

DEVELOPMENT OF FLEX SENSOR AND CHARACTERIZATION FOR INERTIAL SENSING

A Project Report Phase – II

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering in Electronics and Communication Engineering

By

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SATHYABAMA

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(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Final year Project Report is the bonafide work of **THUMULA NAGA SATYA NEERAJ** (39130481) and **THOTTEMPUDI SAI KUMAR** (39130477) who carried out the project entitled **"DEVELOPMENT OF FLEX SENSOR AND CHARACTERIZATION FOR INERTIAL SENSING"** under our supervision from November 2022 to April 2023.

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ABSTRACT

The recovery of patients in coma state is completely depends on their sensory, network and their body's self-consciousness. In coma state, the brain is severely damaged and the body loses its co-ordination with the central nervous system and the motor neural pathways. Thus, early diagnosis of recovery is limited. The recovery is often represented in the form of self-consciousness and body movements. In practice, all the patients are intensively monitored through medical aids and 24/7 assistance from nurses for monitoring recovery state of the patients. Herein we have developed a nano material coated Flex sensor for ultra-rapid motion sensing. Such a motion sensing sensor can identify the early stages of recovery in comatose patients such as localized response. We anticipate that this flex sensor can be inbuilt into commercial pulse oximeter for pulse detection.

As the technological advances in smart sensing, motion data of the human can be acquired with accurate data, which benefits in many applications including surgical training. The integration of these motion detecting sensors in electronic devices which alerts the movement of the finger/hand has been rapidly grown. There were different types of sensors which will be used to detect the movement. Conductive flex sensor, Optical Flex sensor, Capacitive flex sensor, MEMS sensor and IMU sensors are few examples for the hand/finger movement detecting sensors. These sensors can be improved in terms of sensitivity. By using Nano substrate coating on these sensors minute change in movement can be detected by sensors. These Enhanced sensors will be more useful in medical applications. By using these Motion detecting sensors trainees can obtained the necessary knowledge and judgment for treatment for the person.

CONTENTS

CHAPTER NO	TITLE	PAGE NO
	ABSTRACT	v
	LIST OF FIGURES	viii
	LIST OF TABLES	ix
1	INTRODUCTION	1
	1.1 ENHANCEMENT OF SENSOR	2
	1.2 FLEX SENSORS	2
	1.3 MEMS AXIS SENSOR	4
	1.4 OBJECTIVE	5
2	LITERATURE SURVEY	6
3	AIM AND SCOPE OF INVESTIGATION	9
	3.1 PROPOSED METHODOLOGY	9
	3.2 APPLICATIONS OF FLEX SENSORS	10
4	MATERIALS AND METHODOLOGY	11
	4.1 QUANTUM DOTS	11
	4.2 SYNTHESIS OF CADMIUM TELLURIDE (CdTe – QUANTUM DOTS)	12
	4.3 QUANTUM DOTS IN MEDICINE	13
	4.4 COATING THE FLEX SENSOR WITH QUANTUM DOTS	14
	4.5 APPLICATIONS OF FLEX SENSORS FOR COMA PATIENT	15
	4.6 CHARACTERIZATION TECHNIQUE – XRD	16
	4.7 CHARACTERIZATION TECHNIQUE – RAMAN SPECTROSCOPY	18
	4.8 CHARACTERIZATION TECHNIQUE – FESEM	20

5	RESULT AND PERFORMANCE ANALYSIS	23
	5.1 ANALYSIS OF UNCOATED FLEX SENSOR	23
	5.2 ANALYSIS OF COATED FLEX SENSOR	26
	5.3 RESULT	30
6	CONCLUSION	31
	REFERENCES	32

LIST OF FIGURES

FIGURE NO	FIGURE NAME	PAGE NO
1.1	OPTICAL FLEX SENSOR	3
1.2	CONDUCTIVE FLEX SENSOR	3
1.3	CAPACITIVE FLEX SENSOR	4
1.4	MEMS AXIS SENSOR	4
1.5	ARCHITECTURE OF MEMS SENSOR	5
2.1	SENSOR WORKING DIAGRAM	7
2.2	HAND MOVEMENT DIAGRAM	8
3.1	ENHANCEMENT PROCESS IN FLOW CHART REPRESENTATION	9
4.1	CdTe QUANTUM DOTS	12
4.2	FLEX SENSOR COATING	14
4.3	BEFORE COATING FLEX SENSOR	14
4.4	AFTER COATING FLEX SENSOR	14
4.5	APPLICATION BLOCK DIAGRAM	15
4.6	XRD SAMPLE TESTING REPRESENTATION	17
4.7	SCATTERING IN RAMAN SPECTROSCOPY	18
4.8	FESEM WORKING MECHANISM	21
5.1	UNCOATED FLEX SENSOR GRAPH FOR VARIOUS RESISTANCE VALUES	24
5.2	UNCOATED FLEX SENSOR GRAPH FOR MEAN RESISTANCE VALUES	25
5.3	LINEAR FITTING GRAPH FOR UNCOATED FLEX SENSOR	26
5.4	COATED FLEX SENSOR GRAPH FOR VARIOUS RESISTANCE VALUES	27
5.5	COATED FLEX SENSOR FOR MEAN RESISTANCE VALUES	29
5.6	LINEAR FITTING GRAPH FOR COATED FLEX SENSOR	29

LIST OF TABLES

TABLE NO	TABLE NAME	PAGE NO
5.1	RESISTANCE VALUES OF UNCOATED FLEX SENSOR	23
5.2	MEAN AND STANDARD ERROR VALUES OF UNCOATED FLEX SENSOR	24
5.3	LINEAR FITTING RESULTS FOR UNCOATED FLEX SENSOR	26
5.4	RESISTANCE VALUES OF COATED FLEX SENSOR	28
5.5	MEAN AND STANDARD ERROR VALUES OF UNCOATED FLEX SENSOR	29
5.6	LINEAR FITTING RESULTS FOR COATED FLEX SENSOR	29

CHAPTER 1

INTRODUCTION

Flex sensor plays an important role in sensing the body movements as there the input information for coma patient health condition monitoring. The main aim is to modify commercially available flex sensor (SEN – 00618) for ultra-rapid motion detection. To improve the sensitivity of the flex sensor, CdTe quantum dots is used as Nano material to coat on the flex sensor. These unique properties of nano sized material quantum dots have led to successful development. To know the properties of before and after coated flex sensor, x-ray diffraction (XRD), Field emission scanning electron microscopy (FESEM) and Raman Spectroscopy characterization techniques are done. The response of the before and after coated flex sensor are recorded and analyzed.

Motion sensing is a critical sensing modality which plays an important role in medical field. For example, head rotation and body orientation are the input information for human health condition monitoring. The movement of hearts chest wall should be continuously monitored when a ventilation machine is used at the time of human operations. The body motion characteristics also need to be evaluated during the process of physical health maintenance. The current methodologies for motion sensing is to use a camera based motion capture system, where the body motion is obtained from the movement of multiple obtaining points attached on the body. Although effective, this technique is difficult, time complex and expensive. It is also difficult to be integrated into a modern medical system, like portable medical device or kits and point-of-care medication. Recently, microscale motion sensing technologies having future advances, which have significantly propelled the development of human health responsibilities. Sports medicine and radiotherapy. In particular, rapid development of micro – electro – mechanical – systems with high accuracy, high reliability and multiple functionalities has provided a powerful tool set for continuous body motion sensing. Over the past two decades, research on different motion sensors has received more attention, growth and continues to be an active domain for applications.

1.1 Enhancement of sensor:

The unique properties obtained by nano materials in comparison to micro-sized materials have led to the successful development of nano structured coatings, which having at least one of their constituents in nanometer scale. Nano structured coatings provide advanced surface protection, and they are being used and utilized in the fields of electronics, medicine, food packaging, shipping, etc.

Due to their compact and diminished in size, nano materials have high surface area to volume ratio, and also can provide chemical/physical properties that are not offered by micro/macro-sized materials. Nano materials have found their abilities in several applications, such as optical, thermal, chemical, mechanical, magnetic and energy conversion/storage applications.

1.2 Flex sensors:

Flex sensors are also called Bend Sensor (Variable Resistor). These Sensors used to Measure amount of deflection caused by bending the sensor. These sensors are Made up of plastic material and sensing by resistance material.

These sensors have two terminals – Power supply, Vout. Resistance in these sensors is directly proportional to the amount of bend produced in the sensor.

Resistance Range of these flex sensors according to the research is

1. Maximum Resistance – 180 Degree – 45kohms.
2. Minimum Resistance – 0 degree - 125kohms.

There are three kinds of Flex sensors

1. Optical flex sensor.
2. Conductive ink-based Flex sensor.
3. Capacitive flex sensor.

In Optical flex sensors, Light source in one end and photosensitive detector in another end. Flexible tube having two ends and with reflective interior wall. Photodiode present in the optical flex sensor Converts light energy into electrical energy. These photodiodes are used for light measurement Increase in light intensity current increases. If

no light falls on the diode, then current will be zero, this case is said to be dark current. More the electromotive force generated, the greater the current flow.

