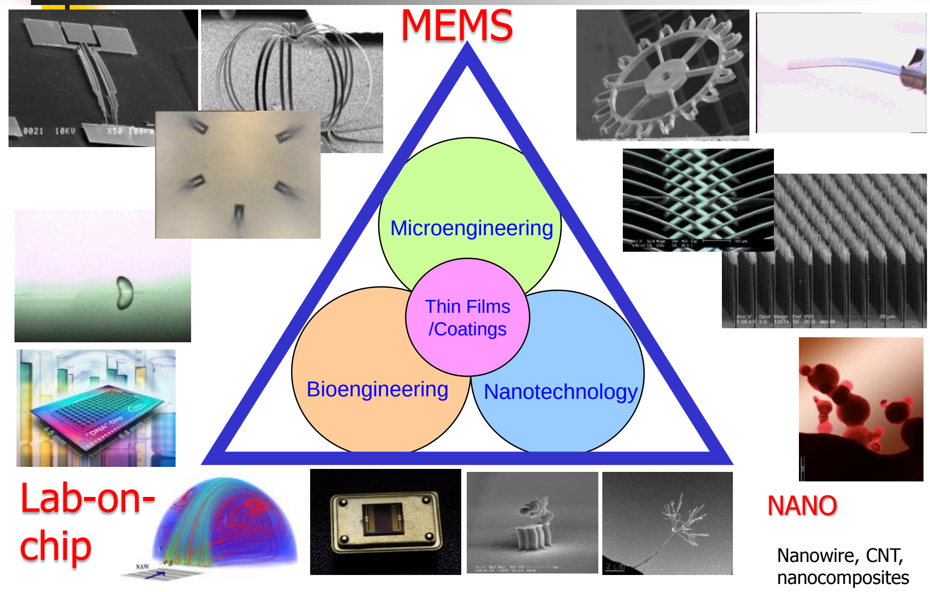
Dr. Richard Fu's work on Functional films for microactuator and lab-on-chip

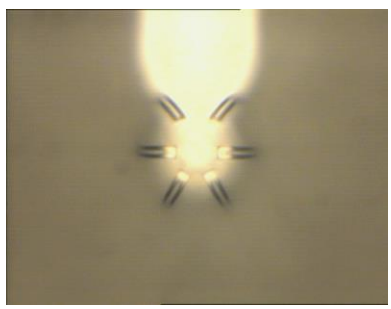


Functional/Smart Materials and Smart Microsystems

Which materials are SMART?

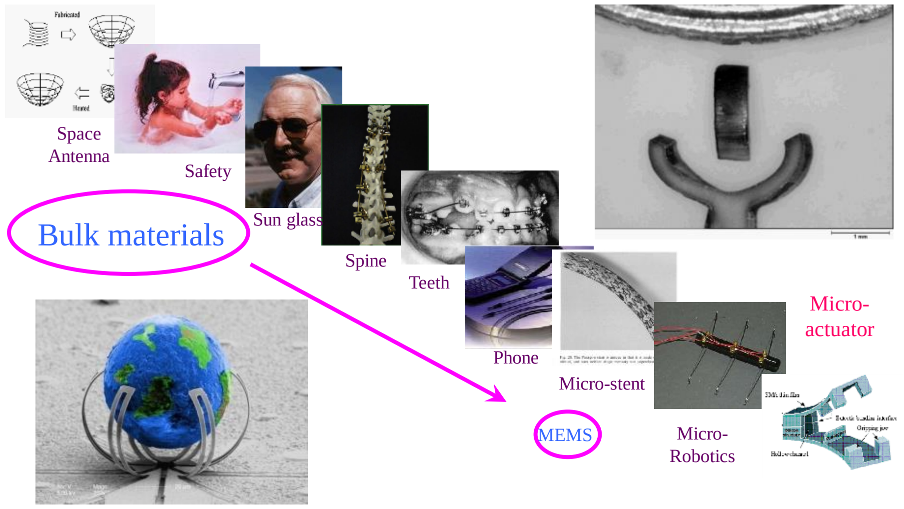
Materials or special design that change the properties in response to an external stimulation

- Piezoelectric Materials
- Shape Memory Alloys
- Smart polymers and nanocomposites
- Functional nanowires
- Diamond, DLC and carbon nanotubes—Smart functions



Shape memory thin films

Part I. Smart thin film Shape memory materials

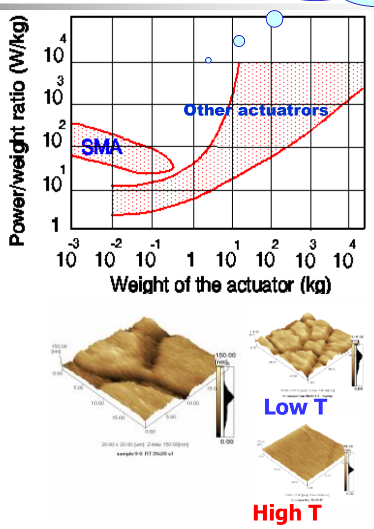


Y.Q. Fu, et al, Sens. Actuat., 112 (2004) 395-408

TiNi-good microactuator

That is why we use shape memory

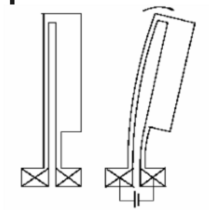
- **Actuation ability**
  - High power
  - Large displacement
- **Sensing ability**
  - Physical properties
  - Mechanical properties
  - Electrical properties
- **Other property**
  - Low-actuation temperature (<80°C)
  - Good biocompatibility



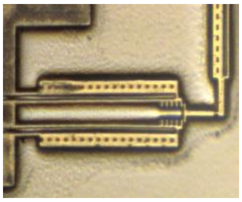
Y. Fu et al, Appl. Phys. Lett., 2006

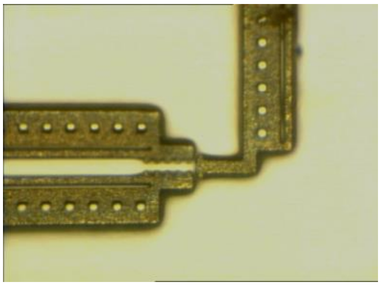
4

Lateral thermal gripper?



