Sensors & Actuators: Basics, Design , Fabrication and Applications

October 17, 2016

Presented to : Prof. Kim, Jong Min

Presented by
Naseem Abbas (아바스 나심), PhD Candidate,
Student ID: 2016210122
Nano Manufacturing Technology Lab, School of Mechanical Engineering, Chung Ang University, Seoul

Nano Manufacturing Lab.
Chung-Ang University

Outline Of Sensors & Actuators

- SENSOR DEFINITION
- NANOSENSOR DEFINITION
- HUMAN SENSE
- TYPES OF SENSORS

I. OPTICAL SENSORS
II. BIO SENSORS
III. CHEMICAL SENSORS
IV. PHYSICAL SENSORS

- APPLICATIONS OF SENSORS

I. PEBBLE
II. TWIN-ACTION NANOSENSOR
III. MULTIMODAL NANOSENSOR

- ACTUATOR DEFINITION
- ACTUATOR BLOCK DIAGRAM
- DESIGN GOALS
- TYPES OF ACTUATOR

I. HYDRAULIC ACTUATOR
II. PNEUMATIC ACTUATOR
III. PIEZOELECTRIC ACTUATOR
IV. ELECTRO MAGNETIC ACTUATOR
V. MECHANICAL ACTUATOR
VI. EAP ACTUATOR

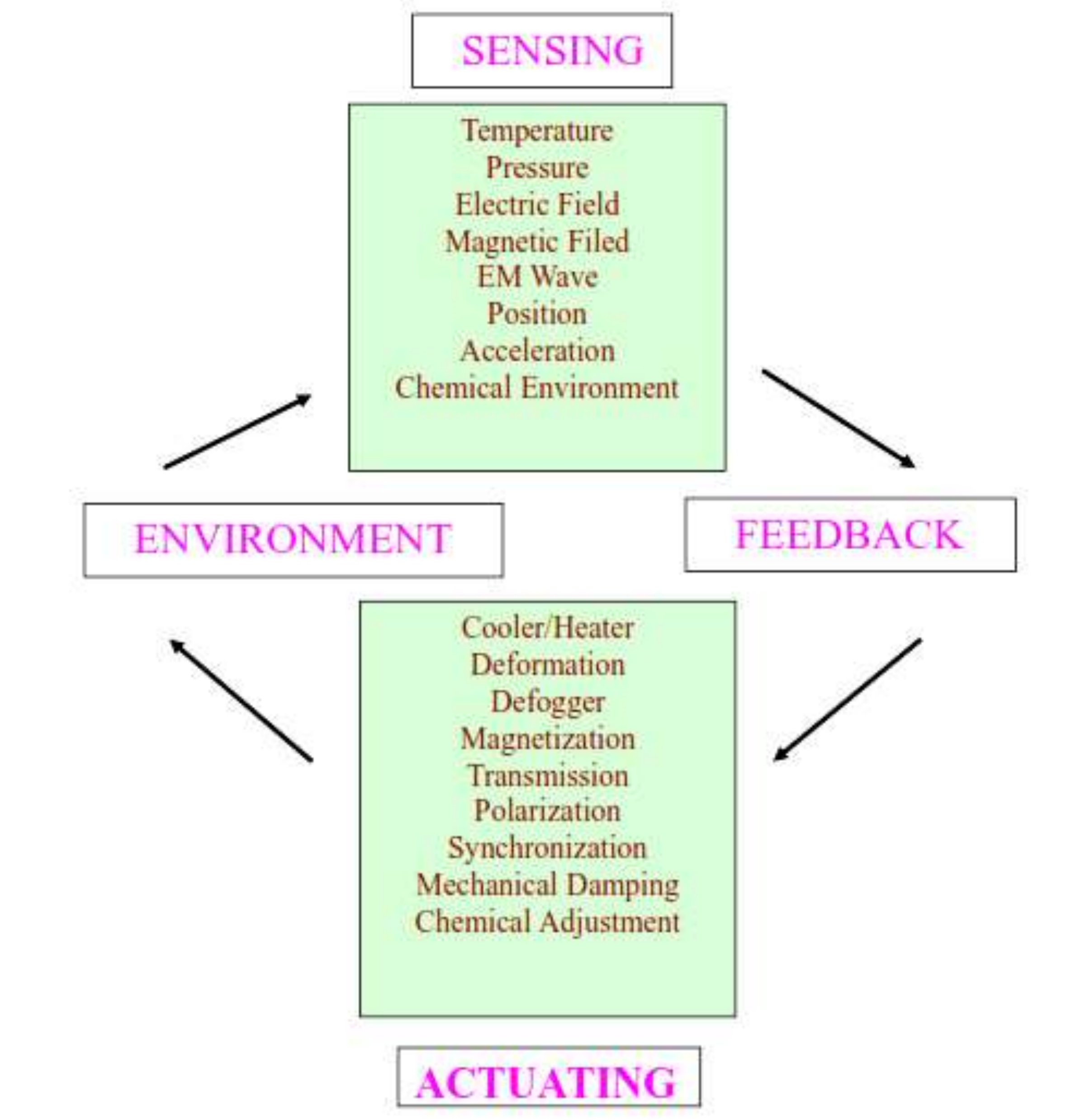
- APPLICATIONS OF ACTUATOR

Introduction

WHAT ARE SENSORS?

THEY ARE DEVICES THAT CAN DETECT AND SENSE CERTAIN SIGNALS , THE SIGNAL COULD BE BIOMEDICAL, OPTICAL, ELECTRONICAL, ELECTRICAL, PHYSICAL OR MECHANICAL SIGNALS.

A sensor is a transducer that converts a measurement (a quantity or parameter) into a signal that carries information.



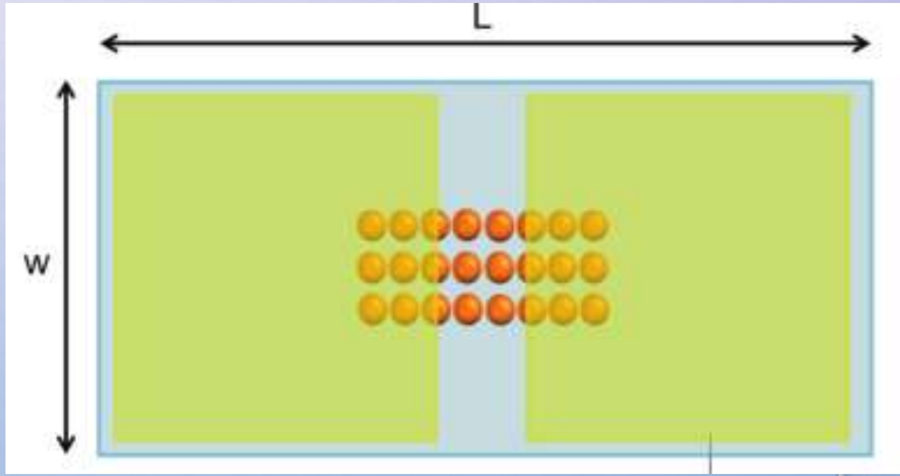
Nano Manufacturing Lab.
Chung-Ang University

WHAT ARE NANOSENSORS?

THEY ARE TINY SENSORS IN THE SIZE OF A FEW NANOMETERS ABOUT 10 TO 100 NANOMETER

THEY CAN DETECT THE PRESENCE OF NANOMATERIAL OR MOLECULES IN THAT SIZE AND EVEN SMALLER!

Nanosensor size



Temperature Nanosensor

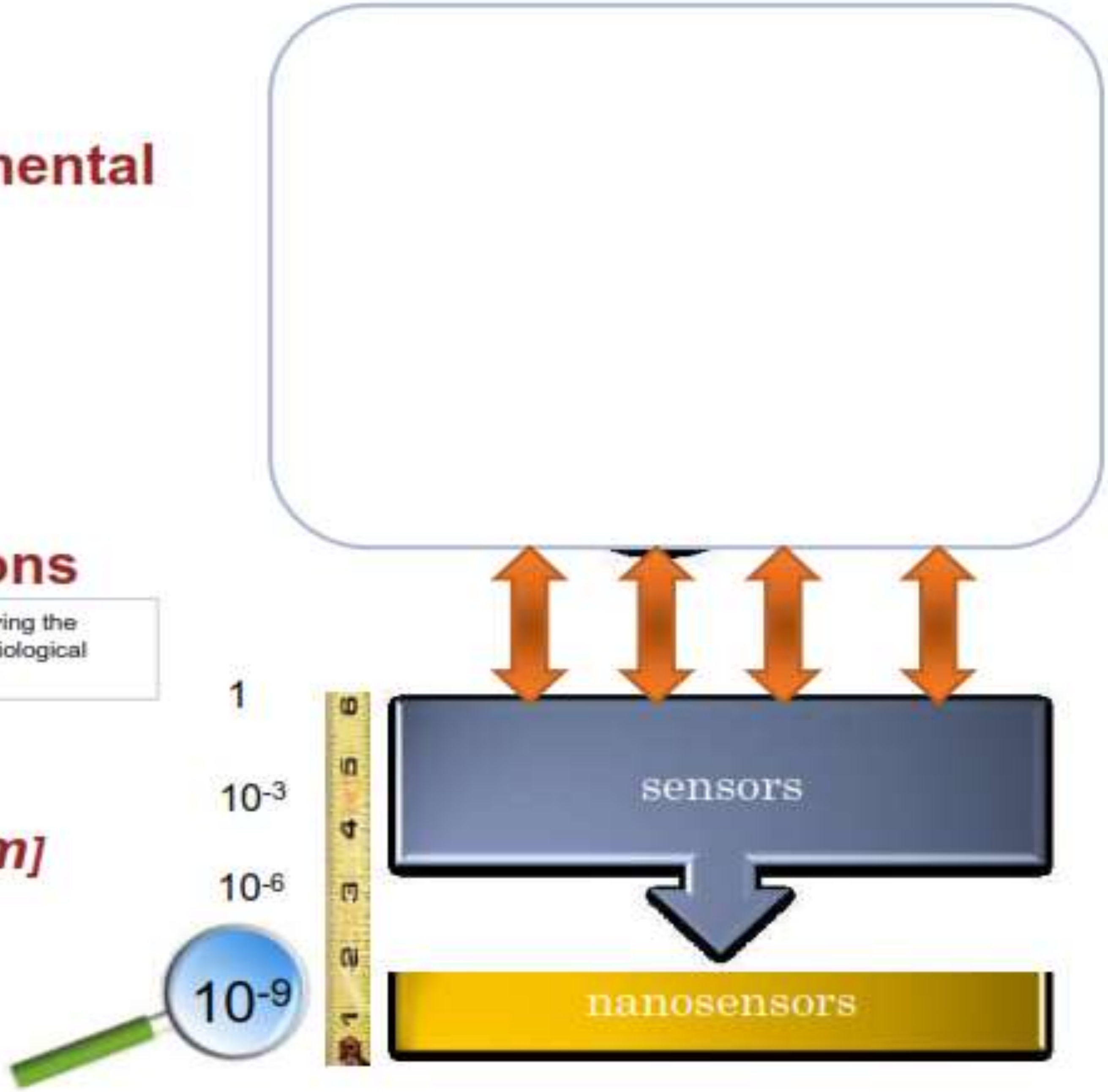
Nano Manufacturing Lab.
Chung-Ang University

Environmental

Interactions

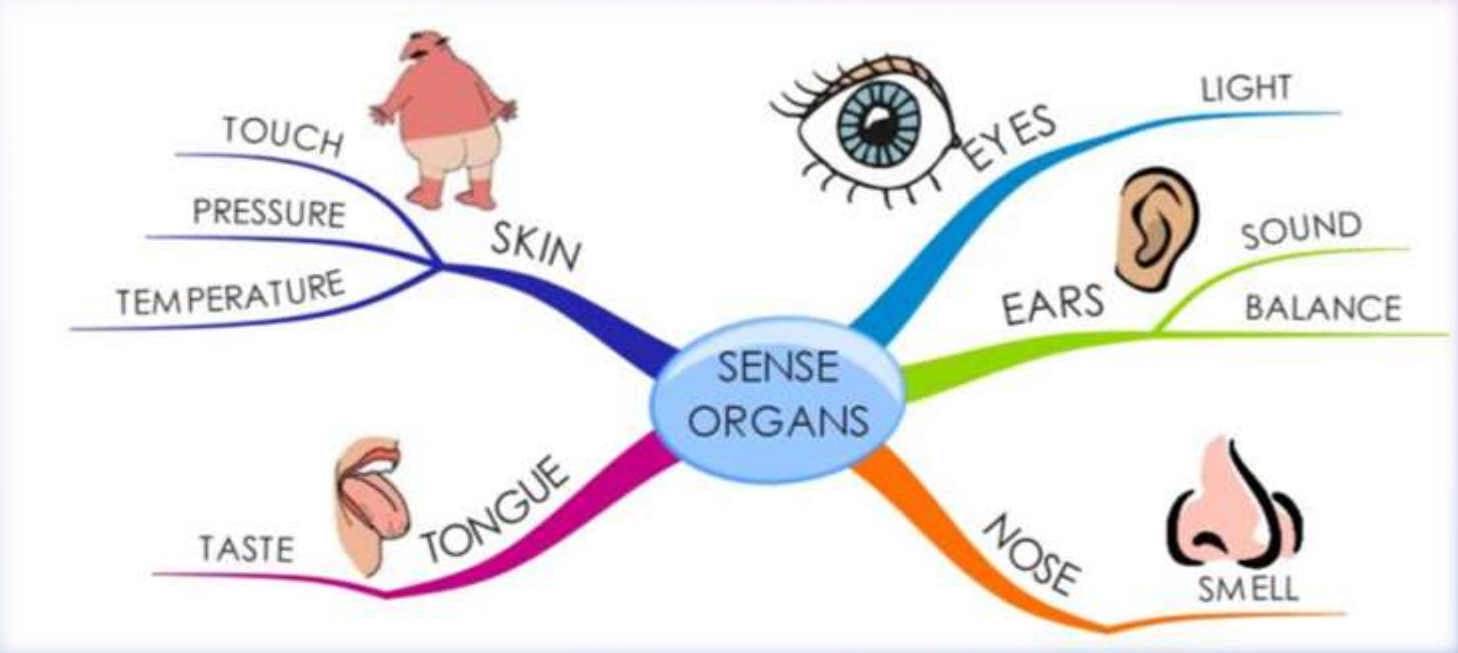
Bio- suffix: Devices having the sensing part made by biological material

