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Modelling and analysis of wavelength selective, silicon based, tunable optical filter

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Abstract— This paper deals with simulation and analysis of an optical filter which is designed using integrated ring resonators. This filter is tunable and we can control its output by electro optic effect. This device enables modern optical networks to be faster and more efficient. It has six channels and these channels are designed using waveguides and spaced in such way which allows best possible signal propagation through them. We supply optical signals of various wavelengths and we can obtain desired signal at the output by tuning the filter. To actuate this device we have used MEMS (Micro Electro Mechanical System) which is a combination of electrical and mechanical system with micro optics. We have achieved tunability in the range of 45.21 to 45.53.

Keywords— ***Integrated Ring Resonators, Optical Communication, Optical filters, MEMS.***

I. INTRODUCTION

Optical networks are overtaking older communication system in recent times and because of their high data rate, compact design and fast and accurate operation they are being favored over other technologies [1] Optical filters are crucial passive components for modern optical communications systems. Micro-waveguide and ring resonators are of great interest due to their various functionalities and compactness. They are being designed for different applications, such as wavelength filtering, multiplexing, switching and modulation Fiber optics and optical equipments are very light in weight with inherent immunity against electromagnetic interference and also because of their security these systems have taken the world of communication by storm. Optical systems have vast bandwidth, theoretically it is infinity but practically it's in the range of THz even than its immensely greater then of other wired or wireless systems. With increasing demand of higher data rate and high quality services need arises to design new equipment that will make communication even faster and efficient. In this case to tackle the problem we have to take help from devices like filters, amplifiers, Multiplexers and demultiplexers. Optical filters of all shapes and sizes depend on their ability to shape and control frequencies of light. The term optical filter is an extremely broad description that essentially includes any optical structure that can purposely differentiate between various frequencies components of an incident light signal and treats them in different ways. An input light signal can be transformed in terms of phase, amplitude or both. The former is achieved mostly through some form of resonance or interference, while the latter involves dispersive and phase delay effects. While a number of structures, such as all-pass filters, offer minimal amplitude distortion, some degree of frequency-dependent phase are always applied by the filter to the incident signal. We have designed and simulated a Tunable optical filter which helps us in designing of high efficiency WDM networks.[2] This filter uses piezoelectric effect for actuation .This filter is multilayered and multichannelled and it is designed using micro ring resonators which are circular in shape. Ring resonators have shown immense potential to dramatically reduce the footprint of most optical photonic integrated circuits, which are also compatible with older technologies. We have designed six channels using arrays of circular ring resonators and optical waveguides. Ring resonator due to their compactness, integrated structure and also because of ease of customization is used extensively in modern optical systems. [3]Ring resonators can be designed to obtain a particular output accurately. Due to its high accuracy and versatility we can boldly design any kind of optical device using various combinations of rings. Also shape of the rings plays a role in shaping the response. We have applied circular rings in this analysis.[4,5].Wavelength tuning is necessary to obtain desired output and to fit transmission curve in allocated bandwidth[6].To achieve wavelength tuning in optical filters three methods are used career injection method, thermo optic method and electro optic method. We are using electro optic method for this study because unlike the thermo optic effect it doesn't require a continuous supply of current and it is also faster compared to the other two methods. In this study we have focused on design, simulation of a MOEMS actuated optical filter [7] [8] [9].We have studied the effect of different Eigen frequencies on results and parameters of beam. For designing this filter we have used design and analysis tool Comsol Multiphysics and Matlab.

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II. MODELLING AND SIMULATION

This entire structure is fabricated on a multilayered cantilever beam of silicon with the length of 300μm, width of 40μm and thickness of 2μm.Radius of rings are 3 μm and sector angle is 360 degrees. On the upper beam ring resonator arrays are designed. One end of both beams is fixed and rest of the beam is free to expand in every possible direction. Figure 1 displays front view of the filter

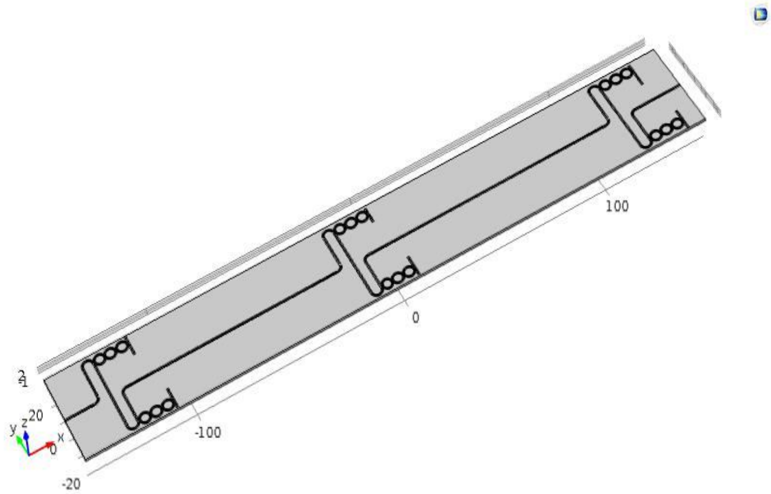

Fig. 1: Front view of the beam

In lower beam PZT-5A is sandwiched. When electric potential is applied and lower beam expands then the upper beam also expands. Figure 2 shows another view of the beam in which entire length of the beam is visible.