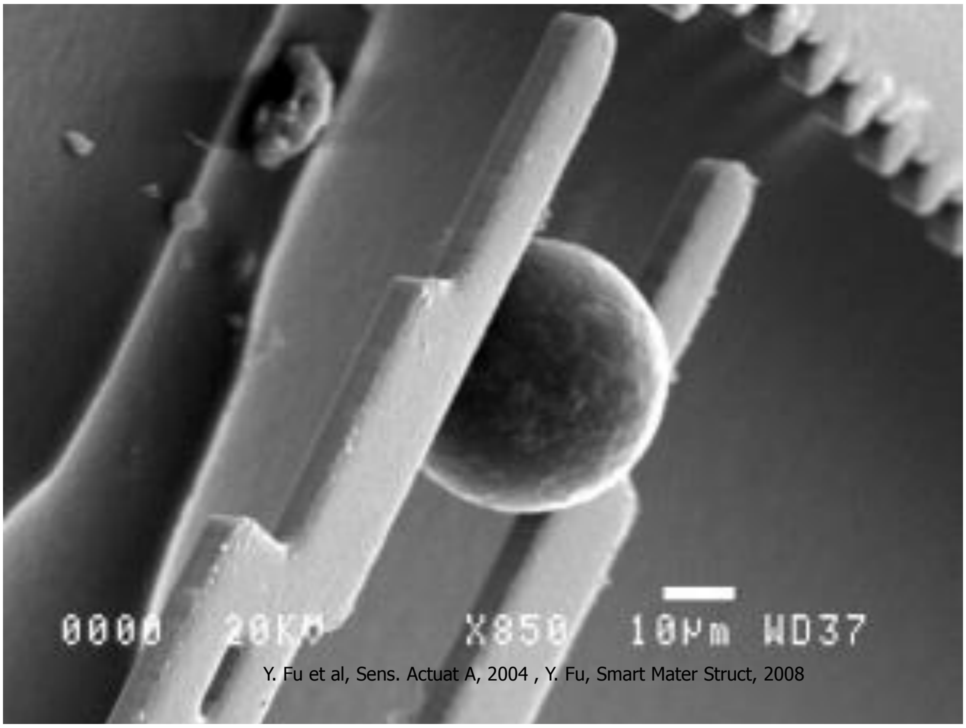
$$q = \text{Power} = I^2 R = \frac{I^2 L \rho}{A}$$





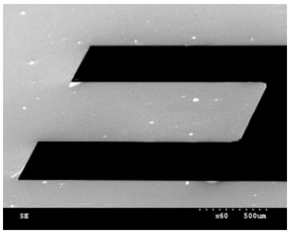
Electroplated Ni microlocker

From J. Luo, Y. Fu, Univ. Cambridge

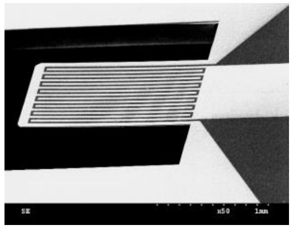


Y. Fu et al, Sens. Actuat A, 2004 , Y. Fu, Smart Mater Struct, 2008

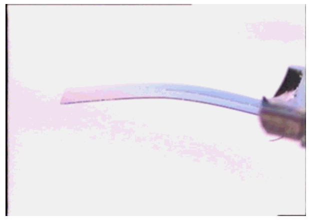
TiNi/Si out-of plane cantilever and gripper



TiNi/Si bimorph



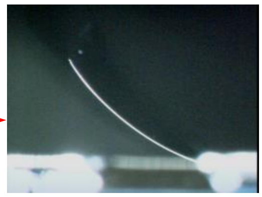
TiNi electrode

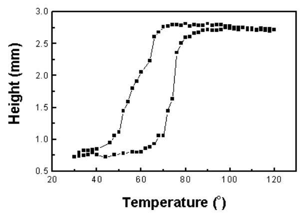


Demonstration

heating

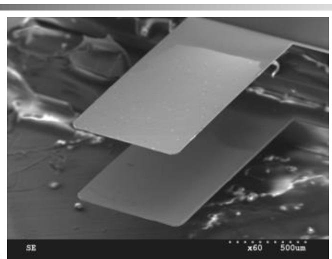
Cooing

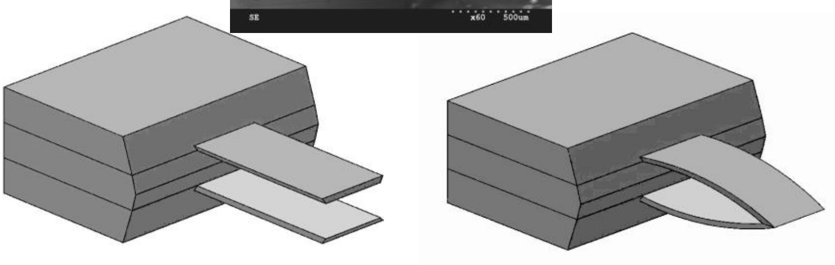




Y. Fu, et al Surface Coat Technol. 2002

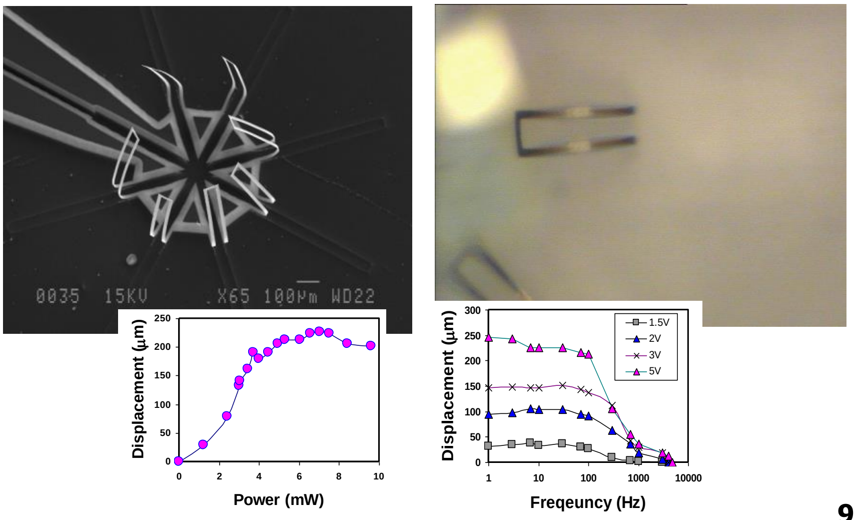
Microgripper by bonding





W.M. Huang, Y.Q.Fu et al J. MMM, 2003

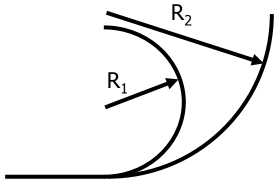
Freestanding upwards TiNi microcage
Microhand!!



