UNIT - IV

Magnetic sensors: Introduction, Villari effect, Wiedmann effect, Hall effect, Construction, performance characteristics, Application. Introduction to smart sensors. Film Sensors: Introduction, Thick film sensors, MEMS - Micromachining, Nano sensors, Applications: Industrial Weighing s/m: Link - Lever mechanism. Load cells - Pneumatic, elastic & their mounting. Different designs of Weighing systems. Conveyors type, Weighfeeder type.

Introduction

* Magnetization changes/produces effects which are mechanical/electrical in nature & which are measurable.

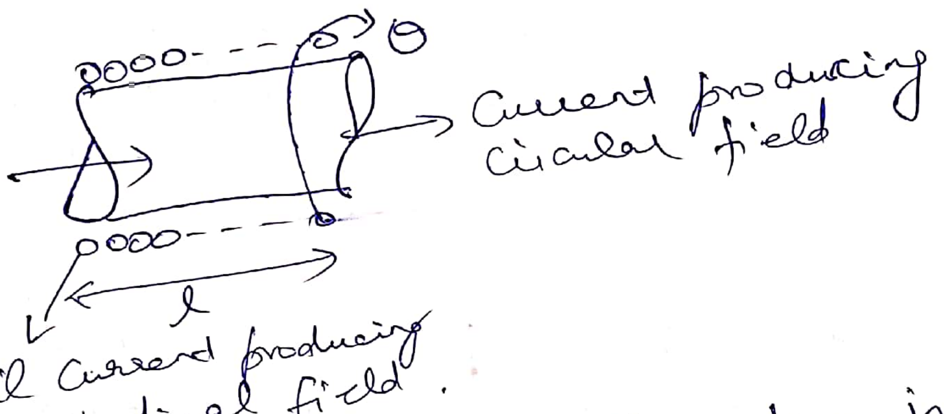
* optical energy may produce changes in magnetization char. of the materials.

1) Magnetic field sensor
2) Magneto - elastic sensor
3) Magnetic elastic sensor
4) Torque / force sensor
5) Magnetoresistive "
6) Hall effect "
7) Proximity "
8) Wiegand & pulse wire
9) Superconducting Quantum Interference Devices (SQUIDs)
10) Magnetostriction

Wiedemann effect

* If longitudinal & transverse magnetostriction constants in a material are λ_l & λ_t & longitudinal & circular magnetic fields are H_l & H_r, then the twist angle 'θ' in a rod of length 'l' & diameter 'd' subjected to these fields are

$$\theta = (\lambda_l - \lambda_t)\frac{4l}{d}\frac{H_l H_r}{H_l^2 + H_r^2}$$



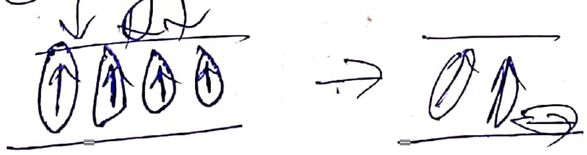
Wiedemann effect has two inverse effects

a) when a ferromagnetic rod which is circularly magnetized is twisted, a longitudinal magnetic field is produced in it

b) when such a rod with longitudinal magnetization is twisted, a circular magnetic field is produced in it.

Villari effect

* If external magnetic field is applied to ferromagnetic material in vertical direction, the dipoles gets arranged in the same direction.
* Applying force to Ferromagnetic material changes the direction of dipoles
* Eventhough the external magnetic field tries to allign the dipoles, the force changes the structure & direction of dipole.



Based on Villari effect, three basic types of magnetoelastic sensors may be designed.

a) the type in which mechanical loading is unidirectional so as to produce compression & this changes the inductance (or) permeability with the specimen having predefined magnetic flux path;

b) one in which mech. loading changes the flux in 2 directions (or) in a plane as in circular rings

c) the third in which loading changes the flux spatially, that is 3-dimensionally in torque transducers for shafts.

