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Other Types of MEMS Actuators

1) Piezoelectric Actuators

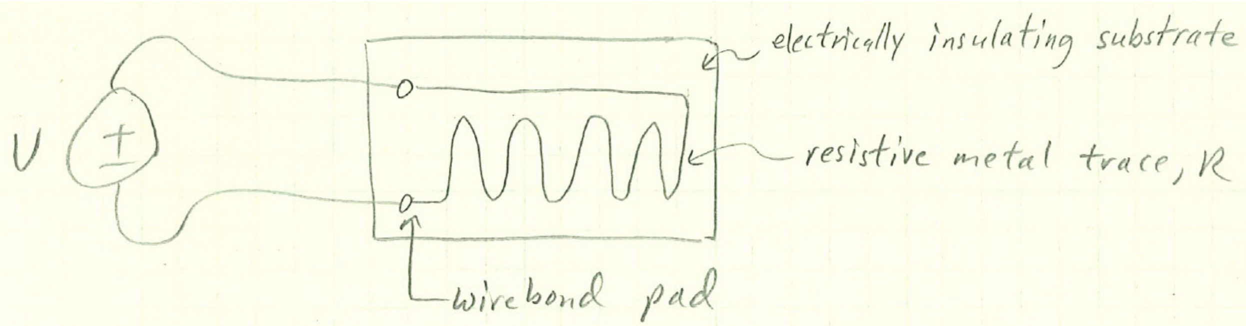
We discussed these earlier when we discussed piezoelectric sensing.

→ Applying a voltage across a piezoelectric crystal results in a small deformation proportional to the electric field strength.

→ It therefore has a very small range of motion.

2) Thermal Actuators

Consider a MEMS electric heating element:

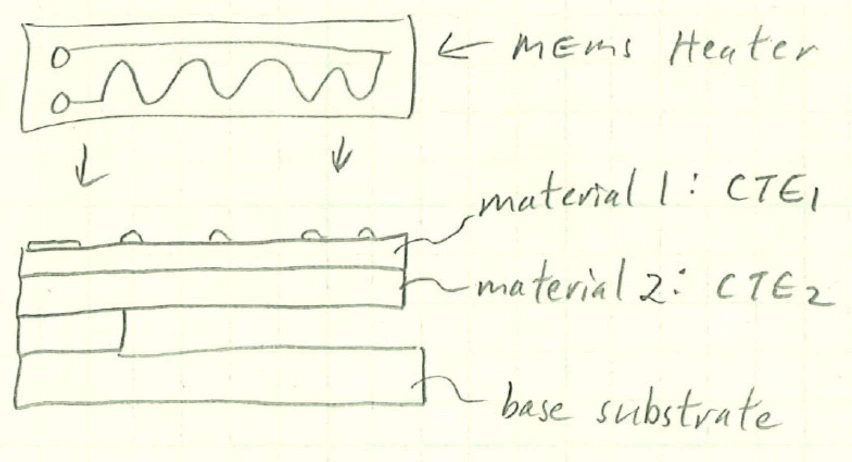


Power dissipated in R by heat: $P = i^2R$ → called Joule heating.

Electricity → Heat: by definition, an actuator

a. Thermal Bimorph Actuator

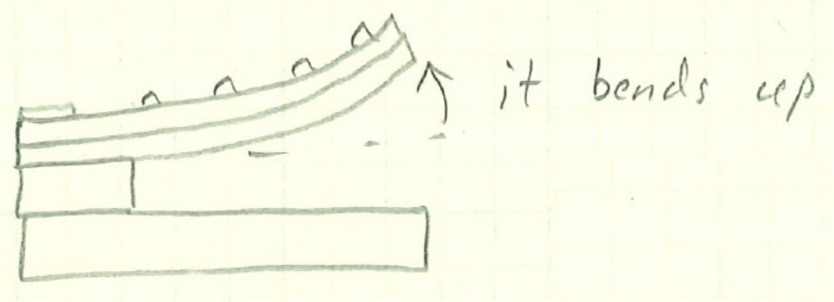
Consider:



Let $CTE_2 > CTE_1$, CTE ≡ Coefficient of Thermal Expansion

Use a Joule heater to heat the structure to a desired temperature.

Results:



But, this requires high power to operate: $P \propto i^2$.

b. Shape Memory Alloys (SMA)

This uses a material that has a rigid state above a certain temperature (T_c) called the <u>Austenite Phase</u>, and a pliable state called the <u>Martensite Phase</u> below T_c.

→ Whatever the shape initially was in the Austenite Phase, it will forcefully return to that shape when the temperature rises above T_c.

T_c is called the “Phase Transition Temperature.”

Nitinol is a commonly used SMA material for MEMS applications:

An alloy of nickel and titanium

It has up to a 5% strain

T_c is tailorable between -100^oC and $+100^oC$ by making small adjustments to the 50/50 Ni/Ti composition ratio

A Joule heater can be used to force the state change from the Martensite Phase to the Austenite Phase.

