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Design and Simulation of MEMS Surface Acoustic Wave Biosensor Based on PVDF Thin Film

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Abstract: Surface acoustic wave sensors, as a class of MEMS, are widely used recently. The sensor can transform an input electrical signal into a mechanical wave which can be easily influenced by physical phenomena. Then, the changed mechanical wave is transduced back into an electrical signal. The presence of the desired phenomenon can be detected through the difference between the input and output electrical signal (amplitude, phase, frequency, or time delay). The basic surface acoustic wave device consists of a piezoelectric substrate, an input interdigitated transducer (IDT) on one side of the surface of the substrate, and a second output interdigitated transducer on the other side of the substrate.
Keywords: MEMS Sensors; IDTs ; Piezoelectric sensors; SAW devices; Rayleigh wave; Polyvinylidene fluoride; Sol-gel process; screen printing.

I. INTRODUCTION

Sensors are the devices that have become so inevitable that they are a integral part of our lives, any person in the present day knowingly or unknowingly is completely reliable on these devices to gather information of the environment and overcome the any danger, these devices are widely used in most of the portable devices, automobiles, electrical appliances, space craft's and air craft's, mobile phone these days use the accelerometer for measuring linear acceleration and gyroscope for measuring the angular rotational velocity they also use light sensors to optimize light and in automobiles the sensors used are accelerometer, speedometer, parking sensors and pressure sensors. Thus there is a large need for sensors, that are smaller, cheaper and highly sensitive [2]. These demands can be met by MEMS (Micro-electromechanical sensors) due to its micro-fabrication process. There are various class of MEMS sensors, the sensor can use delay line or resonator type based on the application, considering the delay line for various application the first order modeling can be done by MathCAD [3] for the application in this paper we focus on surface acoustic wave sensors which uses the principle of piezoelectric effect. Surface acoustic wave technology uses an interdigitated transducer (IDT) to convert electrical energy into an acoustic wave. The acoustic wave then travels across the surface of the device substrate to another interdigitated converting the wave back into an electrical signal. The IDTs and the geometry of the device play a major role in the overall performance of the device, increasing the number of IDTs would lead to increase in the centre frequency[4].

A biosensor can be defined as an analytical device in which a biologically active component(receptor), such as an enzyme, an antibody, etc., is immobilized onto the surface of an electronic, optic or optoelectronic transducer, allowing the detection of target analytes in complex mixtures. Thus, advances in bio-sensing can be achieved by efforts in two main fields: the transduction mechanism and the biological reception mechanism (sensitive film). This fact makes bio-sensing highly interdisciplinary[1]. The biosensors can also be used in detection of food pathogens these type of devices are necessary for the early detection of such bacteria's in prior so that the bacteria does not cause any harmful effect leading to an epidemic[5]. These micro-organisms can contaminate food and water, thus causing harmful diseases among the humans and animals, there have been a few conventional techniques while they take a large time for the determination of micro-organisms these microbes can be detected faster based on transducer properties using potentiometric, amperometric and acoustic sensors[6]. Apart from these there are few direct and indirect method for the detection of the bacteria's, these being : infrared and fluorescence spectroscopy, flow cytometry, chromatography techniques, There is a need for a special attention for the methods that improves sensitivity and analysis time[7].

A. Theory Of Operation

These Surface acoustic wave (SAW) devices have the interdigitated transducers (IDTs) excitation electrodes fabricated on the one side of the piezoelectric film. The sensor can transform an input electrical signal into a mechanical wave which can be easily influenced by physical phenomena. Then, the changed mechanical wave is transduced back into an electrical signal. Surface acoustic wave devices specifically use the Rayleigh wave a transverse, surface wave in operation. The presence of the desired phenomenon can be detected through the difference between the input and output electrical signal (amplitude, phase, frequency, or time delay)[1].