Y. Fu et al, Smart Mater Struct, 2008

Reducing Opening Temperature

$$\frac{1}{R}=\frac{6\cdot\varepsilon_{th}(1+m)^2}{d[3(1+m)^2+(1+mn)(m^2+(mn)^{-1})]}=\varepsilon_{th}\cdot S$$



Opening angle $\theta = 180L/\pi R$

Thermal strain $\varepsilon_{th} = \Delta\alpha\Delta T$

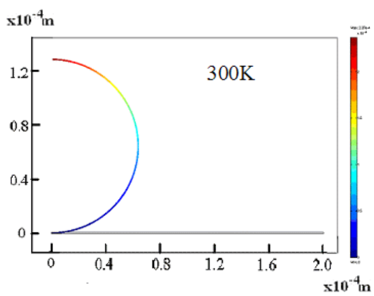
The opening of microcages

$\Delta\theta = 180L/\pi\ (1/R_1 - 1/R_2) = 180L\Delta\alpha\Delta TS/\pi$

To operate, $\Delta\theta = 90^o$ is sufficient

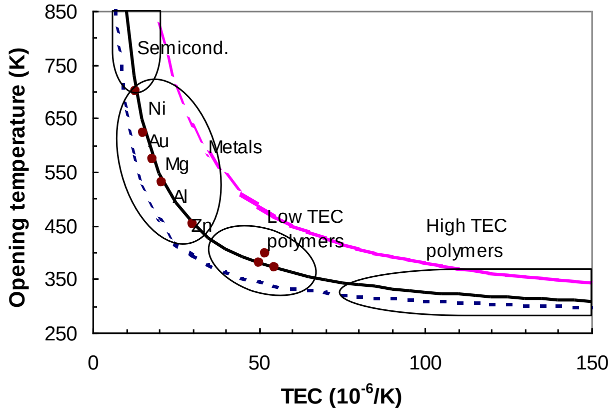
$\Delta T = \pi / 2LS\Delta\alpha$

independent of geometries



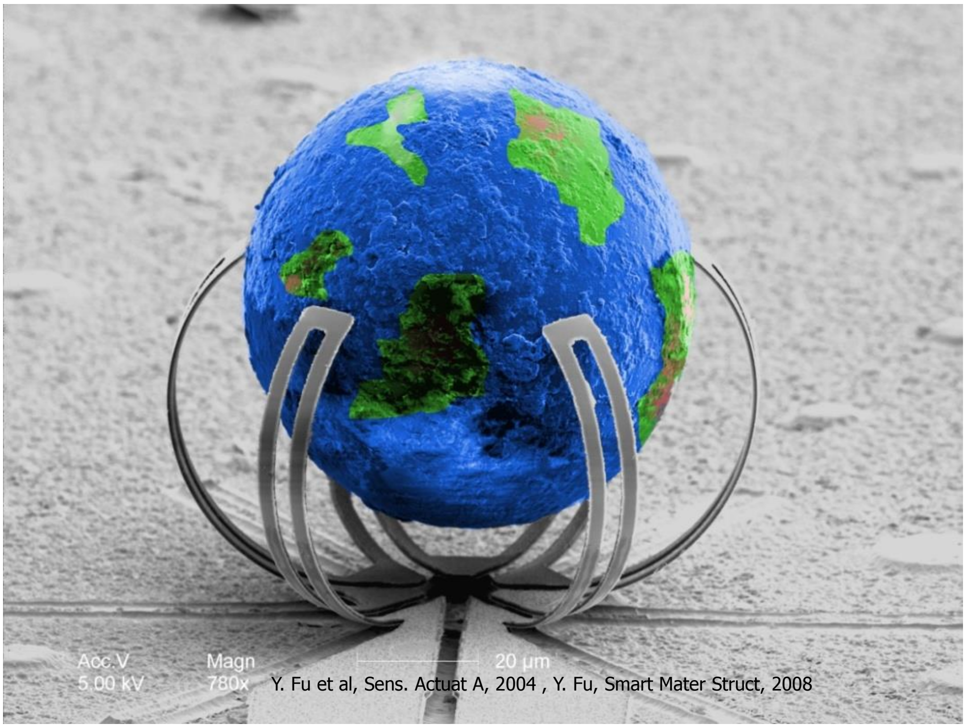
J Luo, Y. Fu, JMM 2005

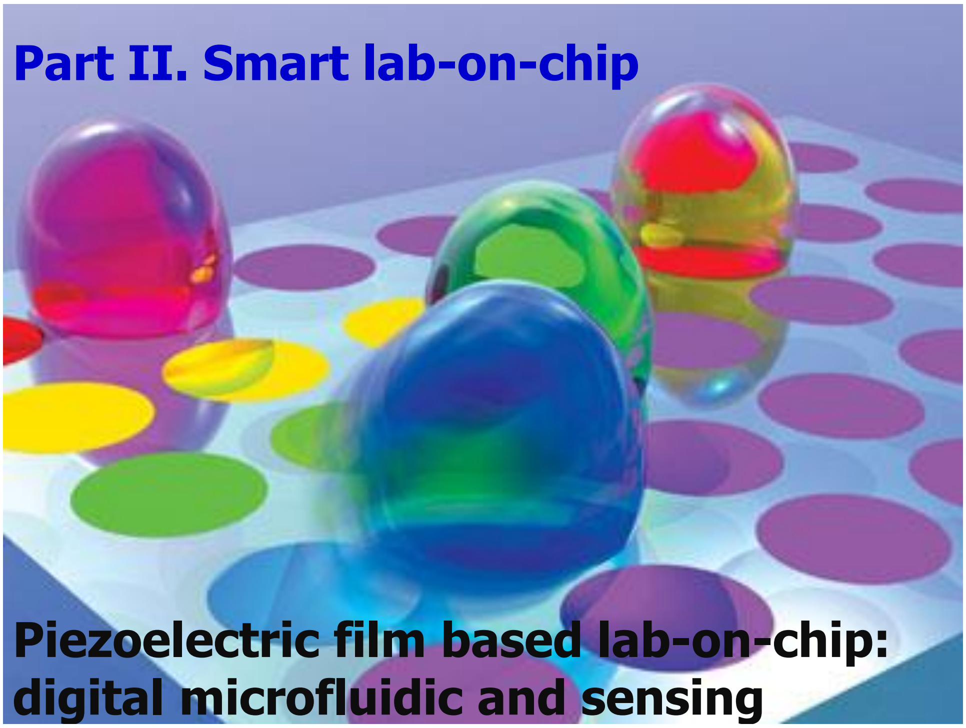
Material Selection for Microcages



- Many materials can be used with DLC to make normally closed microcages
- Polymer based structure gives the lowest operating temperature

11





Lab-on-chip
Trend in diagnostic system

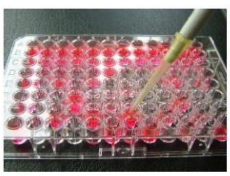
Shrink

Cheaper

Faster

