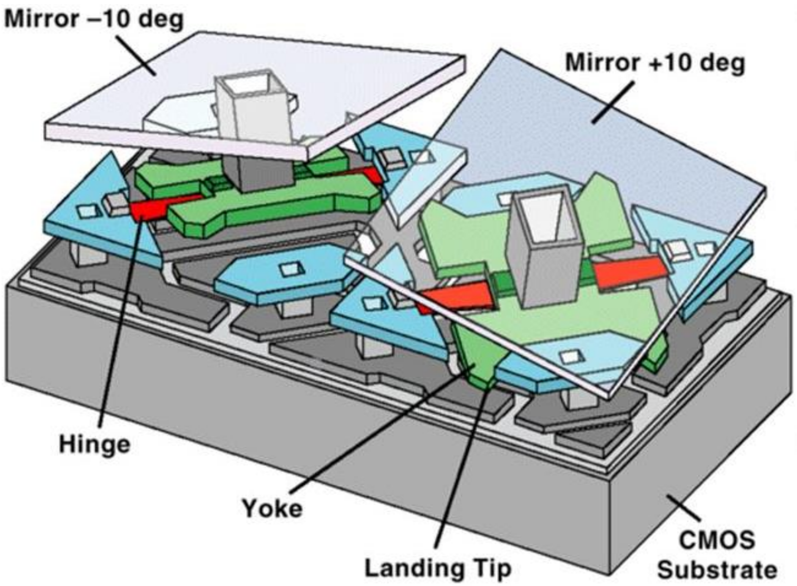


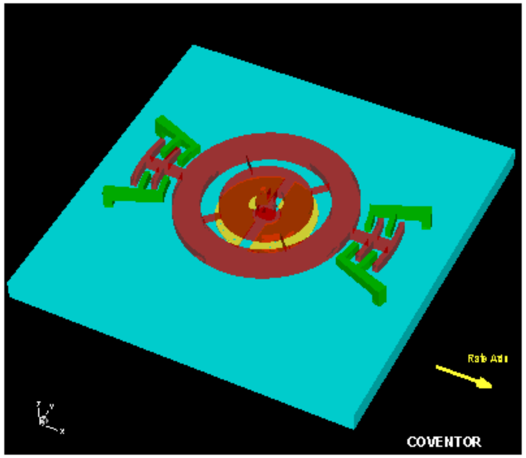


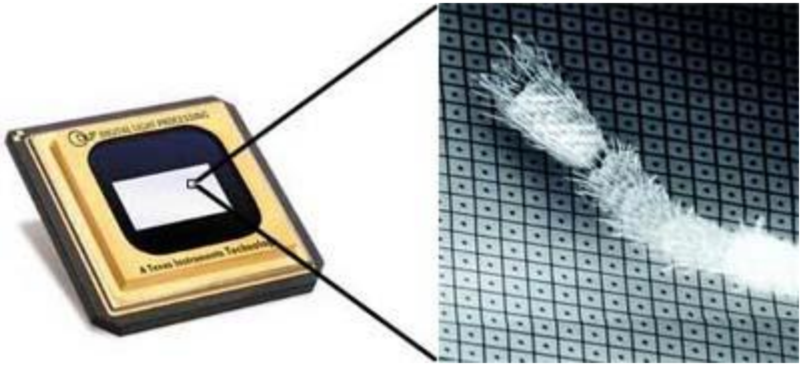


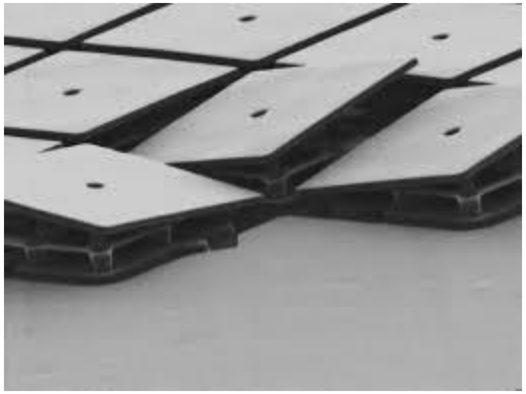
Further Applications – Digital Light Processing (DLP)

- The base concept behind DLP are MEMS which allows highly precise positioning of a mirror then called Digital Micromirror Device (**DMD**)!



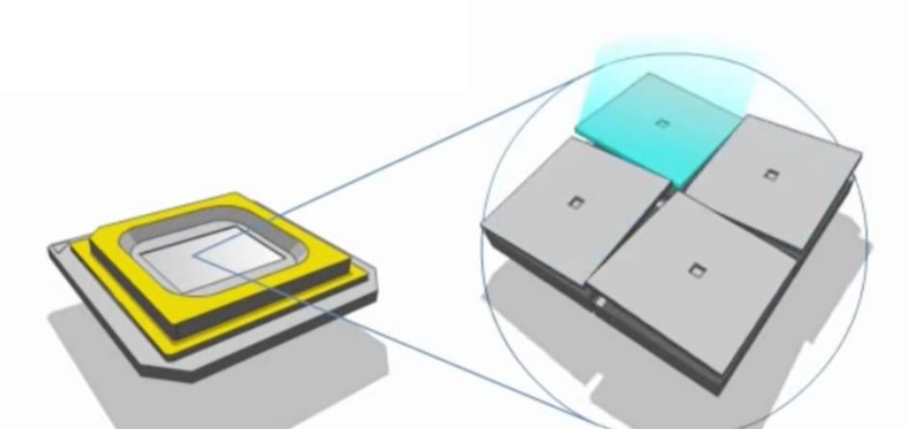


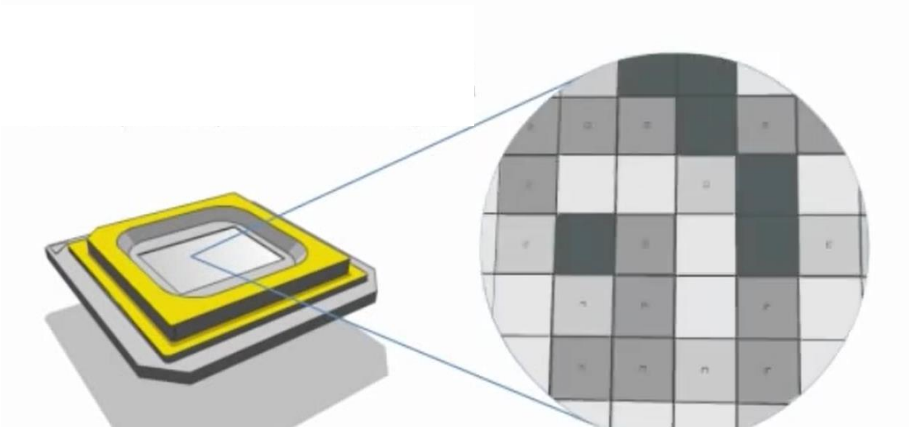




Further Applications – Digital Light Processing (DLP)

