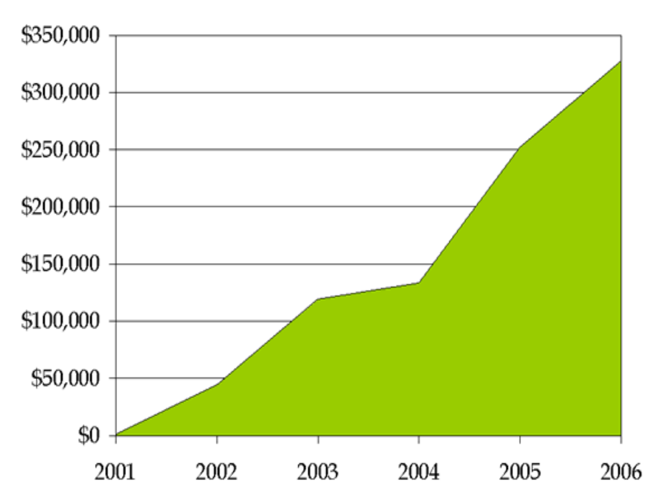
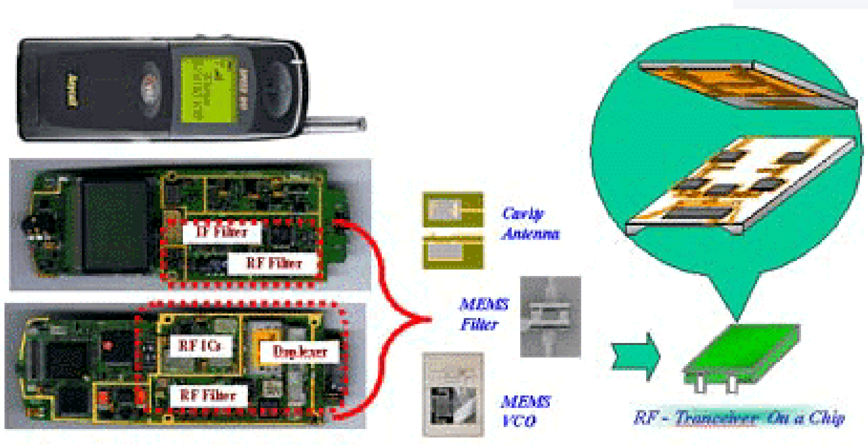
RF, Electrical, and Magnetic Microsystems