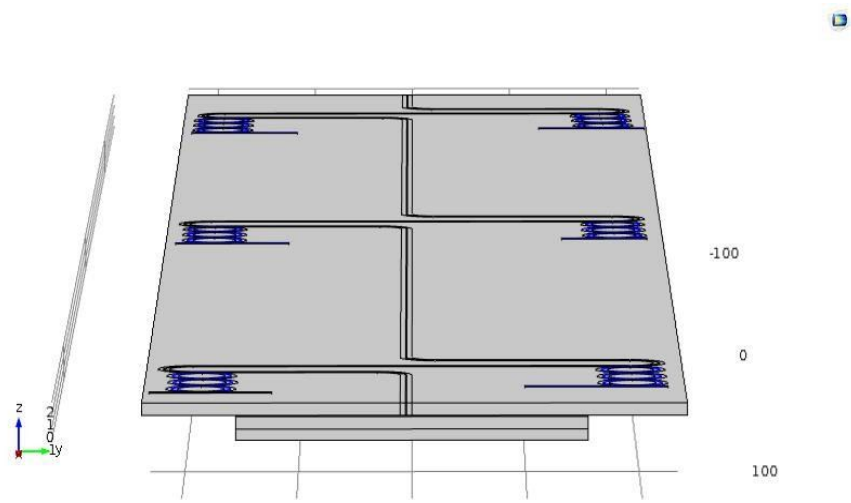

FIG. 2: ZY VIEW OF THE BEAM

As we can see the structure is made using straight and circular waveguide which are placed strategically over the beam. Distance between waveguide is selected in such a way that it will allow signal to pass through it via evanescent field. Coupling length is good enough to allow proper channelling of the signal through them. This device is a combination of several branches of physics and involves Structural mechanics, Electrostatics and Wave properties of light. Structural mechanics deals with the mechanical parameter and their relationships. Electrostatics parts describes how application of electric potential on beam effects it and wave properties explains how the optical energy is supplied to the input and how it appears out of the output.

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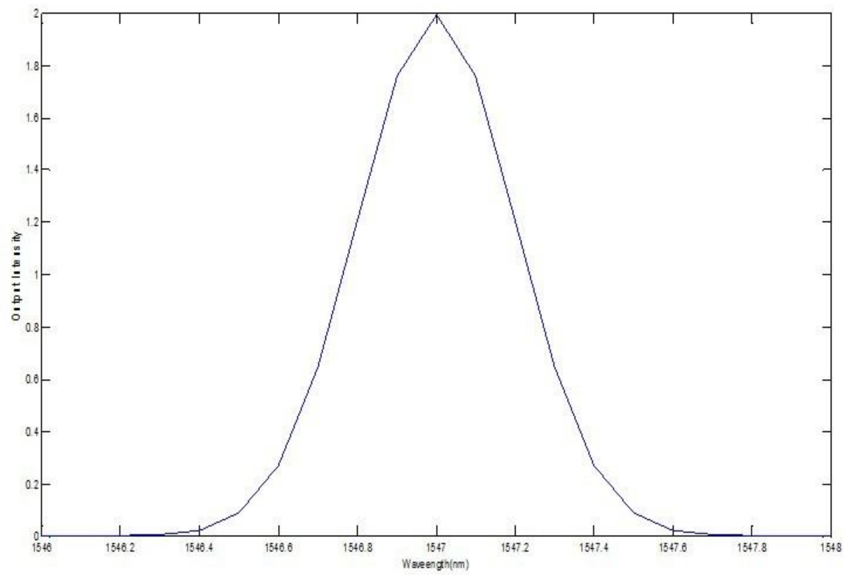
As its name suggests ring resonator when working on resonance wavelength raise the value of input light signal into its



maximum value. This property is being used here. As we have discussed earlier when beam expands mechanical deformation takes place on the rings which changes heir refractive index which in turn affect the output spectrum. There is a relationship between applied voltage and change in the wavelength of output signal. By adjusting the applied voltage, desired tuning of output spectrum can be obtained.

III.RESULT AND DISCUSSION

Figure 3 shows the spectrum of wavelength vs. output intensity in a single channel. Wavelength ranges from 1546 to 1548 nm. As we can see the value of output intensity reaches its maximum value at 1547 nm, at this wavelength filter shows effect of resonance

Fig. 3: Wavelength vs. output intensity

Figure 4 shows wavelength vs. intensity plot of all the six channels simultaneously