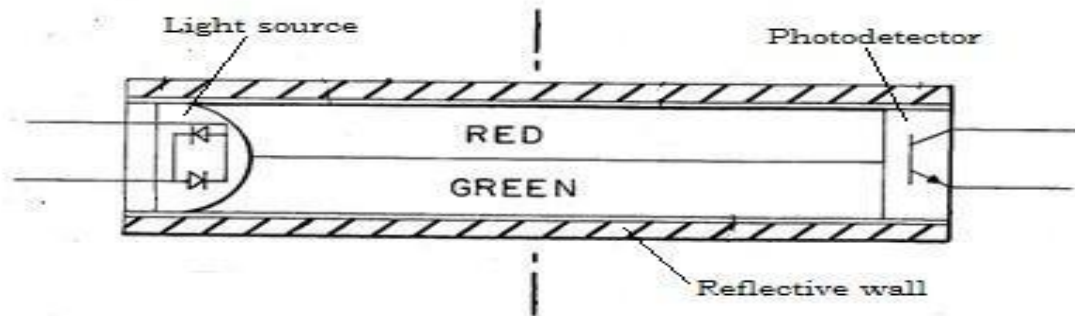


Fig 1.1: Optical flex sensor

Conductive flex sensor formed by a phenolic resin substrate with conductive ink deposited on it. Segmented conductors are placed on that ink acts as flexible potentiometer. Conductive flex sensor is a unipolar sensor ink usually is of carbon or silver to make it conductive. When the sensor is bent away from the ink, the conductive segments which are embedded move apart from each other results in increase in resistance and can also find maximum and minimum resistance. Polypyrrole (PPY), polyaniline (PANI), polythiophene [4], and poly(3,4-ethylenedioxythiophene) polystyrene sulfonate used as polymer conductors.

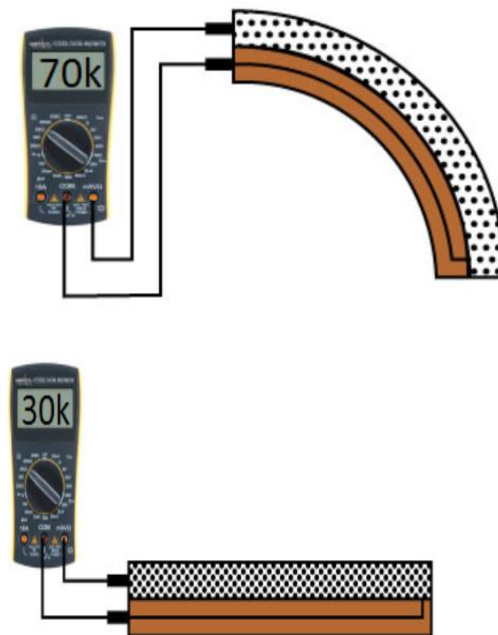


Fig 1.2: Conductive flex sensor

Capacitive flex sensor having two conductive layers. These two conductive layers are arranged in a comb pattern design. A dielectric medium is disposed between these comb pattern position of first conductive layer and second conductive layer. These conductive layers present on the capacitive flex sensor are bonded in such a way that the first element of the first layers relative to second element of the second layer when the two conductive layers when the conductive layers are bend.

Bend angle will be measured according to the alignment of the comb patterned of first conductive layer and comb patterned of the second conductive layer.

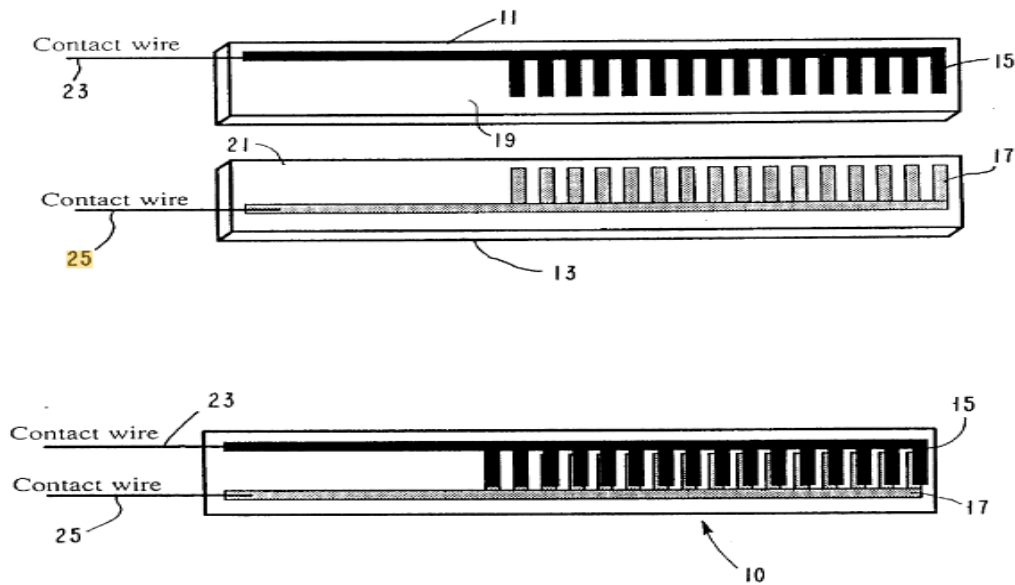


Fig 1.3: Capacitive flex sensor

1.3 MEMS AXIS SENSOR



Fig 1.4: MEMS AXIS Sensor

MEMS axis sensor is used to sense the acceleration changes in the person as this sensor is placed on the fingers of the person. Whenever there are an acceleration changes in the patient, whenever there is any movement, it will be recorded and by using phase demodulation principle the system is used to determine the value and direction and this information will be communicated. This sensor is made up of a polysilicon surface micro machined structure which is built on the top of a silicon wafer.

This MEMS sensor works on a principle of measuring the deflection using a differential capacitor which has independent fixed plates that are attached to the moving mass. These plates are at 180 degrees out of phase. When there is an acceleration there will be a deflection in the moving mass which unbalances the differential capacitor which results in a output amplitude is proportional to acceleration, than a Phase sensitive demodulation process is used to estimate the value and direction of acceleration. This sensor can be used as single structure for a complete 3-axis sensing.

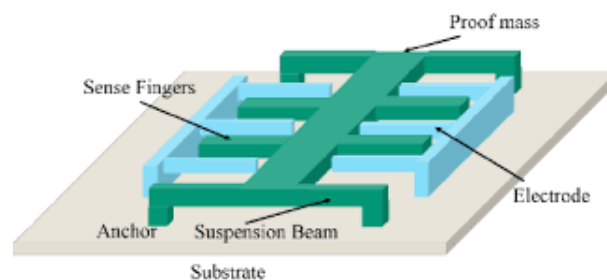


Fig 1.5: Architecture of MEMS Sensor

1.4 OBJECTIVE

The development of coated sensor application is a challenging thing that effect several factors and influence the properties and performance of coating. The selection of coating material, chemical complexity, cost and time effectiveness in synthesizing coating make the development of effective even more challenging. Developed nano structured coating have shown good performance. The key issues that should be considered are strategies to improve the adhesion between coating and substrates, the development of low cost for coating preparation, coating design, development of model using the coating processes.

CHAPTER 2

LITERATURE SURVEY

1. Müller, P, proposed that Due to their relative ease of handling and low cost, inertial measurement unit (IMU)-based joint angle measurements are used for a widespread range of applications. These include sports performance, gait analysis, and rehabilitation (e.g., Parkinson's disease monitoring or poststroke assessment). However, a major downside of current algorithms, recomposing human kinematics from IMU data, is that they require calibration motions and/or the careful alignment of the IMUs with respect to the body segments. In this article, we propose a new method, which is alignment-free and self-calibrating using arbitrary movements of the user and an initial zero reference arm pose. The proposed method utilizes real-time optimization to identify the two dominant axes of rotation of the elbow joint. The performance of the algorithm was assessed in an optical motion capture laboratory. The estimated IMU-based angles of a human subject were compared to the ones from a marker-based optical tracking system.

2. Nguyen-Tri, P.; Nguyen, T.A proposed, Incorporation of nanofillers into the organic coatings might enhance their barrier performance, by decreasing the porosity and zigzagging the diffusion path for deleterious species. Thus, the coatings containing nanofillers are expected having significant barrier properties for corrosion protection and reduce the trend for the coating to blister or delaminate. On the other hand, high hardness could be obtained for metallic coatings by producing the hard nanocrystalline phases within a metallic matrix. This article presents a little review on recent development of nanocomposite coatings, which provides an overview of nanocomposite coatings in various aspects dealing with the classification, preparative methods, the nanocomposite coating properties and characterization methods. It covers potential applications in areas such as the anti-corrosion, anti-wear, superhydrophobic, self-cleaning, antifouling/antibacterial, electronics. Finally, conclusion and future trends will be also reported.

