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Design And Analysis Of Intracranial Pressure Sensor With Liquid Crystal Polymer For Sensitivity Enhancement

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ABSTRACT

This article proposes a MEMS capacitive pressure sensor with Liquid Crystal Polymer material as a membrane.Due to the more tensile strength and multi phased applications LCP is the best suitable replacement of steel in medical diagnosis. In the present study authors considered three types of LCP (ZENITE5145L,VECTRA E530i, RTP 3405-3) and compared the displacement sensitivity with varying membrane thickness (20um, 30um,40um). Among the three LCPs VECTRA E530i (LCP-2) shown thehighest sensitivity of9.68 X 10^{6} at membrane thickness of 30micro meters. Further, the capacitance and their sensitivities for each design was calculated and compared. The LCP-2 (VECTRA E530i) shows best capacitive sensitivity of 1.2 X 10^{-11} at a thickness of 20um. From the observations the LCP -2 (VECTRA E530i) is the best selective material for membrane in vibrational sensors. The Proposed sensor is planned to place to the human brain to monitor Intracranial pressure (ICP) which will detect cerebral brain flow (CBF) and identifies the abnormalities in functioning of brain.

Keywords: Intracranial pressure (ICP); liquid crystal polymer (LCP); Microelectromechanical systems(MEMS)

I. INTRODUCTION

Research on liquid crystal has been involved in chemistry, physics, biology, electric and electronic engineering, and many other fields. Liquid crystal's (LC's) are having different applications in many fields [1-3]. Because of their different optical, thermal, and electrical properties [4-7], LC's are exceptionally impressive in the region of condensed matter physics.The liquid crystal polymer is a thermoplastic polymer materialwith unique structural and physical properties. As a result of the unique structure, LCP offers a combination of electrical, thermal, mechanical and chemical properties unmatched by other engineering polymers. Results from high-frequency tests show that LCP has a uniform relative dielectric constant of 3 in the range 0.5 to 40 GHz and an extremely low loss factor of ~0.004 [8]. LCP has very low moisture absorption (~0.02%) and low moisture permeability. The LCP film also shows excellent chemical resistance. Research shows that LCP is virtually unaffected by most acids, bases and solvents for a considerably long time and over a broad temperature range [9]. There are many potential microdevice applications in which LCP materials can be used. LCP can serve as a flexible substrate material to fabricate devices such as planar neuron probes, micro tactile sensors and radio frequency MEMS. A significant number of polymer materials have been introduced for MEMS applications in recent years. Examples of polymers used in MEMS include polydimethylsiloxane (PDMS), biodegradable polymers, polyparaxylylene (parylene), polyesters, polyimide and ceramic tapes.In recent years,MEMS has been considerable as a most explored area corresponds to its biomedical applications. Several innovations for health monitoring have been developed, which madeMEMS as a promising technology.MEMS contains components of sizes in 1 micrometer (μm) to 1millimeter (mm) (1mm = 1000 μm) which is called as miniaturization. There are a wide range of benefits due to this miniaturization such as small, weight reduction, cost per device becomes potentially low, high reaction rate, low reagent consumption and there is a scope for manufacturing minimally invasive devices and systems. All these factors made miniaturization as a key factor for accepting challenges in BIO-MEMS[10].

MEMS components include micro sensors,microelectronics, micro actuators,microstructures.Over the past several decades MEMS researches and developers have demonstrated an extremely large number of microsensors such as temperature, pressure, inertial forces, chemical species, magnetic fields, radiation, etc.The vision of MEMS whereby microsensors, micro-actuators and microelectronics and other technologies, can be integrated onto a single microchip is one of the most important technological breakthroughs of the future and enable the development of smart products by augmenting the computational ability of microelectronics with the perception and control capabilities of microsensors and micro-actuators[11].Micro sensors are built to sense the existence and the intensity of certain physical, chemical or Biological quantities, such as temperature, pressure, sound, force light, Nuclear radiation, magnetic flux and chemical compositions. Common sensors include Bio sensors, Chemical sensors, optical sensors, thermal and pressure sensors. In a pressure sensor, an input signal such as pressure from source is sensed by a micro sensing Element and the output includes the corresponding change in input signal. One of the application of this pressure sensor in field of BIO-MEMS is monitoring of intracranial pressure (ICP)[12].Here the ICP estimation can be done through ICP monitoring techniques by using pressure sensors. In this work, Liquid Crystal PolymerLCPpressure sensor has been demonstrated where a LCP was used in a sensing membrane. A pressure sensor was a device used to measure the pressure in liquids or gases thatconsists of a pressure sensing element which considers pressure as input and covers this physical data into an electrical signal further produces the sensor readout as output [13]. The figure.1 explains the capacitive pressure sensor flow. Figure -2 represents the cross-sectional block diagram of capacitive pressure sensor. Figure – 3 represents equivalent circuit of a capacitance pressure sensor.

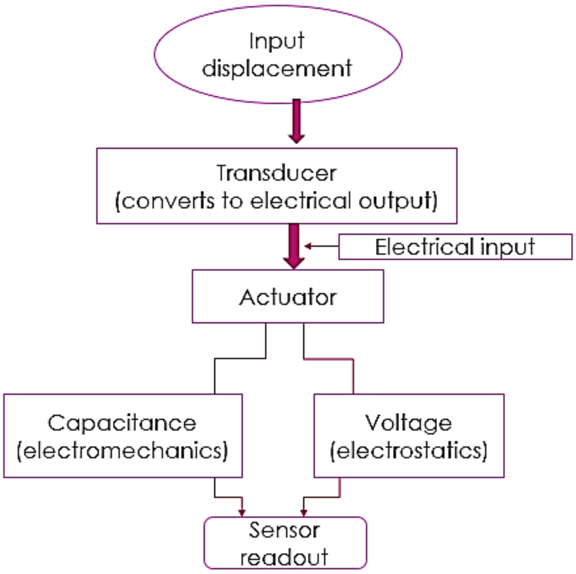

Fig.1.Capacitive pressure sensor flow diagram.