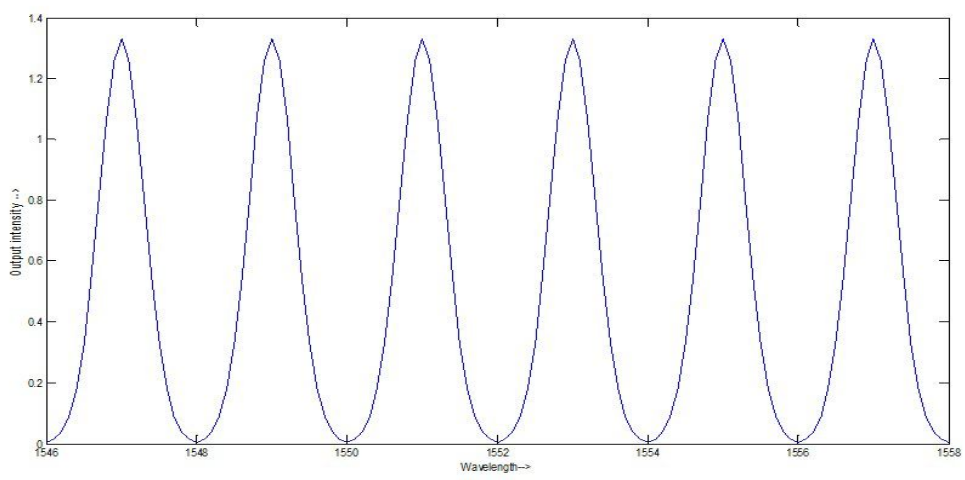


Fig. 4: Wavelength vs. output intensity of six channels

A biasing voltage of ± 5 v is applied to the beam as shown by figure 5.Entire structure is subdivided in small tetrahedron meshes and effect of bias varies in the beam.

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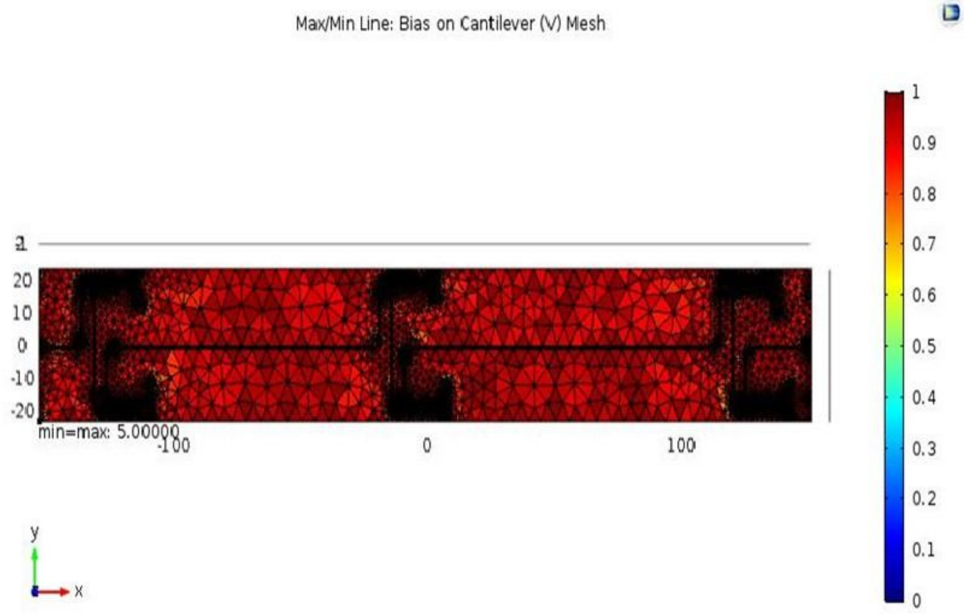

Fig. 5: Bias on cantilever

Von Misses stress is widely used by designers to check whether their design will withstand a given load condition. It is used to estimate yielding of materials under given loading condition from resulting due to simple uniaxial tensile tests. The von Misses stress satisfies the property that two stress states with equal distortion energy have equal von Misses stress. Figure 6 shows Von Misses stress, Principle stress volume and total displacement for Eigen frequency 17.301.

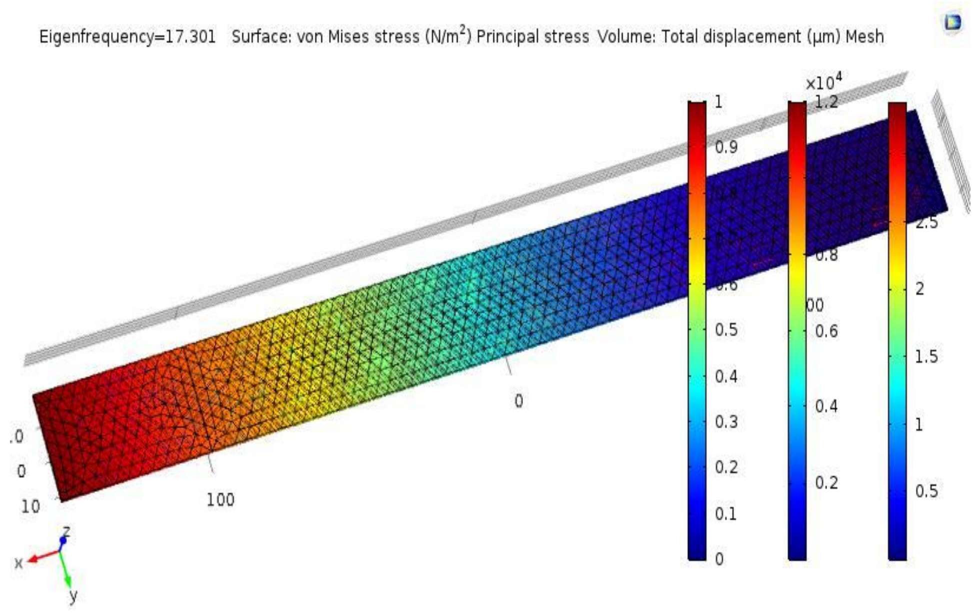

Fig. 6: Von Misses stress, Principle stress volume and total displacement for Eigen frequency 17.301