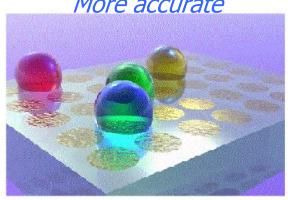
More accurate

~20ml
=20 000 000



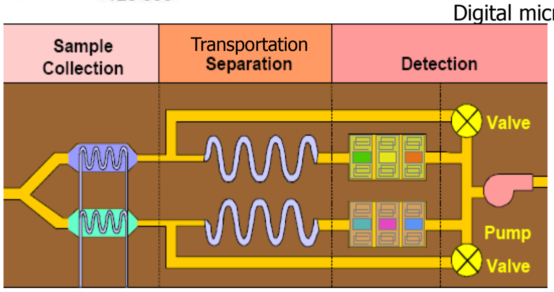
120µl
=120 000

1nl
=1



Advalytix 2006

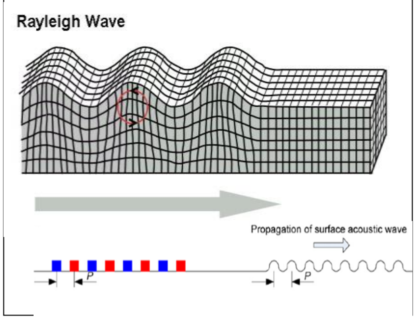
Digital microfluidics



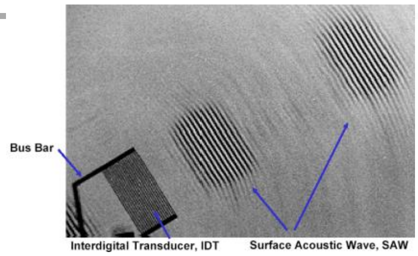
basic procedure for disease diagnosis

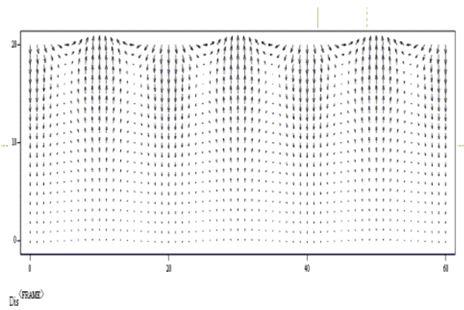
Surface acoustic wave (SAW)

- Piezoelectric film material
- Interdigital transducer
- RF signal
- Acoustic wave

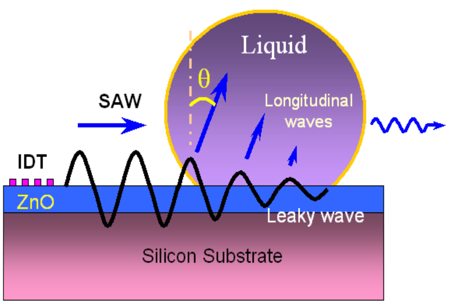


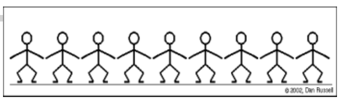
(Remark) P is a periodic length of surface acoustic wave, same as one periodic length of the inter-digital transducer (IDT)

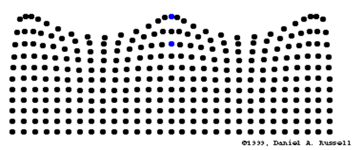




Part I: Surface Acoustic wave microfluidics







•Rayleigh angle

$$\theta_R = \sin^{-1}\frac{C_w}{C_s}$$

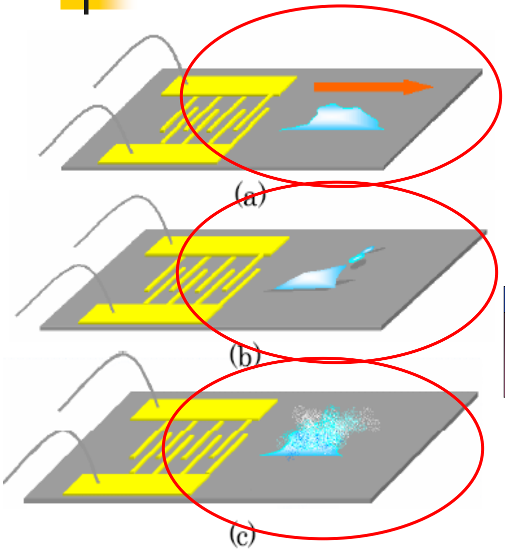
•Reynold's stress

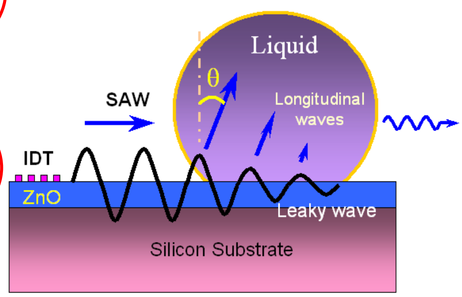
$$\sigma_{ij} = \rho\,\overline{u_i u_j}$$