HALL EFFECT

* Hall effect sensors are also galvanomagnetic ~~s~~effect sensors. It is observed both in metals & semiconductors

* when a current is sent thro' a very long semiconductor strip of extrinsic homogeneous the plane xy Ir in x direction & across to it, a magnetic field is applied to produce a flux density B_Z, then an electric field E_y in the direction of y is produced which is called the Hall field.

* With electrodes across the strip in the 'y' direction, a Voltage V_H called the Hall Voltage is

$$V_H \simeq B_Z I_x$$

It arises because of Lorentz force on charge carrier transport given by

$$F = eE + e[v \times B]$$

where e - charge of the carrier

E - electrical field   B - Magnetic induction
v - Carrier Velocity

If 'J' is the total current density, then the carrier transport eqn is

$$J = J_0 + \mu_H [J_0 \times B]$$

μ_H - Hall mobility
J_0 - Current density due to E

$$J_0 = \sigma E - eD\nabla n$$

Hall mobility μ_H is the product of the carrier μ the drift mobility of the 2 Hall scattering factor r.

$$r = \frac{\langle \tau^2 \rangle}{\langle \tau \rangle^2} \quad \& \quad \mu_H = r\mu$$

If a long strip of extrinsic & homogeneous semiconductor material with xy-plane is considered as the strip plane,

$$V_H = \int_{y_2}^{y_1} E_H \, dy = -\mu_H B_z E_x W$$

$$\tan \theta_h = \frac{E_y}{E_x} = -\mu_H B_z$$

THE HALL EFFECT SENSOR.

the long strip of material with

negligible thickness has to be made a practically feasible structure which is a rectangular plate of semiconductor material with 4 electrodes two covering the width-thickness faces (supply electrodes (SUE)) & two covering small parts of length-thickness faces (sensor electrodes (SEE)).

$$V_{Hi} = \frac{h_c B_z I_x}{t}$$

Sensor Performance

The performance criteria for these sensors are specified as
i) sensitivity ii) noise iii) drift
iv) nonlinearity.

Absolute sensitivity $S_a = \left.\frac{\partial V_H}{\partial B_z}\right|_{I_x = \text{Constant}}$

Relative sensitivity $S_{ri} = \frac{1}{I_x}\left(\frac{\partial V_H}{\partial B_z}\right)$

$$S_{rv} = \frac{1}{V_c}\left(\frac{\partial V_H}{\partial B_z}\right)$$

Cross sensitivity $S_{ssp} = \frac{1}{S_{a,r}}\left(\frac{\partial S_{a,r}}{\partial P}\right)$

It is known that Hall device is susceptible to two types of noise - that due to thermal variation & that due to freq. variation in the low range which becomes dominant & is known as 1/f noise.

One very convenient method of eliminating the offset is to bias two matched devices orthogonally

Nonlinearity is observed if effective thickness of the plate vary with field or current & the non-linearities are then called 'material'.

$$\%\ \text{non-linearity} = 100\,\frac{V_H - V_{Hb}}{V_{Hb}}$$

Introduction to Smart Sensor

Film Sensors.

* Basically smart sensors are produced by film deposition of different thickness on appropriate substrates.
* Deposition techniques used are different for the thick & thin film sensors.

Thick Film Sensors

* It is use for producing capacitor, resistor & conductors.

* Step 1 : Selection & preparation of a substrate

  Step 2 : Preparation of the initial Coating material in paste or paint form

  Step 3 : Pasting or painting the substrate by the coating material (or) screen printing it

  Step 4 : Firing in an oxidising atmosphere at a programmed temp! format)

		dielectric const.	thermal exp. coeff
* Substrates	- Alumina -	9.5	6.5×10^{-6}
	Berylia -	7	7.5×10^{-6}

* Temperature - Gold, platinum,

  Pressure - Al_2O_2, $Bi_2Ru_2O_7$

  Conc. of gases - $SnO_2 + Pd$, SnO_2 + hydrophobic sion

  Humidity - RuO_2

  Glass ceramic / Al_2O_3

* The other thick film variety is the ceramic-metal (or) cermet which consists of gold/silver based oxides in insulating medium.