3. Kok, M proposed, In inertial human motion capture, a multitude of body segments are equipped with inertial measurement units, consisting of 3D accelerometers, 3D gyroscopes and 3D magnetometers. Relative position and orientation estimates can be obtained using the inertial data together with a biomechanical model. In this work we present an optimization-based solution to magnetometer-free inertial motion capture. It allows for natural inclusion of biomechanical constraints, for handling of nonlinearities and for using all data in obtaining an estimate. As a proof-of-concept we apply our algorithm to a lower body configuration, illustrating that the estimates are drift-free and match the joint angles from an optical reference system.

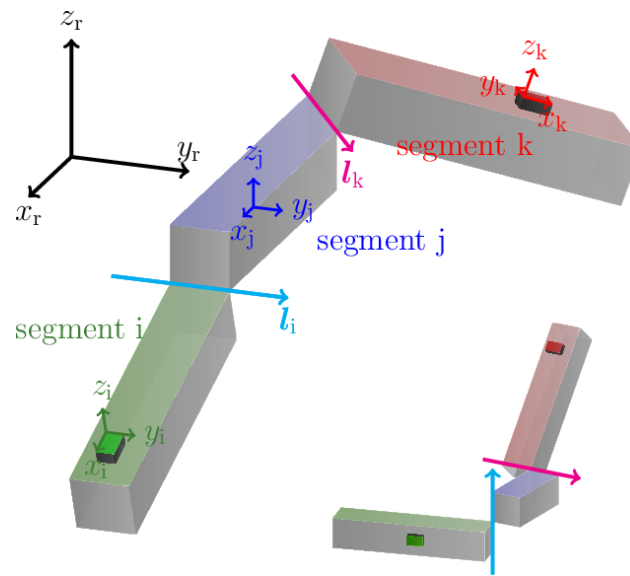


Fig 2.1: Sensor working diagram

4. Sengupta, D proposed, demonstrates the application of electrospun single and bundled carbon nanofibers (CNFs) as piezoresistive sensing elements in flexible and ultralightweight sensors. Material, electrical, and nanomechanical characterizations were conducted on the CNFs to understand the effect of the critical synthesis parameter—the pyrolyzation temperature on the morphological, structural, and electrical properties. The mechanism of conductive path change under the influence of external stress was hypothesized to explain the piezoresistive behavior observed in the CNF bundles. Quasi-static tensile strain characterization of the CNF bundle-based flexible strain sensor showed a linear response with an average gauge factor of 11.14 (for tensile strains up to 50%). Furthermore, conductive graphitic domain discontinuity

model was invoked to explain the piezoresistivity originating in a single isolated electrospun CNF. Finally, a single piezoresistive CNF was utilized as a sensing element in a NEMS flow sensor.

5. hand posture and kinematics is increasingly important in various fields. This includes the rehabilitation of stroke survivors with restricted hand function. This paper presents a modular, ambulatory measurement system for the assessment of the remaining hand function and for closed-loop controlled therapy. The device is based on inertial sensors and utilizes up to five interchangeable sensor strips to achieve modularity and to simplify the sensor attachment. We introduce the modular hardware design and describe algorithms used to calculate the joint angles. Measurements with two experimental setups demonstrate the feasibility and the potential of such a tracking device.

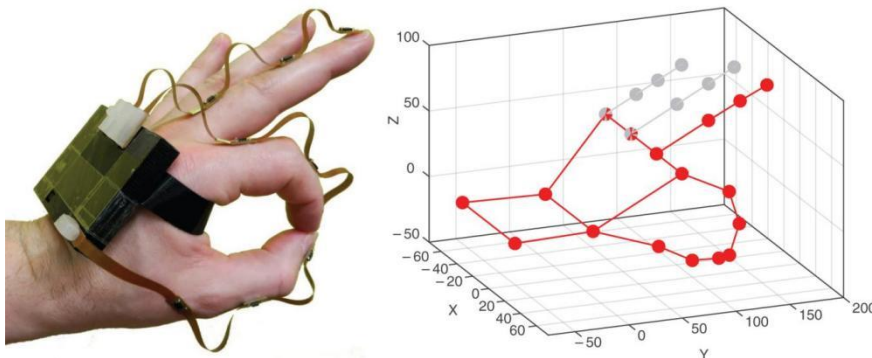


Fig 2.2: Hand Movement Diagram

6. Flexible electronics with continuous monitoring ability is an extensively preferred in various medical applications. In this work, a flexible pressure sensor based on porous graphene is proposed for continuous cardiovascular status monitoring. The whole sensor is fabricated in situ by ink printing technology, which grants it the potential for large-scale manufacture. Moreover, to enhance its long-term usage ability, a polyethylene terephthalate/polyethylene vinyl acetate laminated film is employed to protect the sensor from unexpected shear forces on the skin surface. The sensor exhibits great sensitivity high resolution, wide detecting range, desirable robustness, and excellent repeatability. With the assistance of the proposed pressure sensor, vital cardiovascular conditions can be accurately monitored, including heart rate, respiration rate, pulse wave velocity, and blood pressure.

CHAPTER 3

AIM AND SCOPE OF INVESTIGATION

Flex sensor plays an important role in sensing the body movements as there the input information for coma patient health condition monitoring. The main aim is to modify commercially available flex sensor (SEN – 00618) for ultra-rapid motion detection. To improve the sensitivity of the flex sensor, CdTe quantum dots is used as Nano material to coat on the flex sensor. These unique properties of nano sized material quantum dots have led to successful development. To know the properties of before and after coated flex sensor, x-ray diffraction (XRD), Field emission scanning electron microscopy (FESEM) and Raman Spectroscopy characterization techniques are done. The response of the before and after coated flex sensor are recorded and analyzed.

3.1 PROPOSED METHODOLOGY

The Commercially available flex sensor (SEN – 00618) will be analyzed and then the nano material called Cadmium Telluride Quantum dots will be coated on the flex sensor. After coating the flex sensor with quantum dots it will be analyzed again.