Bruce K. Gale
Fundamentals of Micromachining

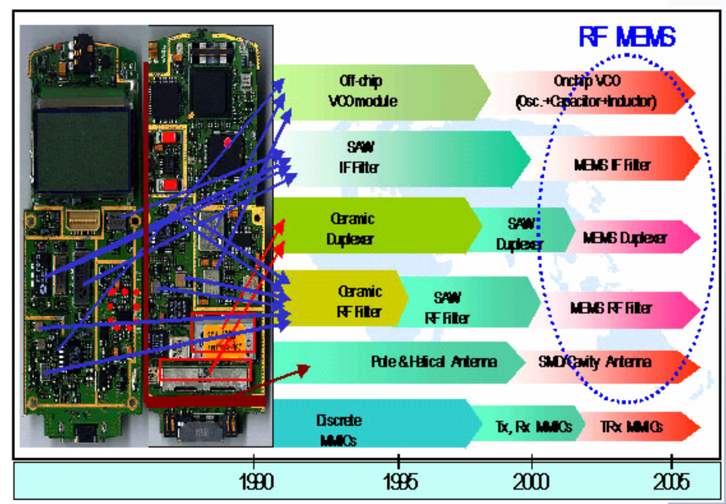
RF MEMS Growth Projections



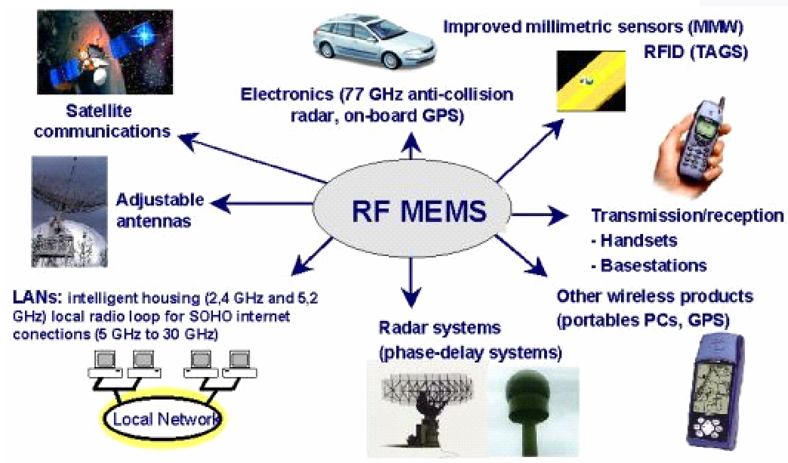
RF MEMS Concept



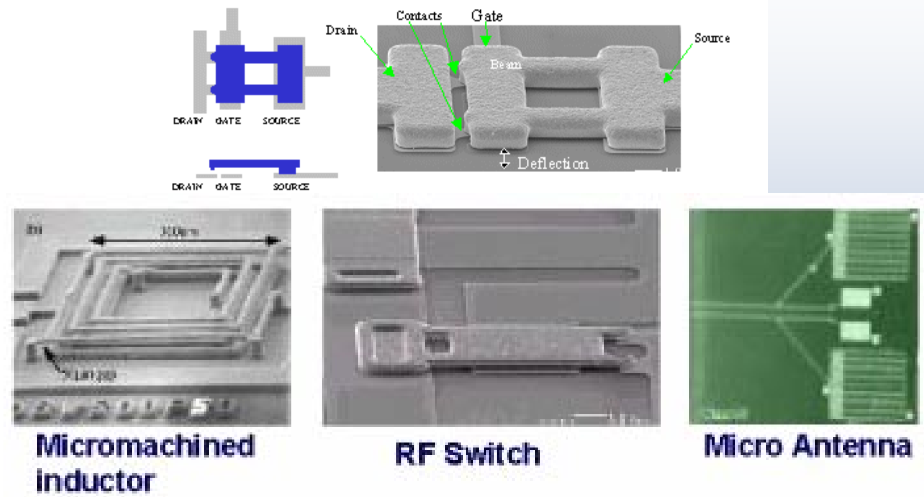
Cell Phone Components



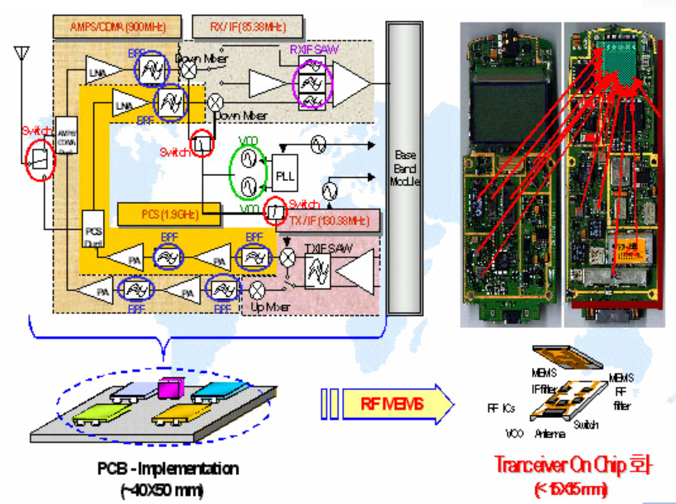
RF MEMS Applications



RF MEMS



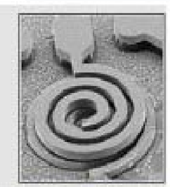
Cell Phone on a Chip



Integrated Passive Components

Problems with integrated passive components today

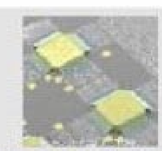
- ☹ Low Q factor
- ☹ High occupied surface (60% of total aera)
- ☹ Very cumbersome packaging



low loss Inductor
Q > 55 à 2 GHz L = 0,5 nH
(15 nH)

Advantages of MEMS integrated passive components

- ☺ Improved performance
  - very high Q from 40 to 70 at 4 GHz for inductances
  - reduction of capacitive effects for inductances
  - less noise
  - low consumption
- ☺ **Integration**: light, small volume, compatibility
- ☺ **Packaging**: substantially improved packaging efficiency