* There are thick film resistors of the cermet which require precise control of heat treatment.

Processing steps in Semiconductor technology

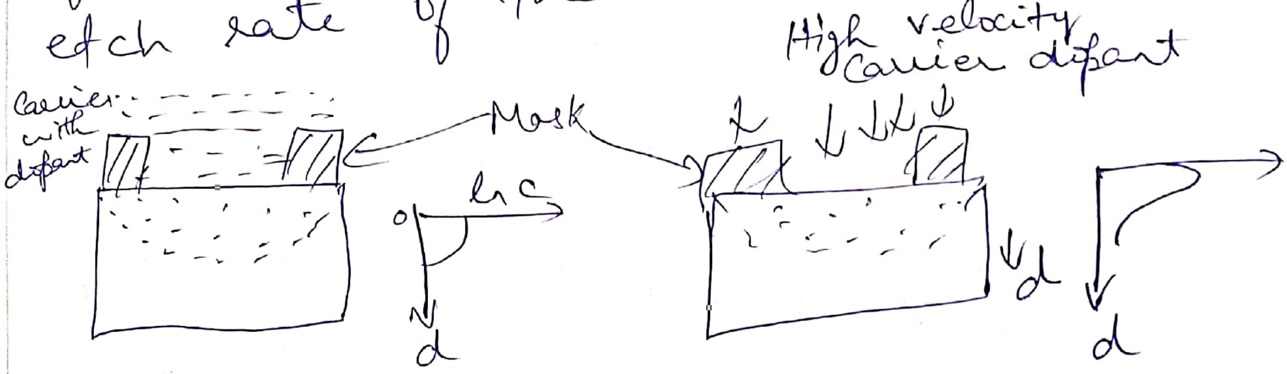
Wafer
↓
Film formation ⟷ Doping
↓
Mask set → Lithography → Etching
↓
Processed wafer.

* Doping
  - ion implantation
  - diffusion.

* Lithography
  - X-ray
  - Photo
  - E-beam
  - Ion-beam

* Etching
  - Wet
  - Dry - Sputtering, Plasma, Reactive ion.

Selectivity is the ratio of etch rate of the material to be etched to the etch rate of the material of the mask.



Diffusion

Microelectromechanical systems (MEMS)

* These are basically miniature devices on a silicon chip which have found a major use in sensors. Eg. Car air bag systems.

* A microsystem is an assembly whose overall dimensions do not exceed 30×10^{-3} m.

* Microsystems & miniaturisation are gaining ground because of the contention that
  a) transistors work faster with shorter gate length
  b) more devices can be accommodated in a given area.

* while other kinds of processing such as deposition follow the conventional techniques it is the micromachining tech. that has given special significance to the new technology.

* It comprises machining conventional silicon, the use of silicon-on-insulator (SOI) as the initial requirement & the use of deep profile lithographic processes.

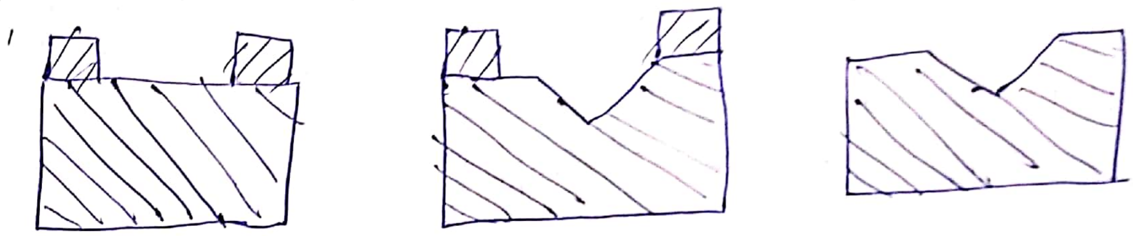
Micromachining.

a) Bulk micromachining.