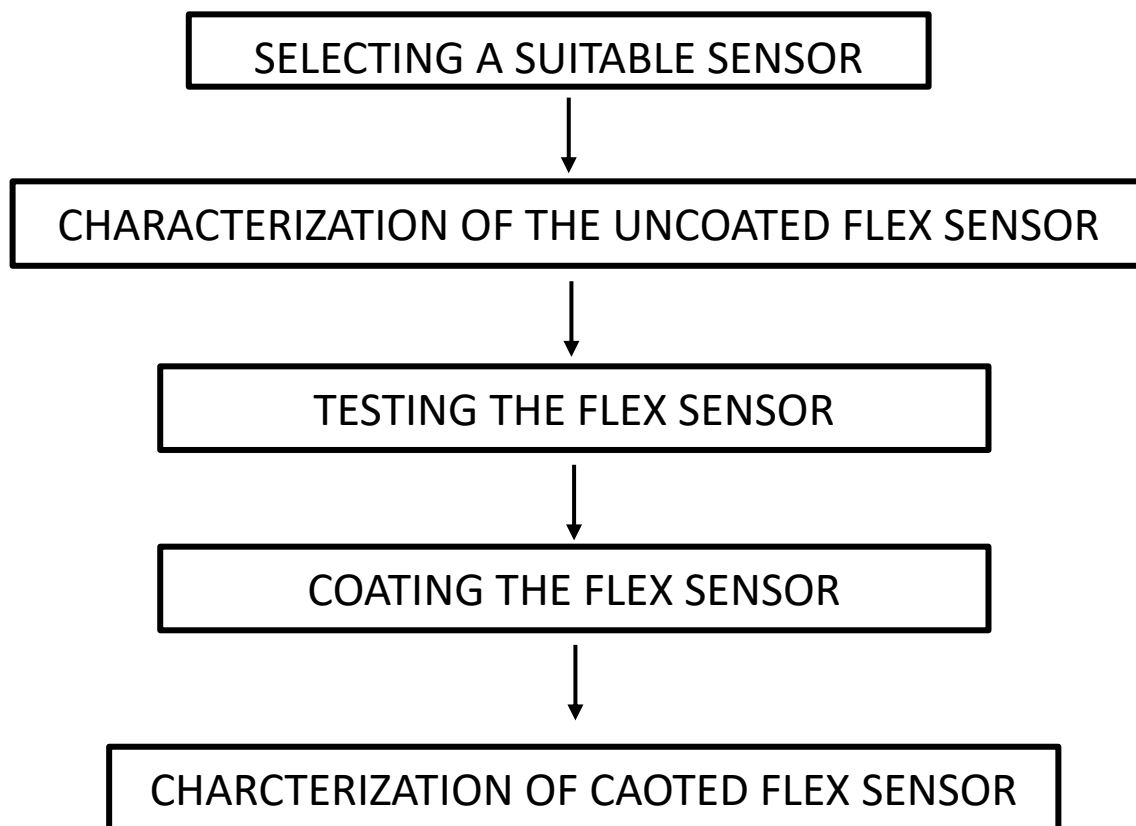


Fig 3.1: Enhancement process in Flow chart representation

3.2 APPLICATIONS OF FLEX SENSORS

- 1. Medical Instruments** – Biological signals generated by a human body, representing the electrical, chemical, and mechanical activities that occur during various biological events, contain very important information about the human's physiological status. These Flexible Sensors which was integrated microelectronics, materials science, mechanics, physics, biology, etc. has great potential in various applications, such as wearable electronics, electronic eye cameras, electronic skins for diagnosis and treatment, flexible biomedical devices, flexile displays, etc. .The main advantage of flexible electronics is the ability to fit onto arbitrary curved surfaces, such as the human skin and organs, without significant changes in their characteristics, which makes it possible to manufacture wearable or implantable devices for human healthcare and monitoring.
- 2. Robotics** – To capture the motion of human limbs, flex sensors can be used. Sensor plays an important role in robotics. Sensors are used to determine the current state of the system. Robotic applications demand sensors with high degrees of repeatability, precision, and reliability. Flex sensor is such a device, which accomplish the above task with great degree of accuracy. The pick and place operation of the robotics arm can be efficiently controlled using micro controller programming. This designed work is an educational based concept as robotic control is an exciting and high challenge research work in recent year. Sensing plays an important role in robotic paradigms. Robotic arm manipulators can have different configurations and kinematic constraints. Few of these constraints can be effectively mapped from the human arm domain to the robot's restricted joint space.
- 3. Motion Detecting Gaming** – Body movements are communicated with the host computer that calculates physical activity via the flex sensor and runs signal processing algorithms to classify and enforce movements. Human activity monitoring, through the use of body-wearable sensors, allows for many exciting possibilities, from gaming, to exercise, to preventative health care, where childhood obesity is a growing epidemic. The rapidly increasing nature of this trend requires serious thought at targeting its causes and finding solutions. One major influence is video gaming and the hours of sedentary behavior associated with it.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 QUANTUM DOTS

Quantum dots are nano sized semiconductors are also called nanoscale crystals. Quantum dots exhibit unique optical and electronic properties which includes ability to transport electrons and emit light of various colors when exposed to UV light. These artificially synthesized semiconductor particles have a wide range of potential applications like used in composites, solar cells, fluorescent biological labeling, displays, lighting and medical imaging.

Quantum dots are nanoparticles of semiconductors. It was first theorized in the 1970s and then successfully synthesized in the early 1980s. When semiconductor particles are made small enough, they exhibit quantum effects, which restrict the energies at which electrons and holes (the absence of electrons) can exist within the particle. As energy is linked to wavelength (or color), this results in the optical properties of the particle being tunable based on its size. By controlling the size of the particle, it can be made to emit or absorb specific wavelengths (colors) of light. Quantum dots are artificial nanostructures that can possess many varied properties, depending on their material and shape. For instance, due to their particular electronic properties they can be used as active materials in single-electron transistors.

The properties of quantum dots (QDs) are determined by various factors, include size, shape, composition, and structure, such as whether they are solid or hollow. To utilize QDs effectively across multiple applications, including catalysis, electronics, photonics, information storage, imaging, medicine, and sensing, a dependable manufacturing technology is needed that can consistently produce large quantities of nanocrystals with uniform parameters. This will ensure that each batch of QDs has consistent and predictable properties for a given application. Because certain biological molecules are capable of molecular recognition and self-assembly, nanocrystals could also become an important building block for self-assembled functional nano devices.

4.2 SYNTHESIS OF CADMIUM TELLURIDE (CdTe – QUANTUM DOTS)

There are two parts in preparing the Cadmium Telluride. In the first process, 204 mg of Sodium borohydride, 804 mg Tellurium and 10 ml of DI water are mixed in a flask. This prepared solution in flask is kept in a bowl of ice cubes. Continuous supply of nitrogen gas into the flask using injector until the black solution turns into pink solution. The outcome of the first process is Cadmium chloride. In the second process 152 of Cadmium chloride and 100 micro liters of kye TGA in 250 ml of water and this mixture is present at 100 – 150 degrees Celsius. For every 10 minutes sample has to take from the solution. As the temperature of liquid increases the diameter of the quantum dots increases there after results in increase in wavelength of the cadmium Telluride. The below figure shows the wavelength changes from blue to red. The red solution is having more wavelength.

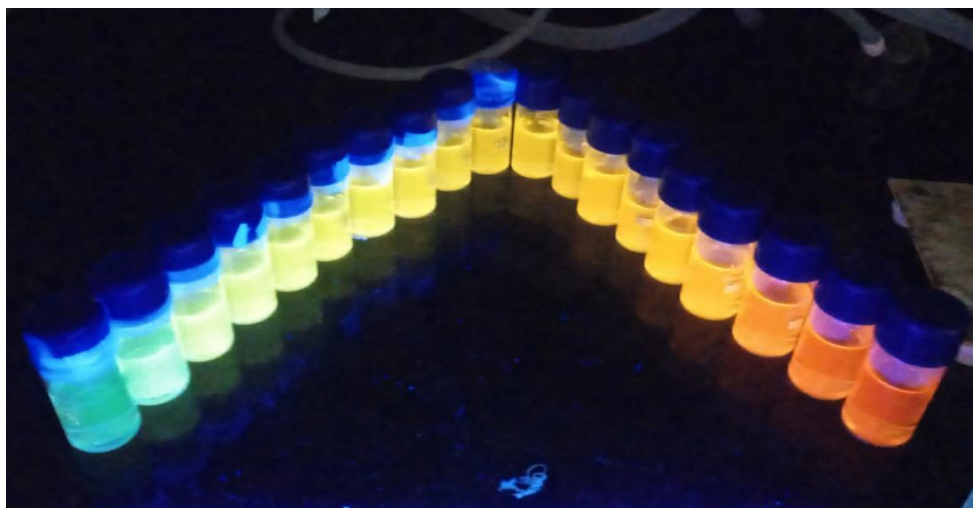


Fig 4.1: CdTe Quantum Dots

4.3 QUANTUM DOTS IN MEDICINE

Quantum dots enable researchers to study cell processes at the level of a single molecule and may significantly improve the diagnosis and treatment of diseases such as cancers. QDs are either used as active sensor elements in high-resolution cellular imaging, where the fluorescence properties of the quantum dots are changed upon reaction with the analyte, or in passive label probes where selective receptor molecules such as antibodies have been conjugated to the surface of the dots. Quantum dots could revolutionize medicine. Unfortunately, most of them are toxic. Ironically, the existence of heavy metals in QDs such as cadmium, a well-established human toxicant and carcinogen, poses potential dangers especially for future medical application, where quantum dots are deliberately injected into the body. As the use of nano materials for biomedical applications is increasing, environmental pollution and toxicity have to be addressed, and the development of a non-toxic and biocompatible nanomaterial is becoming an important issue.

Quantum dots (QDs) are semiconductors-based nanomaterials with numerous biomedical applications such as drug delivery, live imaging, and medical diagnosis, in addition to other applications beyond medicine such as in solar cells. Nevertheless, the power of QDs is still underestimated in clinics. In the current article, we review the status of QDs in literature, their preparation, characterization, and biomedical applications. In addition, the market status and the ongoing clinical trials recruiting QDs are highlighted, with a special focus on the challenges limiting the clinical translation of QDs. Moreover, QDs are technically compared to other commercially-available substitutes. Eventually, we inspire the technical aspects that should be considered to improve the clinical fate of QDs. QDs are semiconductors-based ultra-small nanocrystals (1–15 nm) with amazing optical properties. The evolution of COVID-19 vaccines based on nanomedicines has rekindled the hope in the power of nanomedicines as a protective tool to rescue the world during the pandemic. However, inorganic nanoparticles represent another interesting category of nanomedicines which is still underestimated. Most inorganic nanoparticles are based on metals.

4.4 COATING THE FLEX SENSOR WITH QUANTUM DOTS (CdTe)

Flex sensor is built with two conductive materials. One is carbon which is black colored region of anode electrode (positive charged particles) and another is an metal element which is white colored region of cathode electrode. As my nano material Cadmium Telluride (CdTe- Quantum dots) is a negatively charged particles. These quantum dots has been coated on the white colored region of the flex sensor. The below figures shows the coating of the flex sensor and difference between before and after coating of the flex sensors.