One non-MEMS SMA application is as a replacement for explosive bolts.

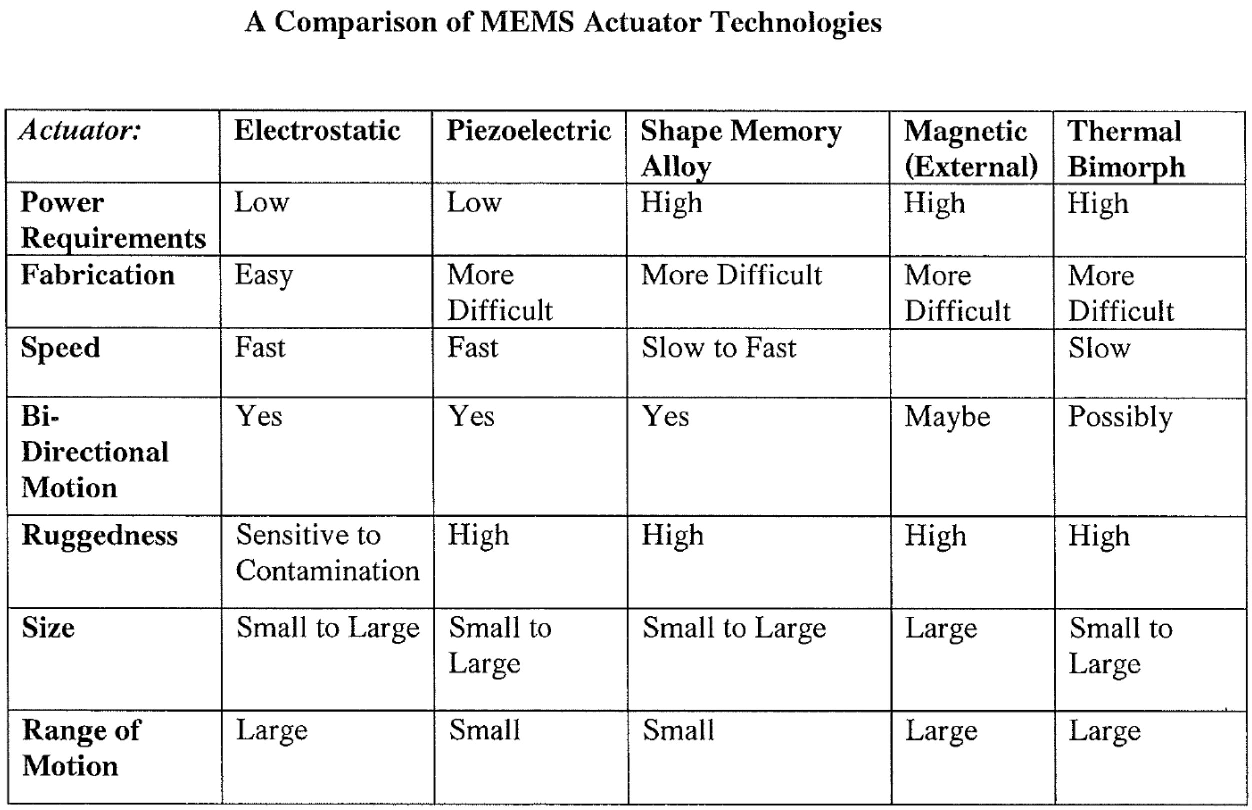
3) Magnetic Actuators

a. Traditional Electromagnetic Actuation

While it is possible to make traditional electromagnetic actuators at the MEMS level, they are not widely used, due to issues such as scaling inefficiency and difficulty in realizing 3-D coils.

b. Use of an External Magnetic Field

Here, movable MEMS structures are fabricated out of ferromagnetic materials such as Ni or Fe. These structures can be fabricated using a number of techniques, such as electroplating. Then an externally generated magnetic field is used to actuate the device, such as with an electromagnet.