For different Eigen frequencies the total surface displacements are different. When we keep increasing its value then there comes a point when entire beam becomes twisted which is strictly unwanted. This change in shape of beam causes the shape of ring resonator to change which results in change of refractive index of them. This change in refractive index is needed for tuning of desired signal output. Figure 7 shows total surface displacement for Eigen frequency 6.8077.

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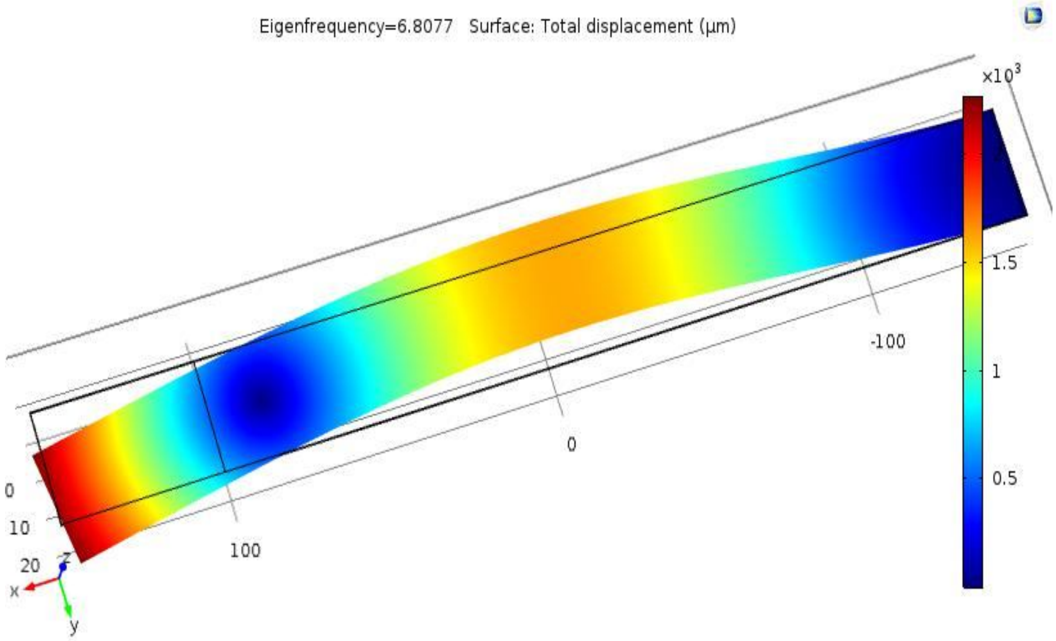

Fig. 7: Total surface displacement for Eigen frequency 6.8077

In figure 8 various parameters for Eigen frequency 1.1132 is shown. This image displays how applied stress is working on the beam and the directions at which it is subjected is shown by arrows and contours.