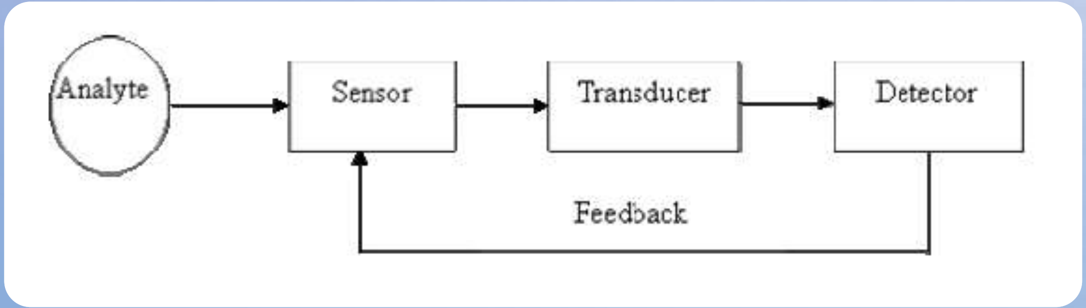
Scale [m]



Human senses

- ANY BIOLOGICAL OR CHEMICAL SENSORY POINTS USED TO CONVEY INFORMATION



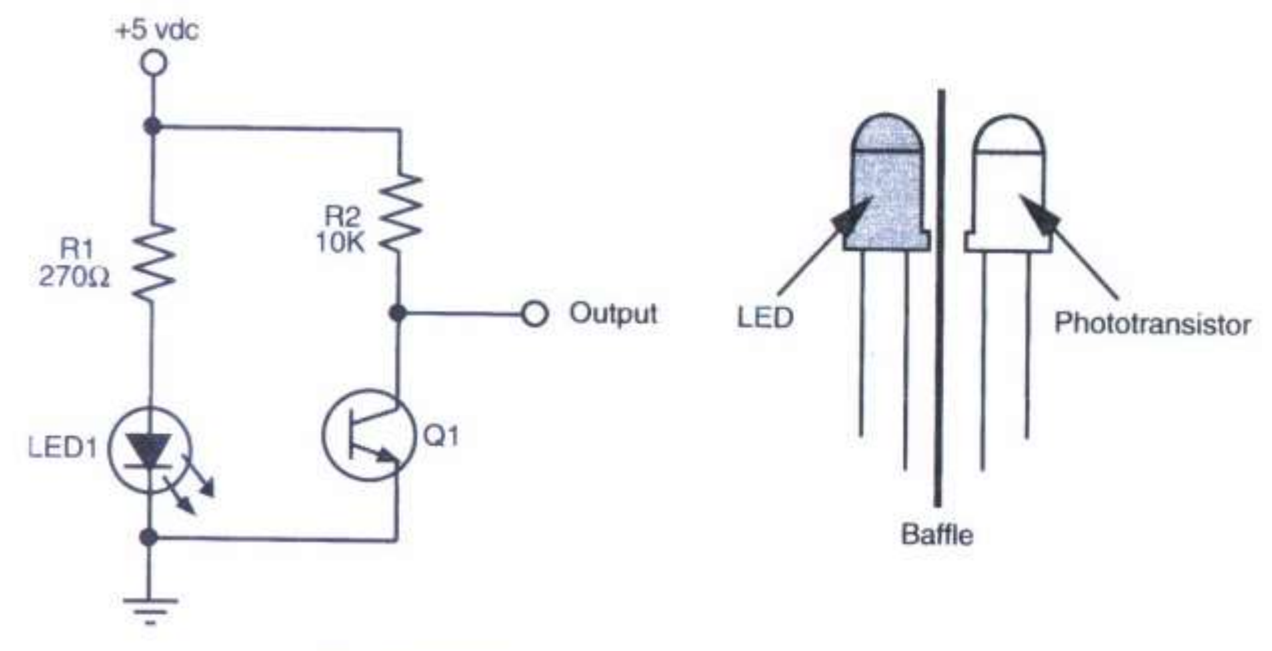


Types of Nanosensors

- Sensors
  - Optical sensors
    - Proximity sensors
    - Ambient Light sensors
  - Biological sensors
    - Antibody/Antigen Interaction
    - DNA Interaction
    - Enzymatic Interaction
  - Chemical sensors
    - Chemical Composition
    - Molecular Concentration
  - Physical sensors
    - Pressure
    - Force
    - Mass
    - Displacement

Optical Sensors– Proximity Sensors

- ✓ PROXIMITY SENSORS ARE DESIGNED FOR USE IN DETECTING THE PRESENCE OF AN OBJECT OR MOTION DETECTION IN VARIOUS INDUSTRIAL, MOBILE, ELECTRONIC APPLIANCES AND RETAIL AUTOMATIONS.
- ✓ EXAMPLES OF PROXIMITY SENSOR USAGE INCLUDE THE DETECTION OF AN OUT-OF-PAPER CONDITION IN A PRINTER OR A MOBILE PHONE SCREEN THAT DIMS TO SAVE BATTERY LIFE WHEN PLACED NEAR A FACE.

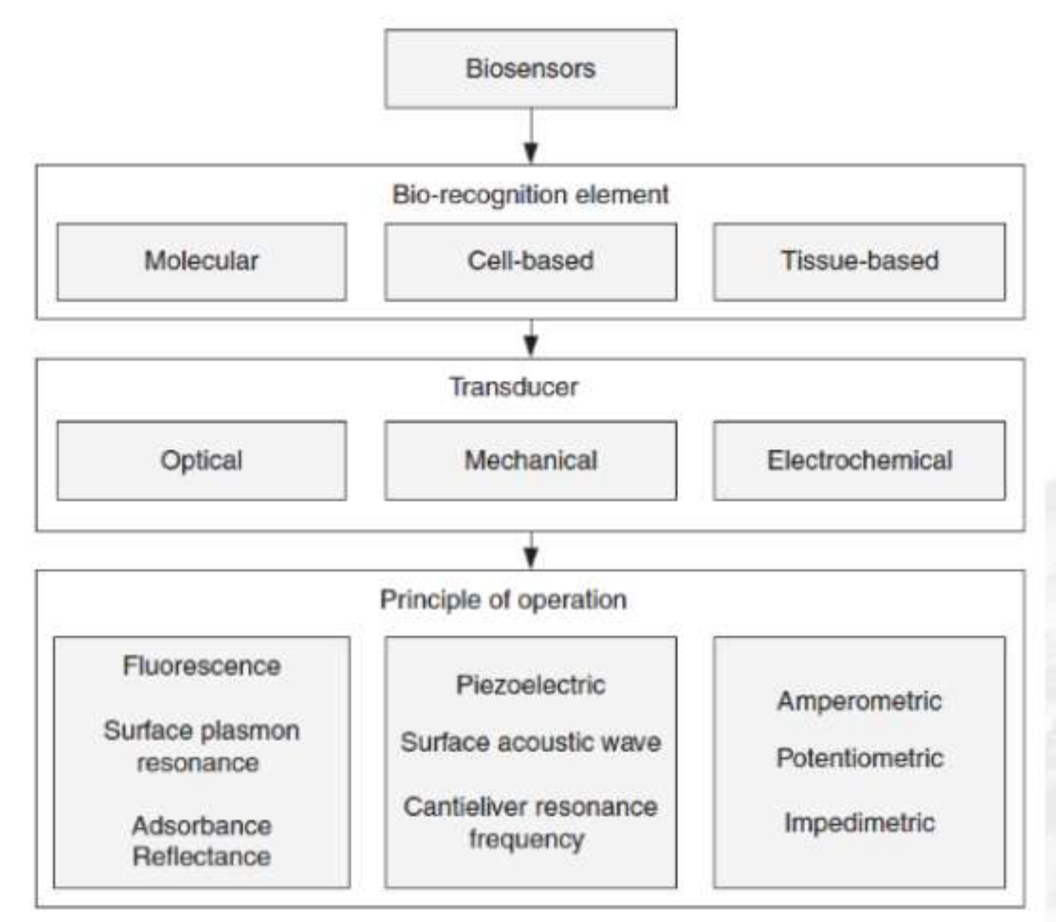


The basic design of the infrared proximity sensor.

ptical Sensors– Ambient Light Sensor

- ✓ Ambient light sensors provide precise light detection for a wide range of ambient brightness and are commonly used in LCD backlight control in mobile phones, LCD TV/panel, and notebook applications.
- ✓ One way to convert the optical signal is by using electro-optical sensors – electronic detectors that convert light, or a change in light, into an electronic signal. Light has many components that can be sensed, such as the wavelength, the intensity, the polarization and the phase. The interaction of light with matter can be quantified by measuring absorbance, reflectance, luminescence and more.

Bio-Nanosensor



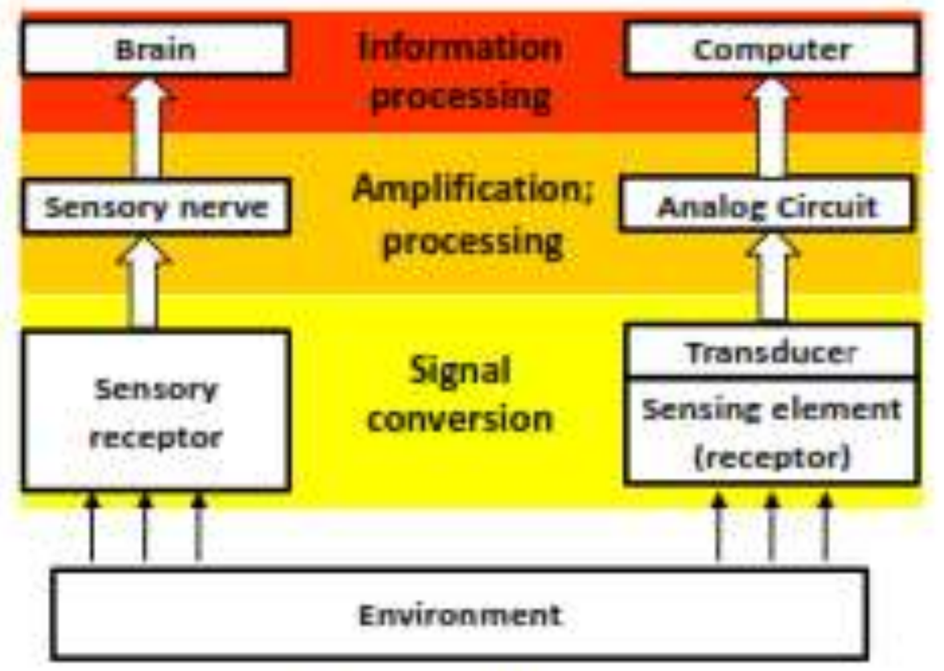
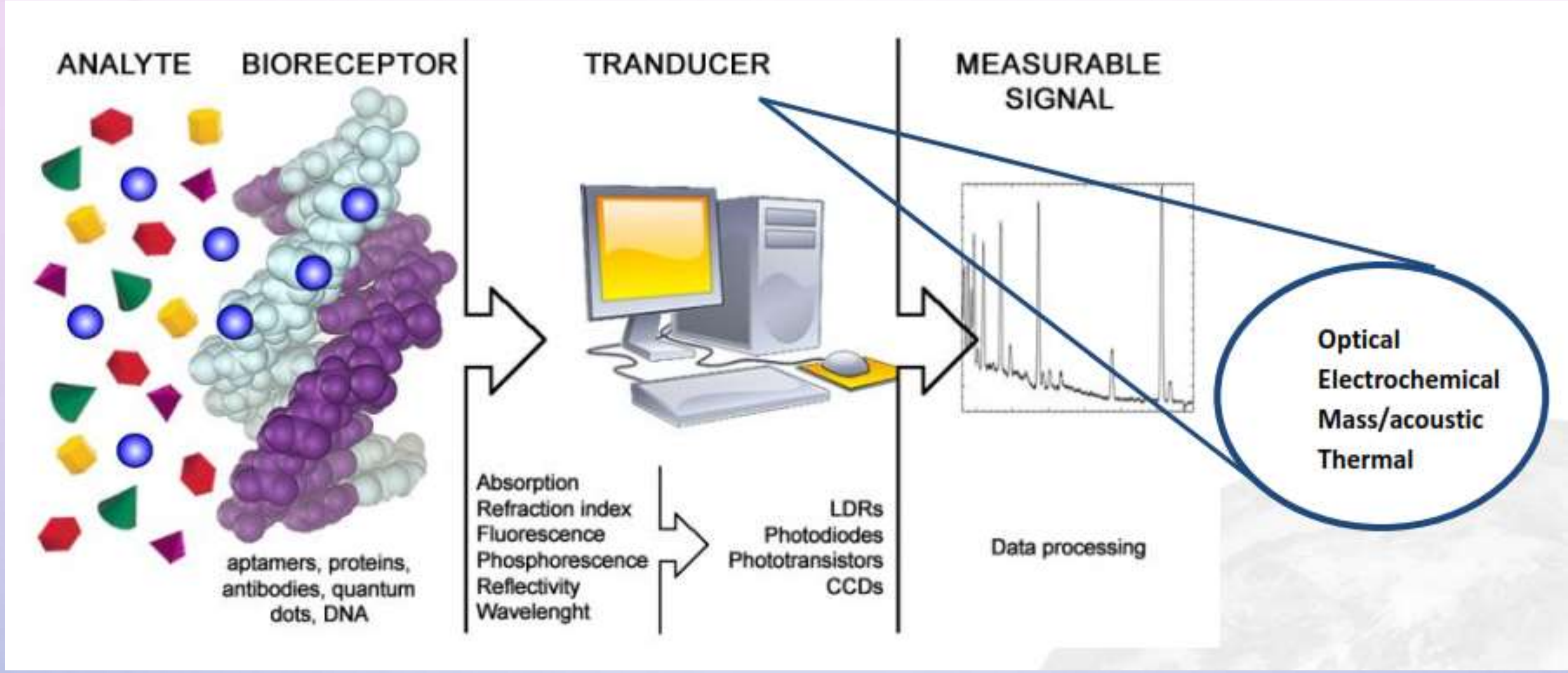