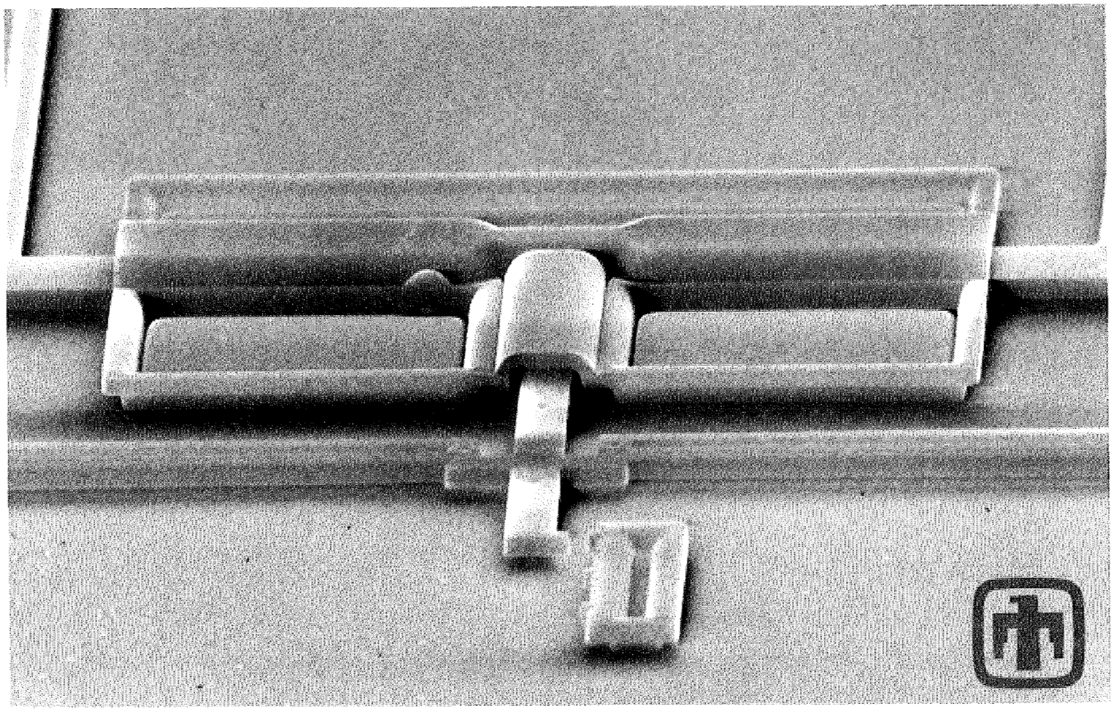
A Comparison of MEMS Actuator Technologies

Actuator:	**Electrostatic**	**Piezoelectric**	**Shape Memory Alloy**	**Magnetic (External)**	**Thermal Bimorph**
Power Requirements	Low	Low	High	High	High
Fabrication	Easy	More Difficult	More Difficult	More Difficult	More Difficult
Speed	Fast	Fast	Slow to Fast		Slow
Bi-Directional Motion	Yes	Yes	Yes	Maybe	Possibly
Ruggedness	Sensitive to Contamination	High	High	High	High
Size	Small to Large	Small to Large	Small to Large	Large	Small to Large
Range of Motion	Large	Small	Small	Large	Large

4) Other Less Commonly Used MEMS Actuators

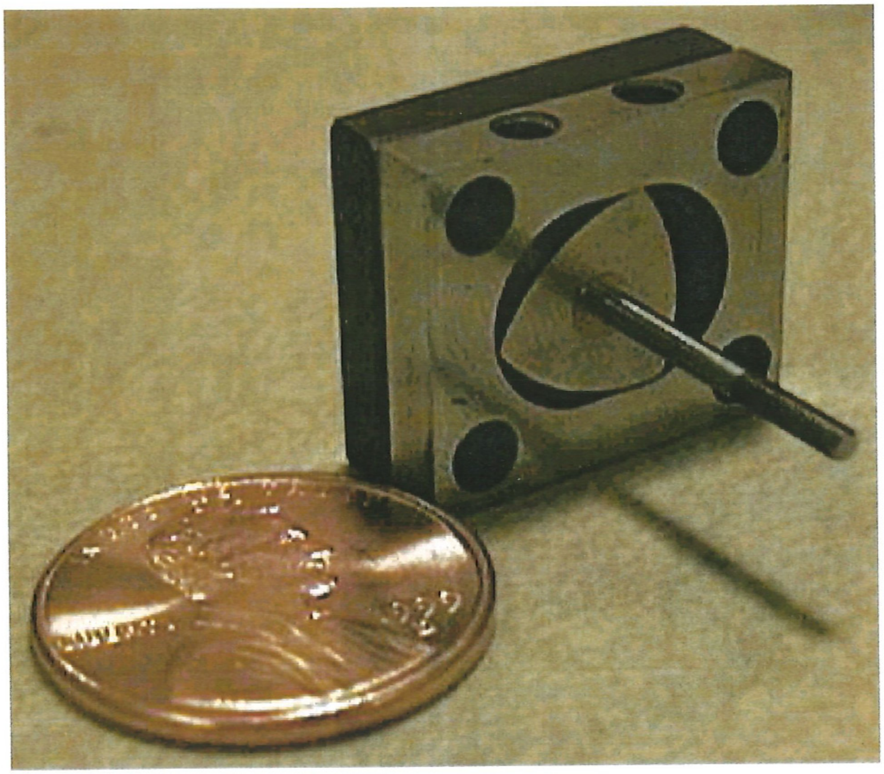
a. Steam Engine on a Chip

Yes, a MEMS steam engine on a chip has been successfully built (Sandia National Labs):