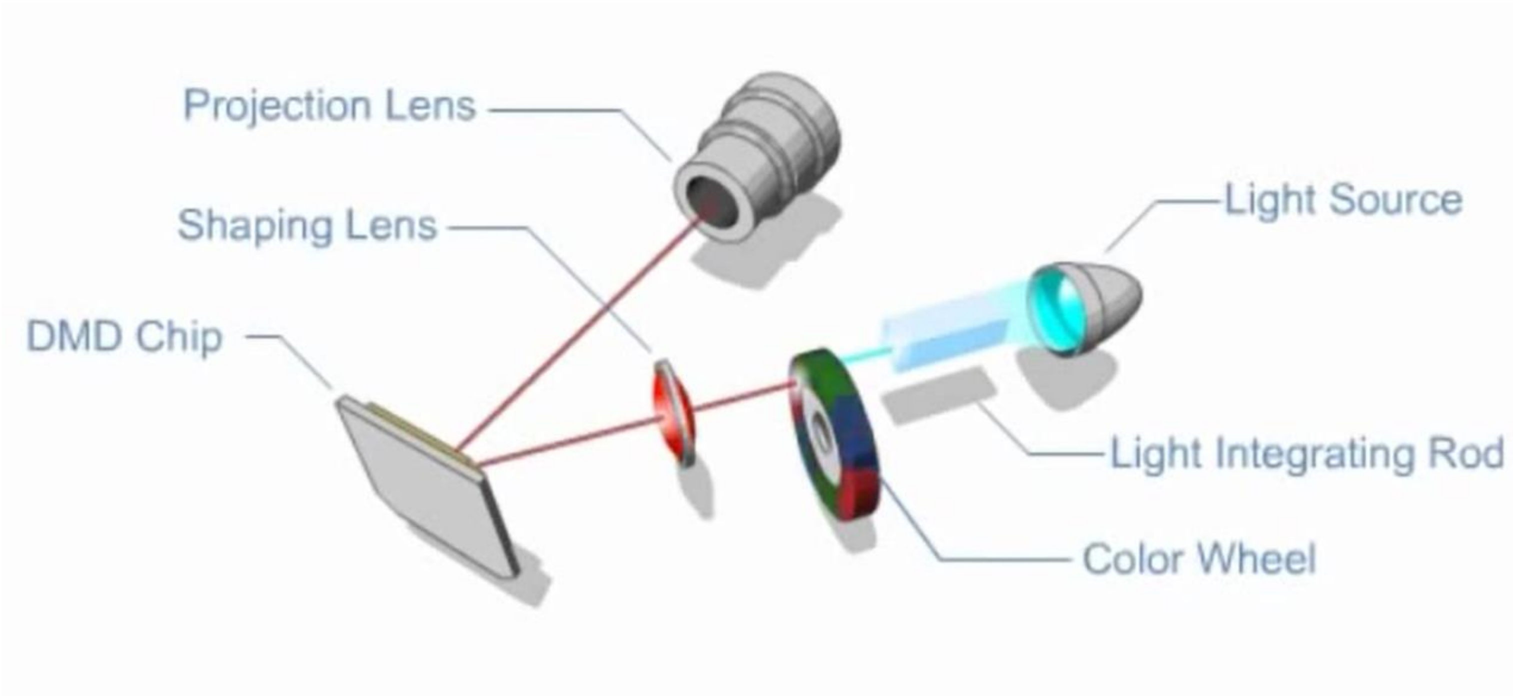
- The full DMD technology either reflects light into the final projector lens or away from it
- By adjusting the duration of ON – OFF, typical 1024 intensity values can be realized





Further Applications – Digital Light Processing (DLP)

- The colour comes into the game via a colour wheel, which filters white light
- By synchronizing the colour wheel with the DMD elements, a RGB image can be created
- The amazing detail is that such DMD chips consist of the same numbers of mirrors as for the final resolution up to 4k UHD (up to 4096×2160 pixels → more than 8.8 million mirrors!!!



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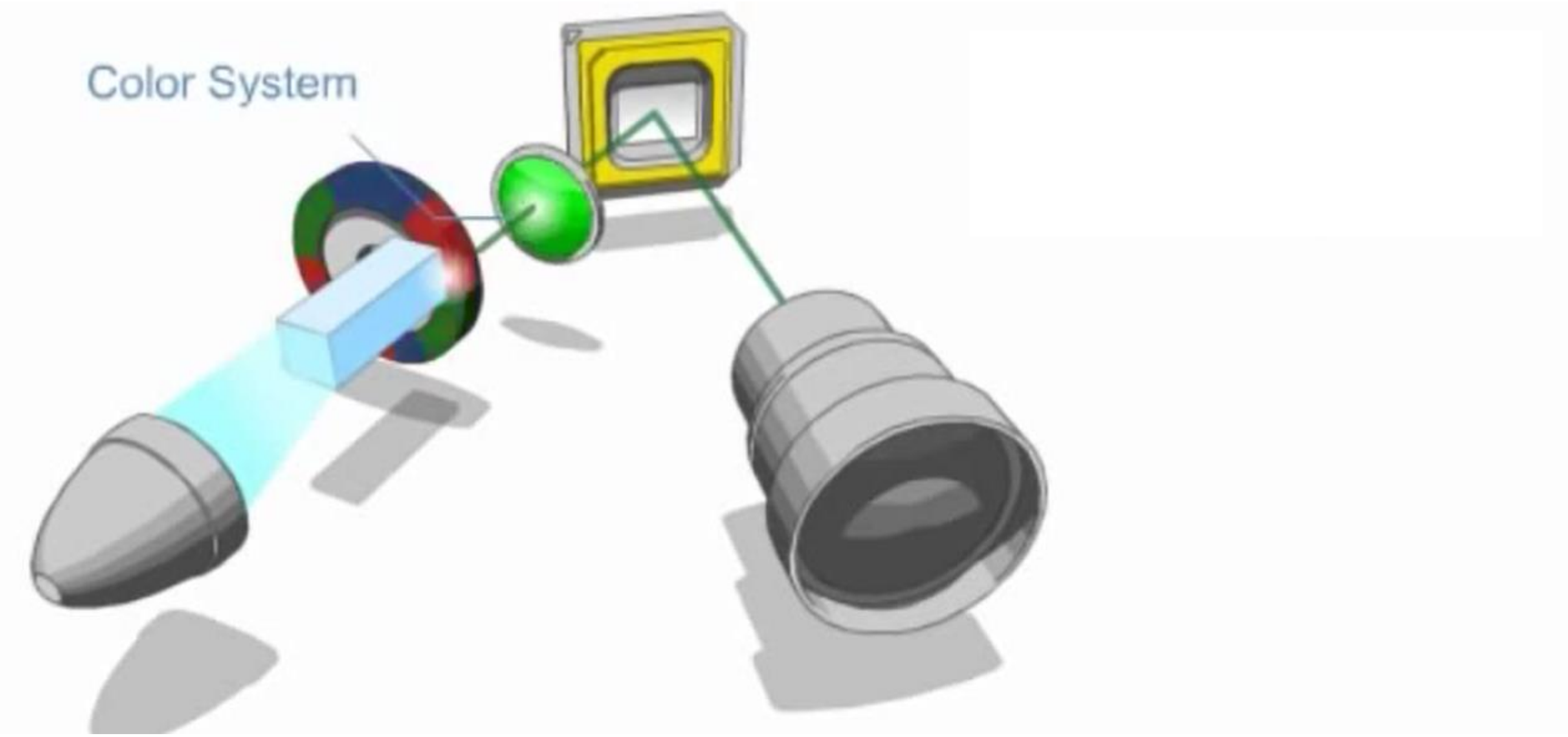
Further Applications – Digital Light Processing (DLP)

- While single-chip DLPs still provide high performance, the trend goes towards 3-chip DLPs



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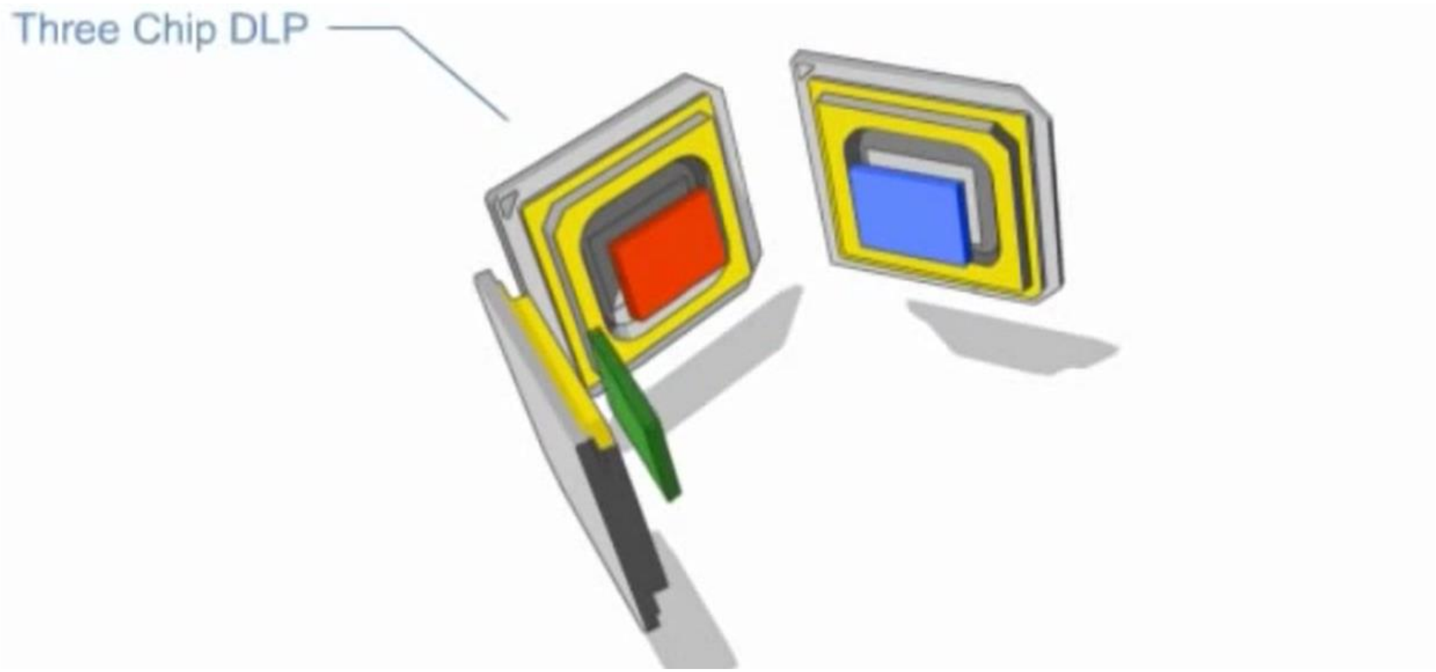