Figure 3-1: Analogy between the human sensing system and artificial sensors.

Nano Manufacturing Lab.
Chung-Ang University

Biosensors

- Biosensor: analytical device for measurement of a specific analytes biological material + physicochemical transducer(electrochemical, optical, thermometric, piezoelectric, magnetic or micromechanical)
- Nanomaterials and nanosensors increase sensitivity and detection level to pico-, femto-, atto- and even zepto- scales (10^-12-10^-21) - this facilitates helps in early disease detection.
- Biomarkers, molecules with a function indicating physiologic or pathologic state, interact with specific receptors fixed onto the surface of a biosensor transducer.



"A biosensor is an analytical device incorporating a biological or biologically derived sensing element either intimately associated with or integrated within a physicochemical transducer. The usual aim is to produce a digital electronic signal which is proportional to the concentration of a specific analyte or group of analytes"

Chemical Sensors

- CHEMICAL SENSORS USUALLY CONTAIN TWO BASIC COMPONENTS CONNECTED IN SERIES: A CHEMICAL (MOLECULAR) RECOGNITION (RECEPTOR) AND A PHYSICOCHEMICAL TRANSDUCER. IN THE MAJORITY OF CHEMICAL SENSORS, THE RECEPTOR INTERACTS WITH THE ANALYTE MOLECULES. AS A RESULT, THE PHYSICAL PROPERTIES ARE ALTERED IN SUCH A WAY THAT THE APPENDING TRANSDUCER CAN GAIN AN ELECTRICAL SIGNAL. IN SOME

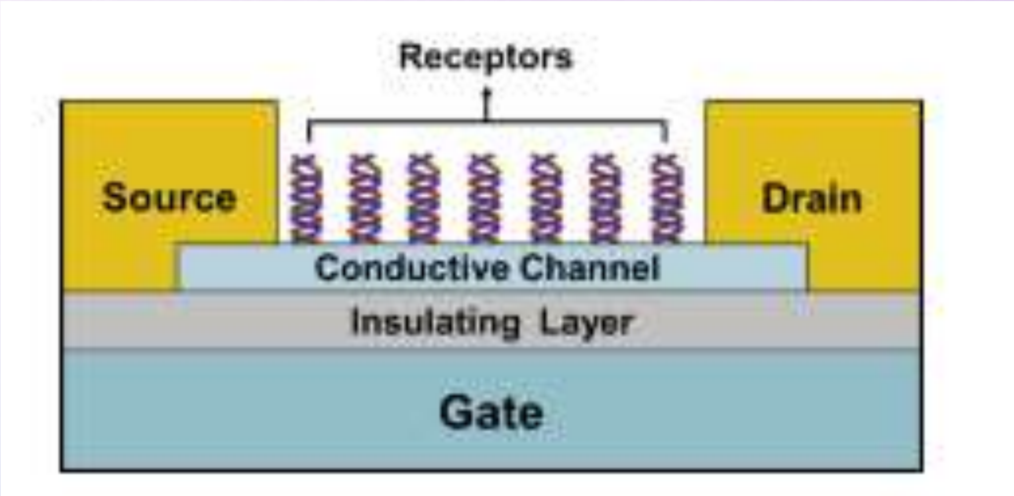
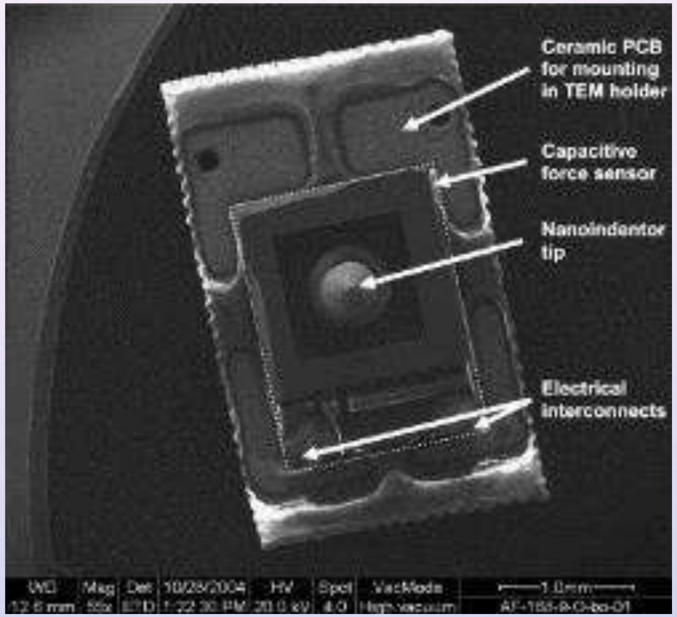


Illustration of chemiresistors with receptors, the binding of bio-molecule with net electrical charges changes the channel conductance.

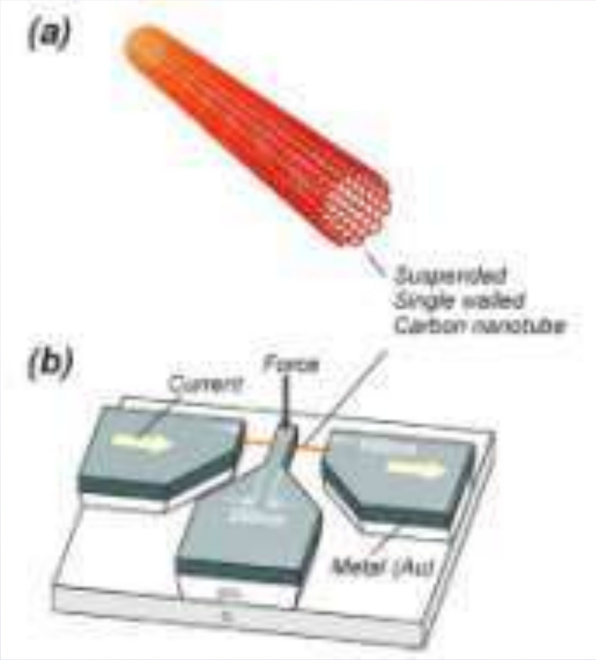
Nano Manufacturing Lab.
Chung-Ang University

Physical Sensors

- ✓ The physical nanosensor sense the environmental physical change such as
- ✓ Force
- ✓ Acceleration
- ✓ Flow rate
- ✓ Mass
- ✓ Volume
- ✓ Density
- ✓ pressure



Nano indentor: The force range is up to 500 μN and 1 mN for the two main designs, with a force resolution of to 0.3 μN.



CNT force sensor

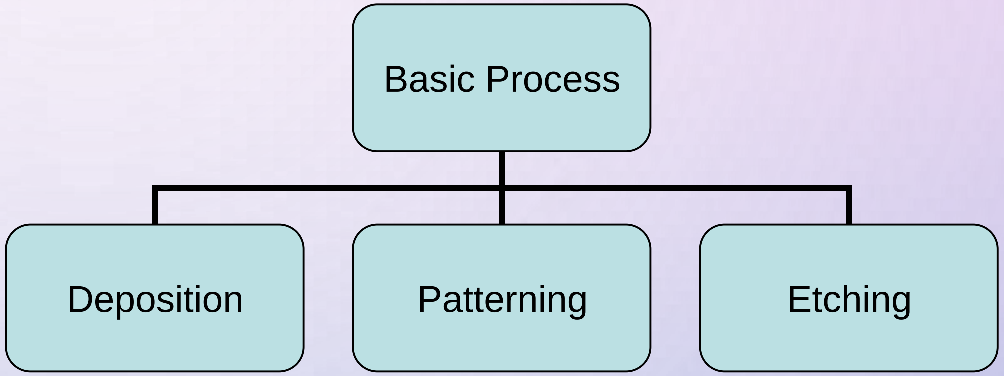
Fabrication

Materials used are:
Silicon

Polymers

Metals

Ceramics



asic Process of Fabrication

Deposition

Deposition that happen because of a chemical reaction or physical reaction.

Patterning

The pattern is transfer to a photosensitive material by selective exposure to a radiation source such as light. If the resist is placed in a developer solution after selective exposure to a light source, it will etch away.

Etching

Etching is the process of using strong acid to cut into the unprotected parts of a metal surface to create a design in.

There are two classes processes:

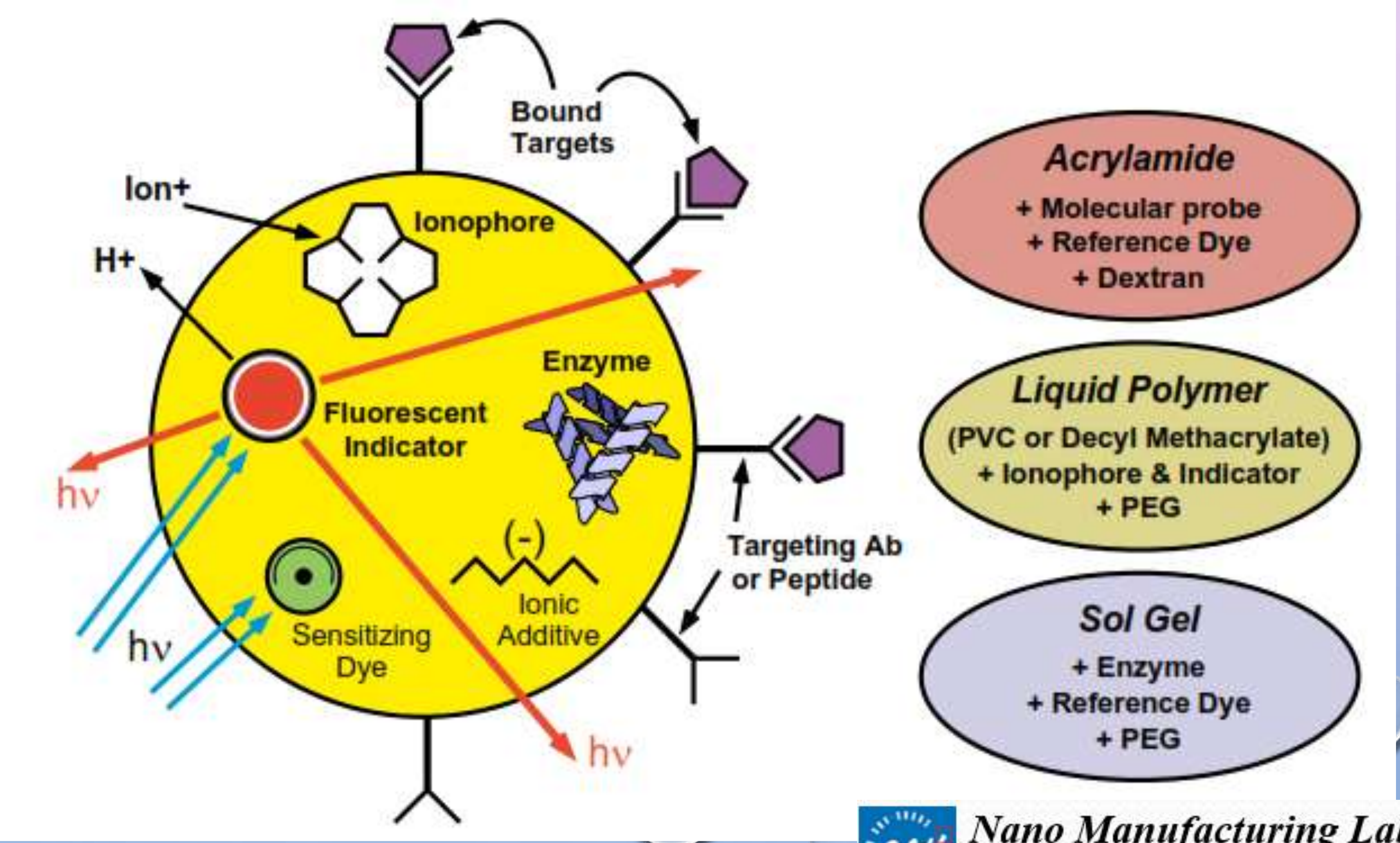
Applications of Sensors & Nanosensors

PEBBLE

- ✓PROBE ENCAPSULATED BY BIOLOGICALLY LOCALIZED EMBEDDING.
- ✓ PEBBLES ARE NANO-SCALE SENSING DEVICES WHICH ENCAPSULATE AN ANALYTE-SPECIFIC DYE AND A REFERENCE DYE INSIDE A BIOLOGICALLY INERT MATRIX
- ✓ THESE HAVE BEEN DEVELOPED FOR SEVERAL ANALYTE, INCLUDING CALCIUM, POTASS