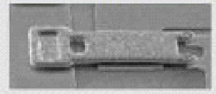
Tuneable capacitor

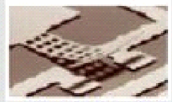
MEMS Switches

Advantages of micro switches

- ☺ **Low insertion loss** (<0,1 dB on [0;3 GHz])
- ☺ **Low power consumption**
- ☺ **Very good insulation** (> 30 dB at 10 GHz) in off state, good impedance matching
- ☺ **Linearity** (required for UMTS)
- ☺ **Miniaturization** (<100 µm²), integration possible with MMIC
- ☺ Better stability with temperature (on R_{IN} et R_{OUT} in ON or OFF)
- ☺ Multiple frequencies range without sacrificing performance
- ☺ Volume production possible, with multiple relays produced in a single package, low cost

Ohmic contact cantilever switch
Northeastern University



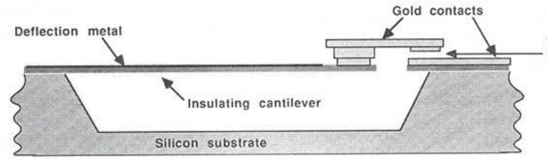


Electromechanical switch
Fraunhofer Inst

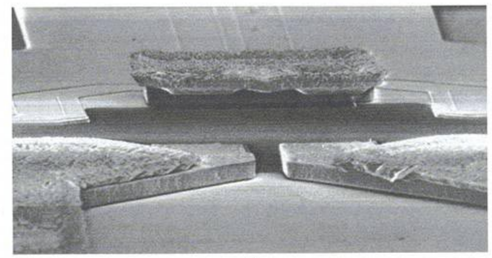
Drawbacks

- ☹ **High actuation voltage**
- ☹ Greater brittleness than with traditional relays: shorter lifetime
- ☹ Uncertainty for price and reliability