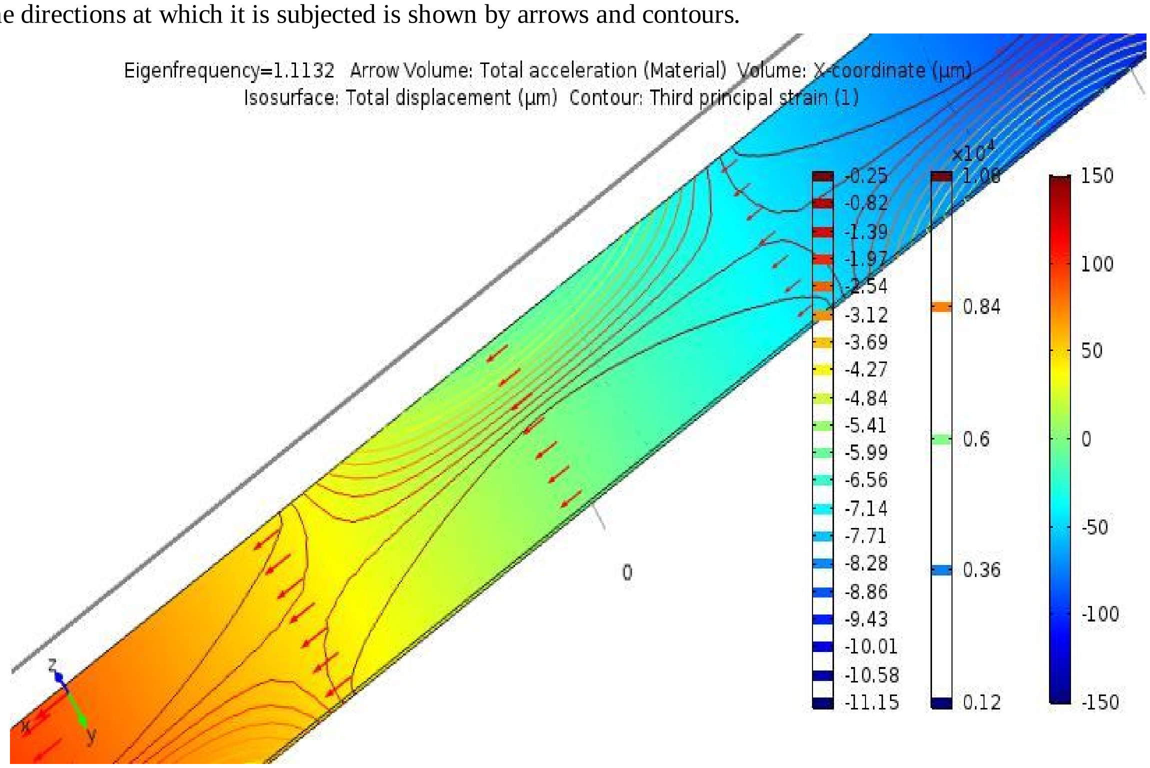

Fig. 8: Different parameters for Eigen frequency 1.1132

As we know principal strain is a parameter which describes the state of strain in X, Y and Z axes in any material which is under stress. Figure 9 shows effect of strain direction 2 for Y component.

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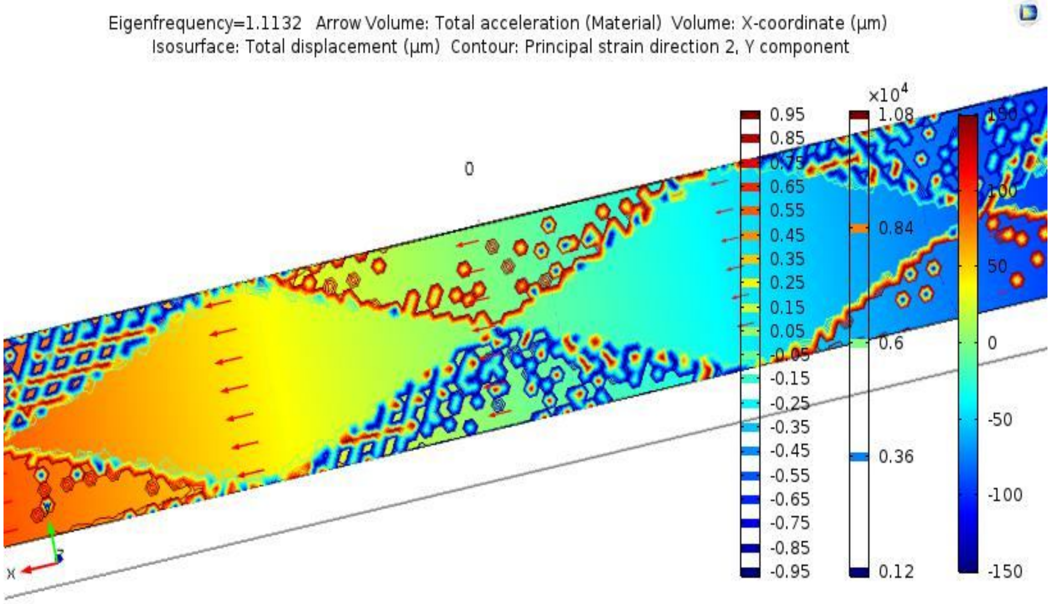

Fig. 9: Principle strain in direction 2, Y component

Figure 10 shows a graph between applied phase and total surface displacement of the beam. As we can see from it, displacement varies with changing phase, it becomes nearly zero and again its value increases for a duration and again reduces.