PEBBLE

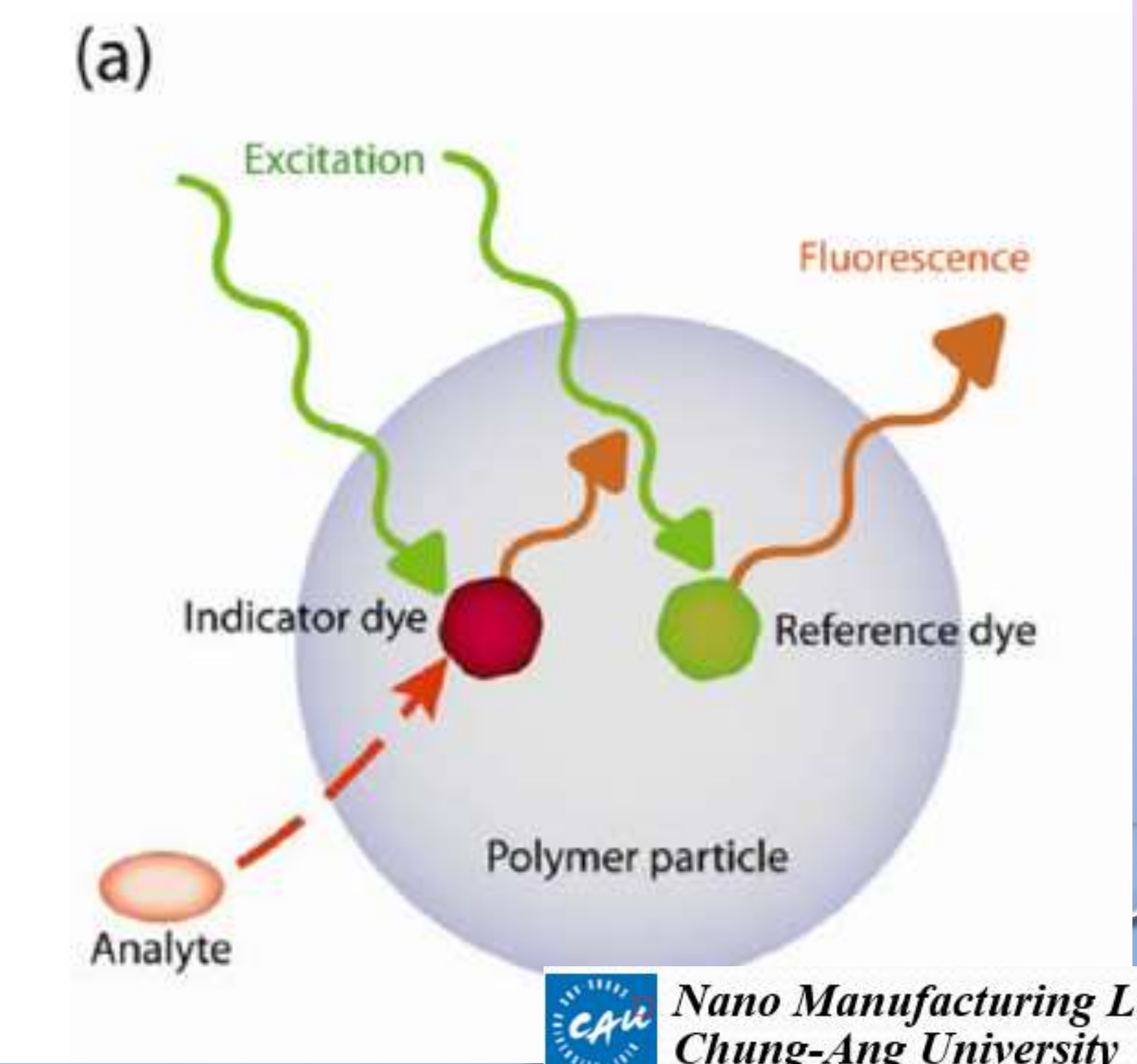
Schematic representation of a PEBBLE sensor, containing various active ingredients within the boundaries of a biocompatible polymeric matrix



WORKING PRINCIPLE

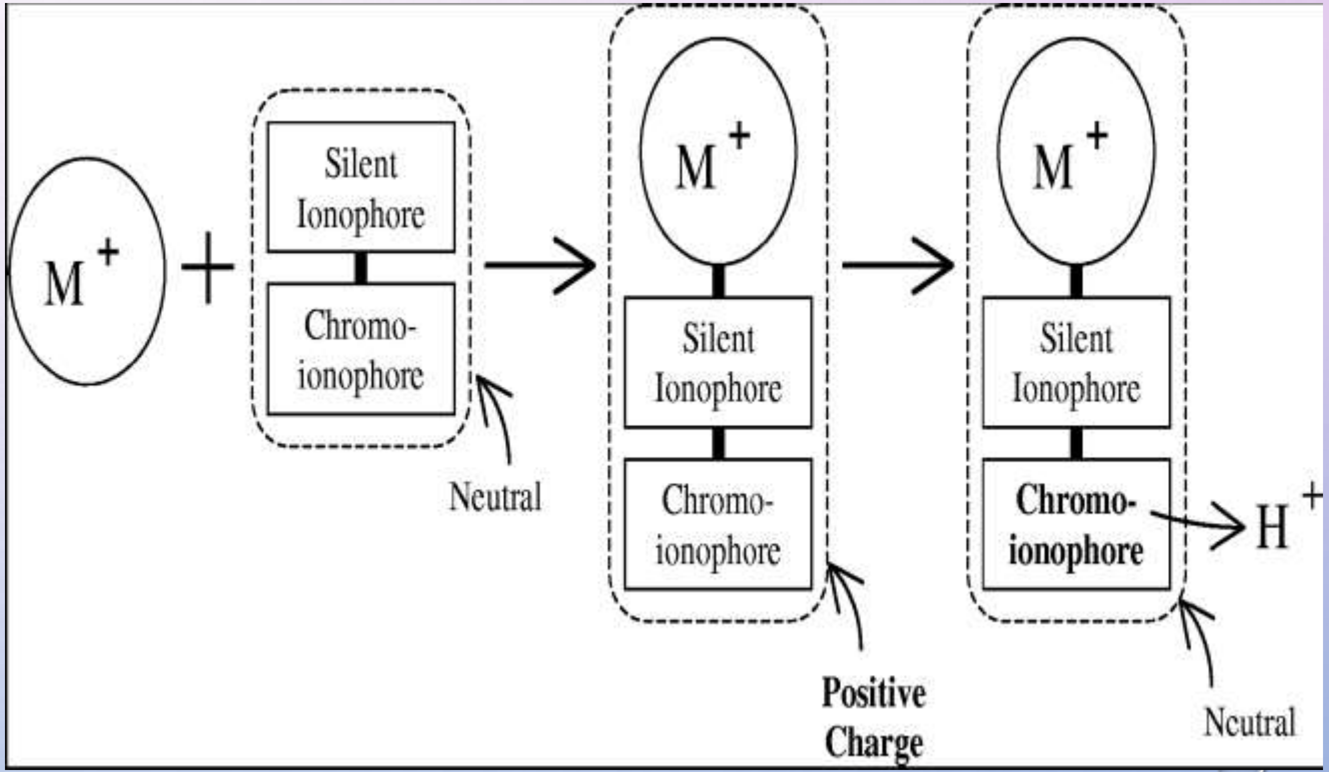
A. Direct Measurement PEBBLEs

* Sense ions and small molecules
* used for sensing H+, Ca2+, Mg2+,Zn2+ and glucose.
* some analyte lack highly selective



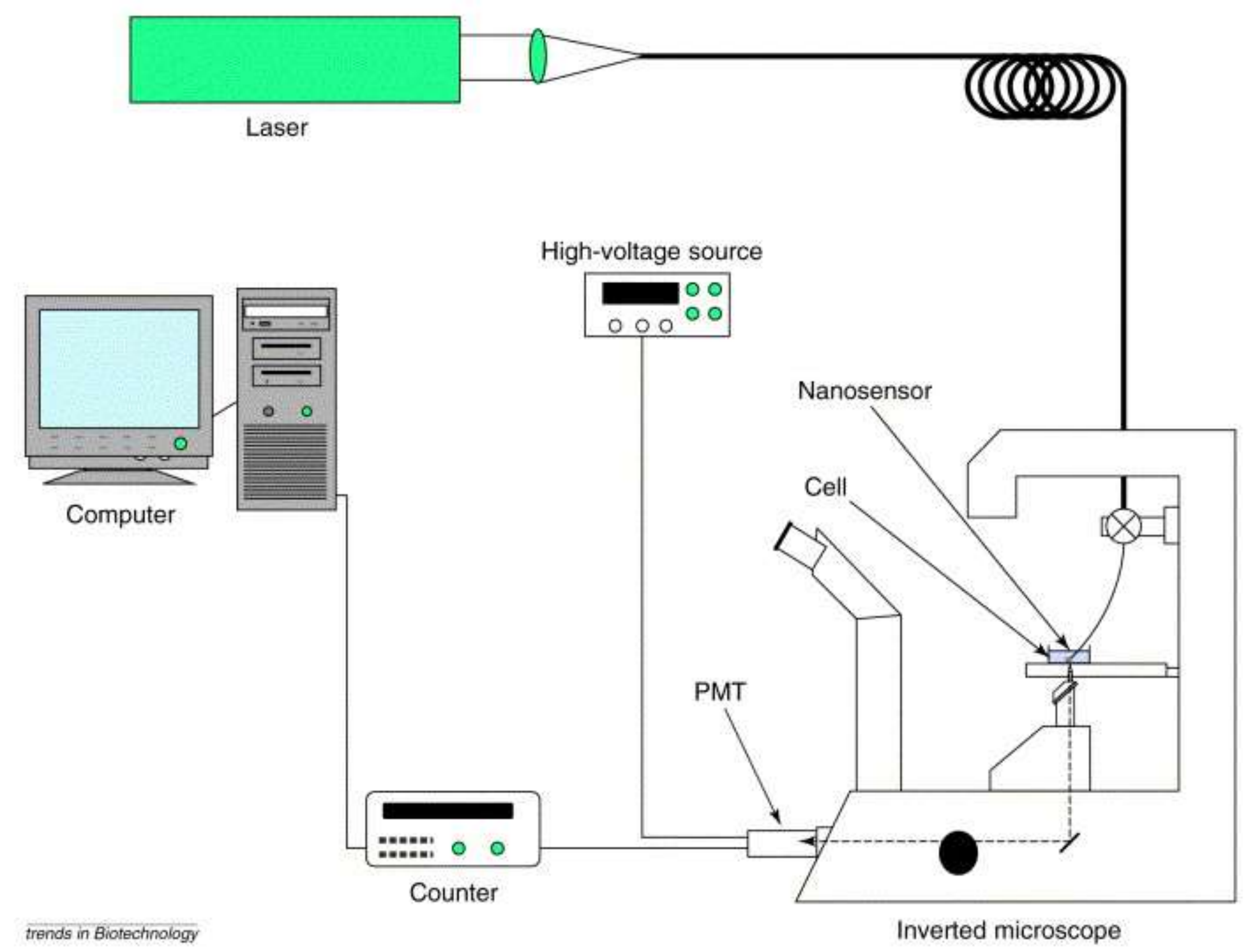
B. ION CORRELATION PEBBLES

- CONSISTS OF A SILENT IONOPHORES AND A CHROMOIONOPHORE BOUND TOGETHER
- SILENT–HIGH AFFINITY TOWARDS THE ION OF INTEREST
- CHROMO–FLUORESCENT BEHAVIOUR
- DUE TO A CHANGE IN PH OF THE CHROMOPHORE AS A RESULT OF THE CHANGE IN THE H+ CONCENTRATION, THE FLUORESCENT BEHAVIOUR OF THE



Measurements

- ✓ Excitation is by argon laser 514.5 nm and a measurement is by a fluorescent microscope and a photomultiplier tube