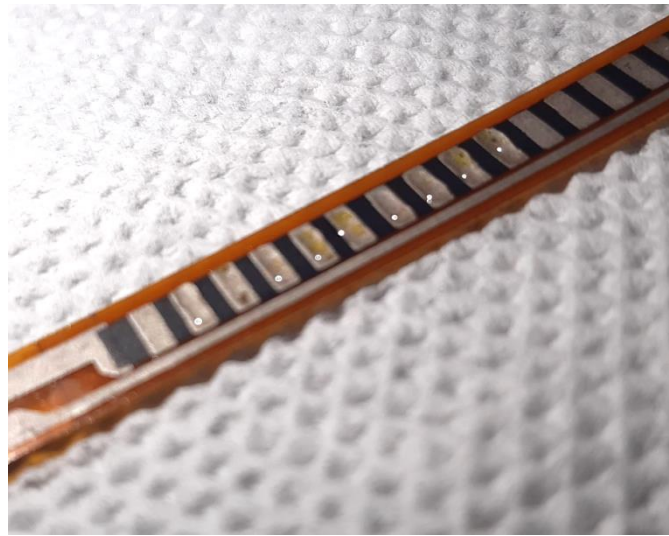


Fig 4.2: Flex Sensor Coating



Fig 4.3: Before Coating Flex Sensor



Fig 4.4: After Coating Flex Sensor

4.5 APPLICATIONS OF FLEX SENSOR FOR COMA PATIENT

The system is based on motion detection sensor system. The system is used for monitoring physical health and physical changes in a vegetative state individual. The various hardware requirements and their working principles.

The proposed system consists of four sensors in which two sensors are used for monitoring vitals of the comatose. Temperature and pulse rate are the two vitals recorded and monitored to understand health status of a comatose. The other two sensors are MEMS accelerometer sensor and Eye blink sensor which are used recording any physical changes that occur in a comatose. These signals which provides information are recorded and monitored continuously to understand the body functioning. These sets of sensed signals which are outside normal ranges typically imply the need for some care or possible evacuation to a higher level of treatment during which we alert the doctor.

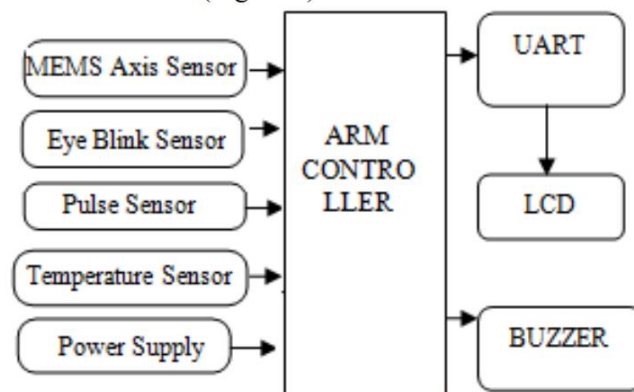


Fig 4.5: Application Block Diagram

The sensitivity improvement for finger movement detecting sensors is realized by introducing nano coated on a sensor. A novel structural design for Finger movement based angular motion sensors to enhance the sensitivity by more than 65% without increasing the power consumption. Therein, the heaters are oriented parallel to the temperature detectors rather than the traditional perpendicular distribution. Simultaneously, the intrinsic mechanism regarding nonlinear heat transfer of the TEAM sensors was quantitatively studied based on the analysis of the developed 2D model with the thermal working efficiency of heaters proposed to identify the principle of the sensitivity improvement for

PaH TEAM sensors. The results are of great value for the development of sensor miniaturization and system integration.

A novel structural design of movement based angular motion sensors based on a systematic comparative study to improve the sensitivity. Compared with the traditional motion sensors design with the Heaters oriented Perpendicular to the temperature detectors, the novel structural design employs the Heaters Parallel to the detectors. The dominant superiority of the novel design is the sensitivity enhancement without increasing the chip area and power consumption, which can be attributed to the higher thermal working efficiency of heaters. The sensitivity of a these sensor can be enhanced by more than 65% by adopting the novel design instead of the traditional design. Therefore, the proposed motion movement sensor will be a promising device for future industrial IoT applications and will be improved sensitivity.

4.6 CHARACTERIZATION TECHNIQUE – XRD

XRD is a technique used to get the structure of the solid samples. Diffraction is the main technique used in the XRD to identify the crystal structure. X - Rays are produced by bombarding high energy electrons on a heavy metal. As the X-rays are having the shorter wavelength these are used in crystal diffraction. X-ray diffraction is a non-destructive solid technique for delineating crystalline materials. It gives information on phases, structures, favoured crystal orientations (texture), and different structural parameters, such as strain, crystallinity, medium grain size, and crystal cracks. XRD peaks are designed by the constructive intervention of a monochromatic beam of X-rays interspersed at distinct angles from each collection of lattice planes in a specimen. The peak intensities are defined by the atomic positions inside the lattice planes.

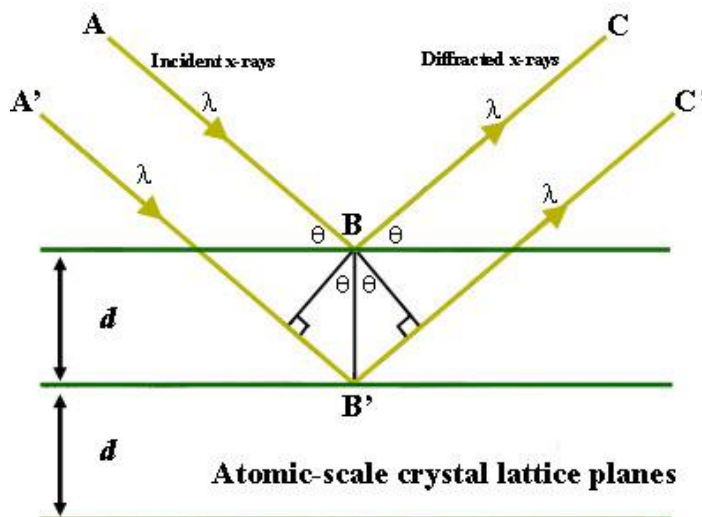


Fig 4.6: XRD Sample Testing Representation

Consequently, the XRD design is the fingerprint of periodic atomic methods in a dispensed material. A standard database of online research for X-ray powder diffraction patterns allows quick phase identification for a wide variety of crystalline samples. X-ray diffraction results from radiation being scattered by a regular array of scattering centres, whose spacing is the same as the radiation. Diffraction gratings need to have spacings equivalent to the wavelength of diffracted radiation.

Crystals are periodic arrays of atoms, whilst X-rays can be deemed as waves of electromagnetic radiation. Crystal atoms scatter incident X-rays, mainly through interaction with the atoms' electrons. This occurrence is identified as elastic scattering; the electron is known as the scatterer. A regular array of scatterers presents a constant array of orbicular waves. In the bulk of directions, these waves eliminate each other out through destructive interference; however, they combine constructively in less explicit directions, as defined by Bragg's law:

$$2d \sin\theta = n\lambda \dots \dots \dots \text{equation 1}$$

here, d is the space between the diffracting planes, θ (theta) = incident angle, n = integer and λ = beam wavelength

The particular directions resemble spots on the diffraction pattern called reflections. Consequently, impinging on a regular array of scatterers, the X-ray diffraction patterns emerge from the electromagnetic waves. To form the X-ray diffraction pattern x-rays are used, because their wavelength, λ , is mostly in the same order of magnitude as the spacing, d , between the crystal planes (1-100 angstroms).

4.7 CHARACTERIZATION TECHNIQUE – RAMAN SPECTROSCOPY

Raman spectroscopy is an analytical technique where scattered light is used to measure the vibrational energy modes of a sample. Raman spectroscopy can provide both chemical and structural information, as well as the identification of substances through their characteristic Raman 'fingerprint'. Raman spectroscopy extracts this information through the detection of Raman scattering from the sample.

When light is scattered by molecule, the oscillating electromagnetic field of a photon induces a polarization of the molecular electron cloud which leaves the molecule in a higher energy state with the energy of the photon transferred to the molecule. This can be considered as the formation of a very short-lived complex between the photon and molecule which is commonly called the virtual state of the molecule. The virtual state is not stable and the photon is re-emitted almost immediately, as scattered light.