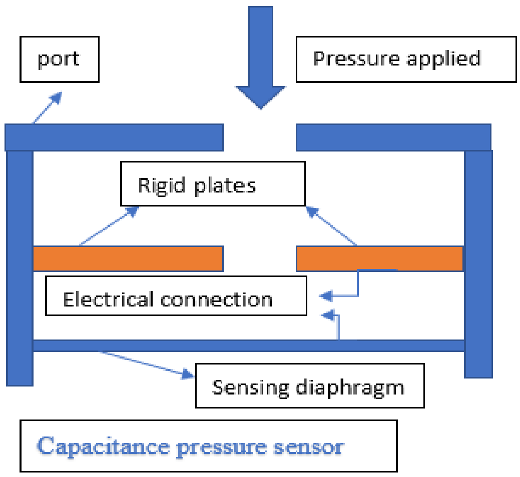

Fig.2.Working principle of a Capacitance pressure sensor.

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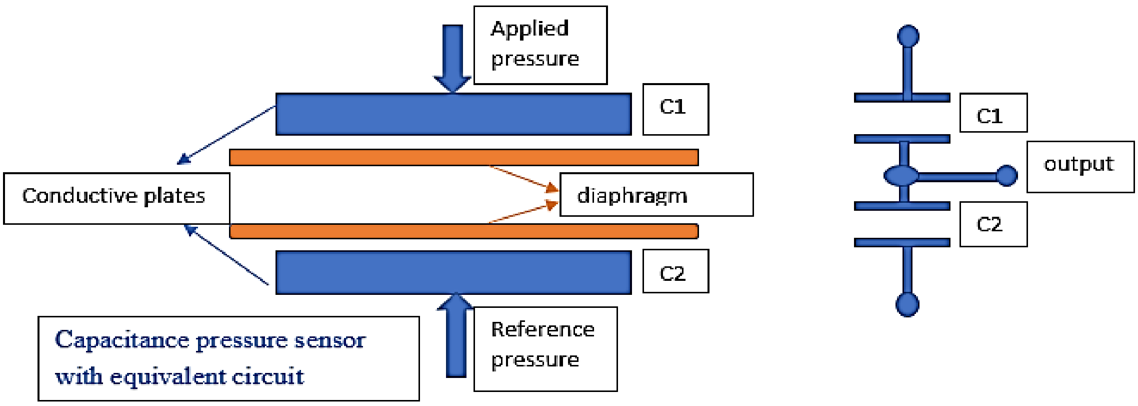

Fig.3.Equivalent circuit of a capacitance pressure sensor.

LIQUID CRYSTAL POLYMER

LCP Liquid Crystal Polymer is mechanically stable and chemically inert and also has low moisture absorption rate compared to many other biocompatible polymers such as Polymide or Parylene.Basically LCP is a thermoplastic material and it consists of a unique structural as well as physical properties[14].The benefits of LCP include the ease and adaptability of manufacture, flexibility, durability withlowtemperaturethermal bonding, low loss factor, mechanical adaptability etc made contrasted with other polymers utilized in MEMS.LCP consists of several links of rigid and flexible monomers which made its structure looks like an isotropic as the rigid molecular segments are aligned in a shear flow direction in the liquid crystal state. It has a high dielectric strength which made it to be suitable for high voltage and power applications. LCP has various chemical resistances so it is preferred to be used in high density printed circuit boards(PCBs) as well as semiconductor packages[15]. At various temperatures it was resistant towards acids, bases, solvents and acts as a barrier that can withstand humidity. LCP can simply integrate with electrical components and other substrates to generate a variety of designs. Hence LCP is an attractive material in MEMS based devices for biomedical applications. Due to its biocompatible and flexible nature LCP is used as an implantable pressure sensor for Intracranial pressure (ICP). Though liquid crystal polymer (LCP) is a brittle component it is preferred much and has to be used under its bearable pressure.

INTRACRANIAL PRESSURE(ICP)

Intracranial pressure(ICP) is the pressure exerted by fluids such as cerebrospinal fluid (CSF) inside the skull and on the brain tissue. ICP is measured in millimeters of mercury (mmHg) andis normally 7–15 mmHg in adults at supine position .If the ICP exceeds this range of 7-15mm Hg and more than 20mm Hg leads to abnormal condition which may result in neurological disorders like paralysis, sensation loss and may lead to comatose. Patients with Traumatic brain injury (TBI)who had head injuries and patients with neurosurgical conditions needs to be monitored their levels of ICP. One of this cause for Traumatic brain injury (TBI) was head injuries during road accidents which causes brain to swell and shift the position within the skull. Some of the monitoring devices for ICP are Intraventricular catheters, Epidural catheter, subarachnoidbolt or screw, Fibreoptic catheters, Microchip transducers and intraparenchymal Systems. Some of these devices need to be safely placed under the supervision of Neurointensivists otherwise lead to risk of infection. Biocompatibility plays an eminent role in BIO-MEMS applications. And this can be fulfilled by Liquid crystal polymer-based MEMS pressure sensor. Figure.4 represents how the intracranial pressure was monitored.

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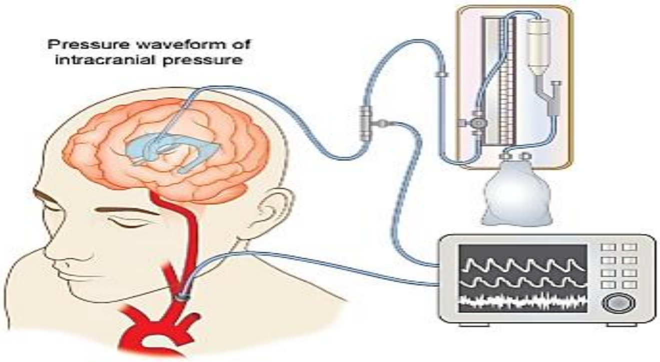

Fig .4.Intracranial pressure monitoring.

Patients suffer from traumatic brain injury (TBI) were identified with excessive cerebral blood flow (CBF) which results in automatic raise of intracranial pressure (ICP) and this condition is nothing but intracranial hypertension (ICH). By exceeding the normal range of 7-15mmHg intracranial pressure was dangerous and this also leads to neurological disorders like headache, confusion, vomit, shallow breathing, coma, raise in blood pressure, paralysis, losing sense and consciousness even carelessness leads to death in severe conditions. Since regular monitoring of ICP in TBI patients was necessary and proper treatment must be given accordingly.Figure–5represents what happens to human brain due to traumatic brain injury or stroke and the symptoms that undergone in patients.