Further Applications – Digital Light Processing (DLP)

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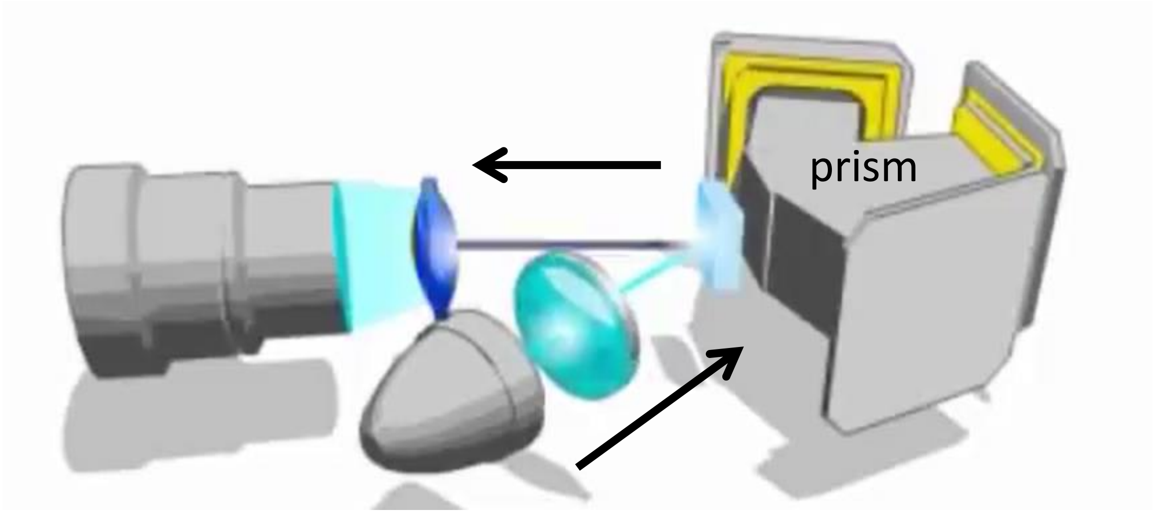
- Here, each DMD chip is responsible for ONE single colour
- The setup uses white light which is then split up in RGB colours by a prism, guiding individual colours to the chip
- By that, the brightness is much higher as the colours are not timely split up!



Further Applications – Digital Light Processing (DLP)

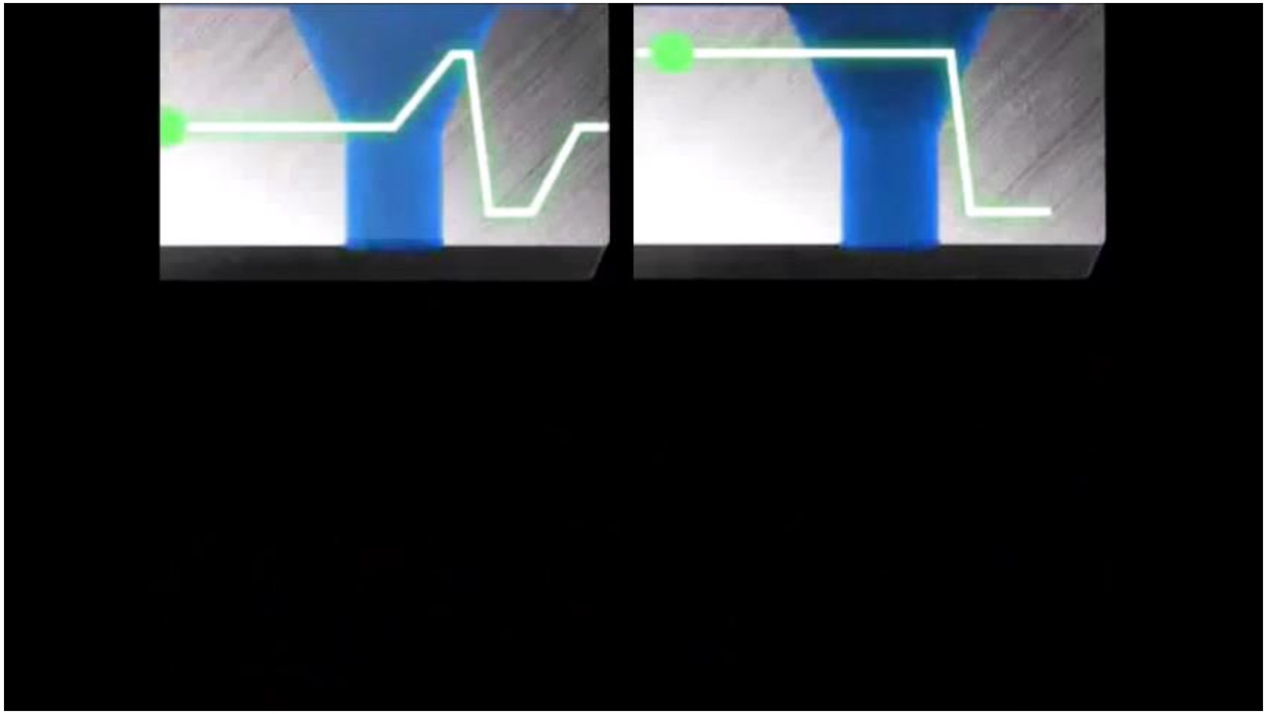
- Just for completeness, the 3-chip LCD technology uses no moving parts but large arrays of LCD elements which can switch the transmission for each pixel ON or OFF (but it is NOT a MEMS ☺)

Further Applications – Ink-Jet Printer

- Inkjet printing also bases on MEMS technology
- It increases / decreases the available volume at the nozzle end via piezoelectric elements

Further Applications – InkJet Printer

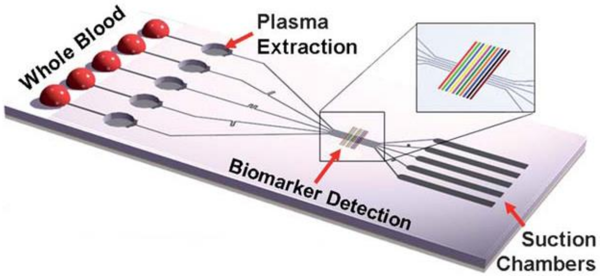
- However, as it is fluid in motion there are post-ejection-movements which need to be taken into account for proper printing concerning droplet shapes and sizes

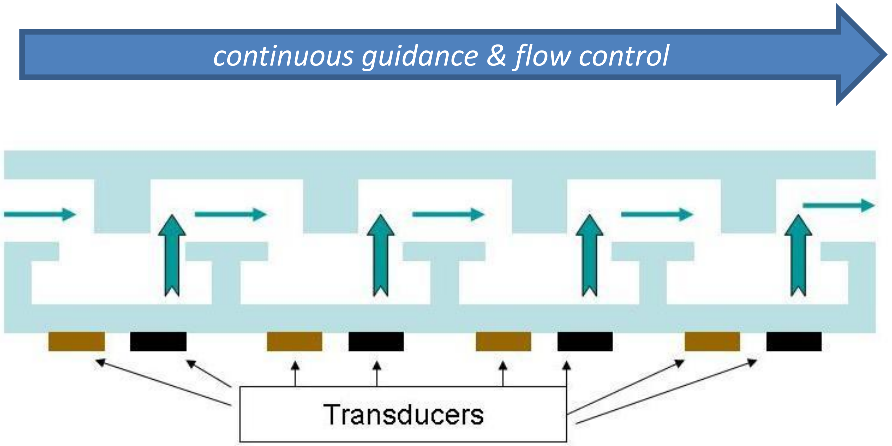


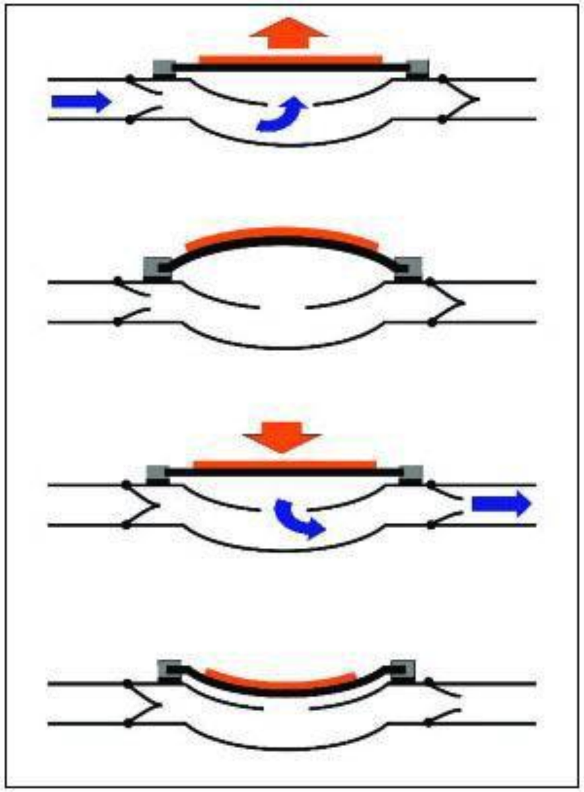
Further Applications – Pumps for Microfluidics

