**Course Materials**

1. **Name of the department:** Electronics and Instrumentation Engineering.
2. **Programme:** M.E (Micro Electronics and MEMS).
3. **Semester:** Second.
4. **Course:** MEMS Technology.
5. **Course Instructor:** Dr. M. Narayanaswamy, Associate Professor.
6. **Unit name:** Design of pressure Sensor.

Design of Capacitive Acclerometer.

**Piezoresistivity in metals**

Usually the resistance change in metals is mostly due to the change of geometry resulting from applied mechanical stress. However, even though the piezoresistive effect is small in those cases it is often not negligible. In cases where it is, it can be calculated using the simple resistance equation derived from [Ohm's law](https://en.wikipedia.org/wiki/Ohm%27s_law).{\displaystyle R=\rho {\frac {\ell }{A}}\,}

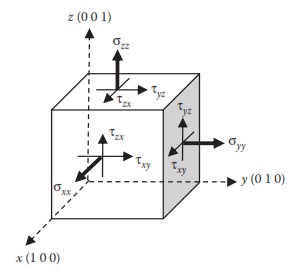
Some metals display piezoresistivity that is much larger than the resistance change due to geometry. In platinum alloys, for instance, piezoresistivity is more than a factor of two larger, combining with the geometry effects to give a strain gauge sensitivity of up to more than three times as large than due to geometry effects alone

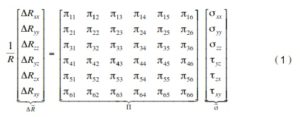
The piezoresistive effect of semiconductors has been used for sensor devices employing all kinds of semiconductor materials such as [germanium](https://en.wikipedia.org/wiki/Germanium), polycrystalline silicon, amorphous silicon, and single crystal silicon. Since silicon is today the material of choice for integrated digital and analog circuits the use of piezoresistive silicon devices has been of great interest. It enables the easy integration of stress sensors with Bipolar and CMOS circuits.

This has enabled a wide range of products using the piezoresistive effect. Many commercial devices such as [pressure sensors](https://en.wikipedia.org/wiki/Pressure_sensors) and [acceleration](https://en.wikipedia.org/wiki/Acceleration) sensors employ the piezoresistive effect in [silicon](https://en.wikipedia.org/wiki/Silicon). But due to its magnitude the piezoresistive effect in silicon has also attracted the attention of research and development for all other devices using single crystal silicon. [Semiconductor](https://en.wikipedia.org/wiki/Semiconductor) [Hall sensors](https://en.wikipedia.org/wiki/Hall_sensor), for example, were capable of achieving their current precision only after employing methods which eliminate signal contributions due the applied mechanical stress.

**Piezoresistors**

Piezoresistors can be fabricated using wide variety of piezoresistive materials. The simplest form of piezoresistive silicon sensors are [diffused resistors](https://en.wikipedia.org/w/index.php?title=Diffused_resistors&action=edit&redlink=1). Piezoresistors consist of a simple two contact diffused n- or p-wells within a p- or n-substrate. As the typical square resistances of these devices are in the range of several hundred ohms, additional p+ or n+ plus diffusions are a potential method to facilitate ohmic contacts to the device.





**Sensing Pressure**

Pressure measurement is a key part of many systems, both commercial and industrial. Silicon has proved to be an astonishingly good material from which to build small pressure sensors. They are millimeter-sized, somewhat smaller than Wordsworth’s objects. Pressure sensors presently constitute the largest market segment of mechanical MEMS devices. Since pressure is a normal stress (force per unit area), one could imagine sensing pressure directly by using a piezoelectric material which can transducer normal stress into voltage. Alternatively, one could apply the pressure to one side of a deformable diaphragm, a reference pressure to the other side, and determine how much the diaphragm deforms. This latter approach is by far the dominant one, in both macrofabricated and microfabricated pressure sensors. There are several ways of sensing the deformation of a diaphragm across which a differential pressure has been applied. The most obvious is to determine the displacement of the diaphragm using either capacitance change, some optical signature, or even the change in current in a tunneling tip. These position-measuring methodsare examined in acceleration measurement, but they apply equally to pressure sensing. An indirect but very powerful way to sense the deformation is to measure the bending strain in the diaphragm. Silicon has the property of piezoresistance,a change in resistance with stress (or strain). It is a material that is ideally suited to this type of device. Another indirect method is to create a resonant structure, either of silicon or quartz, and couple the resonator to the diaphragm in such a way that the diaphragm displacement creates a changing stress in the resonant structure, thereby shifting its resonant frequency. Resonant measurement devices are in the context of a rate-gyroscope, but resonant methods can also be applied to other mechanical measurements such as pressure and acceleration.