b. Internal Combustion Engine on a Chip

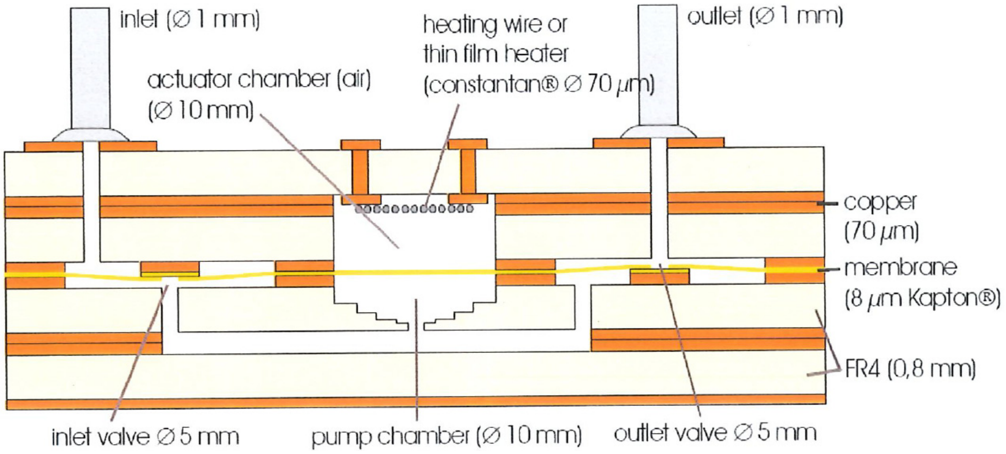
Researchers have developed internal combustion engines on a chip, such as a Wankel engine (U.C. Berkeley):



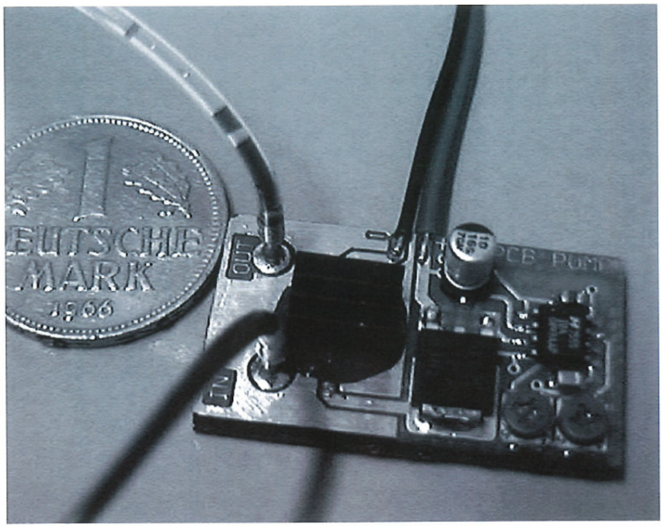
c. Micro-Fluidic MEMS

(1) Microfluidics is a subset of MEMS that involves the handling and processing of liquids for applications such as biomedical.

One developed type of microfluidic devices involves creating flow channels, valves, pumps, mixing chambers, etc. inside a printed circuit board, along with signal processing electronic circuitry:



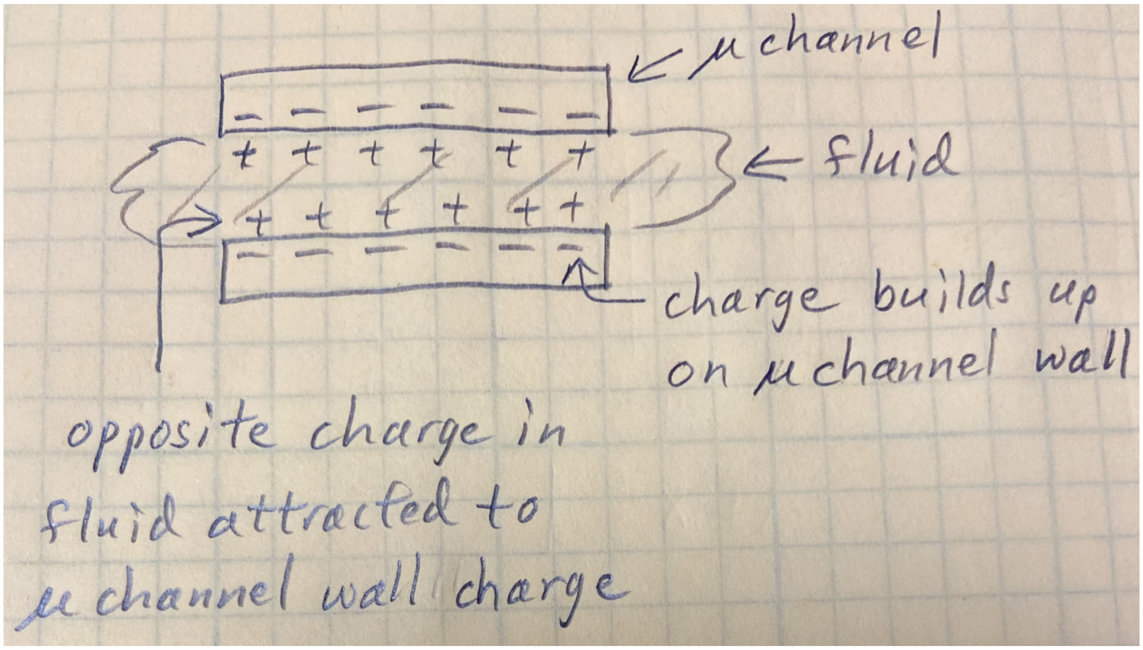
Curtesy Dr. Lienhard Pagel, Univ. Rostock, Germany