- This basic concept can also be used for Lab on a Chip applications in e.g. life sciences
- Multiple stacking allows control of
  - ON – OFF
  - Flow rate
  - Directed fluid flow
  -

unidirectional ON / OFF valve







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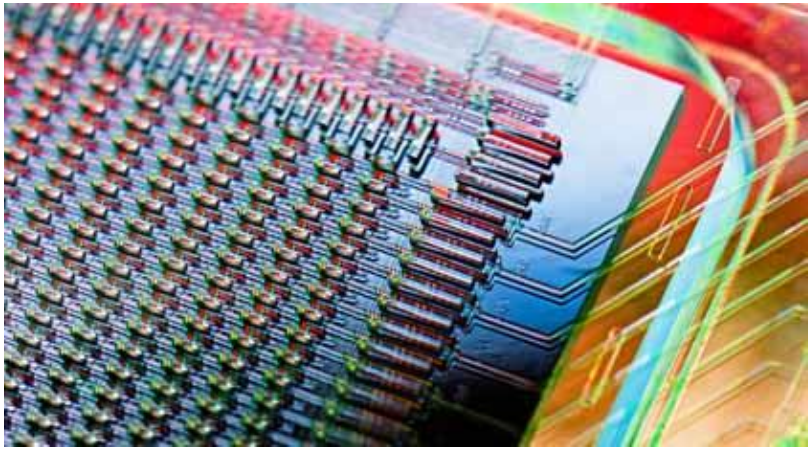
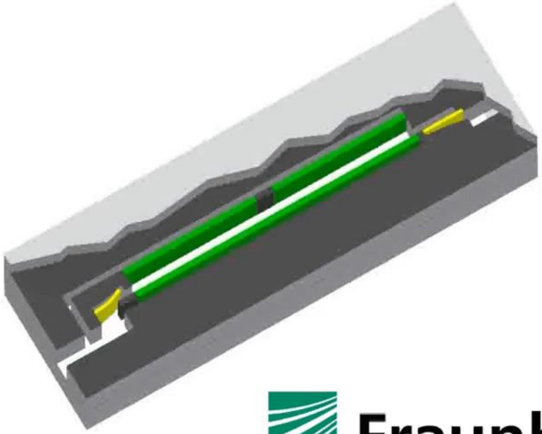
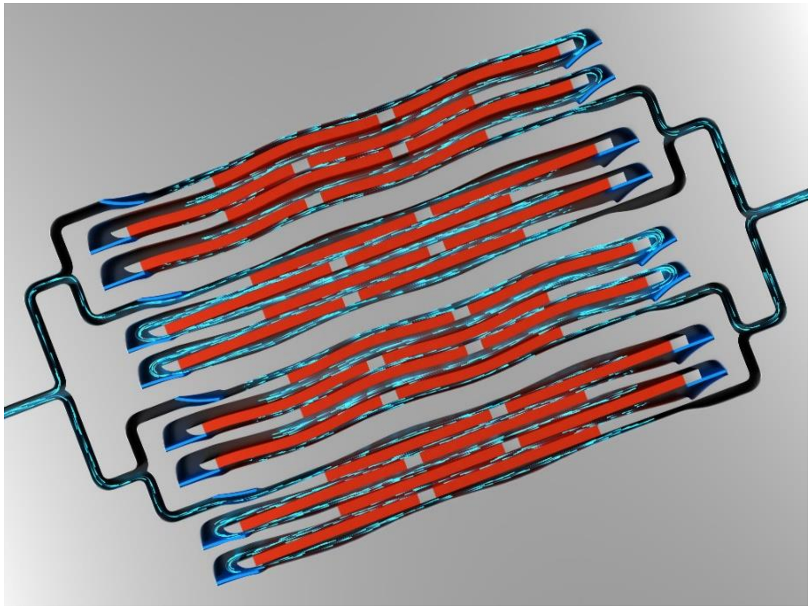
  - Flow rate
  - Directed fluid flow
  - Mixing
  - Automated assays



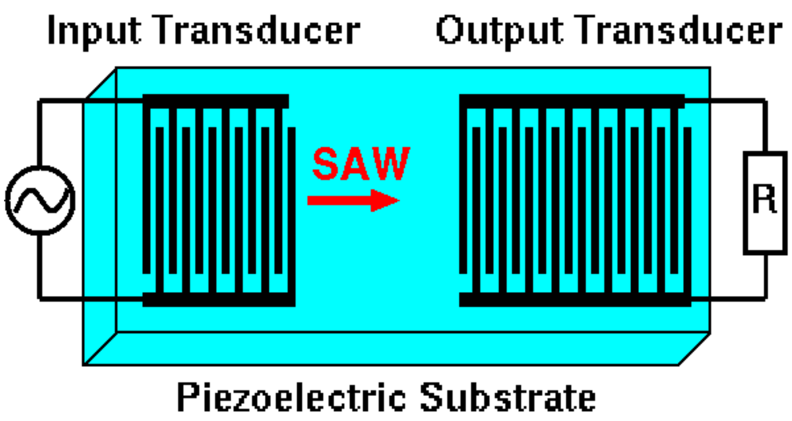


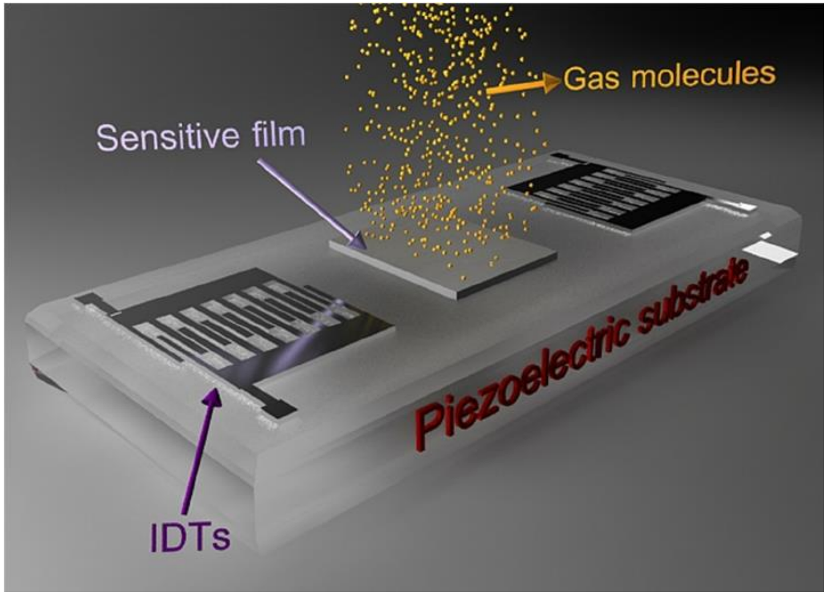
Fraunhofer IPMS



Further Applications - SAW Devices

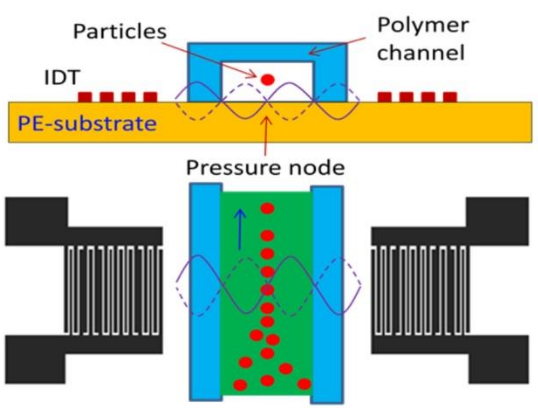
- Lab on a chip devices are often coupled with so called Surface Acoustic Wave (SAW) devices
- SAW devices use a piezoelectric material with two comb like structures
- When applying an AC signal at one side (Input) the piezoelectric material contracts / expands according to the electrode distance
- This induces a surface acoustic wave which propagates perpendicular to the electrodes
- On the other end, there are identical comb structures which act as sensor for the wave
- If there is a wave changing layer in between, the wave is changed by its amplitude / phase → **sensing**!