•SAW streaming force

$$F = \sum_{i=1}^{3}\frac{\partial\,\overline{u_i u_j}}{\partial x_i}$$

Microfluidics-Pumping, jetting and nebulisation



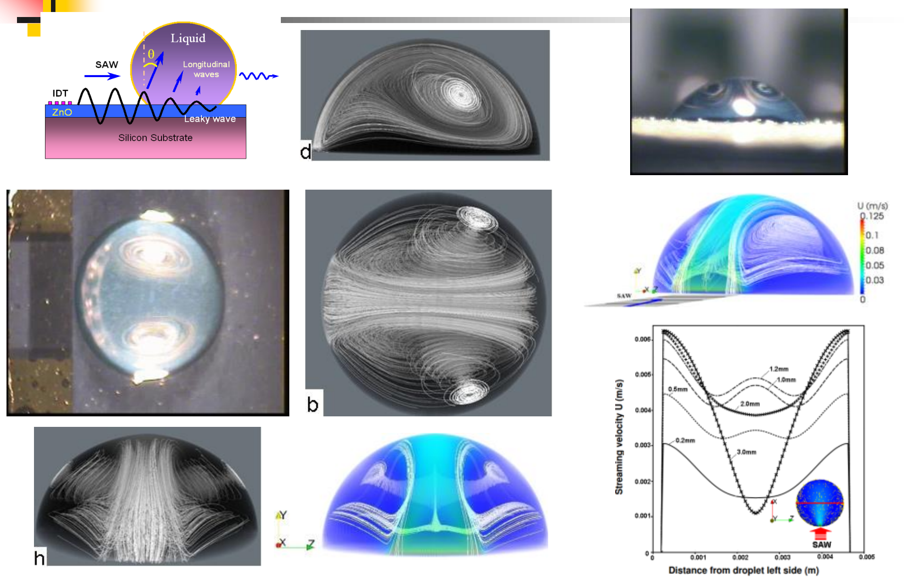


J. Friend and L. Yeo, Rev. Modern Physics, 2013.

Common piezoelectric materials

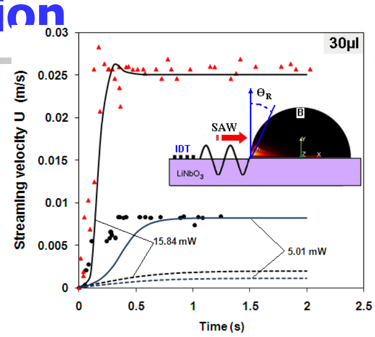
Materials	Density (g/cm^3)	Piezo-constant d_{33} (pC/N)	Coupling coefficient, k	Effective coupling coeff. k^2 (%)	Acoustic speed (m/s)	Dielectric constant ε	TEC (x10^{-6})
ZnO	5.61	12	0.15-0.28, 0.33	1.5-1.7	2650	8.66	3.5-6
AlN	3.3	4.5, 6.4	0.17-0.5	3.1-8	11050	8.5-10	5.2
PZT	7.8	289-380	0.49	22, 5-35	4500	380	1.75
Quartz	2.64	2.3(d11)		8.8, 16	3700	4.3	5.5
LiNbO3	4.64	100	0.23, 0.21	2-11.3	3500	85 (29)	15
PVDF	1.79	-35	0.12-0.2	2.9	2600	6	75
PVDF/TrFE	1.88	-33.5	0.2-0.3	?	2200	6	56

Simulation of SAW Streaming effect- Finite volume analysis



M. Alghane, Y.Q.Fu, et al, J. Micromech. Micorengng., 2010; J. Appl. Phys. 2011

Theory for SAW streaming and simulation



$$\frac{\partial \vec{U}}{\partial t} + (\vec{U}.\nabla)\vec{U} = \vec{F} - \nabla p + \nu\nabla^2 \vec{U}$$

$$0 = \vec{F} - \nabla p + \nu\nabla^2 \vec{U}$$

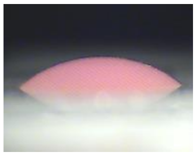
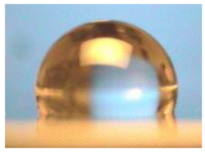
$$F = -(1+\alpha_1^2)^{\frac{3}{2}} A^2 \omega^2 k_i \exp 2(k_i x + \alpha_1 k_i z)$$

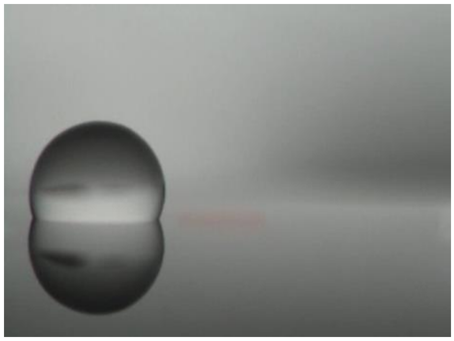
$$\frac{A}{\lambda} = 8.15\times10^{-6} P_D^{\,0.225} + 5\times10^{-6} P_D^{\,0.8} \qquad k_L = k_r + jk_i$$