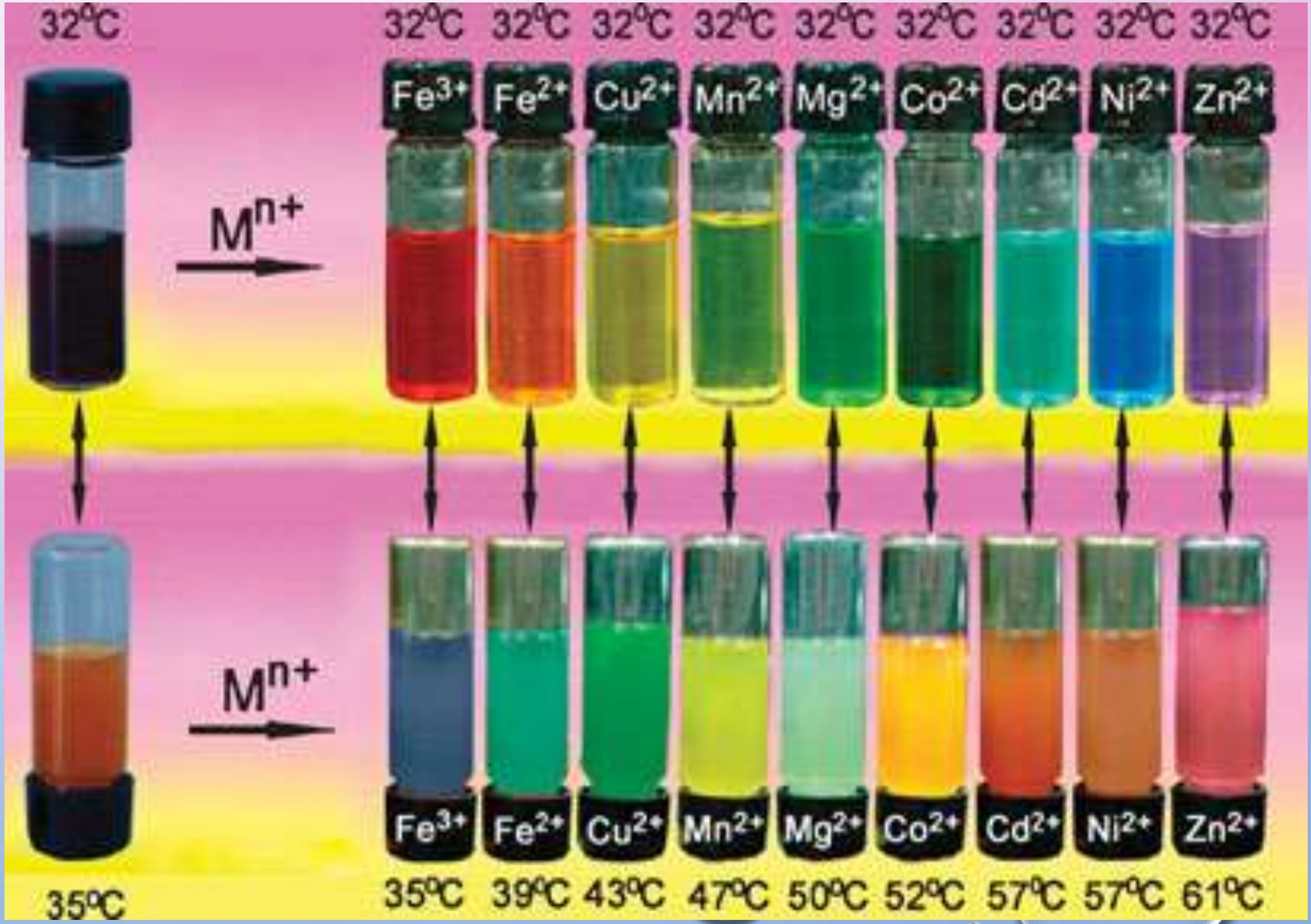


Advantages and Applications

- PEBBLE PROTECTS THE CELL FROM THE DYE , PROTECTS INDICATOR DYES FROM CELLULAR INTERFERENCE , MULTIPLE DYES, IONOPHORES, AND OTHER COMPONENTS CAN BE COMBINED TO CREATE COMPLEX SENSING SCHEMES , MINIMAL PHYSICAL PERTURBATION OF THE CELL
- SMALL SENSOR SIZE ENABLES RAPID MEASUREMENT
- DIAGNOSIS AND MONITORING OF DISEASES.
- STUDY EARLY-EMBRYO DEVELOPMENT
- USEFUL FOR QUANTITATIVE MEASUREMENTS IN INTRACELLULAR ENVIRONMENT.

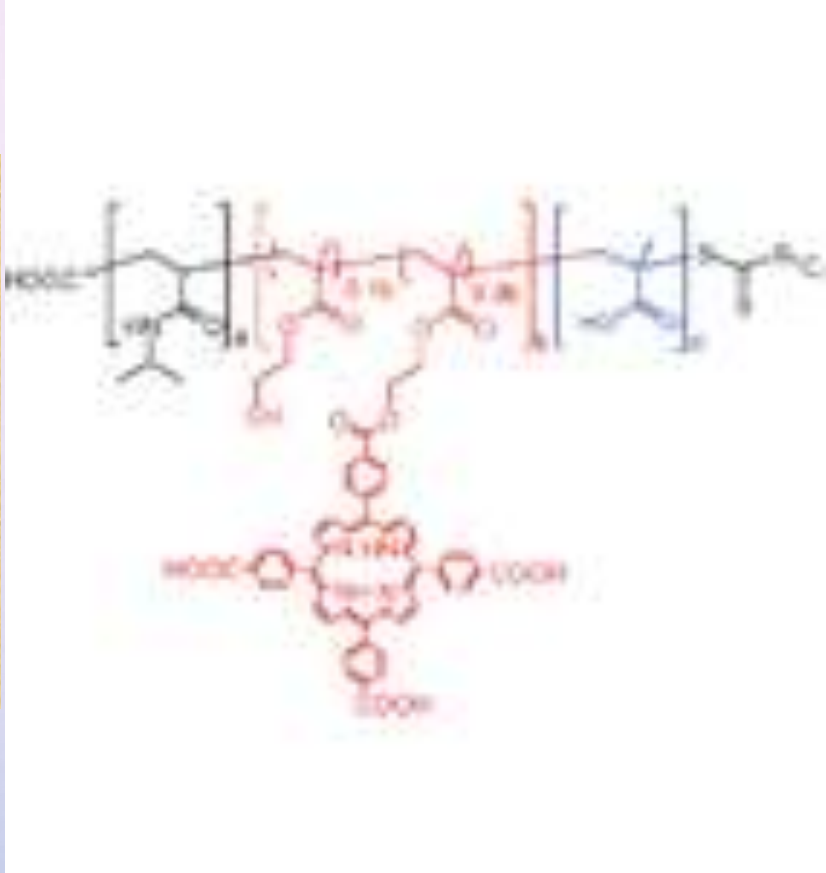
Twin-action Nanosensor

- ✓ A polymer Nanosensor developed by Chinese scientists responds to both metal ions and temperature.
- ✓ The copolymer solution can be used with a variety of metal ions which each give a different colour and allows to create a nanoarray which is capable of simultaneously conveying nine colour signals.

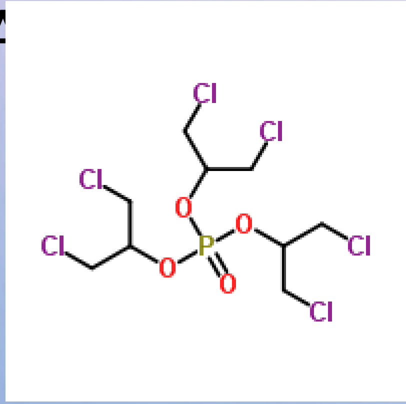


Structure

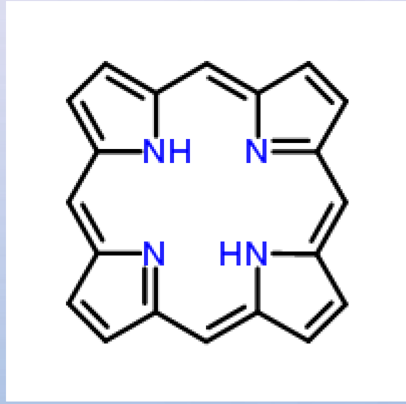
- ✓A FULL-COLOUR OPTICAL NANOSENSOR BASED ON A PORPHYRIN-CONTAINING ABC TRIBLOCK COPOLYMER WAS MADE WHICH OVERCOMES THESE PROBLEMS AND RESPONDS TO BOTH METAL ION AND TEMPERATURE. THIS ALLOWS ITS USE AS BOTH AN ION DETECTOR AND AN ULTRA THERMOMETER



Material structure



Tris (1,3-dichloro-2-propyl) phosphate



Porphine

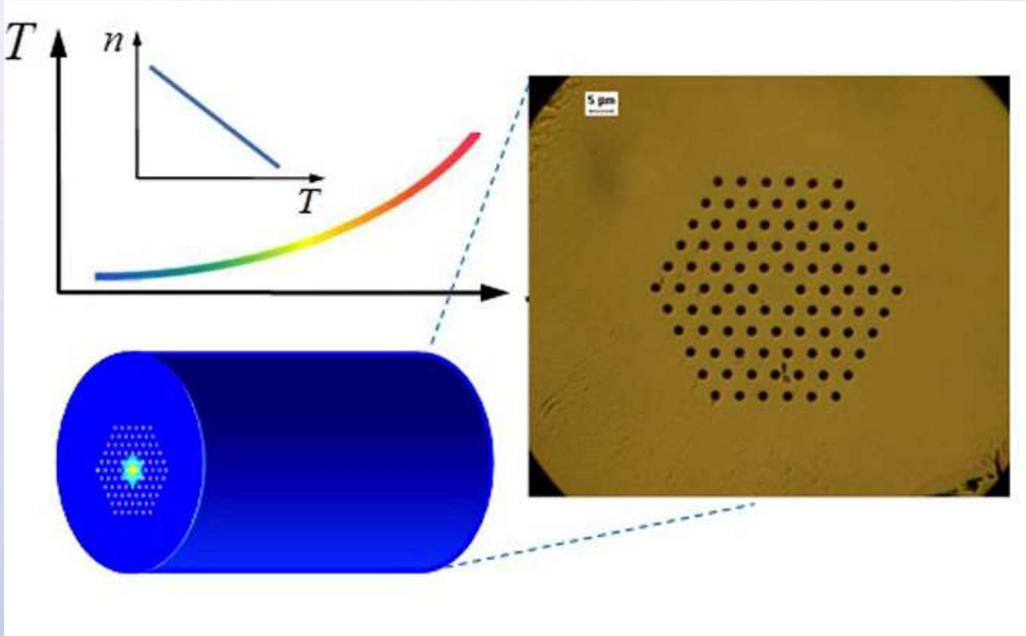
Applications

- ✓THE NANOSENSORS UNDERGO A REMARKABLE COLOUR TRANSITION IN THE RANGE 35–61°C. THE UNEXPECTED LONG RANGE THERMOCHROMIC CHARACTER OF THESE NANOSENSORS COULD ALLOW THEIR USE IN ULTRA-SENSITIVE THERMOMETRIC ARRAYS.
- ✓ OPTICAL NANOSENSORS HAVE A WIDE RANGE OF APPLICATIONS INCLUDING DNA SEQUENCE DETECTION, THERMOMETERS, DISPLAY DEVICES AND BAR CODES

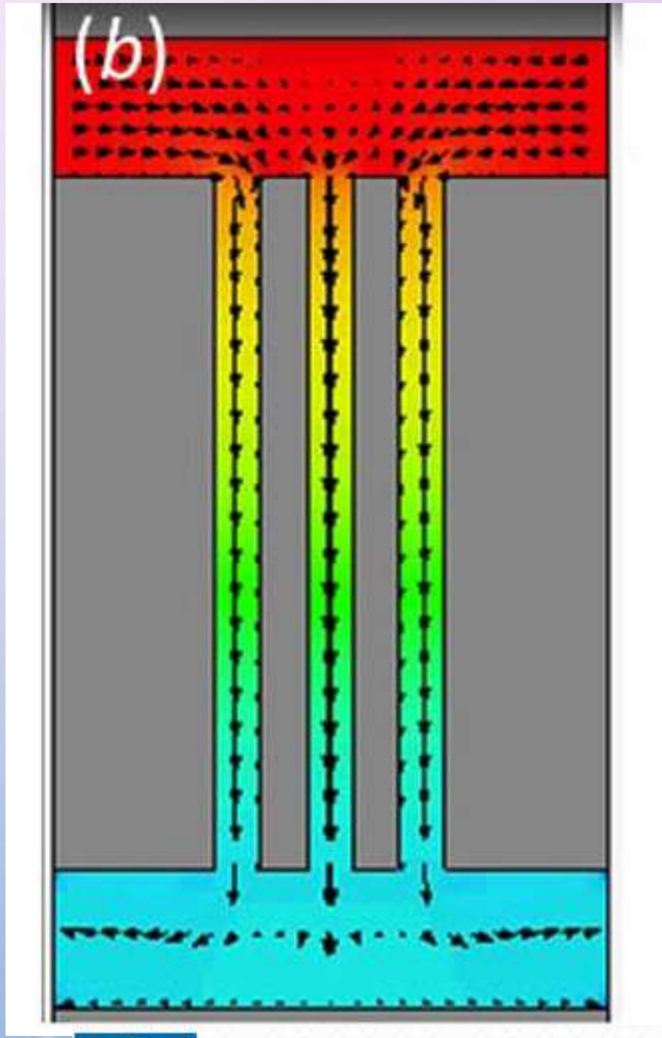
Three new classes of sensors:

- ✓ anti resonant,
- ✓ reflecting,
- ✓ optical fiber-based

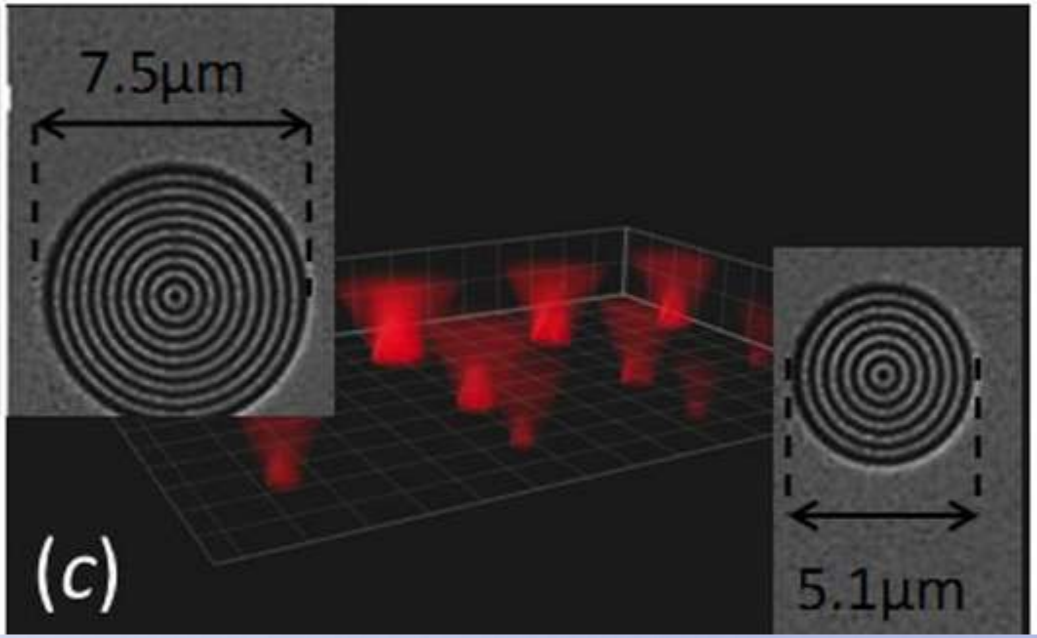
Refracto metric and opto fluidic devices was developed Which had multi-color, highly directional photonic-bandgap-based sensor arrays; and polarization-sensitive devices based on fiber-coupled magnetic metamaterial structures



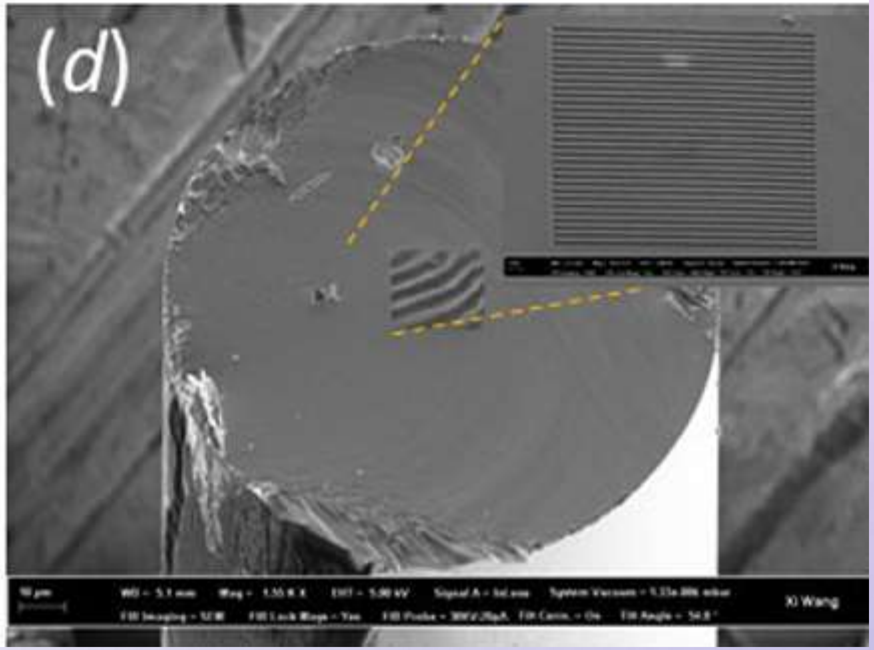
- ✓THE PLATFORM WAS EXTENDED TO DESIGN COMPACT BIOSENSOR THAT COMBINES HIGH DETECTION SENSITIVITY OF ANTI RESONANT OPTICAL WAVEGUIDE WITH OPTO FLUIDIC FUNCTIONALITY. IT ENABLES COMPACT AND RAPID PROCESSING OF SMALL BIOFLUID SAMPLES



- ✓ The second approach is a design for a compact vertically-emitting sensor array based on submicron multi-ring photonic bandgap structures (Figure c).
- ✓ focused ion-beam etching was used, which enables precise dimensional control in the submicron range, to pattern these bull's-eye structures inside a dye-doped xerogel (a type of porous material).
- ✓ We designed the structures to confine light at the fluorescence wavelength in the transverse direction using the photonic bandgap effect.
- ✓ In this way, when excited by a pump light source, the structure emits light in a cone that points perpendicular to the sensor surface.



- ✓ THE THIRD ENABLING TECHNOLOGY IS PHOTONIC METAMATERIALS (MMS), WHICH ARE ARTIFICIAL NANOSTRUCTURES THAT OFFER NEARLY UNLIMITED OPPORTUNITIES TO DESIGN MATERIALS WITH NOVEL PROPERTIES, SUCH AS POSITIVE, NEGATIVE, AND EVEN ZERO INDICES OF REFRACTION.



- ✓ RECENTLY, WE HAVE DESIGNED AND DEMONSTRATED A FIBER-COUPLED MAGNETIC MM ON THE TRANSVERSE CROSS-SECTION OF

- ✓ **In this way, it combines the advantages of fiber and MM technologies. Such fiber-MM integration provides new solutions for simultaneous measurements of several important parameters such as intensity, polarization, and spectral characteristics, which can lead to novel photonic-on-a-chip systems for multimodal sensing.**

Actuators

HARDWARE DEVICES THAT CONVERT A CONTROLLER COMMAND SIGNAL INTO A CHANGE IN A PHYSICAL PARAMETER

- THE CHANGE IS USUALLY MECHANICAL (E.G., POSITION OR VELOCITY)
- AN ACTUATOR IS ALSO A TRANSDUCER BECAUSE IT CHANGES ONE TYPE OF PHYSICAL QUANTITY INTO SOME ALTERNATIVE FORM
- AN ACTUATOR IS USUALLY ACTIVATED BY A LOW-LEVEL COMMAND SIGNAL, SO AN AMPLIFIER MAY BE REQUIRED TO PROVIDE SUFFICIENT POWER TO DRIVE THE ACTUATOR

Definition of Actuator

- ACTUATORS ARE DEVICES USED TO PRODUCE ACTION OR MOTION.
- INPUT(MAINLY ELECTRICAL SIGNAL , AIR, FLUIDS)
- ELECTRICAL SIGNAL CAN BE LOW POWER OR HIGH POWER.
- ACTUATORS OUTPUT CAN BE POSITION OR RATE I. E. LINEAR DISPLACEMENT OR VELOCITY.
- ACTUATION CAN BE FROM FEW MICRONS TO FEW METERS

MORE PRECISE DEFINITION

Signal (electrical, chemical, optical, etc.)

↓

Amplification

↓

Kinetic Energy

↙ ↘

Linear

↓

Example: Muscle, Hydraulic Cylinder

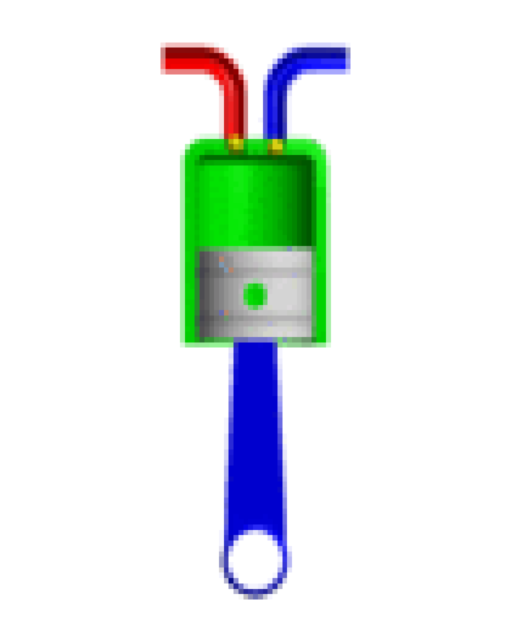
Rotational

↓

Example: Electric motor

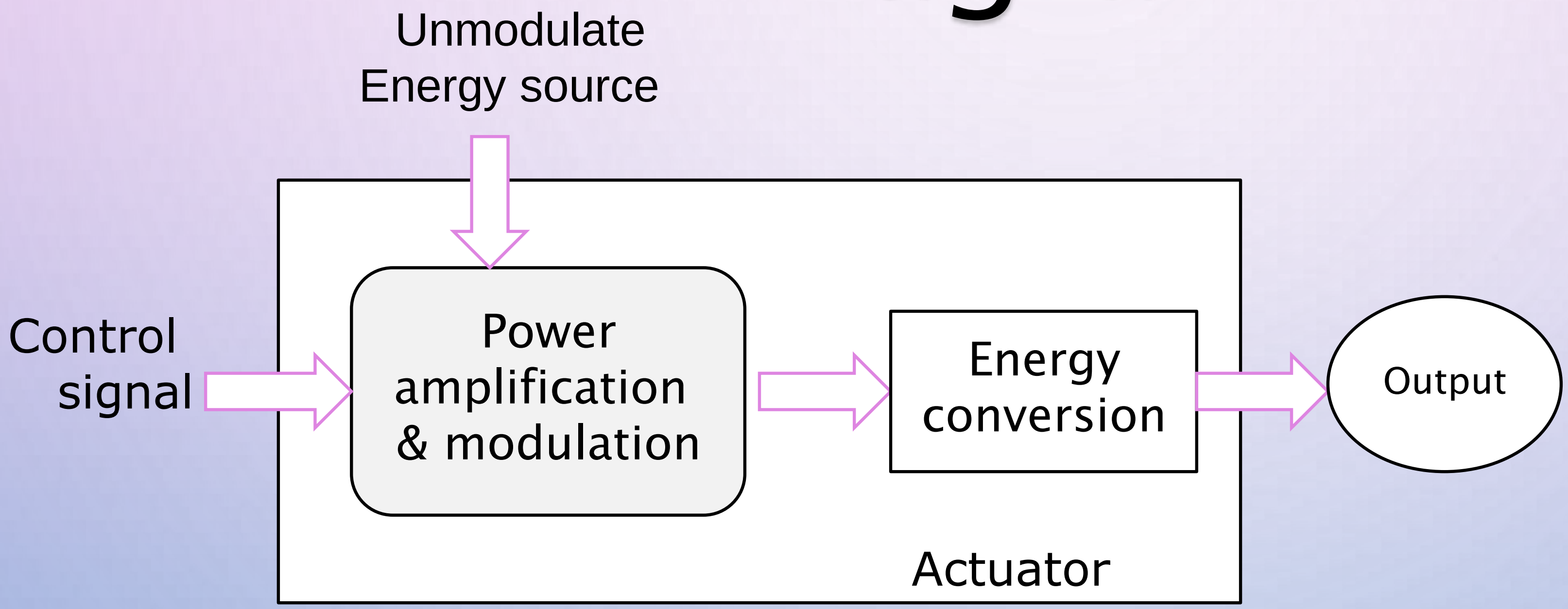
<u>Linear/Rotational Energy Conversion</u>

Example:



Piston

Actuator Functional Diagram



Actuator Video Animation

Actuators: Design Goals

1. SIMPLE
2. LARGE RANGE OF FORCE / DISPLACEMENT / FINE MOTOR CONTROL
3. FAST RESPONSE TIMES
4. LIGHT WEIGHT
5. LOW ENERGY INPUT

Types of Actuators

- HYDRAULIC ACTUATOR.
- PNEUMATIC ACTUATOR.
- MECHANICAL ACTUATOR.
- ELECTRO MAGNETIC ACTUATOR
- EAP ACTUATOR
- EM ACTUATOR
- LINEAR ACTUATOR: SOLENOID, HYDRAULIC/PNEUMATIC.
- ROTARY ACTUATOR: MOTOR, HYDRAULIC/PNEUMATIC.