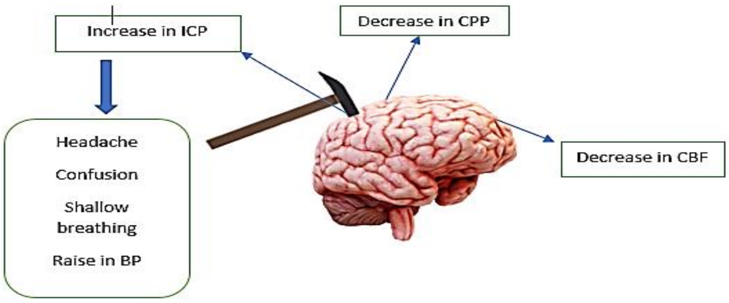

Fig.5.Symptoms of TBI or brain stroke patients.

So many authors have done the pressure sensor with LCP material as membrane for identification of components like Cerebral Perfusion Pressure(CPP),motor cortex simulation(MCS),traumatic brain injury(TBI) etc. [16-22].

II. METHODOLOGY

A 3D model LCP pressure sensor was simulated with device dimensions 8 X 8 X 0.2mm and sensing membrane dimensions 2 X 2 X T(thickness)mm varies from 20-40mm.this 2D model consists of two membranes. The thickness of both the top and bottom membranes are 100mm respectively [23]. The total width and thickness of top and bottom membranes are 8 and 0.2mm respectively and at the top membrane the cavity is sealed with 100mm thick LCP bottom membrane. The following Figure - 6 represents 2D model of cross-sectional area of the LCP pressure sensor consists of top and bottom membrane. This 2D model contains a sensing membrane on the top membrane and a sealed pressure chamber or an air cavity above the middle part of bottom membrane. The green ellipse in the figure represents the sensing membrane with thickness varies from20-40mm. The pressure applied at boundary load on sensing membrane varied from 0-60mmHg.Here we used three different LCP materials for sensing membrane with variation of thickness of 20-40mm for the simulation of pressure sensor with same device dimensions using the software COMSOL Multiphysics.

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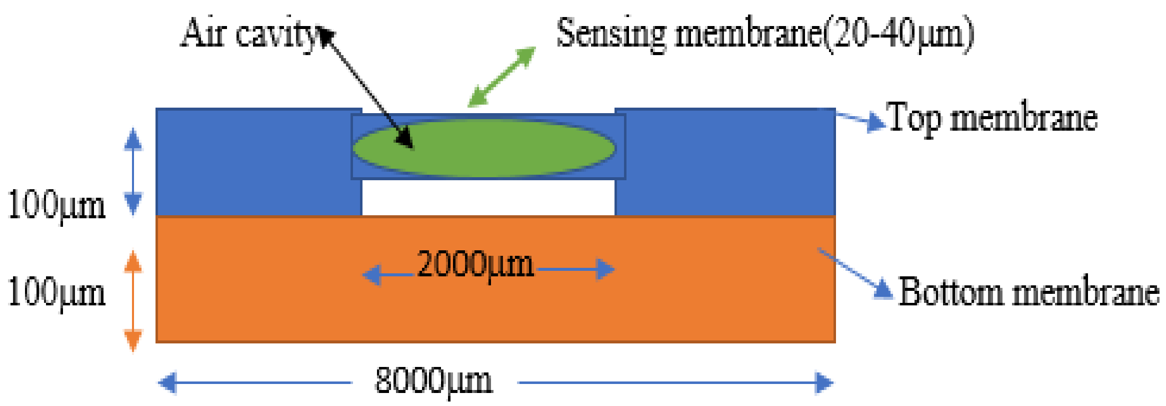

Fig.6. 2D model of cross sectional area of the LCP pressure sensor consists of top and bottom membrane with related dimensions.

IV RESULTS AND DISCUSSIONS.

LCP materials used for the proposed design.

The simulation was done by taking three types of LCPs and the sensitivities are calculated and compared.

The materials like stainless steel have been replaced with Liquid Crystal Polymer (LCP) in medical applications. The LCPs are resistant to gamma radiation, steam autoclaving and most chemical sterilization methods.

The material Properties for different LCP's used for design and their properties are presented in Table-1.

Materials and their Properties			
	ZENITE5145L	**VECTRA E530i**	**RTP 3405-3**
Composition	45% glass fiber reinforced and toughened liquid crystal polymer for injection molding. It has improved toughness.	VECTRA E530i LCP,30% mineral reinforced, very easy flowing grade with very good heat resistance. Good impact strength and mechanical properties.	RTP 3405-3 LCP, glass fiber offers outstanding heat and chemical resistances and are inherently ignition resistant.
Density	1750 (kg/m^3)	1650 (kg/m^3)	1610 (kg/m^3)
Young's modulus	3709Mpa	4285Mpa	8933Mpa
Relative permittivity	3.9	3.7	4.3
Poisson's ratio	0.3	0.3	0.3

Table.1- LCP materials with their respective compositions and properties.

The above table consists of the three different liquid crystal polymers(LCP) materials with their compositions and properties that are used for the simulation in COMSOL MULTIPHYSICS software.

Design Considerations

The performance of the device mainly depends upon the output parameter of the sensor which will vary in accordance to the input applied quantity.

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To calculate the optimum sensitivity, two parameters have been considered and they are displacement and capacitance.

To find Capacitance Sensitivity any one of the three terminal voltages is subtracted fromanotherterminal voltagedivided by differences of capacitance of first component minus second component.

Displacement Sensitivity

The displacement sensitivity is calculated as follows.
Displacement Sensitivity = $\frac{d2-d1}{e2-e1}$
where d is displacement of sensor
e is the Eigen frequency

Capacitive Sensitivity

The capacitive sensitivity is calculated as follows.
Capacitance Sensitivity = $\frac{d2-d1}{v2-v1}$
where d is capacitance
v is the voltage.

Sensitivity for Eigen frequency vs. total displacement

Sensitivity	ZENITE5145L	VECTRA E530i	RTP 3405-3
20mm	4.01×10^6	1.73×10^6	1.65×10^6
30 mm	2.06×10^6	9.68×10^6	1.78×10^6
40 mm	2.40×10^6	2.67×10^6	1.05×10^6

Table - 2.Displacement sensitivity calculations for three LCPs at three different thicknesses of membrane

Table -2 shows the displacement sensitivity of different LCPs with different thicknesses. Among the above LCPs Vectra E530i(LCP-2) shows the best displacement sensitivity of 9.68×10^6.