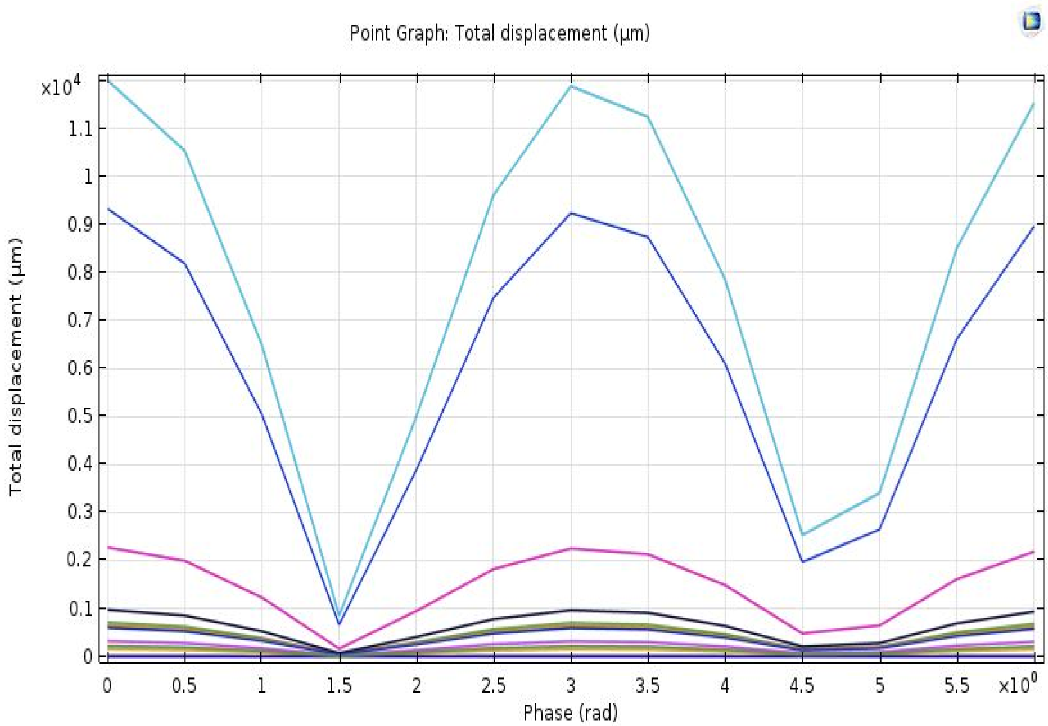

Fig. 10: Total Displacement vs. phase

Within the elastic limit of a structure, all the work done in stretching or deforming it is known as Elastic Strain Energy. Figure 11 shows histogram for total elastic strain energy for Y and Z directions.

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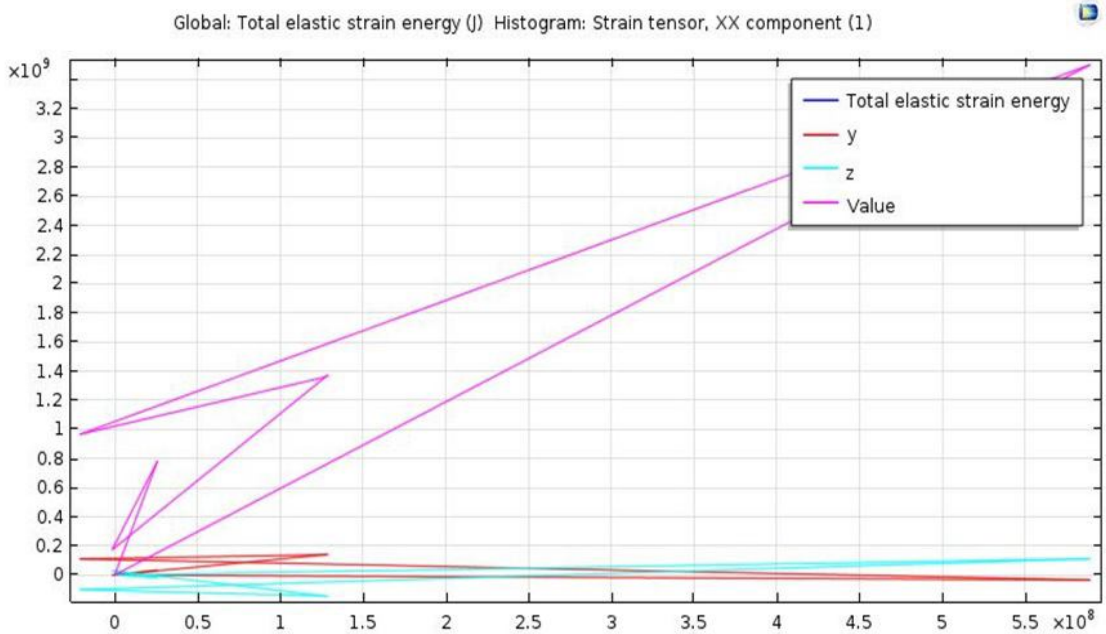

Fig. 11: Total elastic strain energy of the beam

Figure 12 shows relation between first principal strains vs. phase of applied electrical input. Value of strain reaches its optimum value for the range 1 to 4 radians.