Ansgar Wego, Stefan Richter, and Lienhard Pagel, “Fluidic microsystems based on printed circuit board technology,” J. Micromech. Microeng., vol. 11, 2001, pp. 528-531.

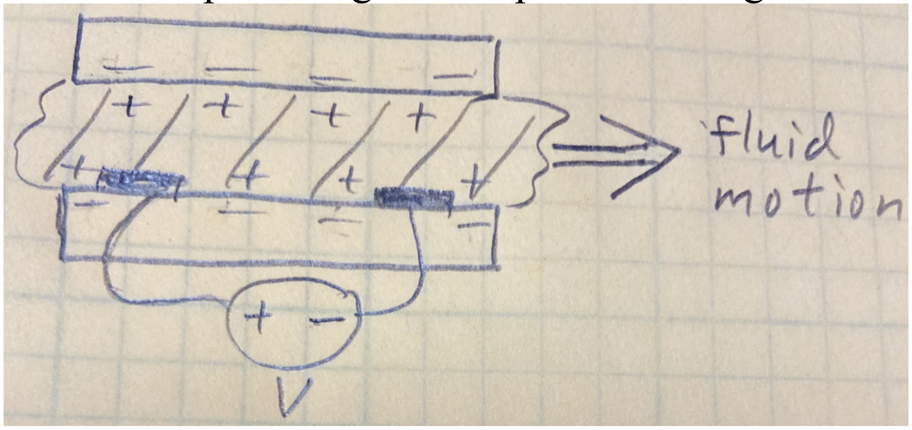
(2) FlowFET

The flowFET is a microfluidics actuator for moving liquids through micro-sized flow channels (μ channels). Its working principle is electro-osmotic flow:

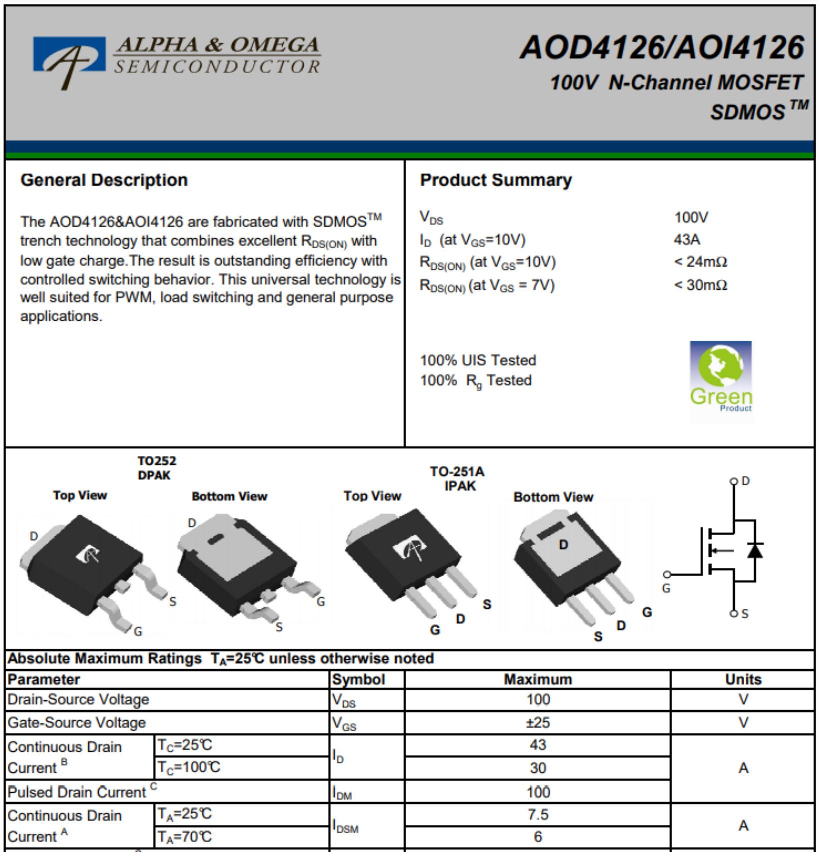


The charge buildup on the sides of the μ channel is like that previously discussed with metal electrodes in water where an electrical double layer forms on them.