As a result, the SAW devices have the acoustic waves propagating along the surface of the piezoelectric substrate. The SAW device could be resonator or delay line depending of the design of the IDTs[1]. For SAW resonators the IDTs are fabricated in a central position and reflectors are added on both sides of the input and output IDTs to trap the acoustic energy within a cavity. The surface between the IDTs is coated with antibodies sensitive to the analyte to be detected. The analyte molecules binding to the immobilized antibodies on the sensor surface influence the velocity of the SAW and hence the output signal generated by the driving electronics. For biosensors it is necessary to take care of toxicity, reliability of the device, so in this work biodegradable and non-toxic polymer materials are used. Polyvinylidene fluoride (PVDF) as a piezoelectric material which has attracted much interest as a next-generation piezoelectric and pyroelectric material because of its light weight, flexibility, low power consumption, and non-toxicity. The enhanced permittivity, which is related to the polarization and dipole moment of PVDF, is key factor for improving the piezoelectric and pyroelectric properties of PVDF. Here we report a highly sensitive functional sensor using a PVDF thin film. PVDF thin film is prepared using PVDF granules from sol-gel process. IDT's are printed on PVDF polymer, using screen printing method.

II. DESIGN METHODOLOGY

In order to design the biosensor we need to know the desired antigen and the necessary anti-body. initially the ac input is applied to the input IDT which passes through the piezoelectric material by electrical to mechanical conversions and then the waves propagate on the surface of the biosensor when the anti-body detects the desired antigen the waves that were propagating will have a change in the phase, amplitude and frequency then these mechanical waves are converted into the electrical signal using the output IDT .

This paper is carried out for an application, where in there is a requirement to sense the desired antigen due to change in phase, amplitude and frequency. The IDT's shown here are of delay line configuration, i.e. the acoustic wave propagates along the surface of the material but is received at the output IDT after a certain delay. There are various factor that are to be considered, these factors depend on the application, such as size, efficiency and sensitivity, Before determining the parameters for a specific surface acoustic wave sensor design, several important device characteristics must be specified. Among these characteristics are the physical size, bandwidth, operating frequency, impulse response, and frequency response of the device [2].

A. Rayleigh Wave

These are the wave that were predicted by Lord Rayleigh in 1885, these waves propagate along the surface of the device at the speed of 3996 m/s , this wave has the capability to conserve the energy and also to travel along the surface of the material farther than any other waveforms. This biosensor was designed to operate at 433MHz, so the wavelength is given by

λ= Rayleigh wave/ target frequency (1)

B. Synchronous Frequency (f0)

The synchronous frequency fo of the device is the frequency f of the generated surface acoustic wave in a normal environment, The important parameters in determining the synchronous frequency of the device is the pitch p of fingers of the IDTs[4], were the fingers are placed at equal intervals. These consecutive fingers are equal but of opposite polarity[4].

$$f_o = V_p / p \quad (2)$$

V_p is the propagating velocity

The fig. 1 shows the general structure of the biosensor with the piezoelectric material being PVDF (Polyvinylidene fluoride) The fig. 2 shows the SAW IDT design were P is the pitch