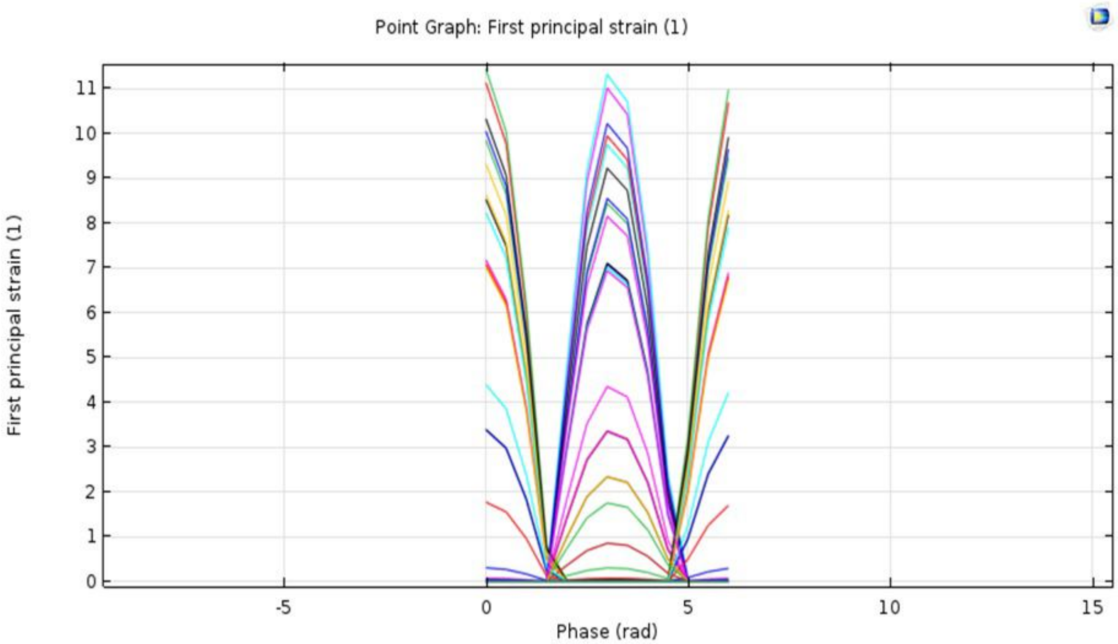

Fig. 12: First Principal strain vs. Phase

Figure 13 shows field intensities inside the optical ring resonator and a single waveguide. We can clearly see due to numerous round trips and because of constructive interference given signal develops fields which have high amplitude. In other words we can say ring resonator works as an optical amplifier with a high gain.

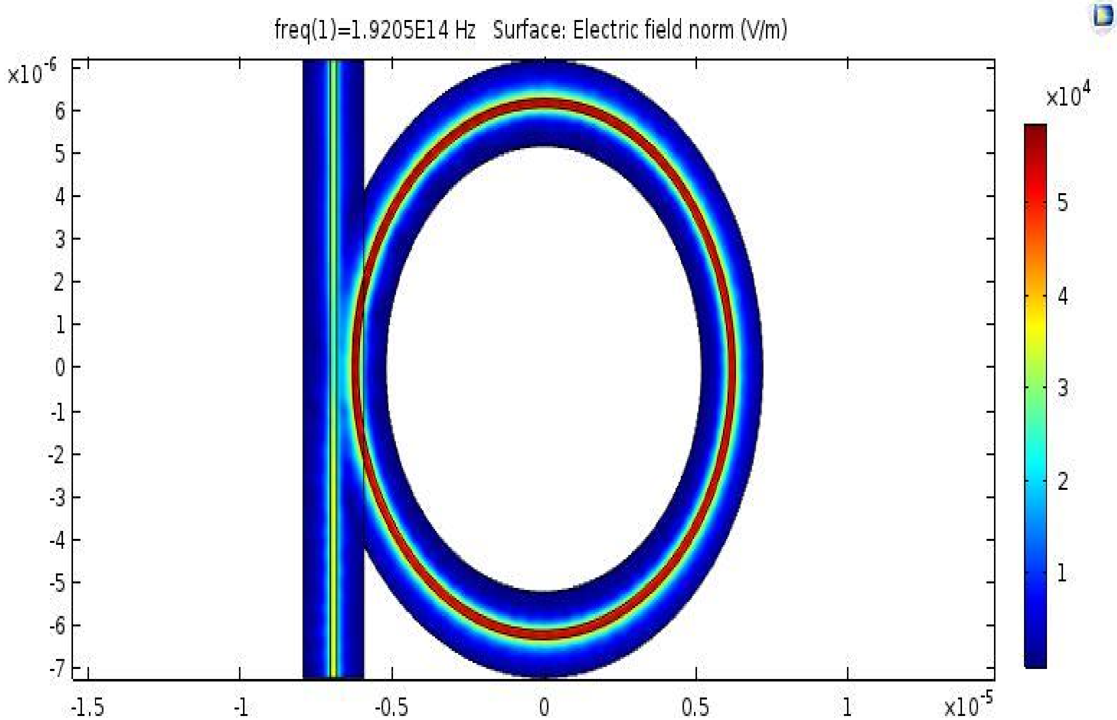

Fig.13: Field Intensity inside the ring resonator

Figure 14 shows plot between Transmittance and wavelength in a ring resonator. As we know Transmittance of a material is its effectiveness in transferring radiant energy which is defined as the ratio of transmitted to incident optical signal.