$$\alpha^2 = 1-\left(\frac{C_L}{C_W}\right)^2 \qquad \alpha = j\alpha_1$$

M. Alghane, Y.Q.Fu, et al, Phys. Rev. E, 2012

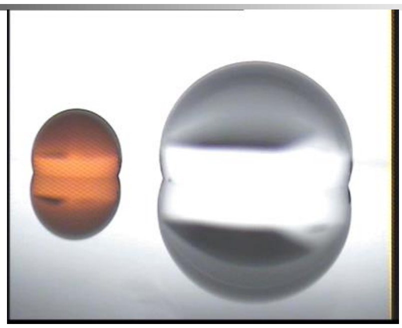
Efficient pumping of liquid droplets

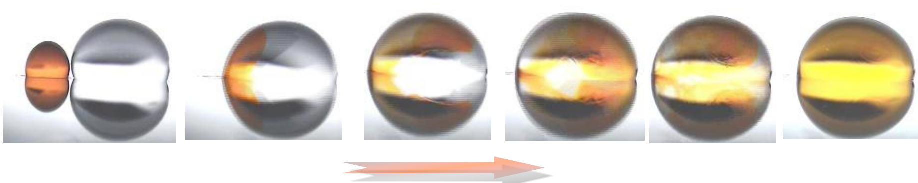
Hydrophilic   Hydrophobic



Droplet pumping

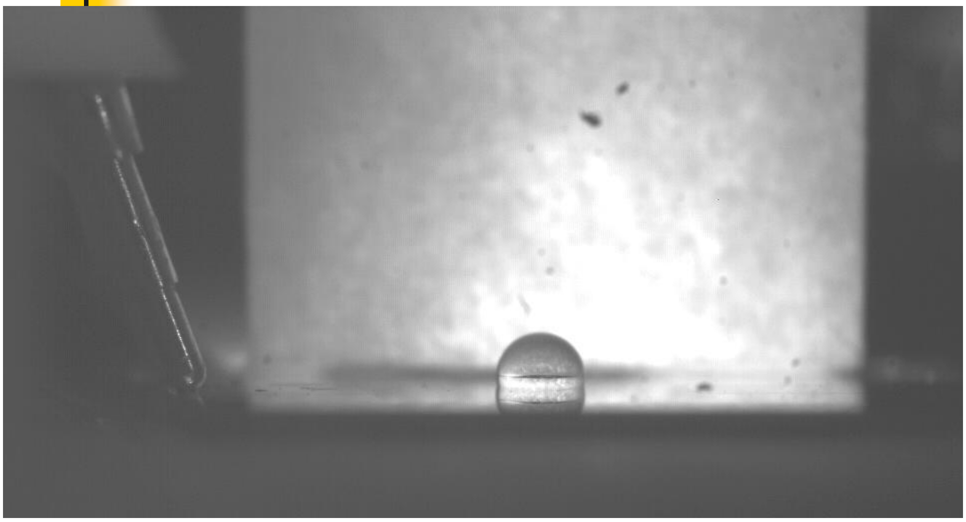
Microdroplet pumping and mixing





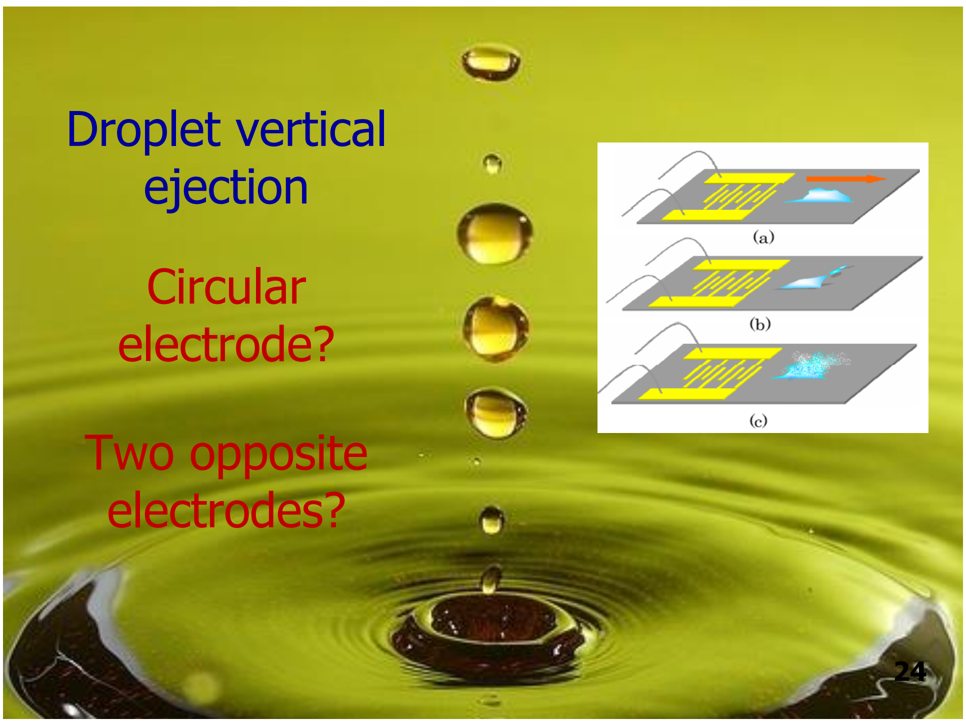
22

High speed ejection

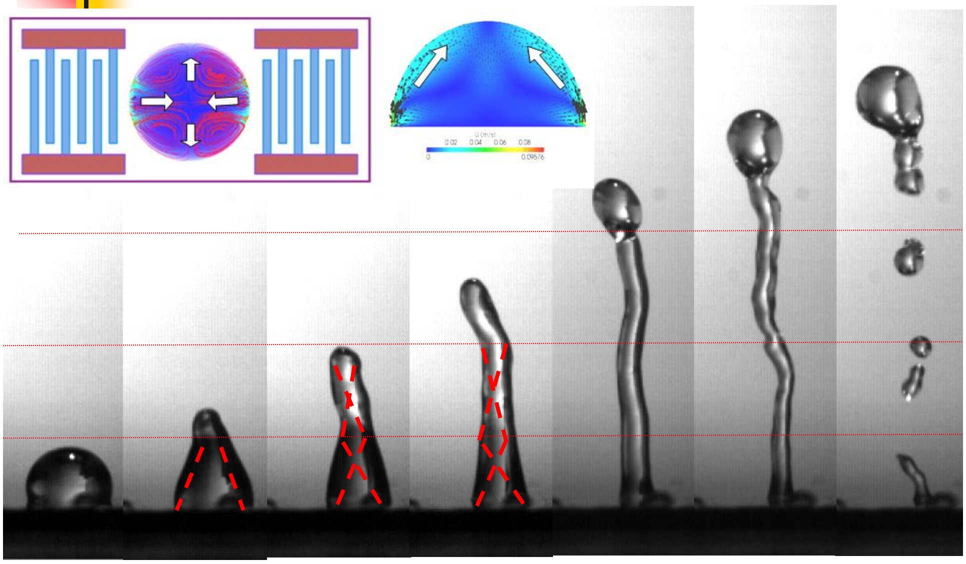


Collaboration with Prof. Jon Cooper, Glasgow University

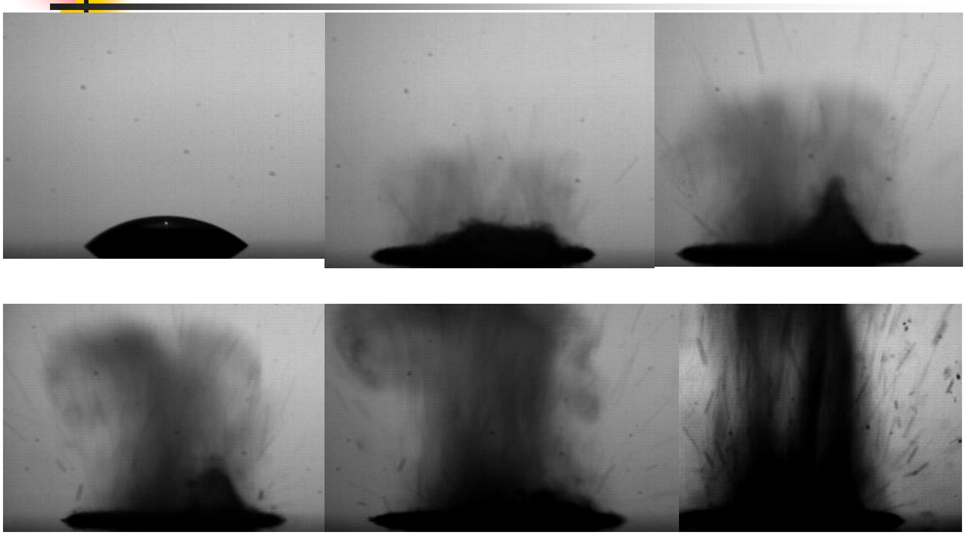
23



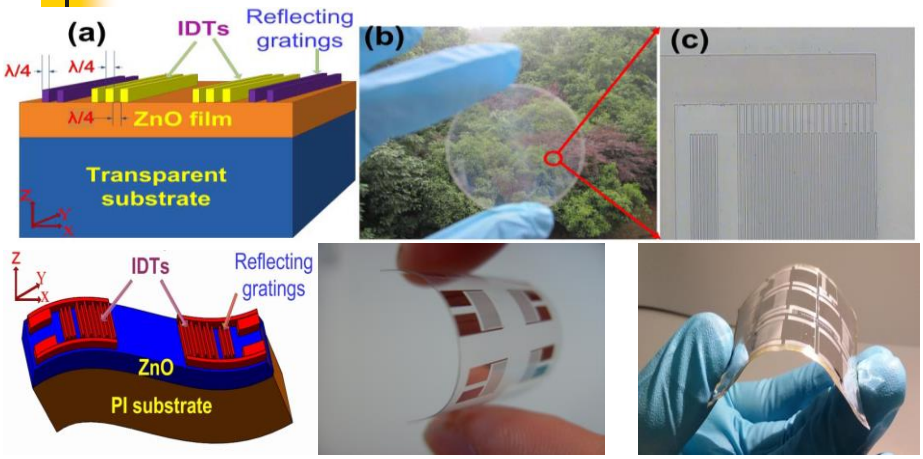
Jetting on hydrophobic ZnO surface



ZnO/Si film based nebulisation/atomization