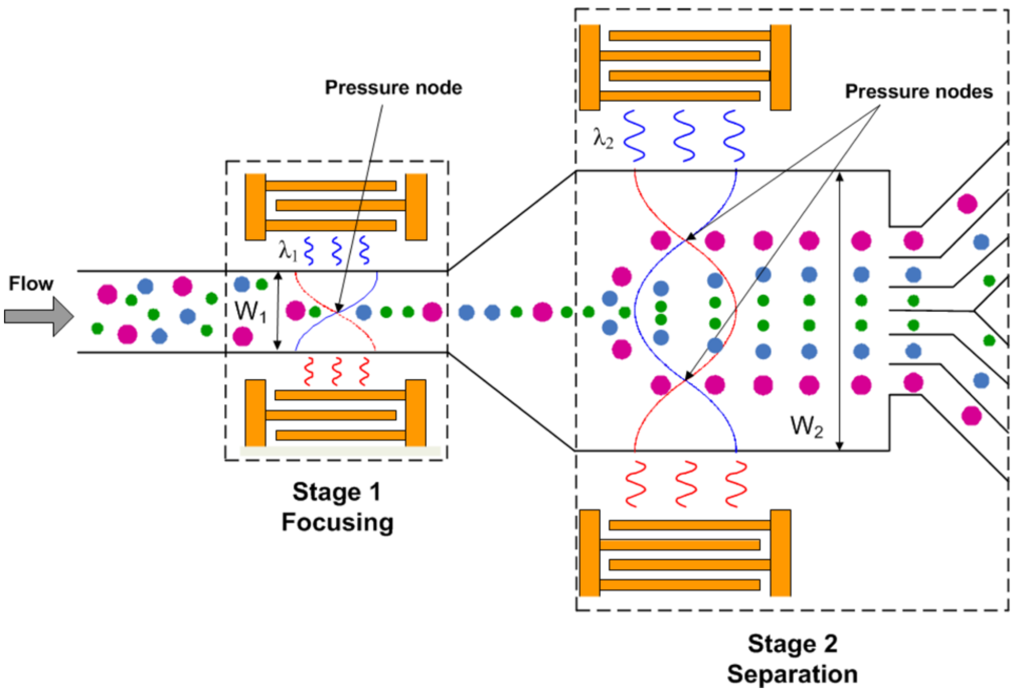




Further Applications - SAW Devices

- By that, SAW devices can detect concentration variations in microfluidic channels without being in contact with the media (contact less MEMS sensors)
- An even more fancy application, however, is the fact that SAWs have spatial force gradients within the microfluidic channels
- By smart design, droplets and even single particles (!) can be FORCED on defined ways and even particle separation becomes possible!





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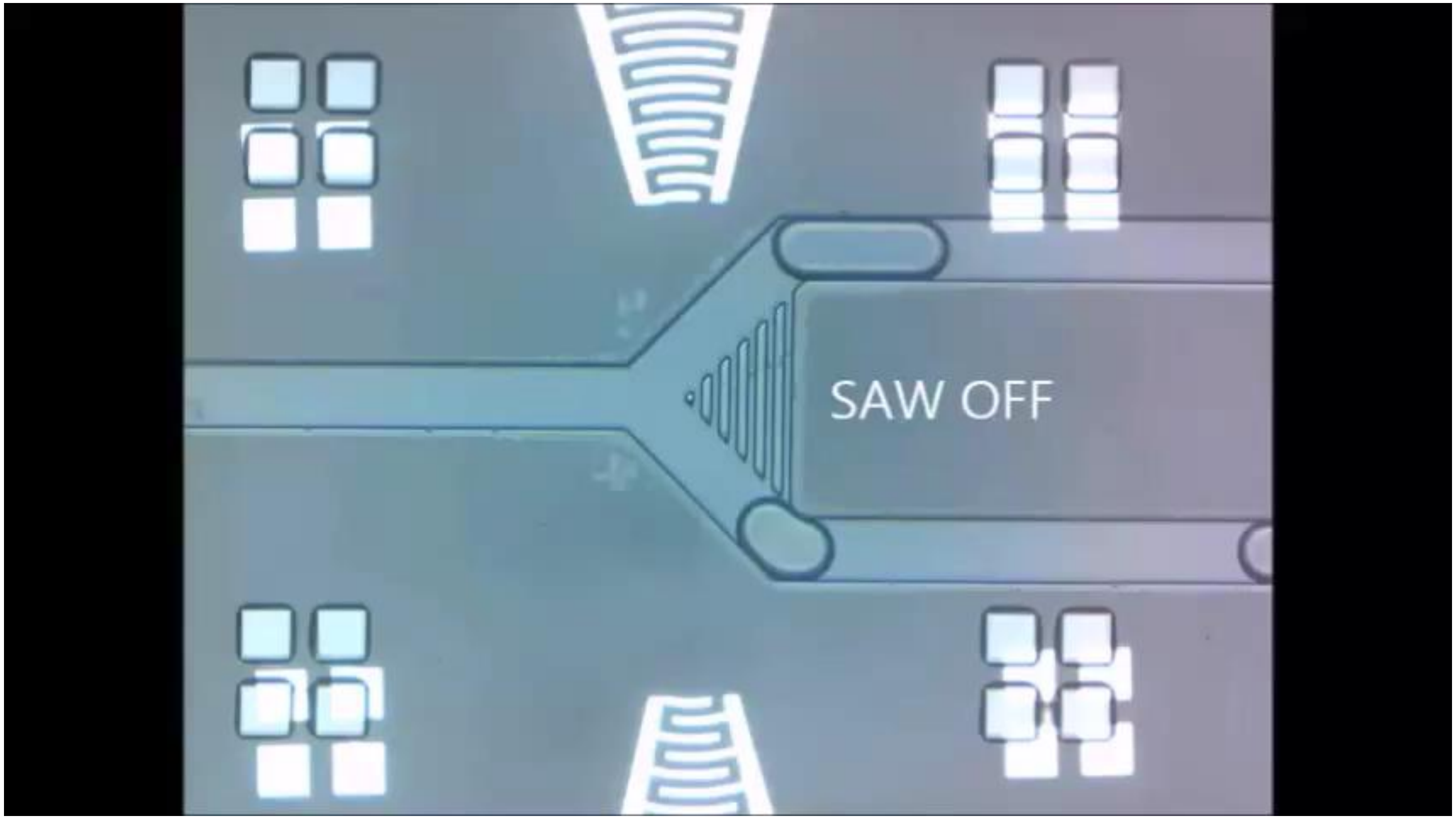
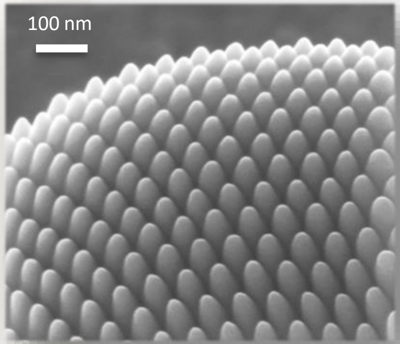


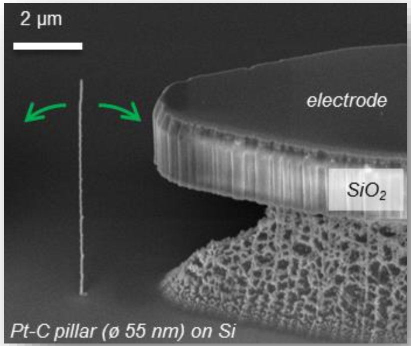
Traditional Nanofabrication and its Limitations

- Traditional lithography approaches are well established and widely used in fundamental and applied physics
- However, there are situations where they can not be applied!