$$p = \lambda \quad (3)$$

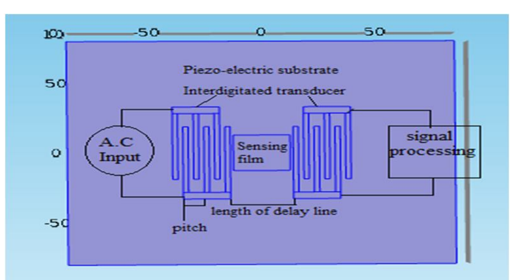

Fig 1: General structure of the biosensor

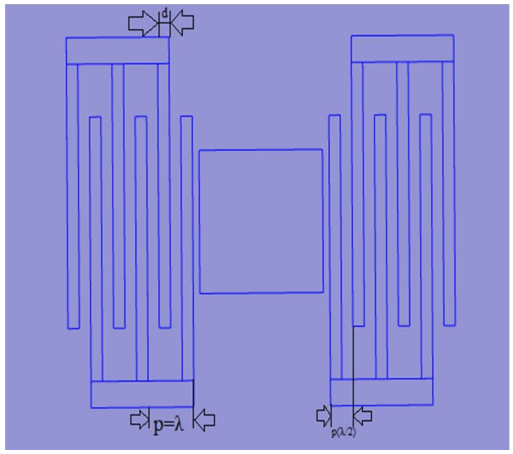

Fig 2: SAW IDT design were P is the pitch

C. Structure

The physical structure of the Biosensor is shown in fig.1., the structure consists of a Si Substrate above which is grown or deposited the PVDF thin film, the PVDF thin film is obtained from the PVDF pallets that are subjected to the sol-gel process, and the same is spin coated using spin coater. Once the PVDF thin film is deposited then the IDTs are printed using screen printing or deposited using sputtering techniques. The IDTs that are used here is a delay line IDT with three electrode, were the electrodes on the left at the top will act as a input, while the electrode on the left bottom and at the right top will act as ground, and lastly the electrode at the right bottom will act as the output. Hence the total electrode configuration at the left will consequently act as the input IDT where the input voltage is applied and the electrode configuration at the right will act as the output IDT. In between the two IDTs is the layer coated with an anti-body which act to detect the desired antigen present in the atmosphere, these antibodies get functionalized as the desired antigens are detected.

III. SIMULATION AND RESULT ANALYSIS

Comparison of Simulation result between with and without mass on the sensitive film we are comparing two simulation of a biosensor, with and without mass on the sensing film, in the simulation we have found that there has been a variation in the output voltage plot, there has been a variation in the amplitude and also there has been a delay in the waveforms, Thus stating that when the mass is applied the acoustic wave propagating on the surface of the material will undergo amplitude and phase changes, meeting the desired result. The mass of E.Coli is added when computing for the addition of mass.

A. Without Mass

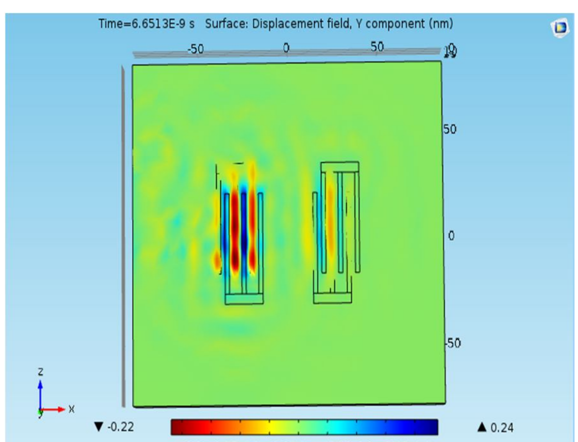

Fig 3: Surface Displacement of Biosensor

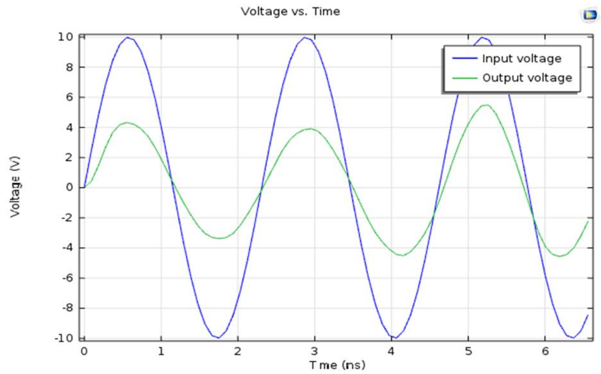

Fig 4: Input vs. output voltage plot

The computation is performed without any mass and PVDF (Polyvinylidenefluoride) as a piezoelectric material. When the simulation is being done the input voltage applied is 10v and the obtained output voltage is 4.338v at the time of 0.53ns. It is shown in figure 4. In figure 3 there is no mass being added. so this image shows the surface displacement of 0.24 for the time 6.6513 ns. Initially there is phase lag of 0.092ns in the output voltage waveform. As the output waveform takes some amount of time to follow the input waveform, this is due to the time required for the wave to propagate from input to output IDT shown in figure 5.