A voltage can be applied to electrodes placed at two locations in the μ channel that causes the liquid to flow by attracting charged fluid particles, which sweep uncharged fluid particles along with them:



A voltage of around 100 V across the two electrodes is sufficient to cause fluid flow. DMOS transistors exist that operate at that voltage level:



ALPHA & OMEGA SEMICONDUCTOR

AOD4126/AOI4126

100V N-Channel MOSFET

SDMOS™

General Description

The AOD4126&AOI4126 are fabricated with SDMOS™ trench technology that combines excellent $R_{DS(ON)}$ with low gate charge.The result is outstanding efficiency with controlled switching behavior. This universal technology is well suited for PWM, load switching and general purpose applications.

Product Summary

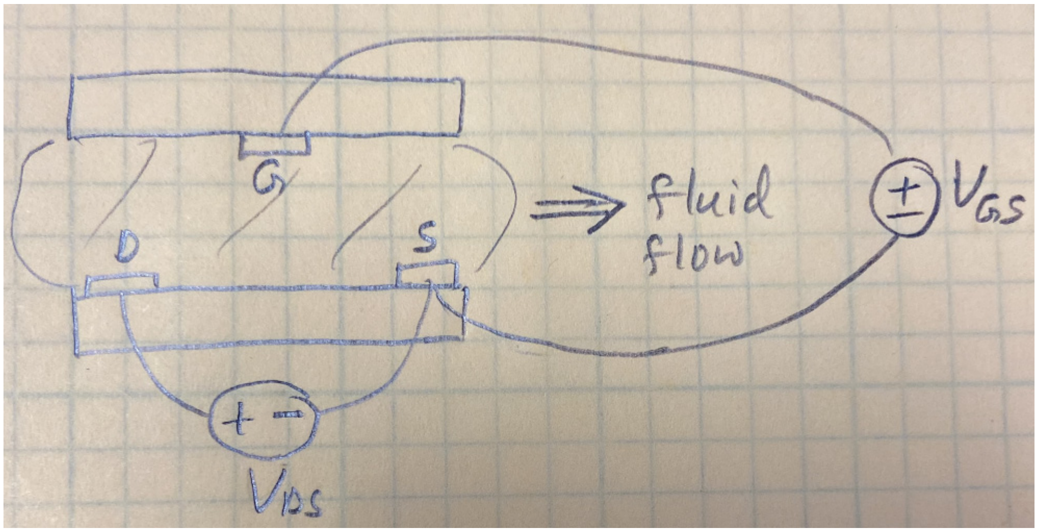
V_{DS}	100V
I_D (at V_{GS}=10V)	43A
$R_{DS(ON)}$ (at V_{GS}=10V)	< 24mΩ
$R_{DS(ON)}$ (at V_{GS} = 7V)	< 30mΩ

100% UIS Tested
100% R_g Tested

Absolute Maximum Ratings T_A=25℃ unless otherwise noted

Parameter		Symbol	Maximum	Units
Drain-Source Voltage		V_{DS}	100	V
Gate-Source Voltage		V_{GS}	±25	V
Continuous Drain Current [B]	T_C=25℃	I_D	43	A
	T_C=100℃		30	
Pulsed Drain Current [C]		I_{DM}	100	
Continuous Drain Current [A]	T_A=25℃	I_{DSM}	7.5	A
	T_A=70℃		6	

Adding a 3rd electrode on the opposite μ channel wall allows the liquid flow to be controlled like current in a MOSFET:



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Pressure Sensors (Introduction)

Chapter 6 in the textbook

Historically, pressure sensors have been the most mature and successful MEMS sensor application. However, I expect that MEMS sensors in cell phones and other applications might be challenging that.

a. So what is pressure?

Pressure is force per unit area, just like mechanical stress and Young's modulus.

The standard unit for pressure is N/m^2 or Pascals (Pa).

However, there are many other units for pressure, including:

Atmospheres: atm
Pounds per square inch: psi
Torrs: Torr
mm of Hg: equivalent to the Torr

Standard Atmospheric Pressure is defined as 1 atm:

$$\begin{aligned} 1\ \text{atm} &= 14.7\ \text{psi} \\ &= 760\ \text{Torr} \\ &= 101.325\ \text{kPa} \end{aligned}$$

b. Pressure sensing → measurement of pressure in a fluid

→ A "fluid" as defined here is a gas or a liquid.

Types of Pressure Sensors:

(1) Absolute Pressure Sensors: measure P w.r.t. a full vacuum.

(2) Vacuum Pressure Sensors: measure P w.r.t. 1 atm = 0; the sensor's output increases as P decreases below 1 atm.

(3) Gauge Pressure Sensors: measure P w.r.t. 1 atm = 0; the sensor's output > 0 for P > 1 atm and < 0 for P < 1 atm.