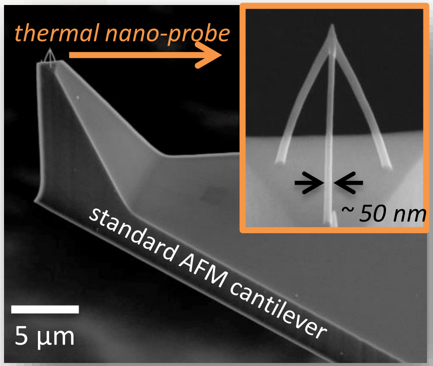
additive light fiber modification



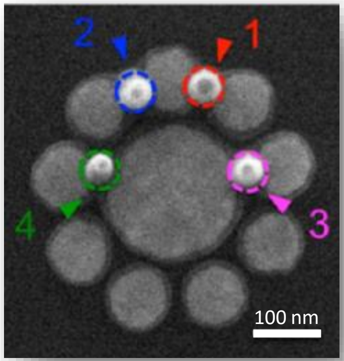
on-demand fabrication



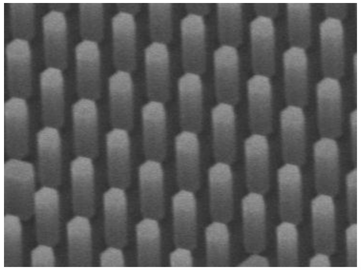
highly exposed areas



plasmonic transmutation



[6]



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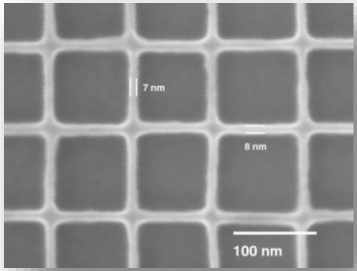
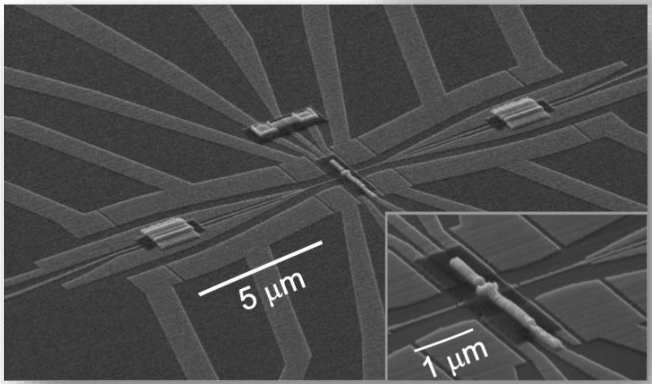
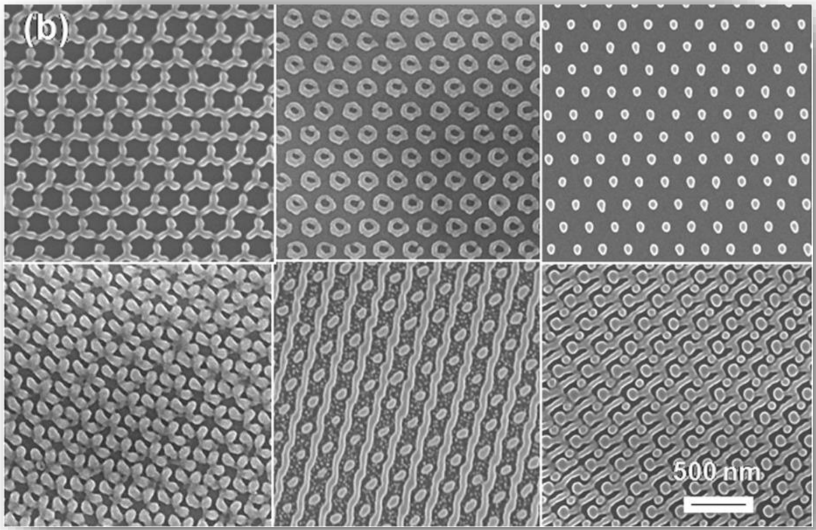


[3]



[1]

[2]



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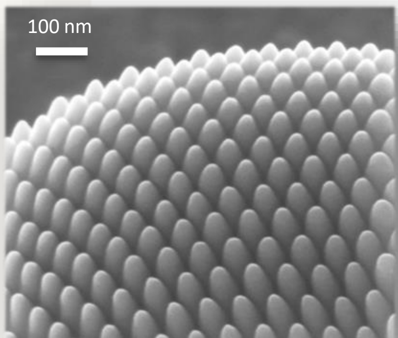
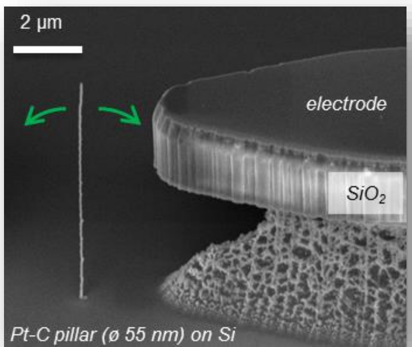
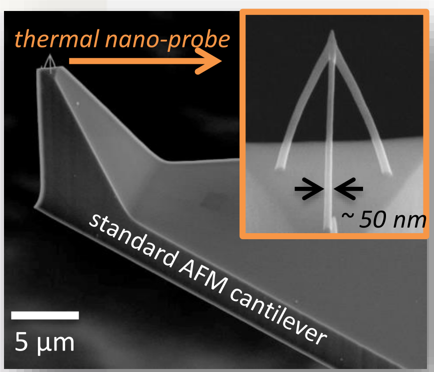


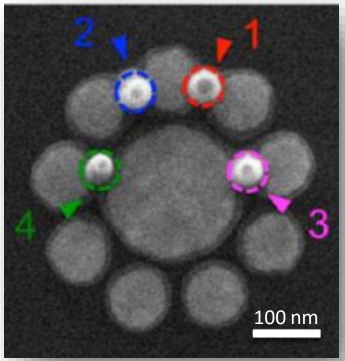
on-demand fabrication



highly exposed areas



plasmonic transmutation



[6]

(nano-) lithography → deposition / etching / modification → resist removal

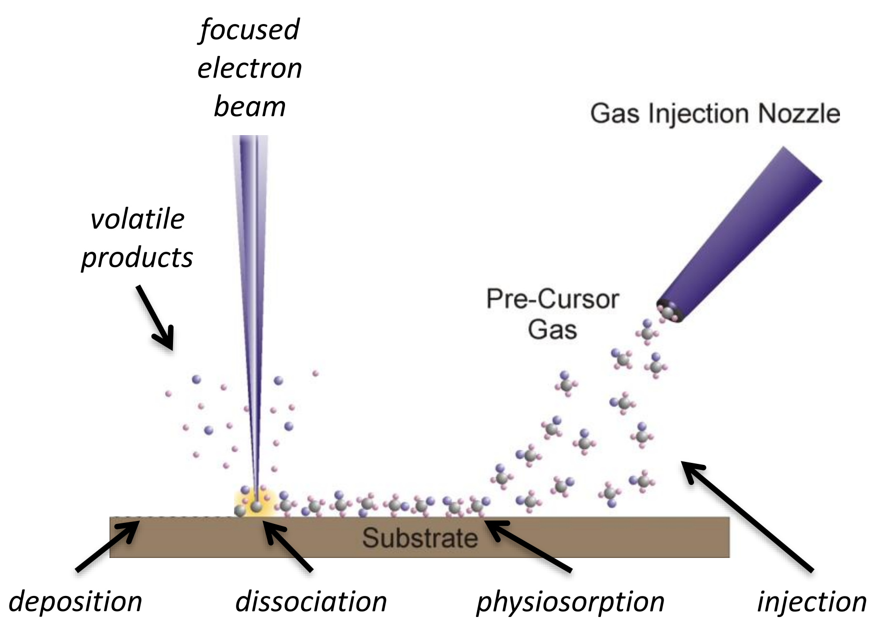
IDEAL Situation

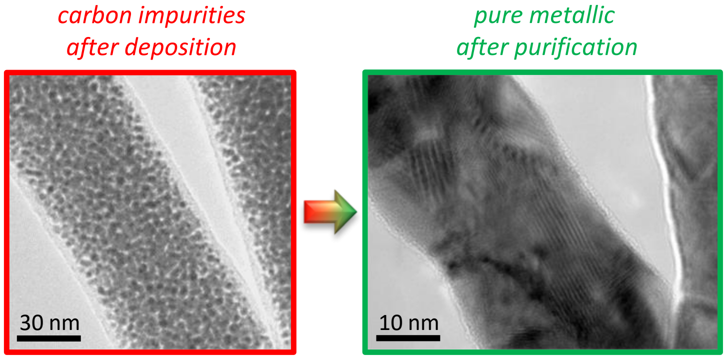
- *No **additional layer** prior to fabrication*
- *No **masks** during lithography*
- *No **elevated temperatures** during processing*
- *No **reactive gases** and / or **liquids***
- ***Minimally invasive** process conditions*
- ***3D** capabilities*
- ***Variable materials** capabilities*
- ***Complex shapes** apart from regular structures*
- ***Nanoscale** capabilities*