Electrostatic Microswitch

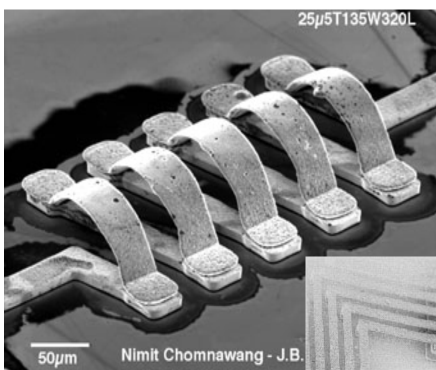


A

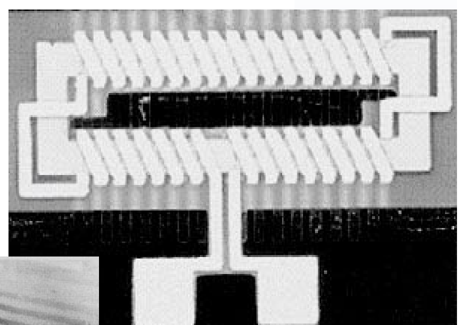


B

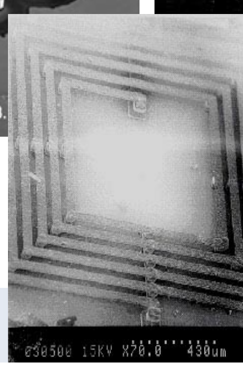
MEMS Inductors



Air Core

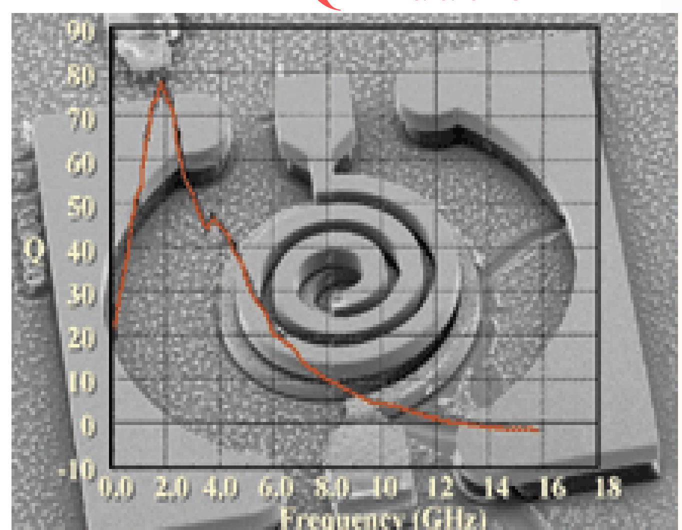


Ni-Fe Core

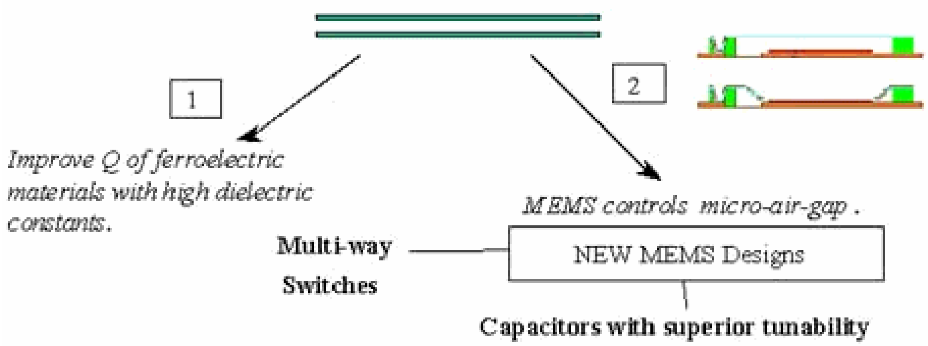


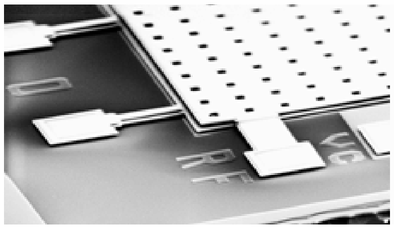
Alternate Configuration

Hi Q Inductor

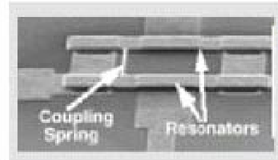


Variable Capacitor





Other RF MEMS Devices

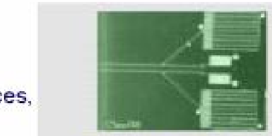


Resonators

- High quality factor Q
- Easy correction of the frequency shifts
- Adjustable reactance, length of line and elements of filters

Micro-antennas

- Integration
- Antennas network: performance, elimination of interferences, powerfull
- Smart antennas



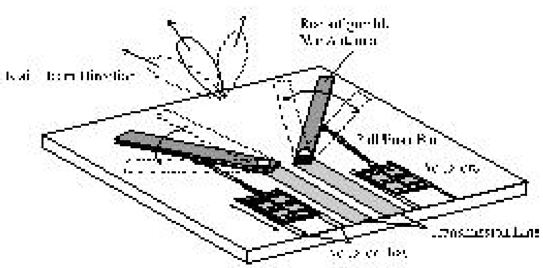
Reconfigurable micro-antenna (directional)
University of Michigan

Micromachined transmission line
University of Michigan

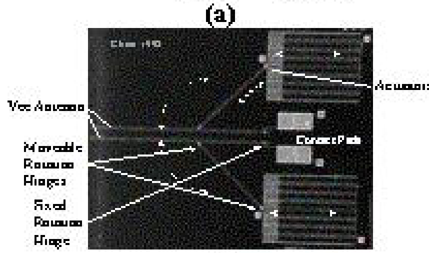
Transmission line

- Dielectric losses strongly reduced
- Limitation of conduction losses during the signal transmission

Recinfigurable Antenna



(a)

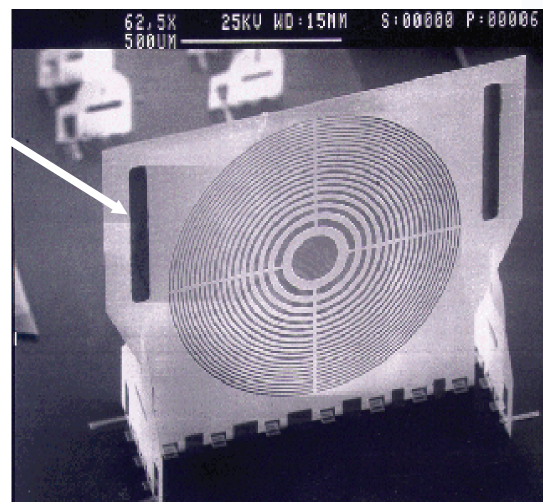


(b)