Transparent, flexible and deformable acoustic wave devices

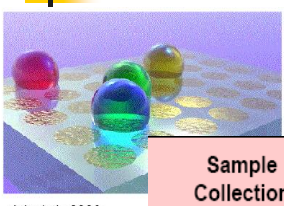


Thin film SAW can be deposited on Si, glass, polymer, metal foils

Y Fu, et al Sens Actuat B, 2010 topic review paper

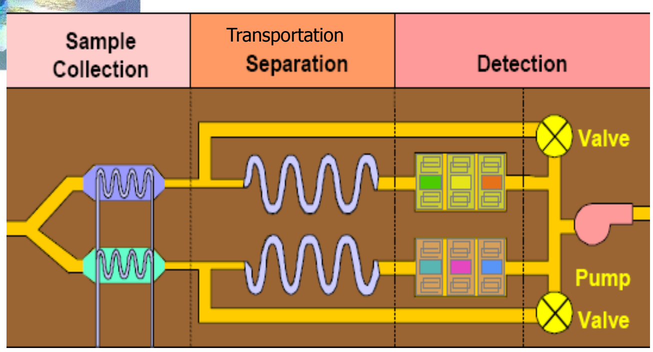
ZnO microfluidics, what about bio-sensing or biodetection?

1nl =1



Advalytix 2006

Biosensing?

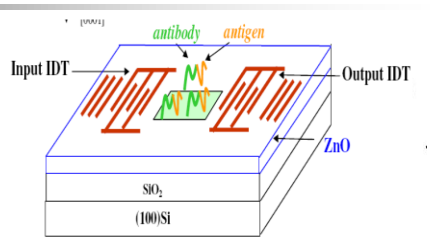


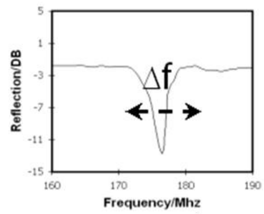
basic procedure for disease diagnosis

28

Biosensing using ZnO SAW devices

- ZnO SAW is sensitive to
  - Mass loading
  - UV and chemical
  - Viscosity change
  - Gas sensing
  - Electrical and capacitance
- SAW signals
  - Resonant frequency
  - Amplitude
  - Phase
  - Impedance