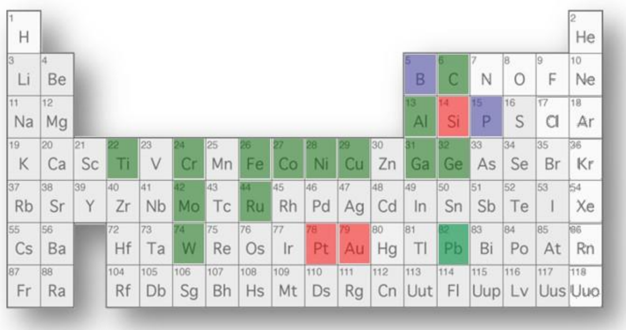
Mask-less Direct-Write Fabrication

Focused Electron Beam Induced Deposition (FEBID)

- FEBID is a very powerful method fabrication of functional nanostructures as it provides:
  - Mask-less, direct-write, bottom-up fabrication on virtually any given material / morphology
  - Different functionalities due to different precursor materials
  - Impurity free material properties
  - True 3D fabrication with spatial nanometer resolution







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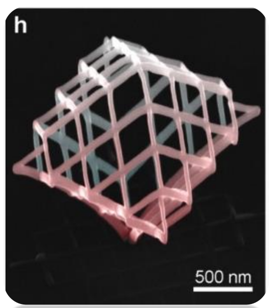
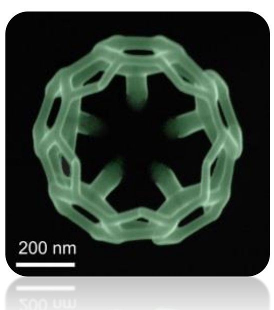
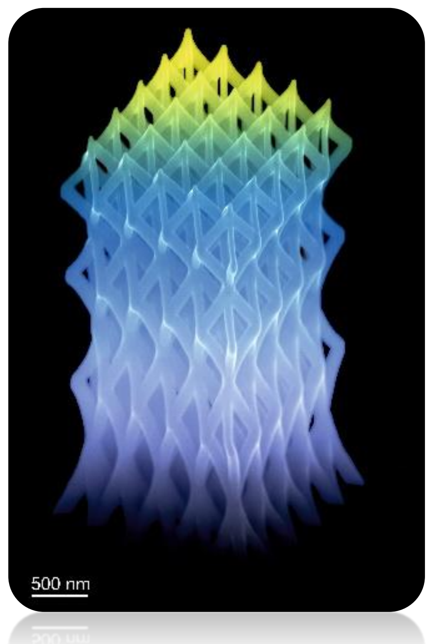
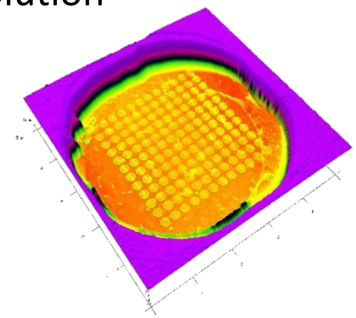
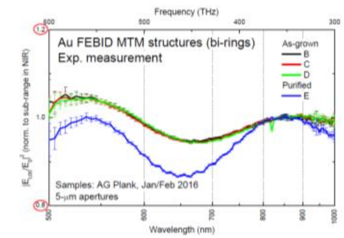




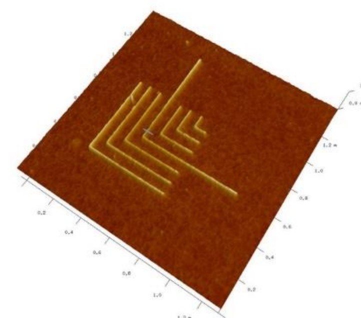


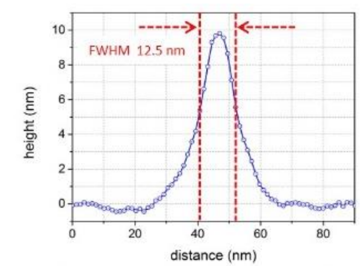
plasmonic light manipulation



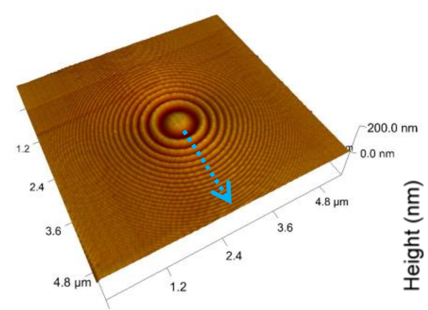


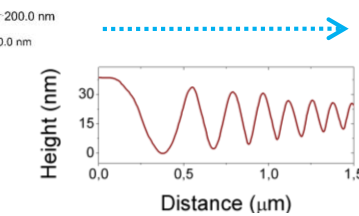
high-resolution fabrication





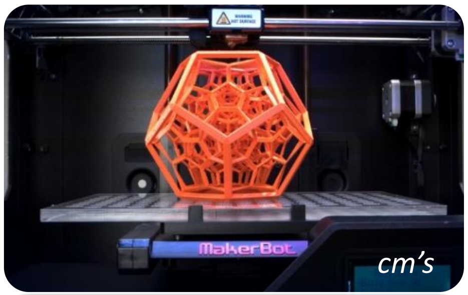
fully sine modulated Gabor lens

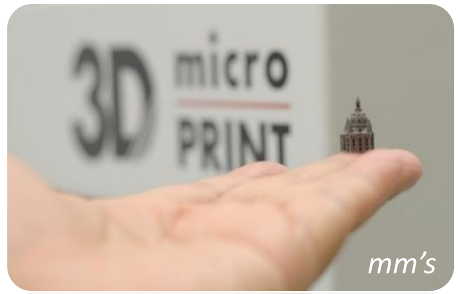


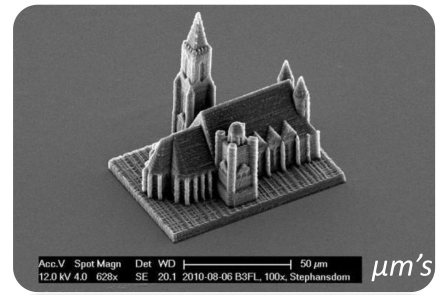


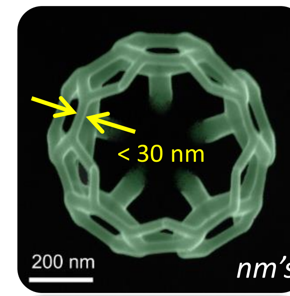
FELMI-ZFE

A Novel Approach for True 3D Nanoprinting









By this, our technology expands the pool of
true 3D Nano-Printing to the real nanoscale with essential advantages

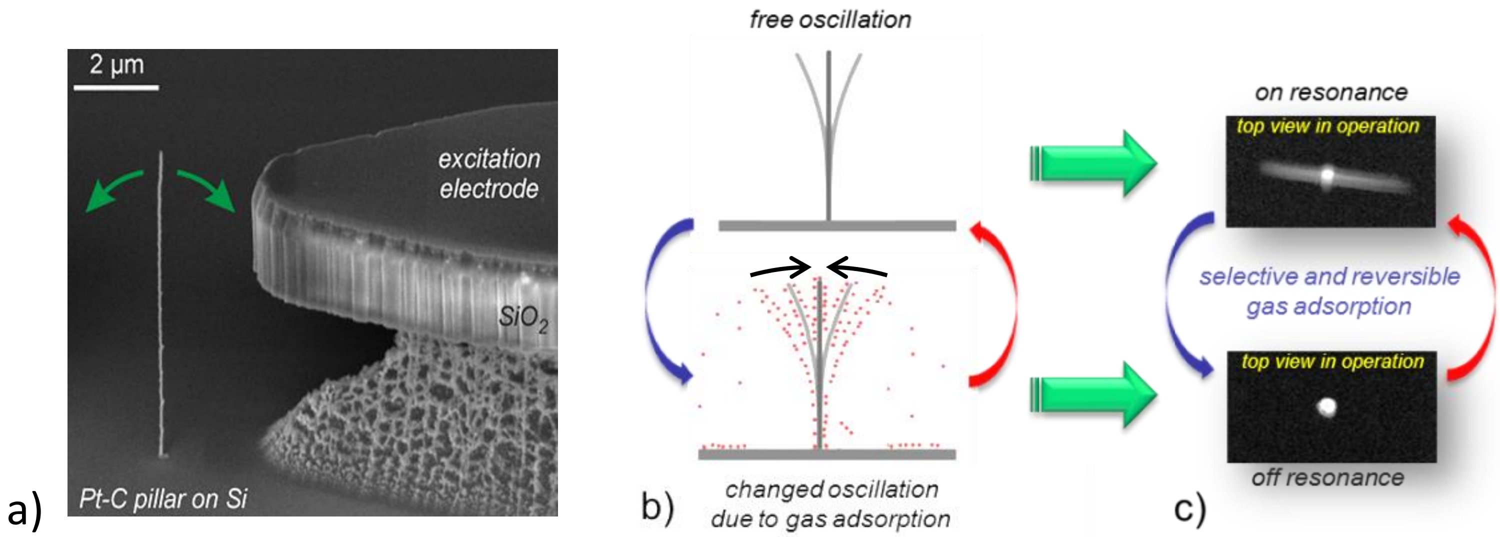
- Minimally invasive direct-write, bottom-up fabrication on almost any substrate material / surface
- Highly precise fabrication of multi-dimensional, functional nanostructures …
- … with the unique strength of true 3D nano-fabrication