It is well-known that there are differences in etch-rates b/w the crystallographic directions of silicon with particular etchants & using this property, features can be fabricated in particular crystal planes.

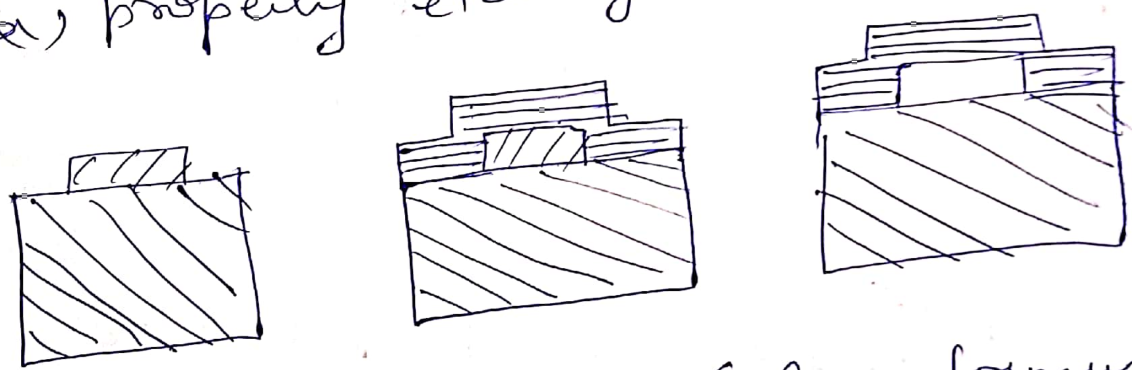
Generally (111) planes etch slowest of all & (100)-oriented substrates are preferred for features. The substrate is masked by SiO_2

when ethylene diamine pyrocatechol is used as etchant.



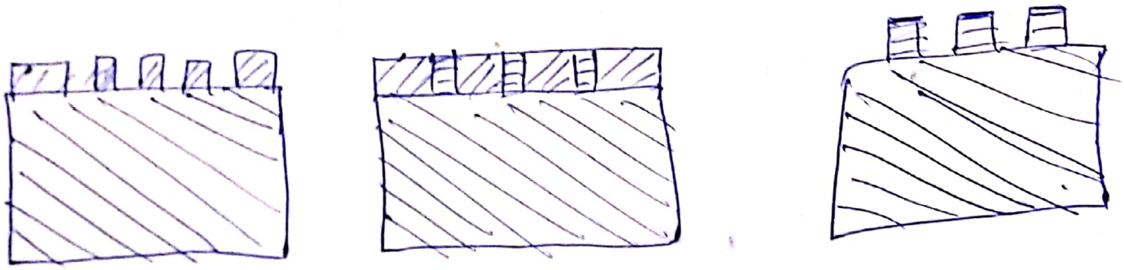
b) Surface micromachining

The process is based on CMOS technology. Polysilicon layer is deposited on top of SiO_2 & then etched. Thickness is limited to a few microns only. Sacrificial layer is used in growing & properly etching other layers.



c) LIGA - Lithographie, Galvanoforming, Abforming is an alternative to surface micromachining. It uses the lithographic exposure of thick photoresist & then electroplating is carried out for building mechanical parts.

This process fabricates thicker structures than that by surface micromachining. Exposure source in LIGA is the Synchrotron radiation of wavelength b/w 0.1 & 2nm that can penetrate deep down to about 500μm.