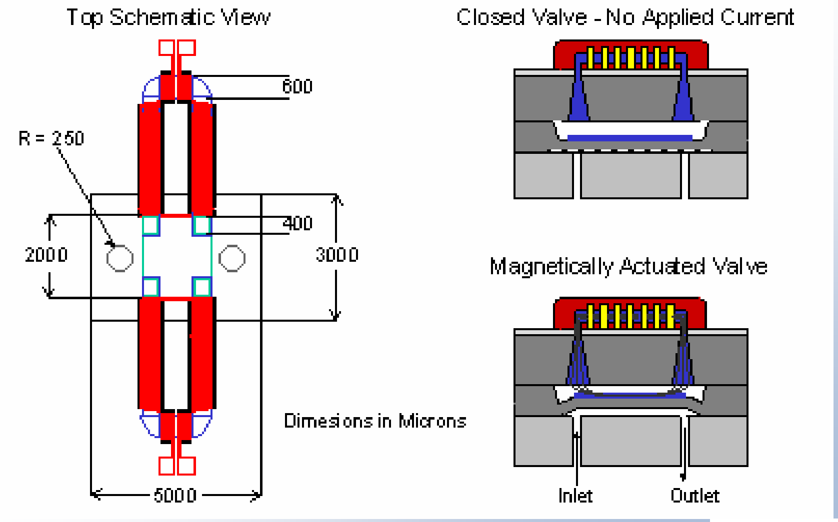
Magnetic Assembly

Magnets to raise structure

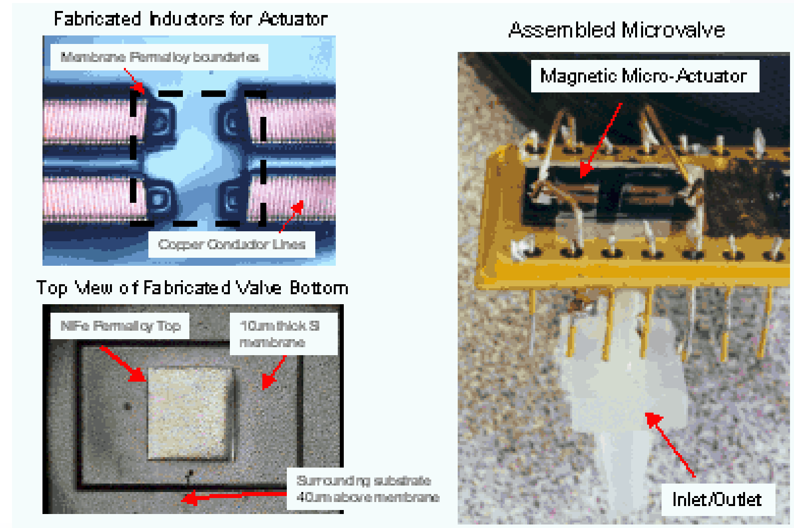
100% efficient assembly



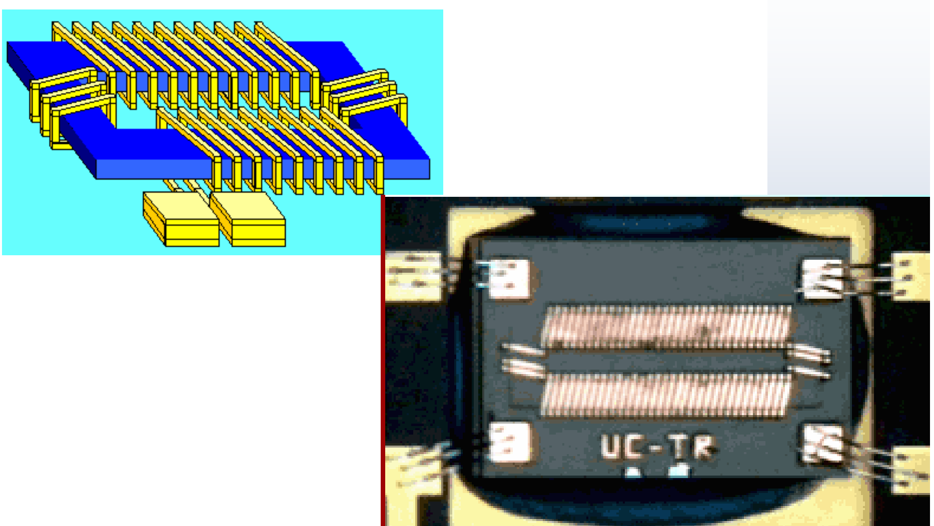
Magnetic Microvalve



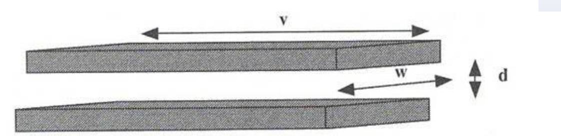
Magnetic Microvalve



MEMS Transformer



Electrostatics



The maximum electrostatics potential energy

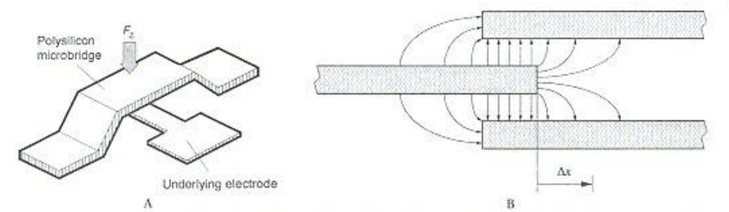
$E_{e,m}=\varepsilon_0 w v V_b^2/2d$ → $E_{e,m}=(l^0)(l^1)(l^1)(l^2)/(l^1)=l^3$

$F=-dE/dx=(l^3)/(l^1)=(l^2)$

Electrostatics Applications

- Actuators
  - micromotors, microvalves, mechanical resonators, switches, micro mirror, etc.
- Sensors
  - Micro accelerometer, micro gyroscope, etc.

Electrostatic Actuation

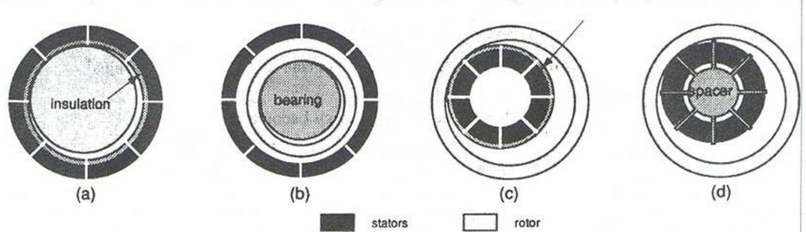


Left: Vertically driven polysilicon bridge
Resonant microstructures/devices
Right: Laterally driven electrostatic actuator
large displacement devices

Electrostatic Wobble Motor

Four wobble motor designs