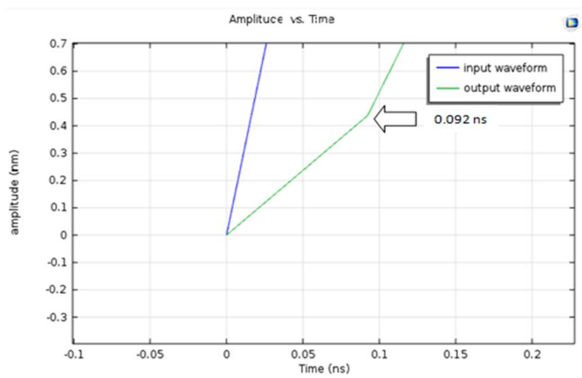

Fig 5: Phase lag

As the wave propagates from input IDT to the output IDT the particles that are present along the wave also gets displaced.

1) Displacement Along Wave Direction

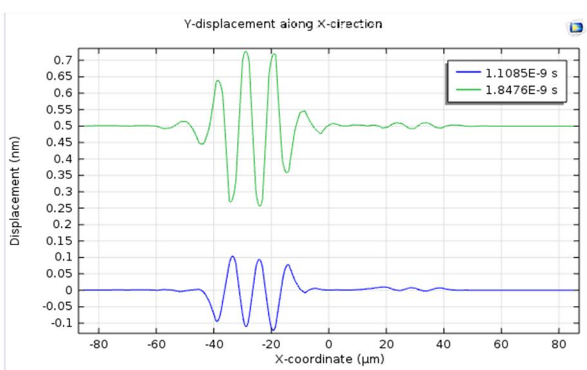

Fig 6: Displacement Along Wave Direction

The displacement along the wave direction is plotted for different timings 1.108 ns and 1.8476ns to distinguish the waveform 0.5 offset is added. The higher peaks are at the input IDT and the small peaks are at the output.

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2) Displacement Along Thickness

The two lines are the displacement along the thickness for different timings. From this waveform it can be verified that the mechanical wave does not propagate beyond the thickness value i.e. twice the wavelength. For the time of 36.952 ns the displacement 0.025nm and for 1.1085 ns the displacement is 0.07nm.

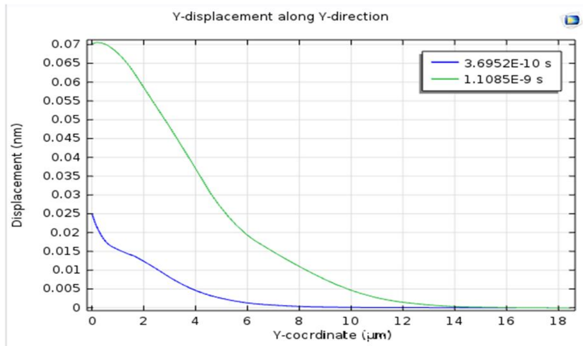

Fig 7: Displacement Along Thickness

3) Eigen Frequency

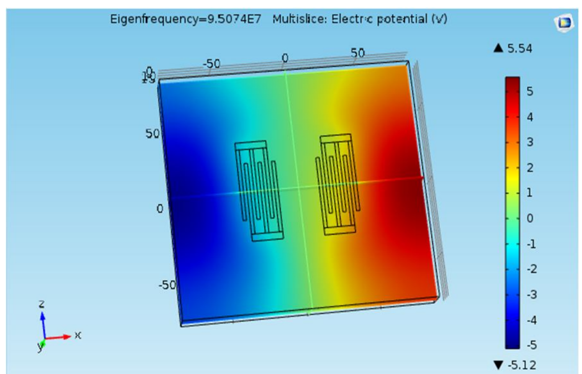

Fig 8: Eigen Frequency

The above figure show the Eigen frequency for the device where the device vibrates naturally at 95.07MHz.