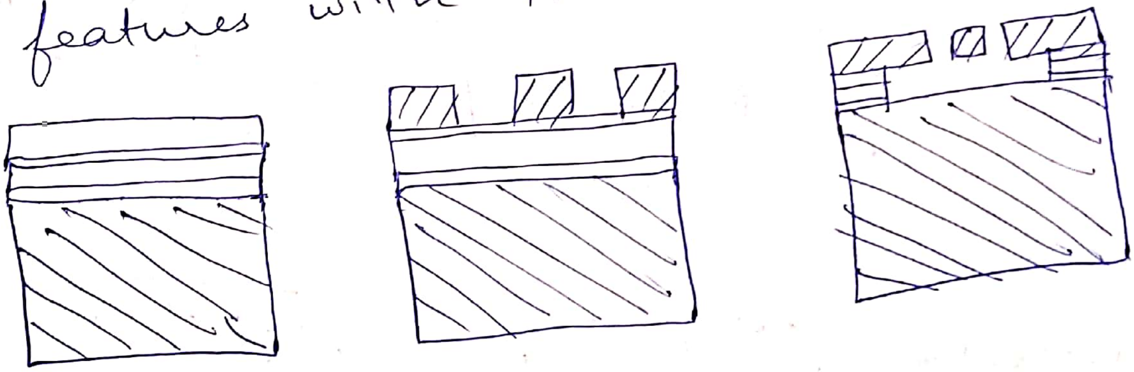


d) DRIE of BSOI

A process, comparatively newer in development, is based on bonded silicon-on-insulator (BSOI) where silicon wafer is thermally bonded to an oxidized silicon (SiO_2) substrate. The bonded wafer is polished to the desired thickness, b/w 5μm & 200μm & the etching is done by Deep Reactive Ion Etching (DRIE).

It uses an inductively coupled plasma etcher with special etching.

techniques to achieve high etch rates. In this process, anisotrophy in the material is used to form very deep features with the vertical sidewalls.



Nanosensors

The development of nanostructures has been accelerated over the past decade because of unexpected breakthroughs in the synthesis & assembly of nanometer scale structures.

Some areas that have seen such unexpected developments are

1. Discovery & controlled production of Carbon nanotubes & the use of proximal probe & lithographic schemes
2. Success in placing engineered individual molecules onto appropriate electrical contacts & in measuring transport thro' these molecules.

3. Availability & use of proximal probe techniques for fabrication of nanometer-scale structures.

4. Development of chemical synthetic methods to realize nanocrystals & also implantation tech. for putting these crystals into a variety of larger organized structures.

5. Implantation/incorporation of biological motors into nonbiological environments

6. Integration of nanoparticles into gas sensors.

7. Fabrication of photonic level band gap structures.

8. Development of quantum effect, single electron memory & logic elements that can operate at room temp.

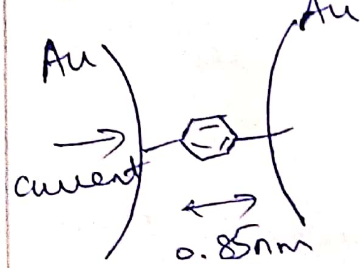
Scanning tunnelling microscopy (STM) or atomic force microscopy (AFM) are the tech. which are used.

While progressing towards the development of fast & miniaturized memory structures, giant magnetoresistance structures have been produced using Thompson effect.

These giant magnetoresistance (GMR) structures consists of layers of magnetic & nonmagnetic metal films & the critical layers have thickness of the order of nanometers.

The spin-polarized electrons are transported b/w the magnetic layers on the nanometer length scale & this process during operation, allows the structure to sense magnetic field. These are already used in sensing magnetic bits stored on computer discs.

Organic nanostructures have been developed combining chemical self-assembly with a mechanical device. It is used to measure the electrical conductivity of a single molecule.



* Molecular electronics are used in the area of sensor development. Molecular switches have been produced by these mechanisms. Carbon nanotubes are used as connecting wires in these ckts.

these devices can be used as power-efficient memories with extraordinary high speed, a billion times faster than CMOS devices.

In the closed state of switch, current flows by resonant tunnelling thro' the states. The switches are opened by applying an oxidizing voltage across the device.

Types

1) optical - Proximity, Ambient light
2) Biological - Anti body/ Antigen interaction
DNA interaction
Enzymatic interaction
3) chemical - chemical composition
Molecular Conc.
4) Physical - Pressure, force, Mass, Displacement.