Displacement sensitivity analysis for LCP 1-ZENITE5145L

ZENITE5145L					
T=20um		**T=30um**		**T=40um**	
Frequency	**Displacement**	**Frequency**	**Displacement**	**Frequency**	**Displacement**
3.017×10^6	4.03×10^6	2.8778×10^6	4.73×10^6	3.024×10^6	3.98×10^6
3.017×10^6	4.02×10^6	2.8778×10^6	4.71×10^6	3.024×10^6	3.98×10^6
3.0215×10^6	3.12×10^6	2.8823×10^6	3.66×10^6	3.0292×10^6	3.09×10^6
3.0317×10^6	3.37×10^6	2.8917×10^6	3.93×10^6	3.0393×10^6	3.33×10^6
3.0399×10^6	3.8×10^6	2.8993×10^6	4.87×10^6	3.0476×10^6	3.76×10^6
3.401×10^6	4×10^6	2.8994×10^6	4.77×10^6	3.0478×10^6	3.95×10^6

Table.3. Eigen-frequency vs totaldisplacement values for LCP1 at three different thickness of membrane

Table-3 shows the eigen frequency and total displacement values that are obtained from the simulations done in COMSOL MULTIPHYSICS software for the liquid crystal polymer (LCP1)

ZENITE5145L at three varying thicknesses of the sensing membrane i.e.,20,30,40 micro meters respectively.

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Figure 7,8,9 represents the minimum and maximum Eigen frequency and displacement for LCP-1(**ZENITE5145L)**for the thickness 20um, 30um and 40um.

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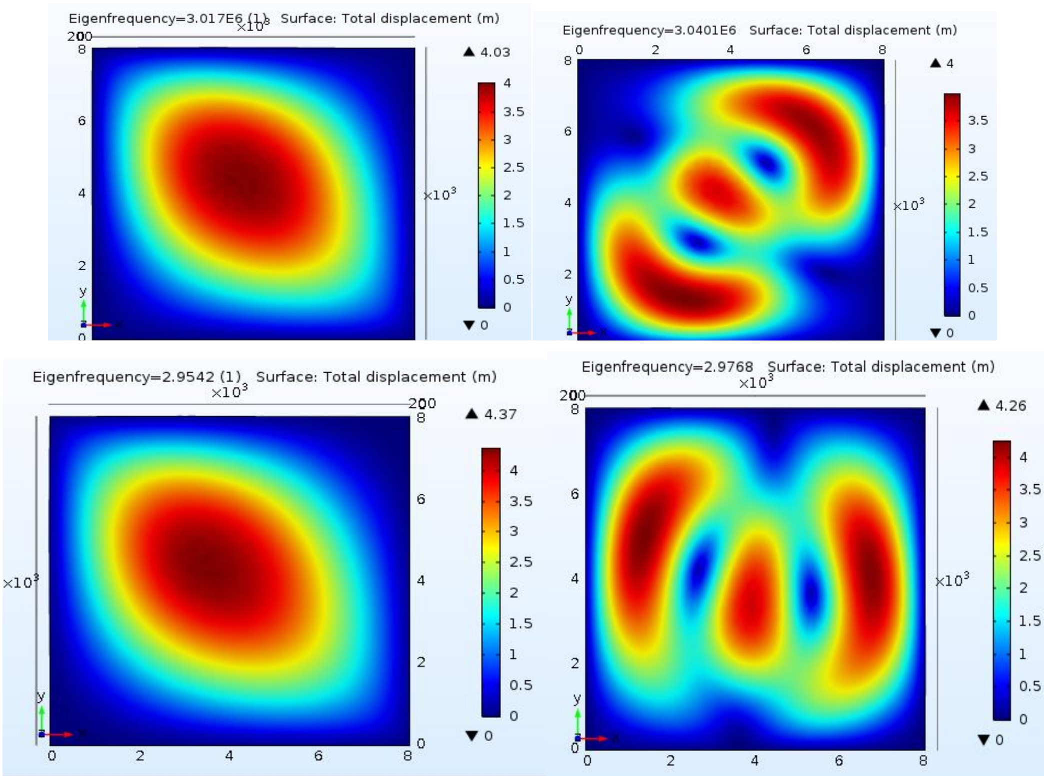

Fig. 8. Eigen-frequency vs displacement for LCP1 at the thickness of 30μm

Fig. 9. Eigen-frequency vs displacement for LCP1 at the thickness of 40μm

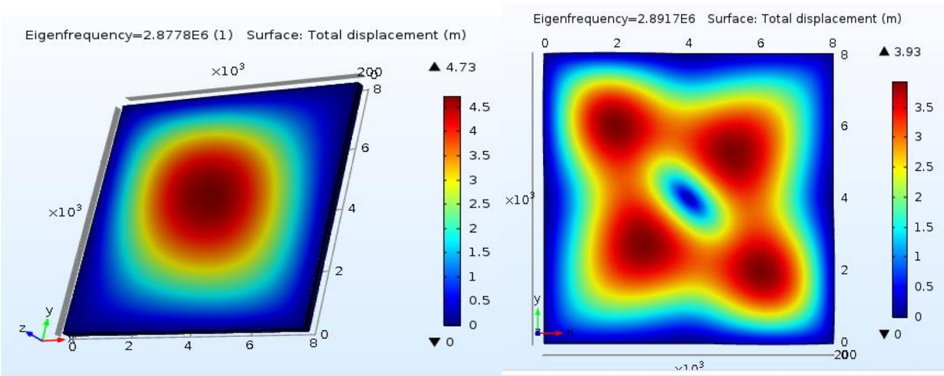

Fig. 10. Eigen-frequency vs displacement for LCP1

The relation between eigen frequency and displacement for the proposed structure with different thickness of the sensing membraneis shown in Fig-10 for LCP-1(**ZENITE5145L).**