(a) Conventional inner rotor design requiring stator insulation; (b) conventional one with bearing; (c) new outer rotor design requiring stator insulation; (d) new outer rotor design with spacer. Types (b) and (d) do not require any insulation.



Magnetic MEMS Devices

Magnetic Force $F \propto L^3$

Magnetic materials are not suitable for microactuators, but are good for microsensors.
However, there are some microactuators under investigation.

Hall Effect Sensors

- Hall Effect
  - Charges traveling through a perpendicular magnetic field are subject to a deflection by a force known as the Lorentz force
  - This deflection causes a voltage that can be measured in the perpendicular direction
  - The Hall effect was discovered by Edwin Hall In 1879 while he was a graduate student at Johns Hopkins University.

Hall-voltage Sensors

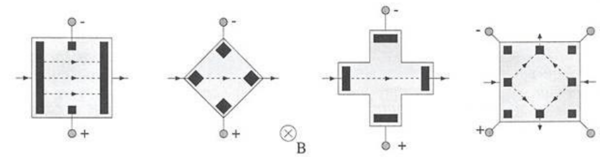
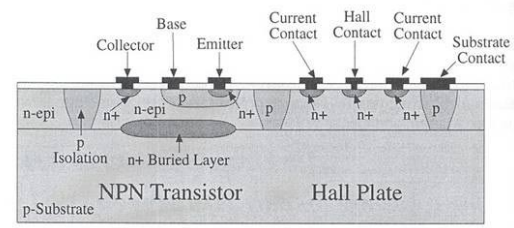


Illustration of several Hall plate designs. Adapted from Middelhoek and Audet (1989).