**Piezoresistance**

Piezoresistivity is the dependence of electrical resistivity on strain. The resistivity of a material depends on the internal atom positions and their motions. Strains change these arrangements and, hence, the resistivity. Historically, the quantitative formulation of the piezoresistive effect has been in terms of stress rather than strain, which is the origin of the piezo prefix (from the Greek peizin).The electronic states of a material depend on the atomic constituents and on their positions. In a crystalline material, these states form quasi-continua in energy called energy bands and are filled according to the requirements of the Pauli Exclusion Principle to a highest filled level. In metals, this highest filled level occurs in the middle of a band, resulting in a large number of empty states lying adjacent in energy to the highest filled states. Application of an electric field slightly shifts the occupancy of these levels, favoring carriers moving in the direction of the field, resulting in a current. Changing the internal atomic positions by applying stresses to the metal distorts the energy bands slightly, resulting in small changes in the amount of conduction that results from an applied field. This is the piezoresistive effect at its simplest.

**Acclerometer**

Accelerometer is a sensor that responds to the acceleration or deceleration and gives an output voltage to the control circuit, which in turn triggers an actuator to deploy the airbag during a crash, so that the persons seated in the front seat are protected from crashing into the front windshield or the dashboard.

**Silicon Capacitive Accelerometer**

Accelerometers measures the acceleration of the body on which the sensor is mounted. Proof mass, suspension, capacitance Principle of operation converts displacement caused by the inertial force on the proof-mass to a voltage signal via a change in capacitance between movable and fixed parts. Application(s) are Automotive, aerospace, machine tools, biomedical, consumer products, etc.

**1. Proof mass:** the inertial mass used in the accelerometer whose displacement relative to a rigid frame is a measure of the influence of external acceleration.

**2. Suspension:** the compliant structure by which the proof mass is suspended from the frame. Capacitance: the capacity of a body to hold an electrical charge.

**3.Capacitance**: It is also a measure of the amount of electric charge stored for a given electric potential. For a two-plate capacitor, if the charges on the plates are þq and \_q and V is the voltage between the plates, then the capacitance is given by C ¼ q/V. The international standard (SI) unit of capacitance is the farad (1 farad ¼ 1 coulomb/volt).

**4. Parallel-plate capacitor:** a pair of parallel plates separated by a dielectric (non-conducting substance) medium.

**5. Differential capacitance arrangement:** in this arrangement, there are three plates with a movable middle plate. As the plate moves, the capacitance between one of the pairs will increase while that of the other decreases. This gives a signal that is linearly proportional to the applied acceleration, and hence is the preferred configuration.

**6. Quality factor:** a system’s quality factor, Q, describes the sharpness of the system’s dynamic response

**Squeezed Film Effects in Electromechanics**

It means that a solid object floating above a substrate with fluid beneath it. When the object translates up and down, rotates, or deforms, the fluid in the gap beneath is squeezed out from the sides and some of it may be compressed as well. In any case, there will be simple pressure distribution on the bottom surface of the solid object. In fact, this pressure distribution, which we denote p ¼ pðx; z; tÞ, will have components that are in-phase with the displacement (or deformation) of the object or 90\_ out of phase. The in-phase component can be thought of as a spring force per unit area. This is because compressible fluid acts like a spring as it is squeezed out from the sides as the object moves down and comes back in again when the object moves up, as a consequence of the compressibility of the fluid. The out-of-phase component will be in phase with the velocity of the object. Thus, this is like the damping force per unit area and is a consequence of the viscous drag on the object.

**Analytic Formulation in Cubic Materials**

The general formulation of the piezoresistivity of a material can introduce a dizzying level of complexity. To begin with, the resistivity must be formulated as a second-rank tensor, coupling an electric field to a current density. Furthermore, stress is itself a second rank tensor, so the piezoresistive effect requires a fourth-rank tensor for its full description. Assuming that the piezoresistive effect is linear (which is true for small strains but can fail at sufficiently large strains), the relationship between electric field and current density.

**Longitudinal and Transverse Piezoresistance**

If a relatively long, relatively narrow resistor is defined in a planar structure, for example, by ion implantation followed by diffusion, then the primary current density and electric field are both along the long axis of the resistor. This axis need not coincide with the cubic crystal axes. Therefore, it is necessary to know how to transform the piezoresistive equations to an arbitrary coordinate system. The structures are typically designed so that one of the axes of principal in-plane stress is also along the resistor axis. This permits a simplification of the piezoresistive formulation to the form

**Piezoresistive Coefficients of Silicon**

The piezoresistive coefficients have been measured for many materials. Primary interest in MEMS is the coefficients for silicon. These coefficients depend strongly on the doping type, a reflection of the fact that the detailed valence-band and conduction-band structures in silicon are very different. It gives typical values for p-type and n-type silicon. These coefficients are weak functions of doping level for doping below about but then decrease markedly at high doping. The coefficients decrease with increasing temperature, dropping to about 0.7 of their room-temperature value at 150°C. The temperature dependence is somewhat nonlinear, which aggravates the problem of compensating for the temperature.