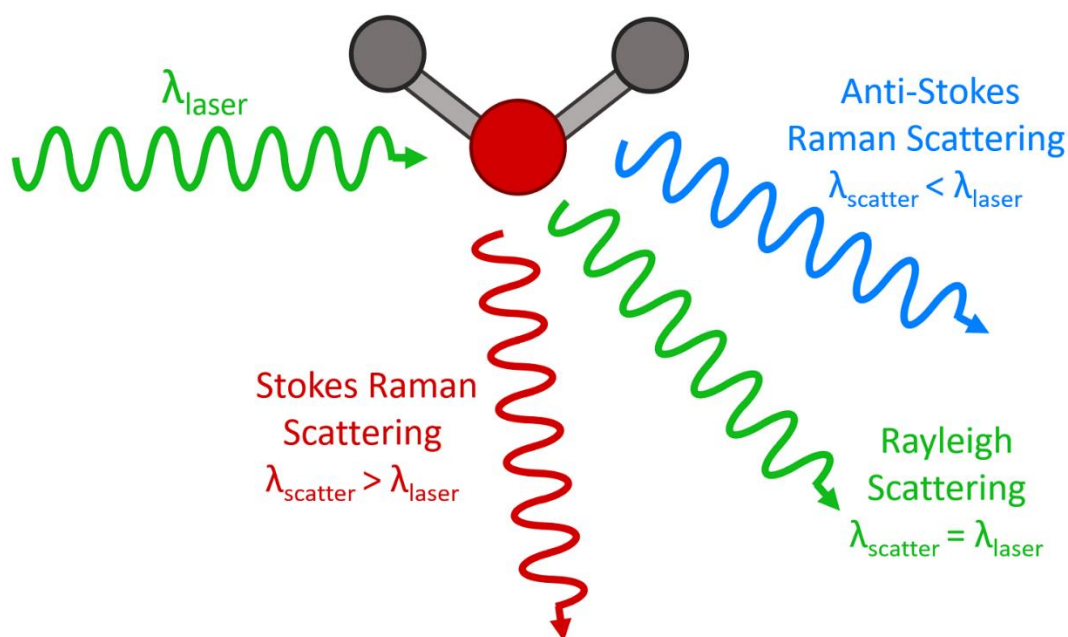


Fig 4.7: Scattering in Raman Spectroscopy

In the vast majority of scattering events, the energy of the molecule is unchanged after its interaction with the photon; and the energy, and therefore the wavelength, of the scattered photon is equal to that of the incident photon. This is called elastic (energy of scattering particle is conserved) or Rayleigh scattering and is the dominant process. In a much rarer event (approximately 1 in 10 million photons)² Raman scattering occurs,

which is an inelastic scattering process with a transfer of energy between the molecule and scattered photon. If the molecule gains energy from the photon during the scattering (excited to a higher vibrational level) then the scattered photon loses energy and its wavelength increases which is called Stokes Raman scattering (after G. G. Stokes). Inversely, if the molecule loses energy by relaxing to a lower vibrational level the scattered photon gains the corresponding energy and its wavelength decreases; which is called Anti-Stokes Raman scattering. Quantum mechanically Stokes and Anti-Stokes are equally likely processes. However, with an ensemble of molecules, the majority of molecules will be in the ground vibrational level (Boltzmann distribution) and Stokes scatter is the statistically more probable process. As a result, the Stokes Raman scatter is always more intense than the anti-Stokes and for this reason, it is nearly always the Stokes Raman scatter that is measured in Raman spectroscopy.

The wavelength of the Raman scattered light will depend on the wavelength of the excitation light. This makes the Raman scatter wavelength an impractical number for comparison between spectra measured using different lasers. The Raman scatter position is therefore converted to a Raman shift away from excitation wavelength:

$$\Delta\bar{\nu}(\text{cm}^{-1}) = \left(\frac{1}{\lambda_0(\text{nm})} - \frac{1}{\lambda_1(\text{nm})} \right) \times \frac{(10^7 \text{ nm})}{(\text{cm})} \quad \text{.....equation 2}$$

The first term is the wavenumber Raman shift in cm^{-1} , $\lambda_{(0)}$ is the wavelength of the excitation laser in nm, and $\lambda_{(1)}$ is the wavelength of the Raman scatter in nm.

Raman spectroscopy measures the energy gap between the vibrational levels of the molecule. Polyatomic molecules will contain many vibrational modes, each with their own ladder of vibrational levels.

For non-linear molecules with N atoms, the number of vibrational modes is given by:

$$3N - 6$$

The 3N is the total degrees of freedom of the molecule and the translational 3 degrees of freedom, and 3 rotational are then subtracted which leaves $3N - 6$ vibrational modes.

For linear molecules, there is one less rotational degree of freedom and the number of vibrational modes is therefore:

$$3N - 5$$

Not all vibrational modes can be detected using Raman spectroscopy. For a vibrational mode to be measured it must be 'Raman Active' which occurs when the molecular polarizability changes during the vibration.

4.8 CHARACTERIZATION TECHNIQUE – FESEM

It is an Advanced Technology used to capture and visualize the microscopic images of the material and provide Elemental information at a magnification of 10x to 3,00,000 x. Magnification refers to enlarging the apparent size without disturbing physical size of the material. Compared to SEM, FESEM gives the clear image and less Electrostatically distorted images with a spacial resolution down to 1 1/2 nanometers (3 to 6 times better than the SEM).

To get ultra-high magnification (250x - 1000000x) in-lens FESEM can be used.

1. FESEM works on electrons with negatively charged instead of light.
2. FESEM Cannot be used to liquid and magnetic samples.

FESEM contains field emission cathode as an electron gun which emits narrower beam passes through anode and magnetic lens after hitting the sample material the reflected beam will be detected by back scattered electron detector and secondary electron detector. Thereafter this reflected back beam will be scanned and converted into image on the display. Electrons are liberated from a field emission source and accelerated in a high electrical field gradient. Within the high vacuum column these so-called primary electrons are focused and deflected by electronic lenses to produce a narrow scan beam that bombards the object.

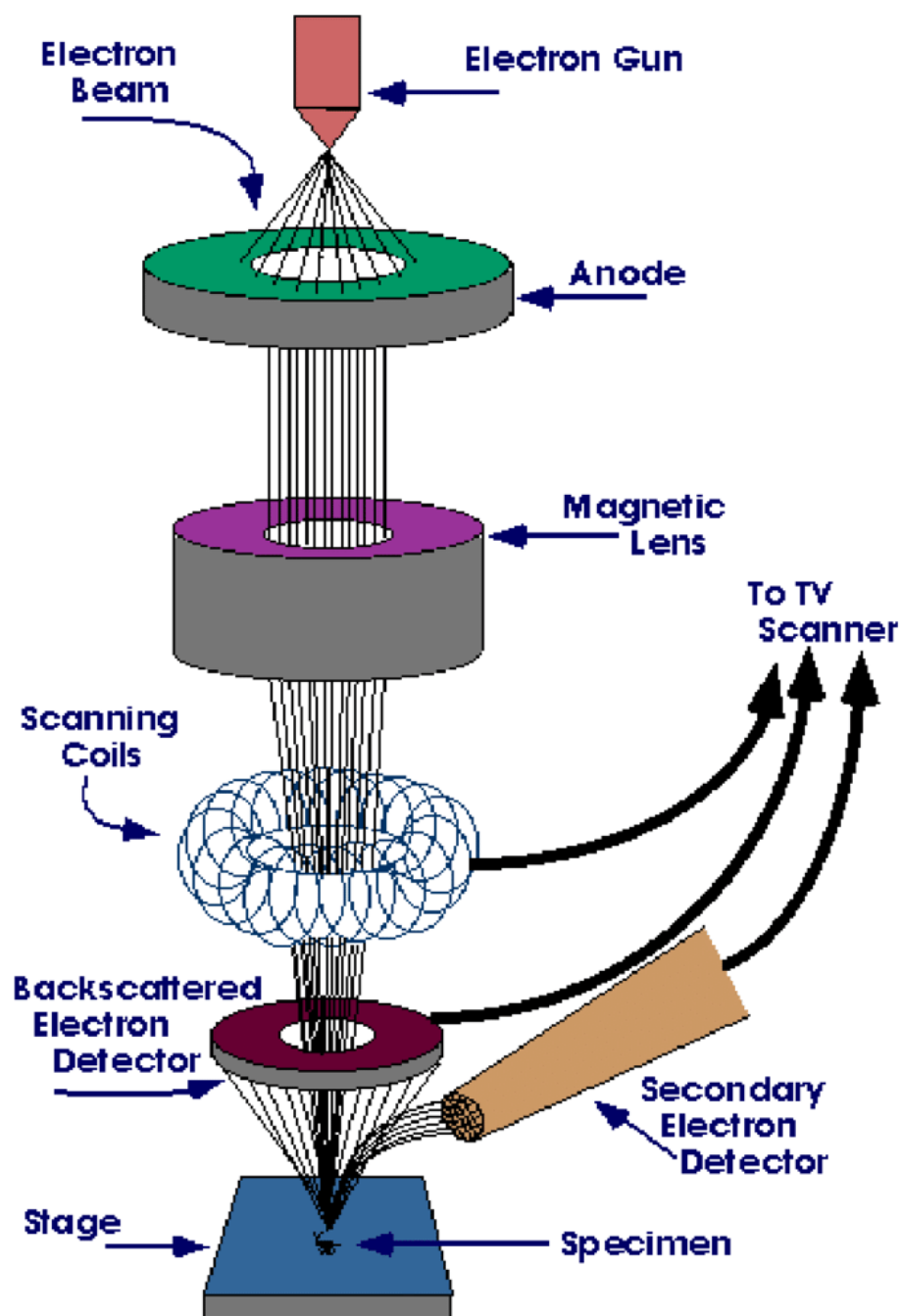


Fig 4.8: FESEM Working Mechanism

As a result, secondary electrons are emitted from each spot on the object. The angle and velocity of these secondary electrons relates to the surface structure of the object. A detector catches the secondary electrons and produces an electronic signal. This signal is amplified and transformed to a video scan-image that can be seen on a monitor or to a digital image that can be saved and processed further.