Displacement sensitivity analysis for LCP 2-VECTRA E530i

VECTRA E530i					
T=20um		**T=30um**		**T=40um**	
Frequency	**Displacement**	**Frequency**	**Displacement**	**Frequency**	**Displacement**
3.024 X 10^6	3.98 X 10^6	2.9683 X 10^6	4.27 X 10^6	2.8219 X10^6	4.97 X 10^6
3.024 X 10^6	3.98 X 10^6	2.9683 X 10^6	4.28 X 10^6	2.8219 X10^6	4.97 X 10^6
3.0292X 10^6	3.09 X 10^6	2.973 X 10^6	3.28 X 10^6	2.8263 X 10^6	3.84 X 10^6
3.0393X 10^6	3.33 X 10^6	2.983 X 10^6	3.53 X 10^6	2.854 X 10^6	4.13 X 10^6

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3.0476X 10^6	3.76 X 10^6	2.991 X 10^6	4.37 X 10^6	2.8427 X 10^6	5.11 X 10^6
3.0478X 10^6	3.95 X 10^6	2.9294 X 10^6	4.16 X 10^6	2.8428 X 10^6	4.97 X 10^6

Table.4. Eigen-frequency vs totaldisplacement values for LCP2 at three different thickness of membrane

Table-4 shows the eigen frequency and total displacement values that are obtained from the simulations done in COMSOL MULTIPHYSICS software for the liquid crystal polymer (LCP2)

VECTRA E530i at three varying thicknesses of the sensing membrane i.e., 20, 30, 40micro meters. respectively

Figure 11,12,13 represents the minimum and maximum Eigen frequency and displacement for LCP-2(**VECTRA E530i)** for the thickness 20um, 30um and 40um.