B. With Mass

Once the mass is applied the input vs. output voltage is plotted here the input voltage is 10 V and there occurs a change in the output voltage waveform with respect to the applied voltage. The obtained output voltage is 4.243 V is shown in the figure 9.

The waveform with and without mass are compared it is seen that in the output voltage waveform without any mass the voltage seen is 4.338V and the output voltage with mass added it is 4.243V. The change in the voltage is due to the mass being added in between the input and the output IDTs also that the wave propagation is affected due to the mass being added.

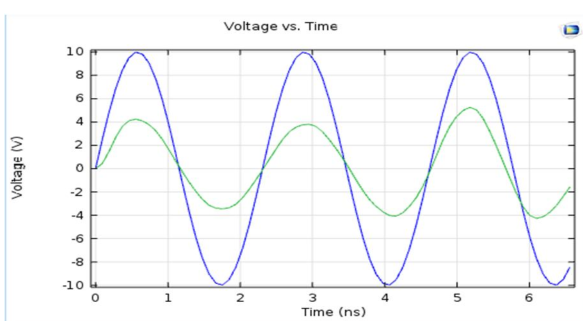

Fig 9: Input vs. output voltage plot

1) Displacement

The Biosensor has a patch in between the input and the output IDT. which is made up of PVDF it is shown in figure 10 the mass is added between the two IDTs. so this image shows the surface displacement of 0.22 for the time 6.6513 ns.

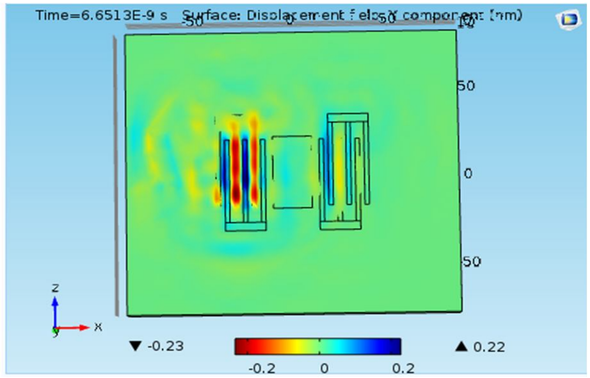

Fig 10 : Surface Displacement of Biosensor

2) Displacement Along Wave Direction

As the wave propagates from input IDT to the output IDT the particles that are present along the wave also gets displaced.

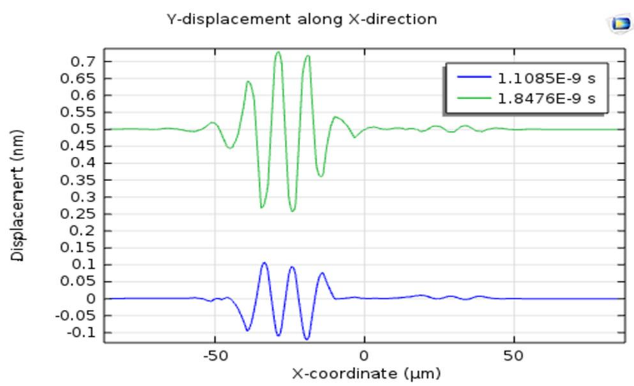

Fig 11: Displacement Along Wave Direction

The displacement along the wave direction is plotted for different timings 1.108 ns and 1.8476ns to distinguish the waveform 0.5 offset is added. The higher peaks are at the input IDT and the small peaks are at the output.

3) Displacement Along Thickness

The two lines are the displacement along the thickness for different timings. From this waveform it can be verified that the mechanical wave does not propagate beyond the thickness value i.e twice the wavelength. For the time of 36.952 ns the displacement 0.027 nm and for 1.1085 ns the displacement is 0.067 nm.