FEBID 3D Nanoprinting can be seen as generic technology for

- research → e.g. fundamental studies in optics, mechanics or sensing
- development → e.g. functional nano-probes / sensors with industry

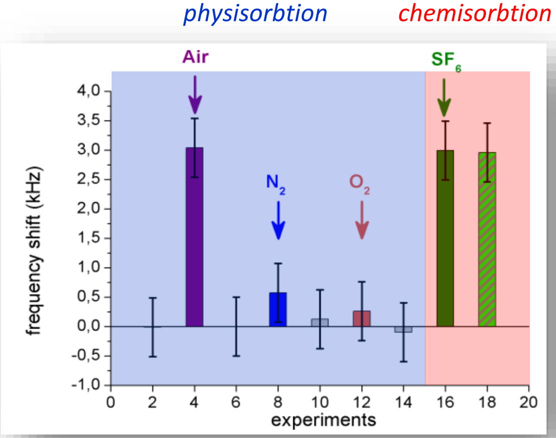
Applications: Quasi-1D Gas / Mass Sensing

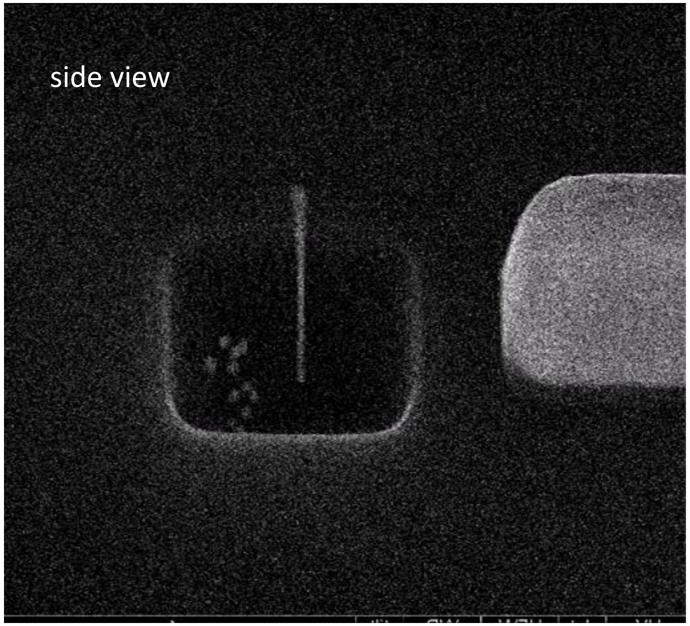
- Quasi-1D Pt-C nano-pillars can be excited via electric AC-fields according to their mechanical resonance frequency
- Once, the diameter and / or the mechanical properties are changed by physical / chemical adsorption from the gas phase, the resonance shifts accordingly

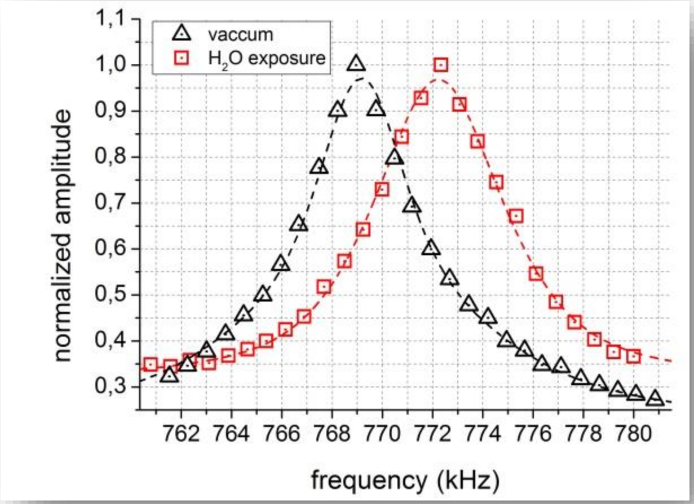


Applications: Quasi-1D Gas / Mass Sensing

- The small dimensions and the soft mechanical character allow highly sensitive
  - gas sensing (reversible)
  - mass sensing (irreversible)
  - Detection limit in the lower Attogram range

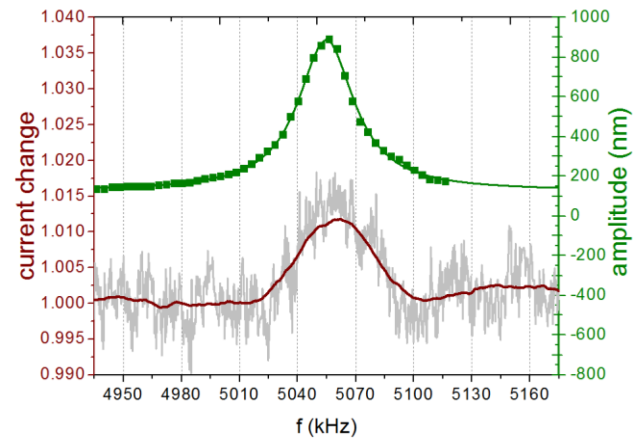




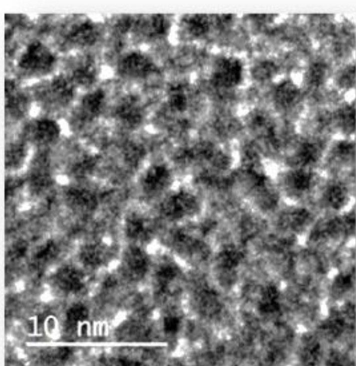


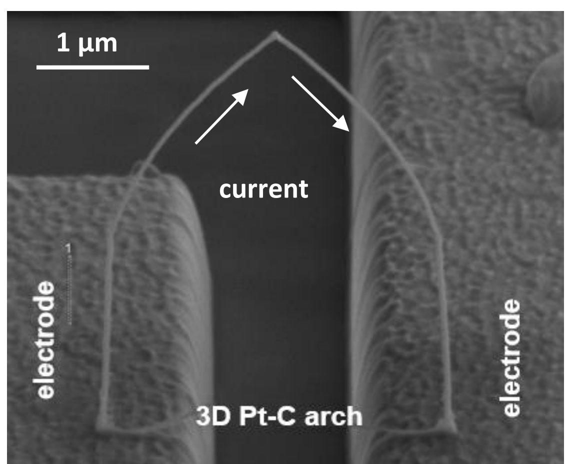
Applications: Quasi-1D Gas / Mass Sensing

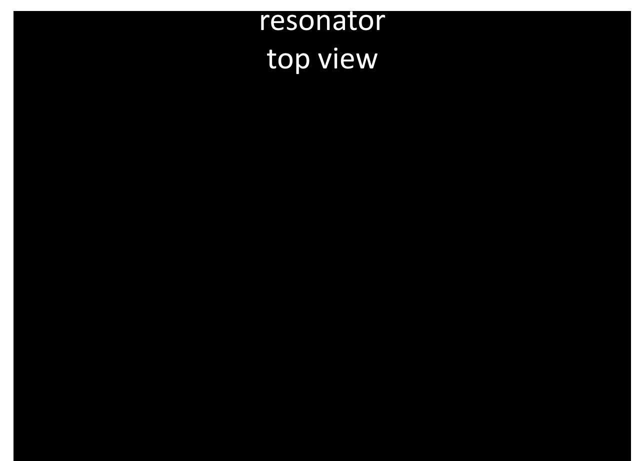
- This basic principle is then expanded by the unique material properties of FEBID materials
- As they consist by ~ 2 nm large metal crystals embedded in an insulating carbon matrix, the electric transport is determined by tunneling processes
- Once the structure is bended, the particles get closer, the tunneling probability increases leading to higher conductivity!
- *<u>That can be used for simple electric detection</u>*!



~ 2 nm metal particle in polymer







Future Applications – 3D Nano-Manipulators

- As we now have the technology under control, further steps goes towards nano-manipulation such as tweezers or optical filter systems …