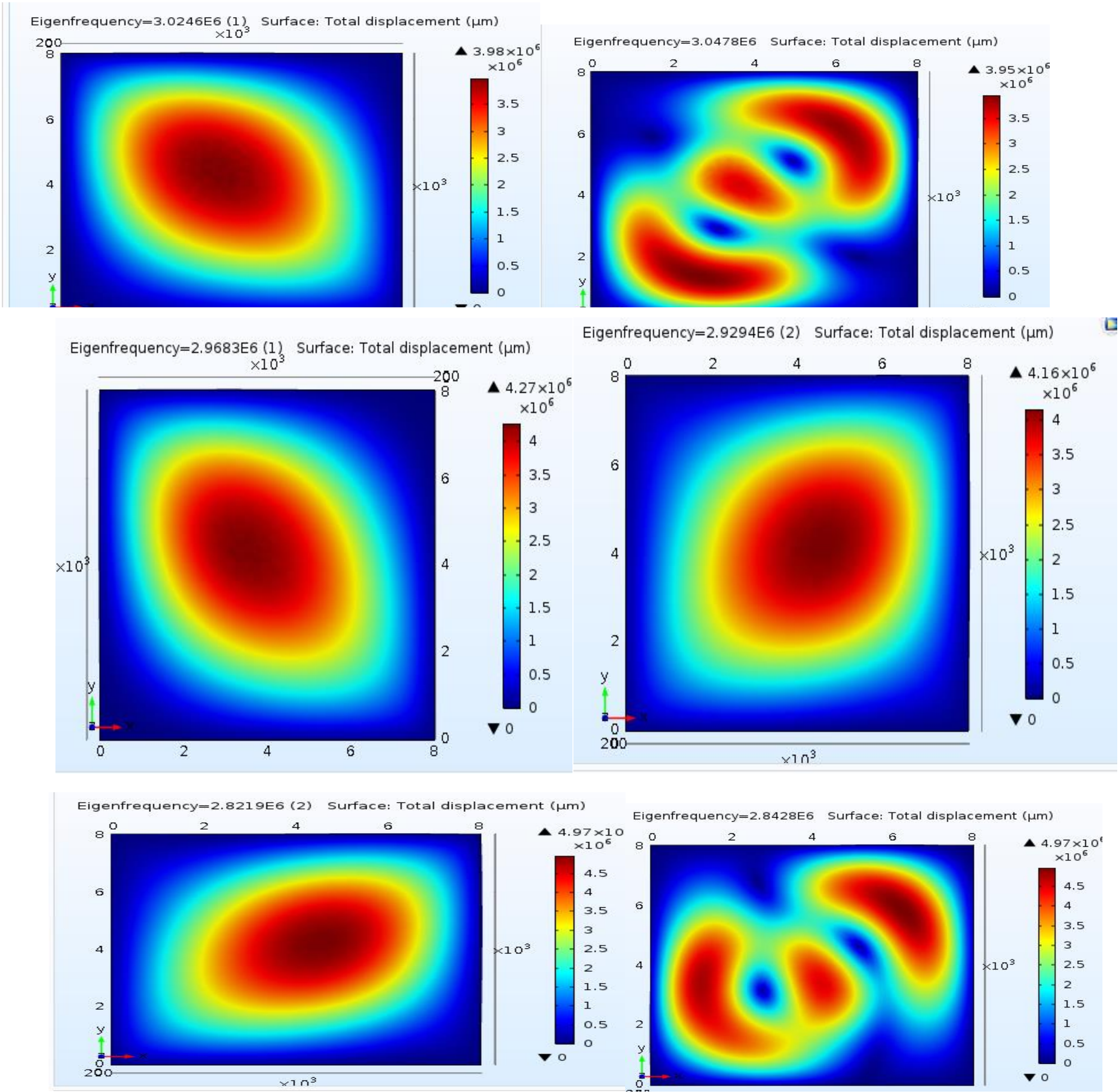

Fig. 13. Eigen-frequency vs displacement for LCP2 at the thickness of 40μm

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Fig. 14. Eigen-

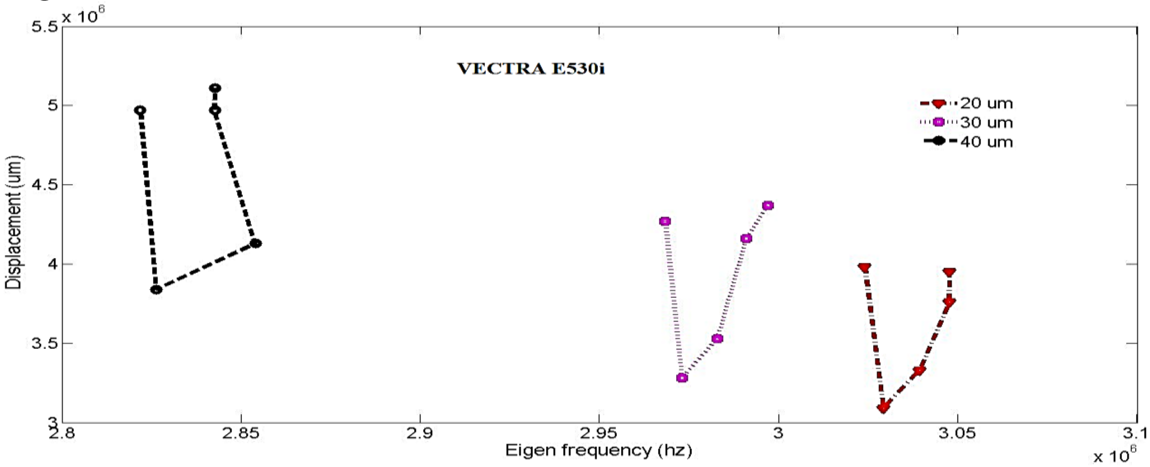


Fig 14. frequency vs displacement for LCP2

The relation between eigen frequency and displacement for the proposed structure with different thickness of the sensing membrane is shown in Fig-14 for LCP-2(**VECTRA E530i)**

Displacement sensitivity analysis for LCP 3-RTP 3405-3

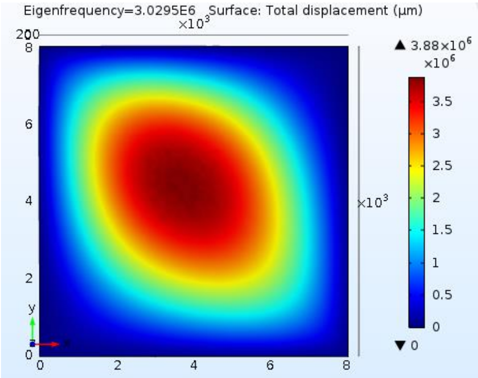
RTP 3405-3					
T=20um		**T=30um**		**T=40um**	
Frequency	**Displacement**	**Frequency**	**Displacement**	**Frequency**	**Displacement**
3.0295X 106	3.88 X 10^6	2.9807 X 10^6	4.05 X 10^6	2.9295X 10^6	4.23X 10^6
3.0296X 106	3.88 X 10^6	2.9807X 10^6	4.06 X 10^6	2.9296X 10^6	4.22X 10^6
3.0342X 106	3.01 X 10^6	2.9856X 10^6	3.1 X 10^6	2.9343X 10^6	3.32X 10^6
3.0445X 106	3.25 X 10^6	2.9958X 10^6	3.34 X 10^6	2.9445X 10^6	3.59X 10^6
3.0529X 106	3.65 X 10^6	3.004 X 10^6	4.07 X 10^6	2.9528X 10^6	4.13X 10^6
3.0531X 106	3.85 X 10^6	3.0042X 10^6	3.95 X 10^6	2.953 X 10^6	4.26 X 10^6

Table.5. Eigen-frequency vs total displacement values for LCP3 at three different thickness of membrane

Table-5 shows the eigen frequency and total displacement values that are obtained from the simulations done in COMSOL MULTIPHYSICS software for the liquid crystal polymer (LCP3)

RTP 3405-3 at three varying thicknesses of the sensing membrane i.e.,20,30,40 micro meters respectively.

Figure 15,16,17 represents the minimum and maximum Eigen frequency and displacement for LCP-3 (**RTP 3405-3)** for the thickness 20um, 30um and 40um



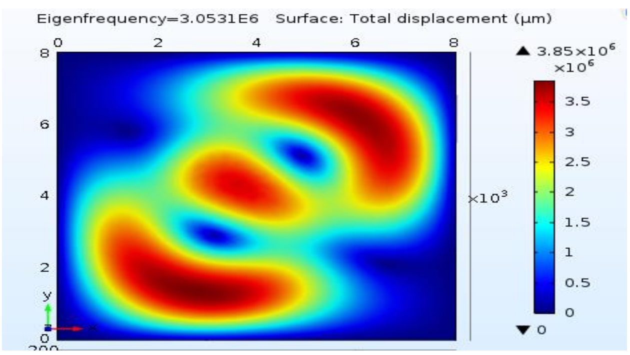


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Fig. 15. Eigen-frequency vs displacement for LCP3 at the thickness of 20μm