Cross section of an NPN transistor (left) and a Hall plate (right) implemented in a typical bipolar process. Adapted from Middelhoek and Audet (1989).

Carrier Domain Magnetometers

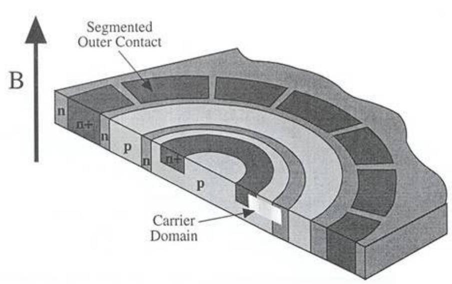


Illustration of a circular, horizontal four-layer carrier domain magnetometer. Adapted from Baltes and Castagnetti (1994). The carrier domain rotates due to an external magnetic field perpendicular to the substrate, causing currents at the segmented outer contacts to vary.

Tunneling Magnetometers

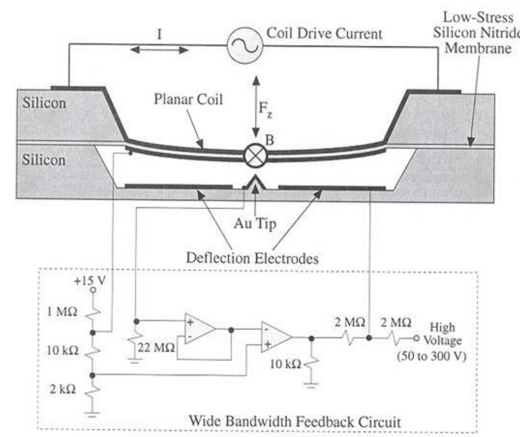


Illustration of a bulk micromachined tunneling magnetometer, showing the closed-loop tunneling current control circuit. Adapted from Miller, et al. (1996).

Magnetic Field Actuators

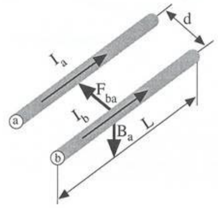


Illustration of parallel currents generating an attractive force between two wires.

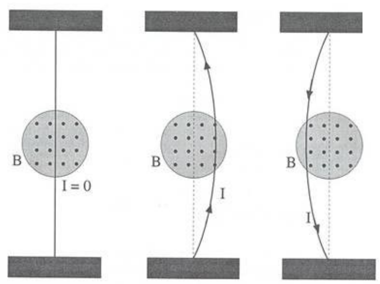


Illustration of a flexible wire unaffected by an external magnetic field (pointing out of the page) with no current flowing, and deflected right or left depending on the direction of current flow. Adapted from Halliday, et al. (1993).

Magnetic Micromotors

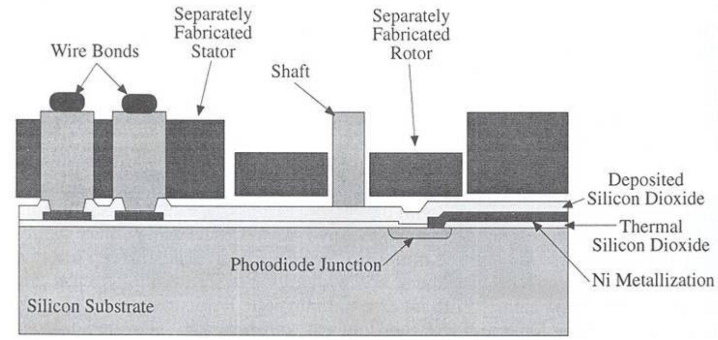


Illustration of the cross section of a magnetic micromotor, showing the separately fabricated and assemble stator and rotor in conjunction with the monolithic coil frame, rotor shaft, and integrated photodiode for rotation/position sensing. Adapted from Guckel, et al. (1993a).