(4) Differential Pressure Sensors: measure the difference in P between two fluids using two measurement ports.

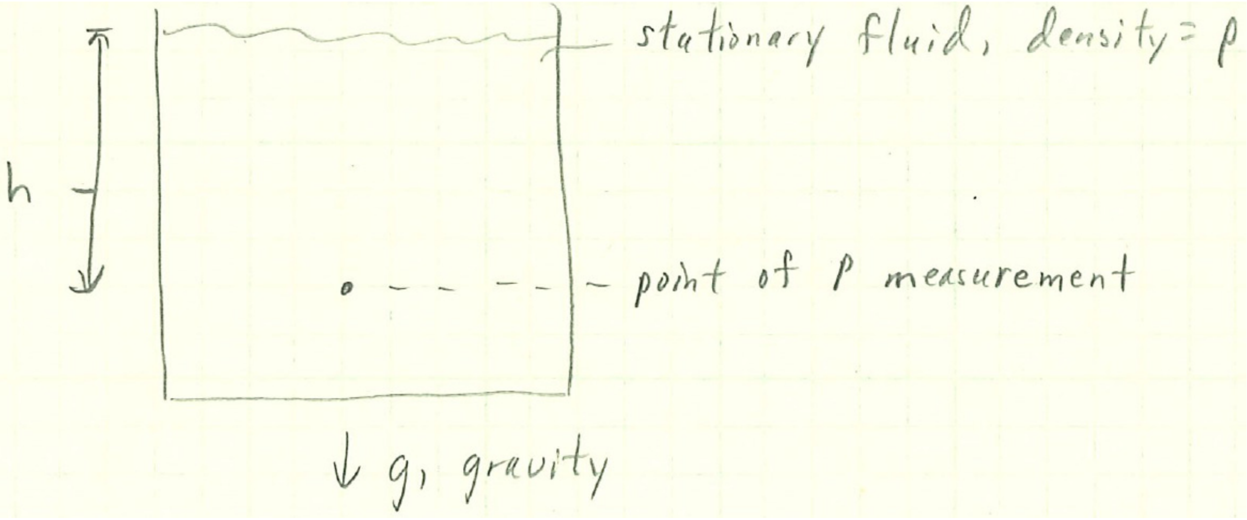
c. Applications of MEMS pressure sensors:

(1) automobile tire pressure measurement
(2) automobile engine fluids measurement
(3) barometric pressure measurement
(4) altimeters
(5) biomedical
(6) vacuum systems
(7) pneumatic equipment (compressed air)
(8) fluid level measurement (example: washing machine)
(9) hydraulic equipment (pressurized liquid)
(10) sound power level measurement
(11) MEMS microphones (example: cell phones)

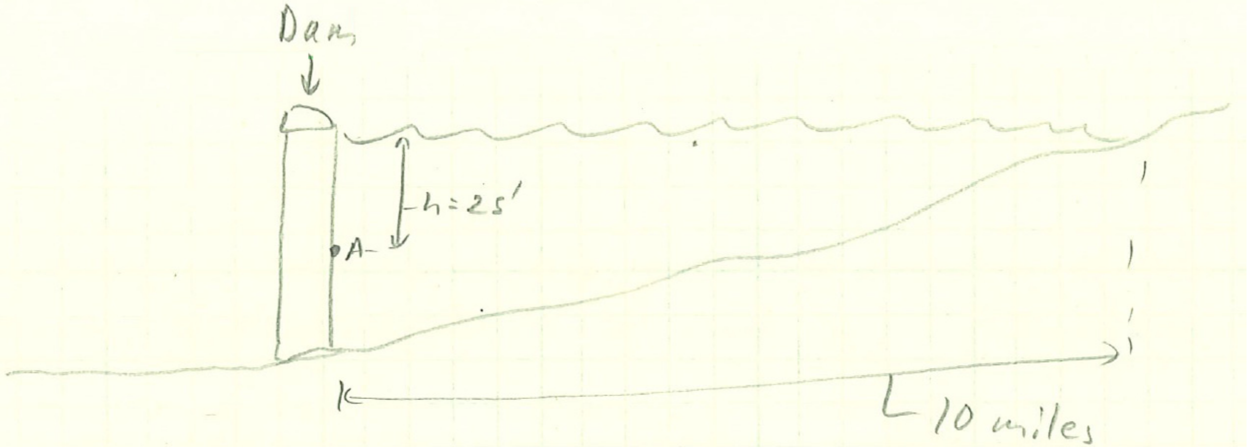
Pressure Sensors (Physics of Pressure)

5) Fluid Mechanics

a) Static Pressure



$P = \rho g h$ → due to the weight of the fluid above the measurement point.



The pressure on the dam at any point is only due to the water above that point: P = ρgh (and the air pressure above the dam) and *not* due to the length of the lake behind the dam.