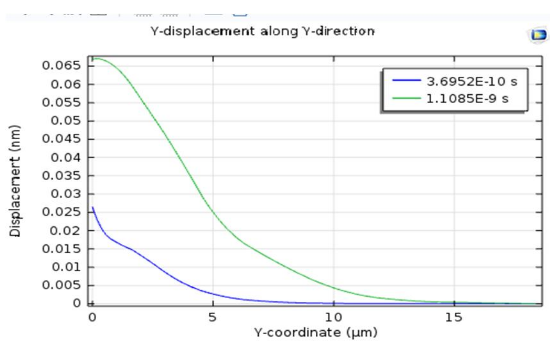

Fig 12: Displacement Along Thickness

4) Eigen Frequency

The figure 50 show the Eigen frequency for the device where the device vibrates naturally at 95.06MHz.

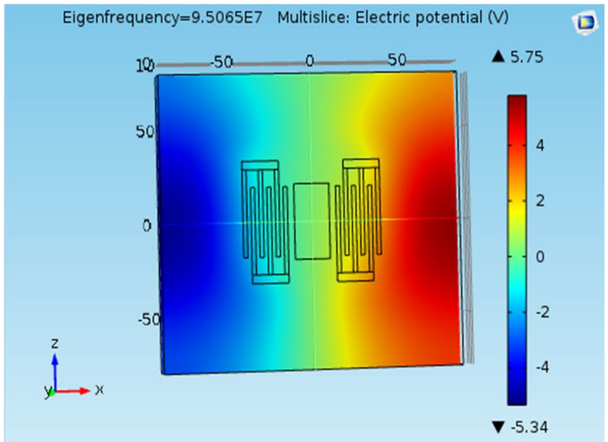

Fig 13: Eigen Frequency

Effect of change in frequency on delay and thickness we have varied the frequency and the change in the delay and thickness is tabulated and plotted.

Table 1: effect of change in frequency on delay and thickness

Frequency (in MHz)	Delay line (in µm)	Thickness (in µm)
9.99	1200	800
100	119.88	79.92
200	59.94	39.96
300	39.96	26.64
400	29.97	19.98
433	27.686	18.457
500	23.976	15.984
533	22.492	14.994

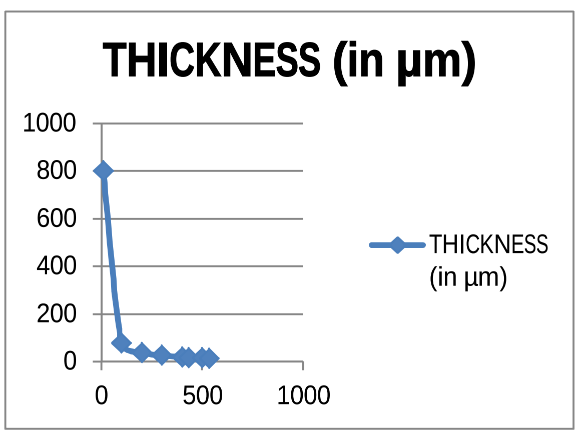

Fig 14: Effect of frequency on thickness.

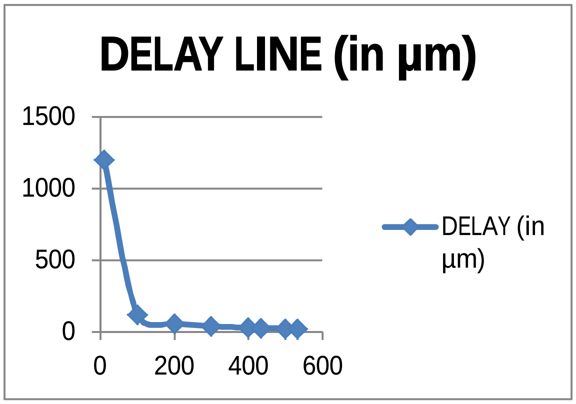

Fig 15: Effect of frequency on delay.

IV. CONCLUSION

The paper is based on the design of SAW Biosensor using PVDF Thin film which gives an insight to design and also a comparison between biosensor with and without adding mass on the sensing film thus showing a desirable change in the input and output voltage waveforms. Also there has been a change in the amplitude.