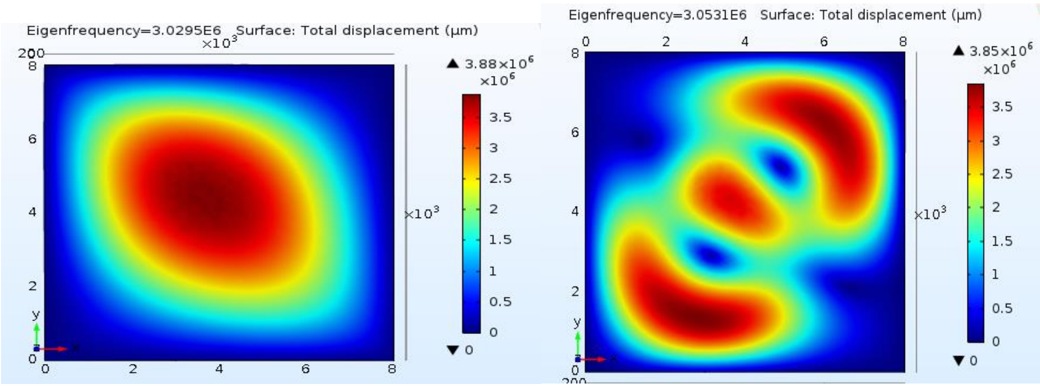

Fig. 16. Eigen-frequency vs displacement for LCP3 at the thickness of 30μm

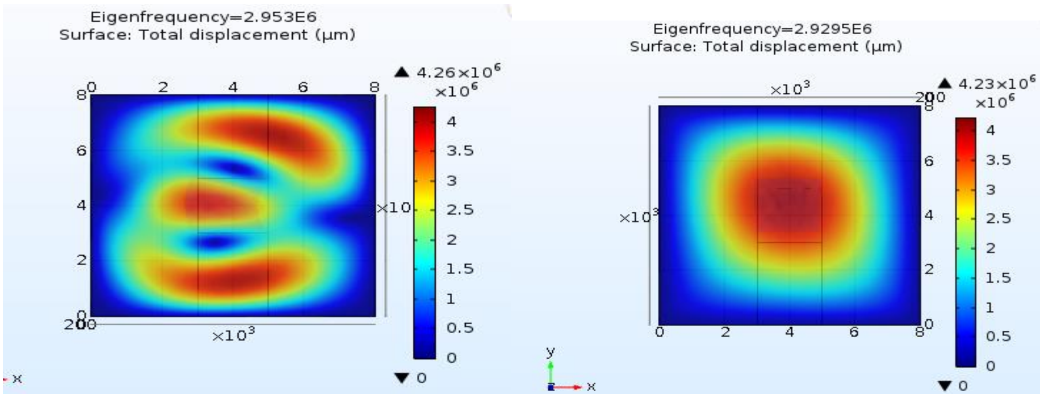

Fig. 17. Eigen-frequency vs displacement for LCP3 at the thickness of 40μm

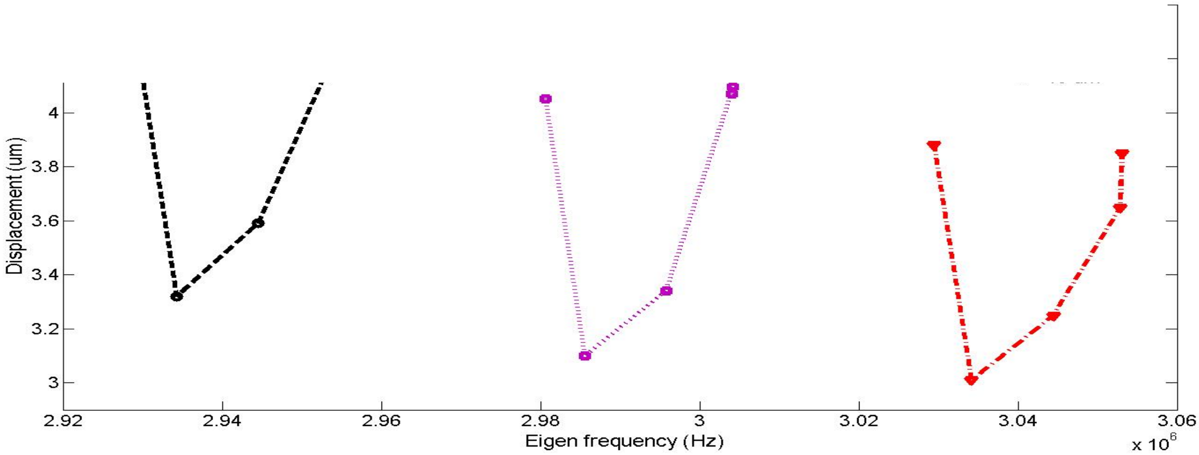

Fig. 18. Eigen-frequency vs displacement for LCP3

The relation between eigen frequency and displacement for the proposed structure with different thickness of the sensing membrane is shown in Fig-18 for LCP-3 (**RTP 3405-3)**

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Capacitance analysis

Terminal Voltage	Capacitance (pf)								
	ZENITE5145L			VECTRA E530i			RTP 3405-3		
	T=20um	T=30um	T=40um	T=20um	T=30um	T=40um	T=20um	T=30um	T=40um
2	0.52	0.775	0.702	0.513	0.457	0.274	0.532	0.479	0.486
4	0.26	0.233	0.21	0.274	0.229	0.257	0.266	0.24	0.243
6	0.173	0.116	0.104	0.257	0.152	0.167	0.177	0.16	0.162

Table.6.Terminal voltage vs capacitance values for three LCPs at three different thickness of membrane.

Table -6 shows the capacitance values with varying terminal voltages of 2,4,6 volts that are obtained from the simulations done in COMSOL MULTIPHYSICS software for three different LCPs with different thicknesses.