After the object has been covered by a conductive layer (see preparation) it is mounted on a special holder. The object is inserted through an exchange chamber into the high vacuum part of the microscope and anchored on a moveable stage. In the virtual FESEM the object can be moved in horizontal and vertical direction on the screen by operating the arrows in the POSITION box. In the real microscope the object can be repositioned in the chamber by means of a joy stick those steers in left right axis, or forward and backward. In addition, the object can be tilted (e.g., for stereo views), rotated and moved in Z direction (= closer or further away to the objective lens). The “secondary electron emission” detector (scintillator) is located at the rear of the object holder in the chamber.

When the primary probe bombards the object, secondary electrons are emitted from the object surface with a certain velocity that is determined by the levels and angles at the surface of the object. The secondary electrons, which are attracted by the Corona, strike the scintillator (fluorescing mirror) that produces photons. The location and intensity of illumination of the mirror vary depending on the properties of the secondary electrons. The signal produced by the scintillator is amplified and transduced to a video signal that is fed to a cathode ray tube in synchrony with the scan movement of the electron beam. The contrast in the ‘real time’ image that appears on the screen reflects the structure on the surface of the object. Parallel to the analog image, a digital image is generated which can be further processed.

CHAPTER 5

RESULT AND PERFORMANCE ANALYSIS

5.1 ANALYSIS OF UNCOATED FLEX SENSOR

Flex sensor used to measure amount of bending. To know the resistance values of the flex sensor, multimeter is used by setting at 20 kilohms. To observe the variation of resistance in flex sensor we recorded the values of resistance by changing the flex sensor position from 0 degree to 180 degrees by 10degree increment. To know the standard error of these resistance values, 3 times had taken.

Table 5.1: Resistance values of uncoated flex sensor

Bend Angle (degree)	Resistance value for 1st time (Kilo ohms)	Resistance value for 2nd time (Kilo ohms)	Resistance value for 3rd time (Kilo ohms)
0(No bending)	17.69 kΩ	17.89 kΩ	17.88 kΩ
10	17.72 kΩ	17.97 kΩ	17.93 kΩ
20	17.85 kΩ	18.02 kΩ	17.94 kΩ
30	17.93 kΩ	18.07 kΩ	18.03 kΩ
40	18.01 kΩ	18.14 kΩ	18.1 kΩ
50	18.07 kΩ	18.21 kΩ	18.14 kΩ
60	18.14 kΩ	18.22 kΩ	18.21 kΩ
70	18.21 kΩ	18.30 kΩ	18.29 kΩ
80	18.28 kΩ	18.38 kΩ	18.34 kΩ
90	18.36 kΩ	18.43 kΩ	18.42 kΩ
100	18.38 kΩ	18.49 kΩ	18.49 kΩ
110	18.41 kΩ	18.56 kΩ	18.54 kΩ
120	18.57 kΩ	18.63 kΩ	18.61 kΩ
130	18.69 kΩ	18.71 kΩ	18.67 kΩ
140	18.73 kΩ	18.79 kΩ	18.71 kΩ
150	18.81 kΩ	18.84 kΩ	18.73 kΩ
160	18.93 kΩ	18.92 kΩ	18.75 kΩ
170	18.97 kΩ	19.04 kΩ	18.83 kΩ
180	19.03 kΩ	19.12 kΩ	18.89 kΩ

These three Resistance values of the flex sensor had plotted in graph representing the bend angle is X-axis and Resistance in Y axis.

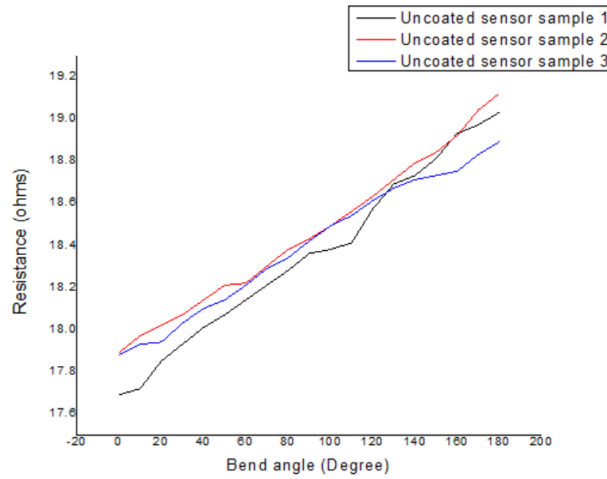


Fig 5.1: Uncoated flex sensor graph for various resistance values

The mean and standard error values had been obtained from these resistance values. To know accuracy and how much disparity in the resistance values of flex sensor standard error value is calculated.

Table 5.2: Mean and Standard error values of Uncoated Flex sensor

Bend Angle(degree)	Mean (kilo ohms)	Standard error (Kilo ohms)
0(No bending)	17.82000 kΩ	0.11269 kΩ
10	17.87333 kΩ	0.13429 kΩ
20	17.93667 kΩ	0.08505 kΩ
30	18.01000 kΩ	0.07211 kΩ
40	18.08333 kΩ	0.06658 kΩ
50	18.14000 kΩ	0.07000 kΩ
60	18.19000 kΩ	0.04359 kΩ
70	18.26667 kΩ	0.04933 kΩ
80	18.33333 kΩ	0.05033 kΩ
90	18.40333 kΩ	0.03786 kΩ
100	18.45333 kΩ	0.06351 kΩ

110	18.50333 k Ω	0.08145 k Ω
120	18.60333 k Ω	0.03055 k Ω
130	18.69000 k Ω	0.02000 k Ω
140	18.74333 k Ω	0.04163 k Ω
150	18.79333 k Ω	0.05686 k Ω
160	18.86667 k Ω	0.10116 k Ω
170	18.94667 k Ω	0.10693 k Ω
180	19.01333 k Ω	0.11590 k Ω

The mean values also plotted on line – symbol graph where X-axis represents bend angle and Y-axis represents Resistance value of flex sensor.

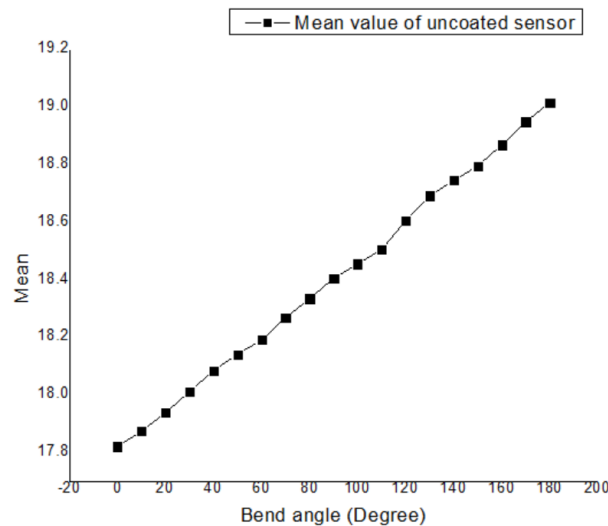


Fig 5.2: Uncoated flex sensor graph for mean resistance values.

To analyze the results of the uncoated flex sensor linear fitting is used. Linear fitting describes the relationship between the response variable and explanatory variable using a linear function. In this, resistance acts as response variable and bend angle of flex sensor acts as explanatory variable. Linear fitting gives intercept and slope value for the graph plotted between response variable and explanatory variable.

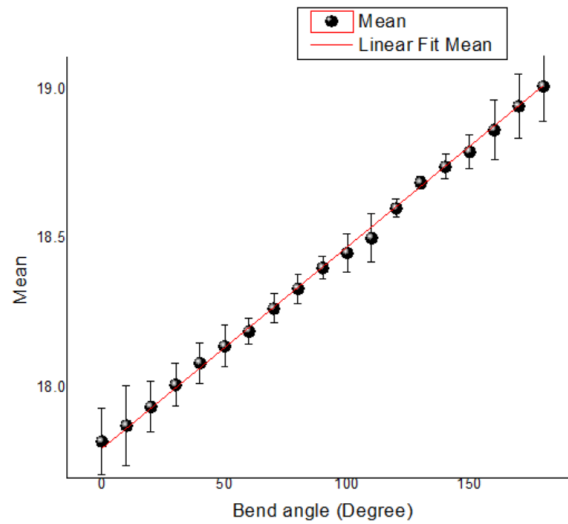


Fig 5.3: Linear fitting graph for uncoated flex sensor.