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1) Buoyancy

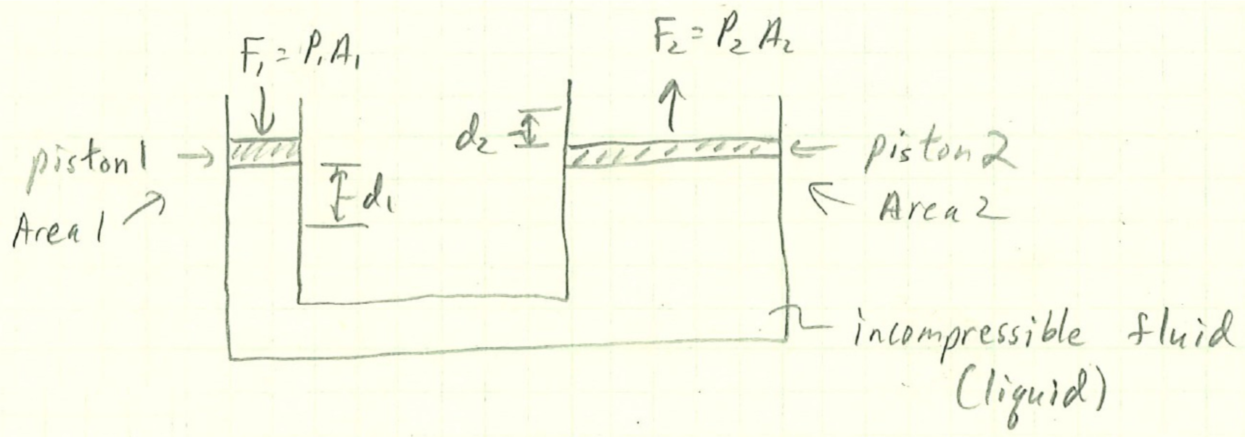
Also known as Archimedes' principle

A submerged object of volume, V, displaces an equal volume of fluid.

If the volume of displaced fluid weighs more than the submerged object, the object floats.

If the object weighs more than the volume of fluid displaced, it sinks.

2) Hydraulic Force



$$P_1 = P_2 = P$$

$$work = F_1 d_1 = F_2 d_2$$

$$P A_1 d_1 = P A_2 d_2$$

$$\therefore d_2 = \frac{d_1 A_1}{A_2}$$

b) Dynamic Pressure

Here, the fluid is in motion.

Bernoulli's equation: $P_t = P_s + \frac{\rho v^2}{2}$, where:

P_t ≡ total pressure
P_s ≡ static pressure
$\frac{\rho v^2}{2}$ ≡ dynamic pressure

This equation exactly holds for an incompressible fluid with zero viscosity. It's an approximation otherwise.

If you can measure the static pressure, the total pressure, and the fluid density, you can calculate the fluid velocity, v, be rearranging Bernoulli's equation:

$$v = \sqrt{\frac{2(P_t - P_s)}{\rho}}$$

An instrument for measuring P_t and P_s to determine airspeed of an aircraft by this technique is the Pitot tube:

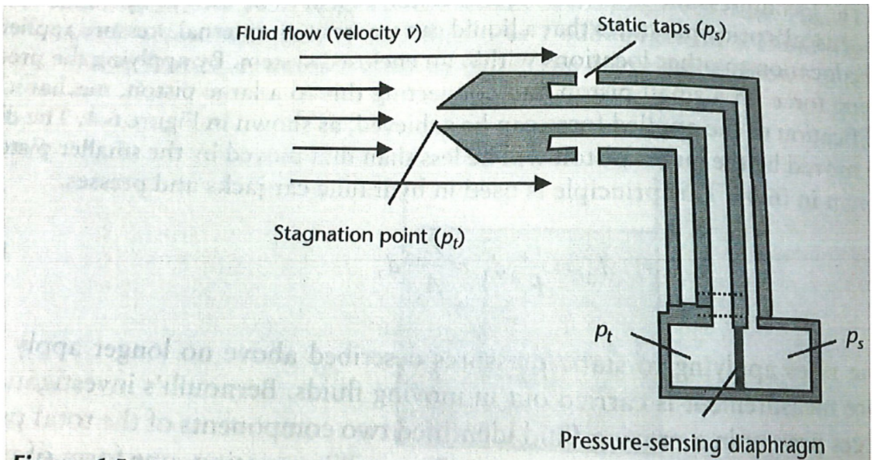


Figure 6.5 Pitot tube arrangement.

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Pitot Tube photo, curtesy Wikipedia

c) Compressible Fluids (i.e. gasses)

Ideal gas law: $PV = nRT$, where:
$P \rightarrow$ pressure
$V \rightarrow$ volume
$T \rightarrow$ temperature (degrees Kelvin)
$n \rightarrow$ number of moles of gas
$R \rightarrow$ universal gas constant (8.314 J/mol·K)