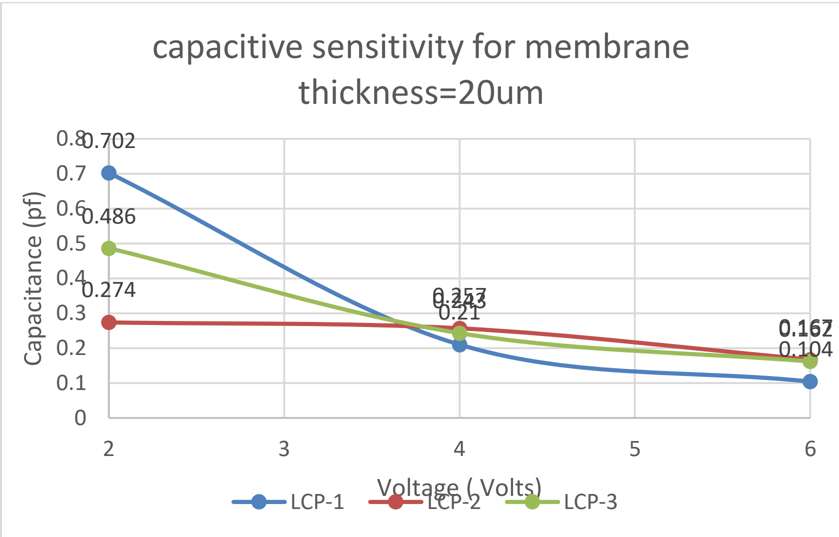

Fig.19.capacitive sensitivity for three LCPs at thickness of 20um

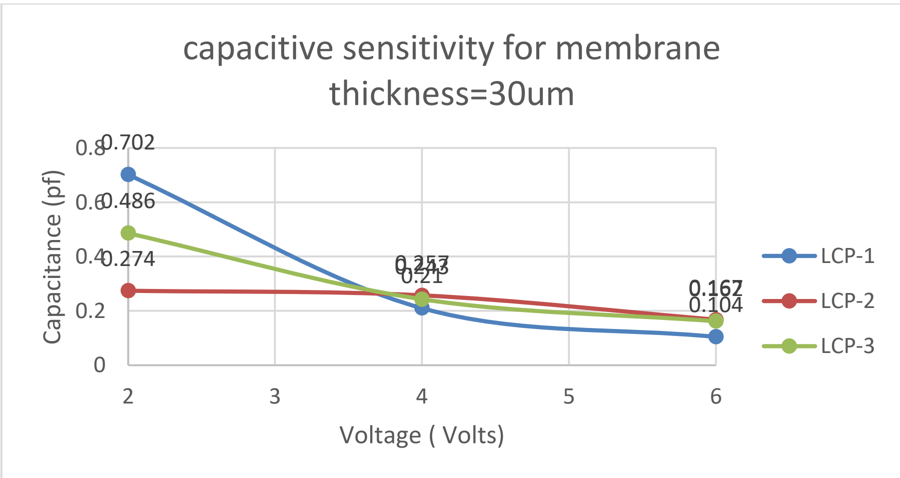

Fig.20.capacitive sensitivity for three LCPs at thickness of 30um

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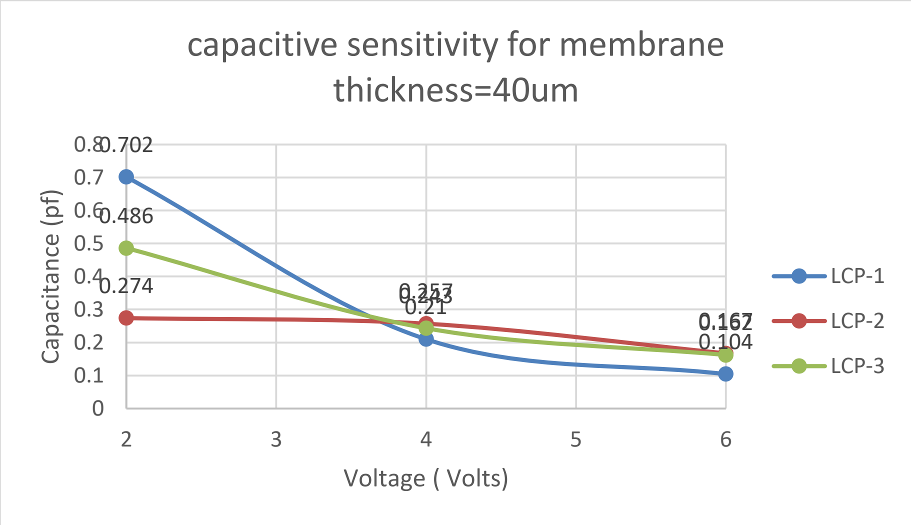

Fig.21.capacitive sensitivity for three LCPs at thickness of 40um

Figure 19,20 and 21 shows the variation of capacitance with respect to applied terminal voltage for proposed structure with three LCPs for varying thickness.

Capacitive Sensitivity (Δ) analysis

	T=20um	T=30um	T=40um
ZENITE5145L	$0.8675\text{x } 10^{-11}$	$0.7775\text{x } 10^{-11}$	$0.715 \text{ x } 10^{-11}$
VECTRA E530i	$1.28 \text{ x } 10^{-11}$	$0.3775 \text{ x } 10^{-11}$	$0.9475\text{x } 10^{-11}$
RTP 3405-3	$0.44 \text{ x } 10^{-11}$	$0.4025 \text{ x } 10^{-11}$	$0.405 \text{ x } 10^{-11}$

Table.7.Capacitance sensitivity calculations for three LCPs at three different thickness of membrane

Table -7 shows the capacitance sensitivity of different LCPs with different thicknesses. Among the above LCPs Vectra E530i(LCP-2) shows the best capacitance sensitivity of. $1.28 \text{ x } 10^{-11}$.

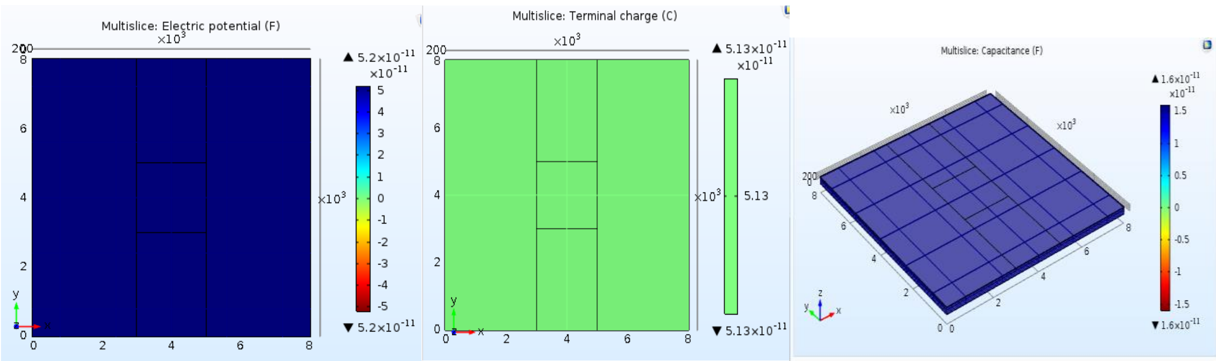

Fig.22. Capacitance for different terminal voltages for three LCPs.
Figure - 22 representsthecapacitancewithrespecttoapplied terminal voltage.

Conclusión:

This paper proposes a MEMS capacitive pressure sensor with Liquid Crystal Polymer material as membrane. The process flow for the sensor was presented in the paper. As the literature is stating that LCP is the replacement of steel for medical applications and having more tensile strength. Three types of LCP (ZENITE5145L,VECTRA E530i, RTP 3405-3) were considered and compared the displacement sensitivity with varying membrane thickness (20um, 30um,40um). Among the three LCPs VECTRA E530i(LCP-2) shown thehighest sensitivity of9.68 X 10^6 at membrane thickness of 30micro meters. The capacitance and their sensitivities for each design was calculated and compared. The LCP-2 (VECTRA E530i) shows best capacitive sensitivity of 1.2 X 10^{-11} at a thickness of 20um. From the observations the LCP -2 (VECTRA E530i) is the best selective material for membrane in vibrational sensors. The Proposed sensor is planned to place to the human brain to monitor Intracranial pressure(ICP) which will detect cerebral brain flow(CBF) and identifies the abnormalities in functioning of brain.

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