Hydraulic actuator:

- HYDRAULIC SYSTEMS ARE USED TO CONTROL & TRANSMIT POWER.
- A PUMP DRIVEN BY PRIME MOVER (ELECTRIC MOTOR) CREATES FLOW OF FLUID

Types of hydraulic actuator

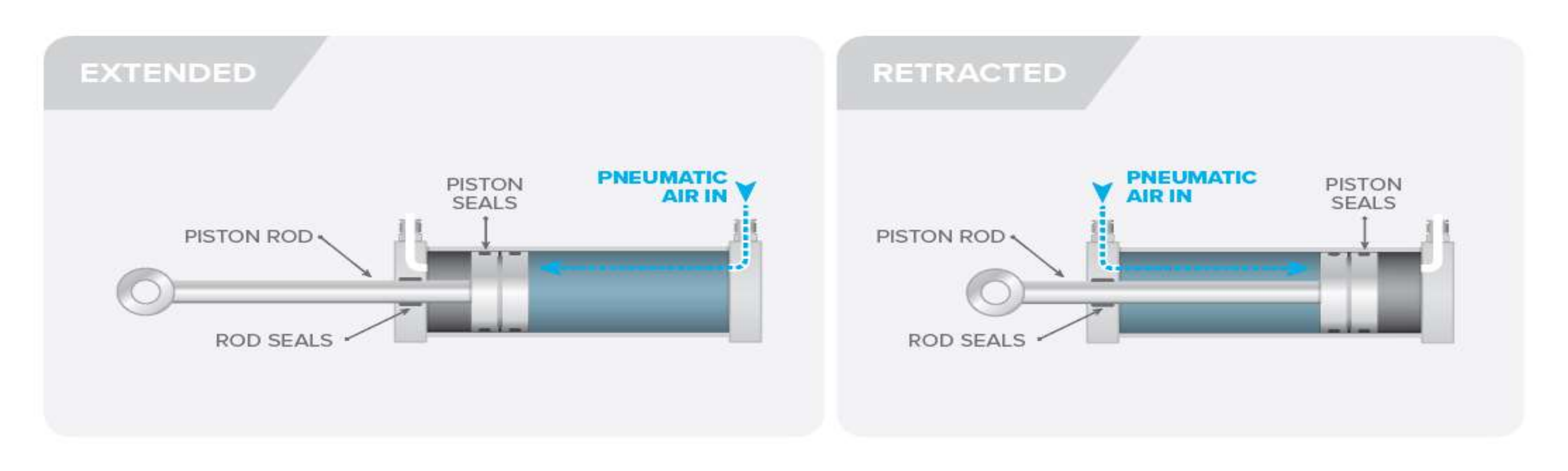
Linear actuator
Rotary actuators

Applications

- HYDRAULIC JACK.
- HYDRAULIC BRAKE.
- HYDRAULIC RAM.
- USED AS SENSOR.
  - CLOSE LOOP VELOCITY CONTROLLING.
  - HIGHLY PRECISE POSITIONING FOR HEAVY LOADS

Pneumatic actuator

- IT CONVERT ENERGY FORMED BY COMPRESSED AIR AT HIGH PRESSURE INTO EITHER LINEAR OR ROTARY MOTION.
- QUICKLY RESPOND IN OPERATION.



Applications

- HYDRAULIC JACK.
- HYDRAULIC BRAKE.
- HYDRAULIC RAM.
- USED AS SENSOR.
    - CLOSE LOOP VELOCITY CONTROLLING.
    - HIGHLY PRECISE POSITIONING FOR HEAVY LOADS

Mechanical actuator

- MECHANICAL LINEAR ACTUATORS TYPICALLY OPERATE BY CONVERSION OF ROTARY MOTION INTO LINEAR MOTION.

Types of mechanics

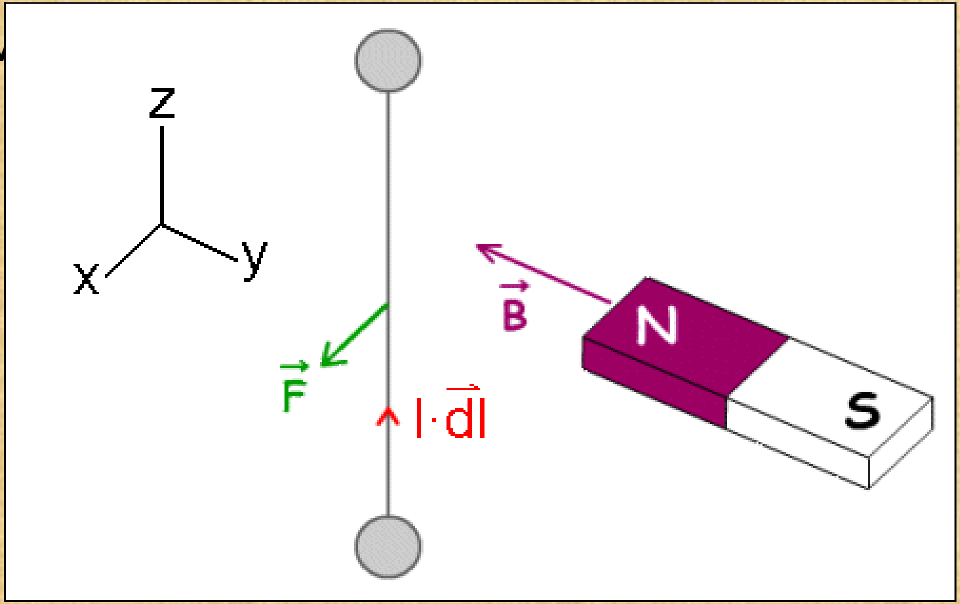
Screw
Wheel and Axle
Cam

Piezoelectric actuators

- THE APPLICATION OF AN ELECTRIC FIELD TO A PIEZOELECTRIC CRYSTAL LEADS TO A PHYSICAL DEFORMATION OF THE CRYSTAL.
- PIEZOELECTRIC MATERIALS ARE: **QUARTZ, CERAMICS, PZT(LEAD ZIRCONATE TITANADE).**
- **ADVANTAGES**
- SHORT RESPONSE TIME.
- AN ABILITY TO CREATE HIGH FORCES.
- A HIGH EFFICIENCY AND A HIGH MECHANICAL DURABILITY.
- **DISADVANTAGE**
- HAVE SMALL STRAINS. (0.1-.2%)
- HIGH SUPPLY VOLTAGE NEEDED.(60-1000V)
- LARGE HYSTERESIS.(ACTUATOR DOESN'T GO BACK TO EXACTLY WHERE IT STARTED).

Actuators: EM Actuation

- ELECTROMAGNETIC FORCE → $F = (I \cdot DL) \times B$
- F IS THE ELECTROMAGNETIC FORCE ON A MOVING CHARGE
- I IS THE CURRENT MAGNITUDE AND DL IS THE DIRECTION OF THE CURRENT
- B IS THE M

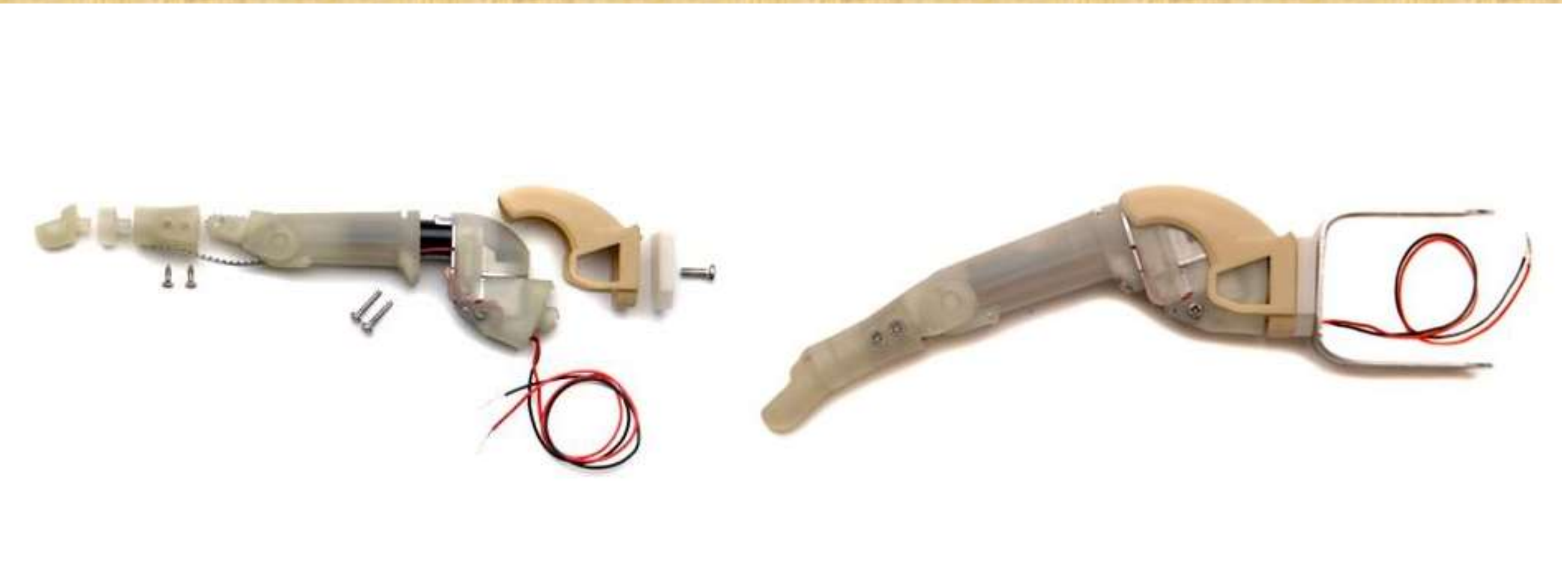


ACTUATORS: EM ACTUATION

EM ACTUATION IS :

Servo = Electric Motor + Reduction Gearbox + Displacement Feedback Sensors

Shown below, exploded and assembled – ProDigit prosthetic finger made by Touch Bionics using servo technology.



Actuators: EM Actuation

ADVANTAGES

- LOW-COST AND RELIABLE BASED ON ~ 50 YEARS OF PRACTICAL USE
- BIDIRECTIONAL
- SERVO

DISADVANTAGES

- NOT AS ENERGY-EFFICIENT AS NEWER ACTUATOR DESIGNS
- SPINNING PARTS CAUSE FRICTION – DEVELOPS LARGE AMOUNTS OF EXCESS HEAT
- LOW STRENGTH/WEIGHT RATIO
- MOTORS – PRECISE DISPLACEMENTS AND VARIABLE SPEED

Actuators: EAP Actuation

ELECTROACTIVE POLYMER THEORY

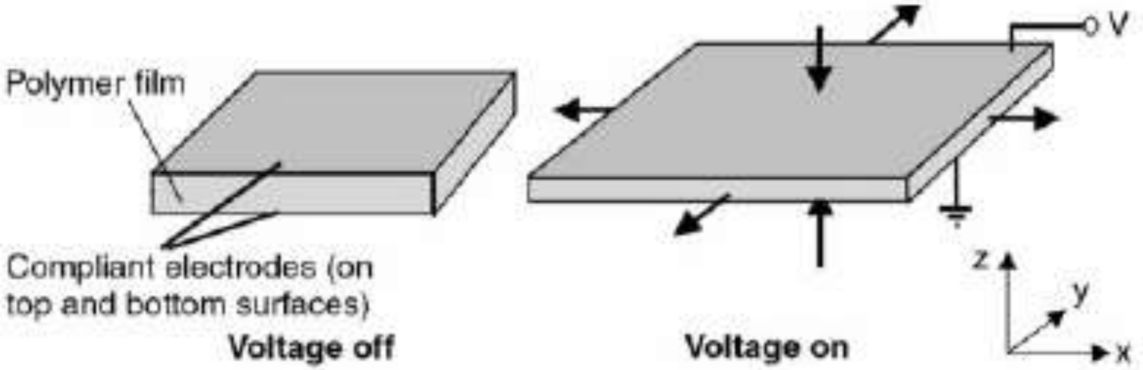


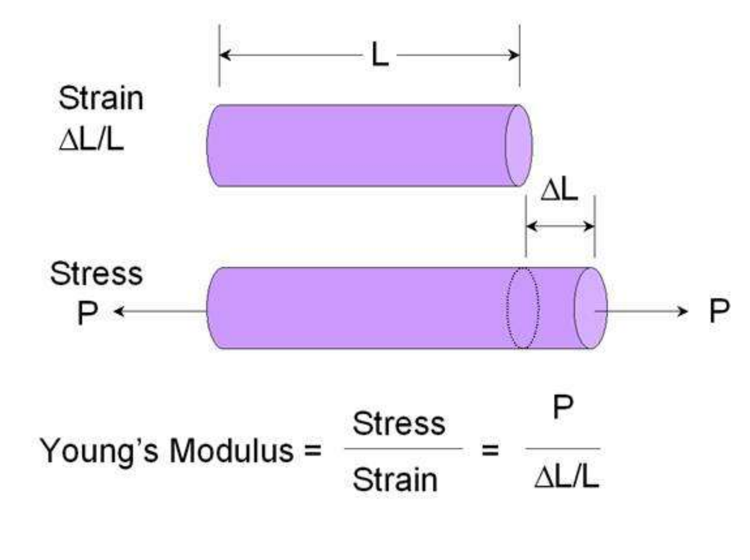
Fig. 1. The dielectric elastomers actuate by means of electrostatic forces applied via compliant electrodes on the elastomer film.