Table 5.3: Linear Fit Results for uncoated flex sensor

		Value	Standard error
Mean	Intercept	17.79674	0.00872
	Slope	0.00678	7.78848E-5

5.2 ANALYSIS OF QUANTUM DOT COATED FLEX SENSOR

After every coating on flex sensor resistance reading was recorded. As four times the CdTe quantum dots was coated on the flex sensor for each coating the resistance values were noted down.

Table 5.4: Resistance values of Coated flex sensor

Bend angle (Degree)	Resistance value for 1 st coating (Kilo ohms)	Resistance value for 2 st coating (Kilo ohms)	Resistance value for 3 st coating (Kilo ohms)	Resistance value for 4 st coating (Kilo ohms)
0	16.48 k Ω	16.49 k Ω	16.49 k Ω	16.49 k Ω
10	16.58 k Ω	16.52 k Ω	16.59 k Ω	16.54 k Ω
20	16.66 k Ω	16.58 k Ω	16.64 k Ω	16.59 k Ω
30	16.72 k Ω	16.62 k Ω	16.70 k Ω	16.67 k Ω
40	16.80 k Ω	16.70 k Ω	16.78 k Ω	16.69 k Ω

50	16.84 k Ω	16.76 k Ω	16.83 k Ω	16.73 k Ω
60	16.87 k Ω	16.84 k Ω	16.87 k Ω	16.75 k Ω
70	16.95 k Ω	16.87 k Ω	16.90 k Ω	16.78 k Ω
80	16.98 k Ω	16.92 k Ω	16.93 k Ω	16.82 k Ω
90	17.03 k Ω	16.94 k Ω	16.95 k Ω	16.86 k Ω
100	17.05 k Ω	16.96 k Ω	17.03 k Ω	16.92 k Ω
110	17.06 k Ω	17.02 k Ω	17.09 k Ω	16.98 k Ω
120	17.08 k Ω	17.17 k Ω	17.16 k Ω	17.09 k Ω
130	17.14 k Ω	17.24 k Ω	17.23 k Ω	17.18 k Ω
140	17.20 k Ω	17.28 k Ω	17.29 k Ω	17.27 k Ω
150	17.25 k Ω	17.32 k Ω	17.36 k Ω	17.34 k Ω
160	17.35 k Ω	17.37 k Ω	17.43 k Ω	17.44 k Ω
170	17.45 k Ω	17.42 k Ω	17.52 k Ω	17.55 k Ω
180	17.54 k Ω	17.47 k Ω	17.57 k Ω	17.67 k Ω

These four Resistance values of the Coated flex sensor had plotted in graph representing the bend angle is X-axis and Resistance in Y axis.

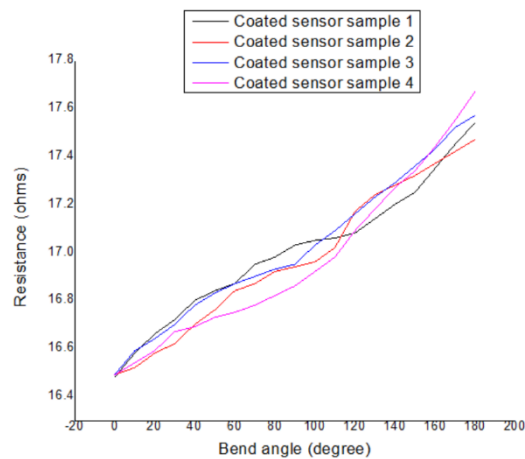


Fig 5.4: Coated flex sensor graph for various resistance values

The mean and standard error values are obtained for the coated flex sensor from the four resistance values. To know accuracy and how much disparity in the resistance values of flex sensor standard error value is calculated.

Table 5.5: Mean and Standard error values of uncoated flex sensor

Bend angle (degree)	Mean (kilo ohms)	Standard error (kilo ohms)
0	16.4875 k Ω	0.00500 k Ω
10	16.5575 k Ω	0.03304 k Ω
20	16.6175 k Ω	0.03862 k Ω
30	16.6775 k Ω	0.04349 k Ω
40	16.7425 k Ω	0.05560 k Ω
50	16.7900 k Ω	0.05354 k Ω
60	16.8325 k Ω	0.05679 k Ω
70	16.8750 k Ω	0.07141 k Ω
80	16.9125 k Ω	0.06702 k Ω
90	16.9450 k Ω	0.06952 k Ω
100	16.9900 k Ω	0.06055 k Ω
110	17.0375 k Ω	0.04787 k Ω
120	17.1250 k Ω	0.04655 k Ω
130	17.1975 k Ω	0.04646 k Ω
140	17.2600 k Ω	0.04082 k Ω
150	17.3175 k Ω	0.04787 k Ω
160	17.3975 k Ω	0.04425 k Ω
170	17.4850 k Ω	0.06028 k Ω
180	17.5625 k Ω	0.08302 k Ω

The mean values also plotted on line – symbol graph where X-axis represents bend angle and Y-axis represents Resistance value of flex sensor.

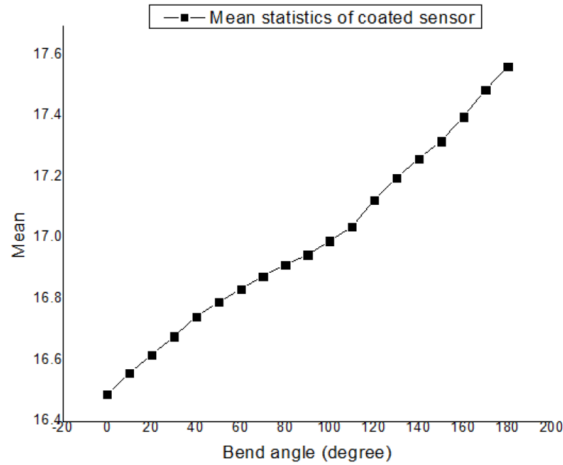


Fig 5.5: Coated flex sensor for mean resistance values.

To analyze the results of the coated flex sensor linear fitting is used. Linear fitting describes the relationship between the response variable and explanatory variable using a linear function. In this, resistance acts as response variable and bend angle of flex sensor acts as explanatory variable. Linear fitting gives intercept and slope value for the graph plotted between response variable and explanatory variable.

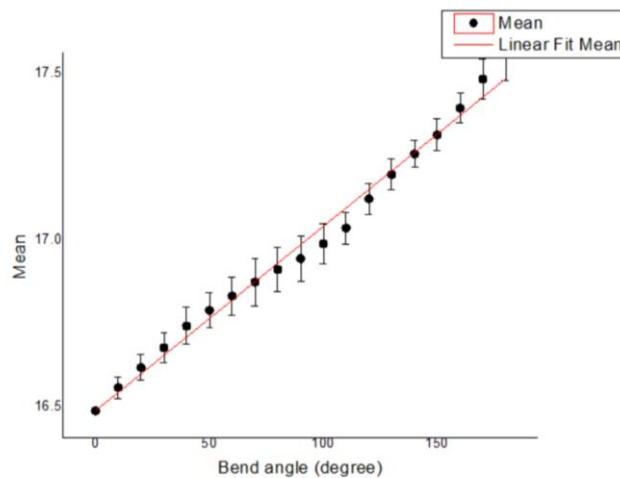


Fig 5.6: Linear fitting graph for Coated flex sensor.

Table 5.6: Linear fit results for coated flex sensor

		Value	Standard error
Mean	Intercept	16.48806	0.003
	Slope	0.00554	7.4359

5.3 RESULT

1. The standard error of uncoated flex sensor was **0.00872**, after coating with the quantum dots (CdTe) the standard error value was reduced to **0.003** which indicates that the range of error of the flex sensor was decreased.
2. For the uncoated flex sensor, the range of resistance was 17.82 k Ω to 19.01k Ω (0° bending to 180° bending) after coating the flex sensor the range of resistance is 16.48 k Ω to 17.56 k Ω that tells us that the even for a small deflection in flex sensor, the resistance value changes.
3. The net cost of preparing this Flex sensor will be less than thousand rupees. These flex sensors are having high cost in bio medical applications. The usage of this quantum dot coated flex sensors gives better results.

CHAPTER 6

CONCLUSION

A comprehensive review and enhancement on nano structured coatings on the finger movement sensor to improve its sensitivity efficiency. dependence on calibration reduces their usefulness in the clinical setting for use with patients for detecting movement. To minimize sensory interference and enhance the malleability of the finger movement detection., The efficiency of flexibility and stretchability can be ensured when bending the finger can be improved. The sensing elements like high gauge factor, excellent sensing resolution, and well repeatability can be improved. Combining the pressure sensor array with the IMUs, both the fingertip pressure and the inertial information of the finger movement can be monitored simultaneously.

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