The difference in the amplitude at the output determine the desired mass applied on the sensing film.

V. ACKNOWLEDGEMENT

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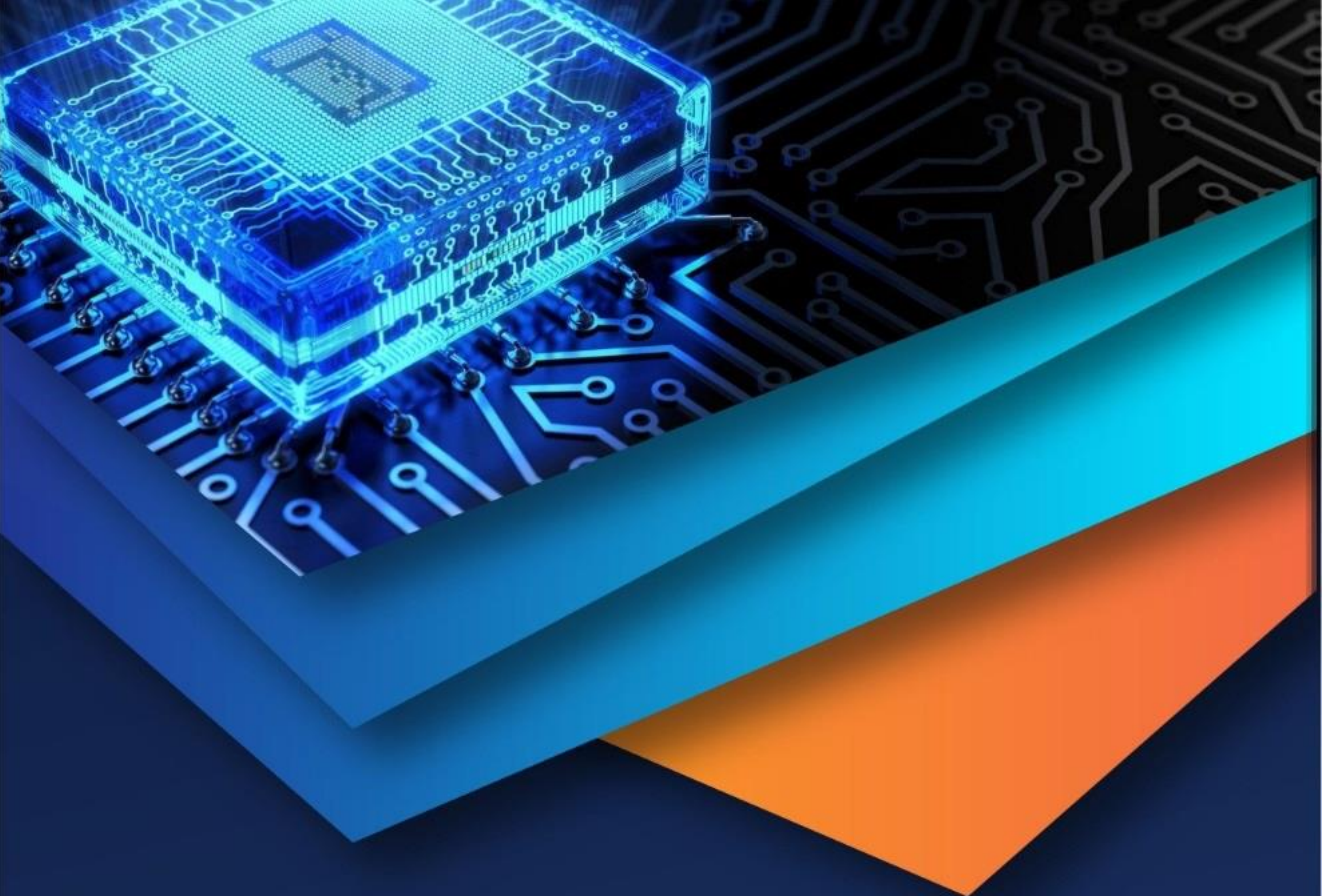

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