- VOLTAGE GIVES ELECTRODES OPPOSITE CHARGES
- PLATES ATTRACT ONE ANOTHER DISPLACING POLYMER

Actuators: EAP Actuation

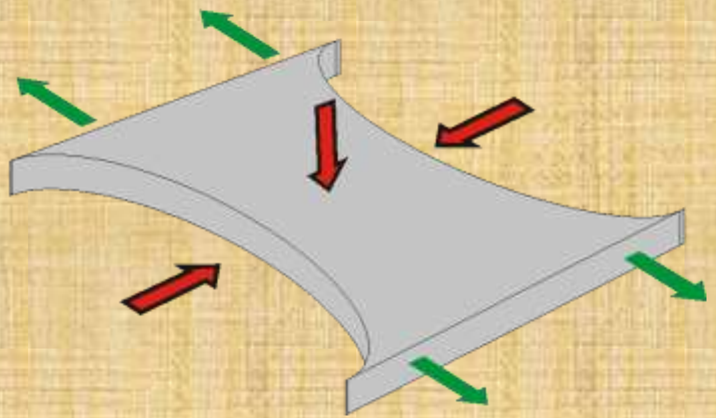
CRITICAL EAP PERFORMANCE PROPERTIE

1. ***Low Elastic Modulus & Pre-strain***



2. ***High Poisson's Ratio***

Increase in length is accompanied by decreases in width and thickness



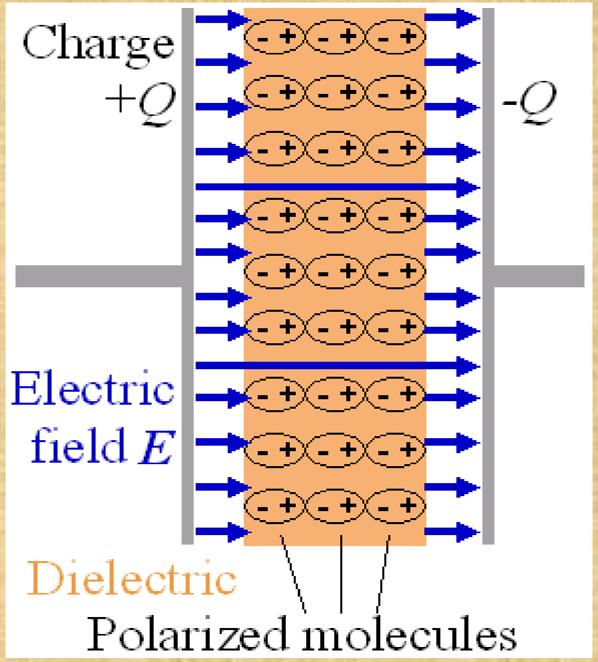
Compliant, conductive electrodes

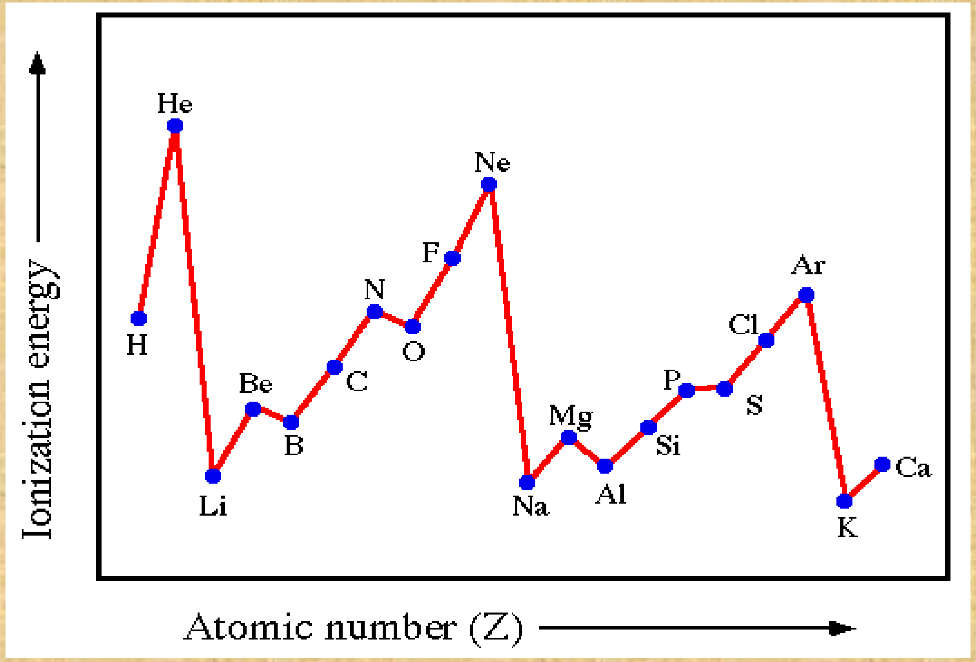
- **Carbon-Impregnated Grease**
- **Graphite Mixtures**

Actuators: EAP Actuation

CRITICAL EAP PERFORMANCE PROPERTIE

3. High Dielectric Constant *4. High Ionization Energy*

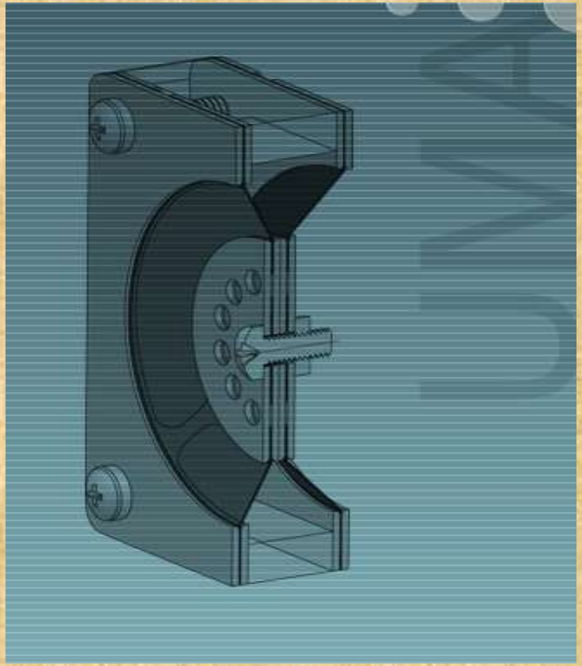




ELASTOMER EXAMPLES: ACRYLIC OR SILICONE COMPOUNDS

Actuators: EAP Actuation

Universal Muscle Actuator Platform
from Artificial Muscle, Inc. 2006
Antagonistic setup



EAP Actuator Setup
Resembling Human Muscle

Actuators: EAP Actuation

ADVANTAGES

- SIMPLE DESIGN AND OPERATION
- ELASTIC – SHOCK ABSORPTION
- HIGH SPEED
- WIDE OPERATING FREQUENCY RANGE
- RECOVERS ELECTRIC POTENTIAL RETURNING TO ORIGINAL STATE
- STRENGTH/WEIGHT RATIO
- PRE-STRAIN
- COST

DISADVANTAGES

- FORCE DECREASES WITH DISPLACEMENT
- UNIDIRECTIONAL
- ELASTICITY – LOWER DISPLACEMENT PRECISION

Other types of actuator

HEATERS - USED WITH TEMPERATURE SENSORS AND TEMPERATURE CONTROLLER TO CONTROL THE TEMPERATURE IN AUTOMATED MOLDING EQUIPMENT AND IN SOLDERING OPERATION.

LIGHTS - LIGHTS ARE USED ON ALMOST ALL MACHINES TO INDICATE THE MACHINE STATE AND PROVIDE FEEDBACK TO THE OPERATOR.

- LED
- LCD'S
- GAS PLASMA DISPLAY
- CRT

SIRENS/HORNS - SIRENS OR HORNS CAN BE USEFUL FOR UNATTENDED OR DANGEROUS MACHINES TO MAKE CONDITIONS WELL KNOWN.

Conclusions

- THE FIELD OF **SENSOR TECHNOLOGY** IS EXTREMELY BROAD, AND ITS FUTURE DEVELOPMENT WILL INVOLVE THE INTERACTION OF NEARLY EVERY SCIENTIFIC AND TECHNICAL DISCIPLINE. THE BASIC DEFINITIONS AND TERMINOLOGY, DESIGN AND TYPES HAVE BEEN PRESENTED TO ESTABLISH SOME CONSISTENCY IN DISCUSSIONS OF SENSOR APPLICATIONS AND TECHNOLOGIES, SINCE CONSIDERABLE AMBIGUITY EXISTS IN SENSOR DEFINITIONS AND CLASSIFICATIONS. IN THE REMAINDER OF THE PRESENT REPORT, A SENSOR CLASSIFICATION SYSTEM BASED ON THE MEASURED, OR PRIMARY INPUT VARIABLE, IS USED. ALTERNATIVE SYSTEMS OF SENSOR TAXONOMY MAY BE USEFUL IN PARTICULAR CIRCUMSTANCES, BUT FOR THE PURPOSES OF THE PRESENT STUDY, THE AFOREMENTIONED SCHEME WAS ADOPTED AS THE MOST PRACTICAL OPTION. IN ORDER TO ACCELERATE THE INCORPORATION OF EMERGING SENSOR MATERIALS IN NEW APPLICATIONS, IT IS CRITICALLY IMPORTANT THAT THE SENSOR MATERIALS COMMUNITY BE ABLE TO READILY IDENTIFY SENSING NEEDS AND TO TARGET THOSE PHYSICAL PHENOMENA THAT MATERIALS COULD SENSE.
- AN **ACTUATOR** IS A COMPONENT OF A MACHINE THAT IS RESPONSIBLE FOR MOVING OR CONTROLLING A MECHANISM OR SYSTEM.
- AN ACTUATOR REQUIRES A CONTROL SIGNAL AND A SOURCE OF ENERGY. THE CONTROL SIGNAL IS RELATIVELY LOW ENERGY AND MAY BE ELECTRIC VOLTAGE OR CURRENT, PNEUMATIC OR HYDRAULIC PRESSURE, OR EVEN HUMAN POWER. THE SUPPLIED MAIN ENERGY SOURCE MAY BE ELECTRIC CURRENT, HYDRAULIC FLUID PRESSURE, OR PNEUMATIC PRESSURE. WHEN THE CONTROL SIGNAL IS RECEIVED, THE ACTUATOR RESPONDS BY CONVERTING THE ENERGY INTO MECHANICAL MOTION.
- AN ACTUATOR IS THE MECHANISM BY WHICH A CONTROL SYSTEM ACTS UPON AN ENVIRO[...] SYSTEM CAN BE SIMPLE (A FIXED MECHANICAL OR ELECTRONIC SYSTEM), SOFTWARE-B[...]

References

1. “TINY BATTERY MAY POWER NEXT-GEN GADGETS”. ARTHUR THAM. NEWS DIGEST. 24-FEB-2003. HTTP://WWW.EXTREMETECH.COM/ARTICLE2/0,3973,901021,00.ASP

2. “CARBON-MEMS ARCHITECTURES FOR 3D MICRO-BATTERIES” POWERPOINT PRESENTATION. MARC MADOU. DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING. UCI, OCTOBER 14, 2003.

3. “MEMS FOR ENVIRONMENTAL AND BIOTERRORISM APPLICATIONS”. SOUTHWESTERN CENTER FOR MICROSYSTEM EDUCATION AND BIOLINK. 2009.

4. “MEMS MOTOR MEANS NO MORE DEAD BATTERIES, SAY RESEARCHERS.” MIKE MARTIN. NEWSFACTOR.COM. MARCH 10, 2005. HTTP://WWW.NEWSFACTOR.COM/STORY.XHTML?STORY_ID=1130000221FU

5. “ELECTRONIC NOSE”. SCIENCE @ NASA. OCTOBER 6. 2007.

6. "REAL-TIME CONTINUOUS GLUCOSE MONITORING". MEDTRONICS. HTTP://WWW.MINIMED.COM/PRODUCTS/INSULINPUMPS/COMPONENTS/CGM.HTML

7. KHALIL NAJAFI, UNIVERSITY OF MICHIGAN, SENSORS PRESENTATION

8. HTTP://WWW.CHEMICAL-UNIVERSE.COM/IMAGES/ELECTROCHEMICAL/GALVANIC%20CELL.GIF

9. PROFESSOR CHUCK HAWKINS, UNIVERSITY OF NEW MEXICO, TRANSDUCERS MEMS V2-CH.DOC

10. WIKIPEDIA, THE FREE ENCYCLOPEDIA, CATEGORY: SENSOR.

11. HTTP://WWW.ENGINEERINGTOOLBOX.COM/LINEAR-THERMAL-EXPANSION-D_1379.HTML

12. HTTP://WWW.FARM.NET/~MASON/MATERIALS/EXPANSION-COEFFICIENT.HTML

13. E. J. GARCIA AND J. J. SNIEGOWSKI, "SURFACE MICROMACHINED MICROENGINE," SENSORS AND ACTUATOR

Than
k

Nano Manufacturing Lab.
Chung-Ang University