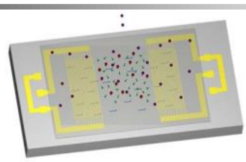


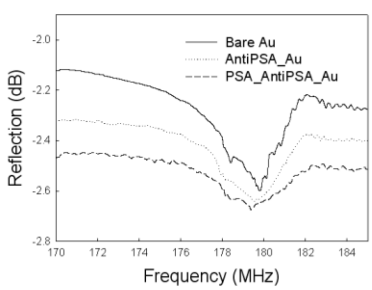
Frequency change

$$\Delta f = \frac{2\Delta m f_o^2}{A\sqrt{\rho\mu}}$$

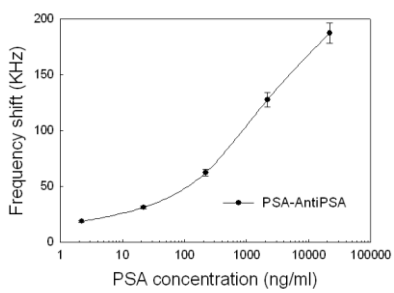
Handheld and wireless

Biodetection results using ZnO thin Films





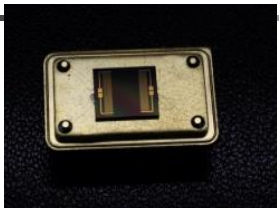
Reflection signals

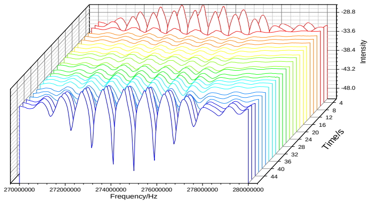


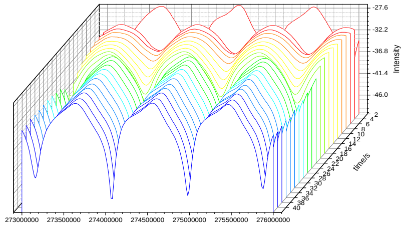
Detection of PSA concentration by Frequency changes

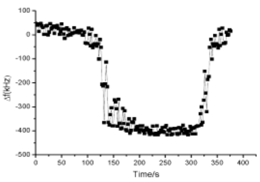
Kim, Luo ,Fu, J. Nanosci. Nanotechnol, 2009

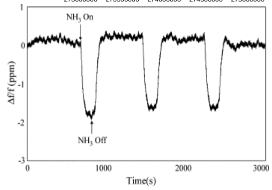
NH_3 gas and VOC sensing results using nanowire based ZnO SAW



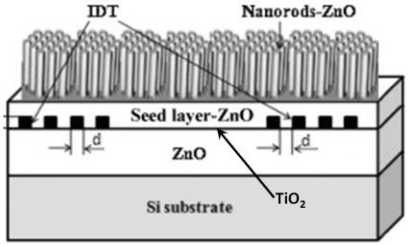


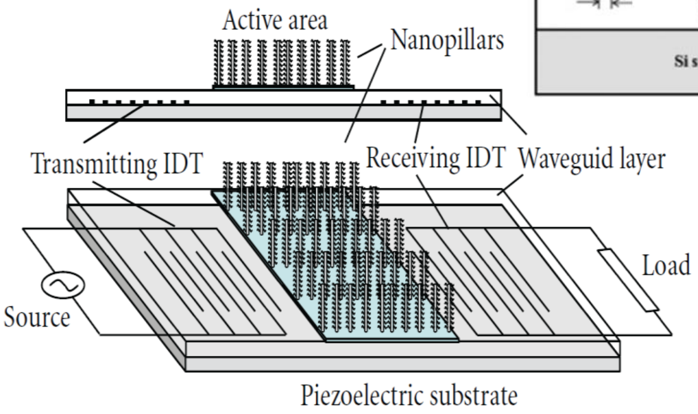


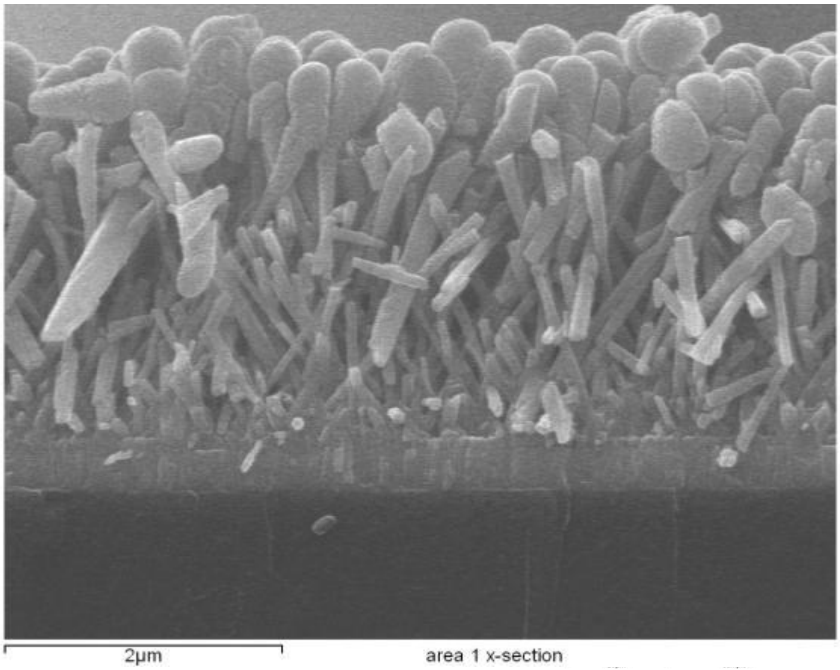




Enhanced sensing with nanowires

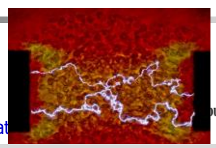


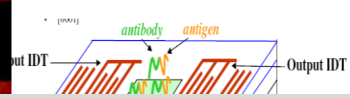




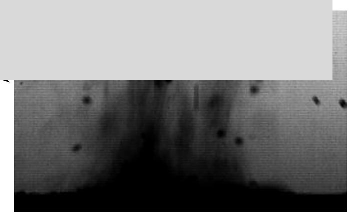
TiO2 NW-ZnO nanowire and ZnO SAW device

Summary: ZnO/AlN film based Microfluidic lab-on-Chip





Integration with photonics, DEP, SPR, SERS, magnetic particles, or others on ZnO SAW platform



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5