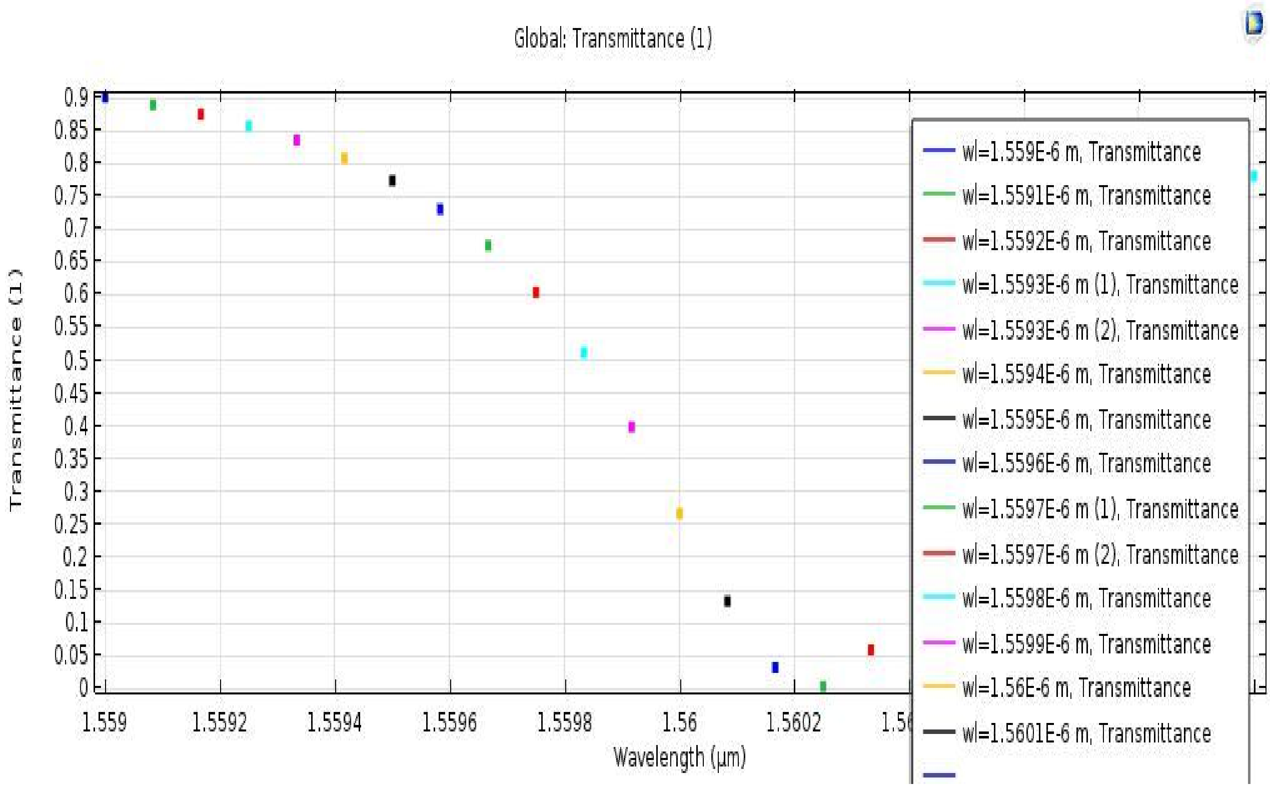

Fig 14: Transmittance vs. Wavelength in ring resonator.

Figure 15 shows a plot between Fourier coefficient of the given signal and frequency of the same signal.

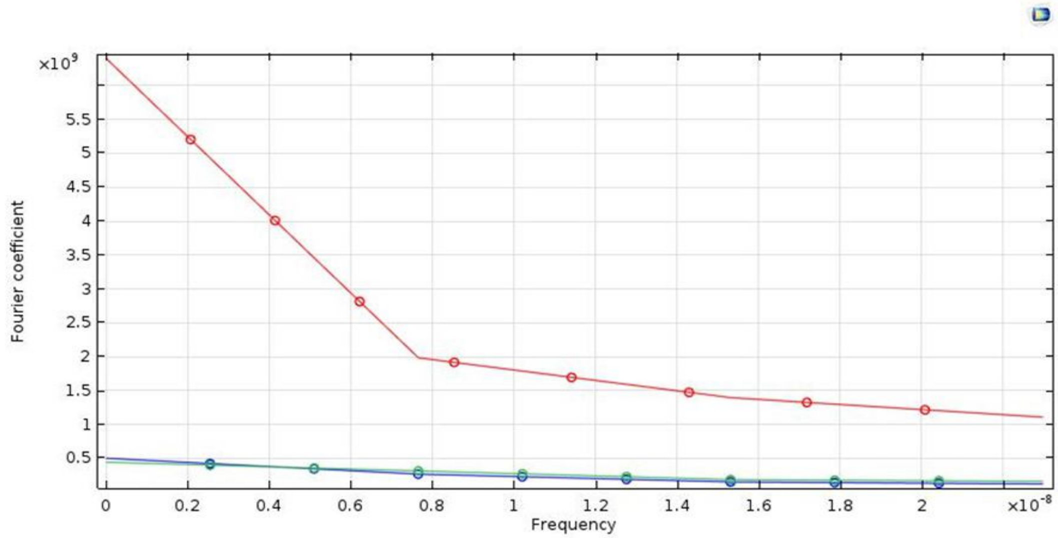

Fig 15: Fourier coefficient vs. Frequency

Figure 16 shows a plot between total displacements of the beam in micrometers vs. solution number

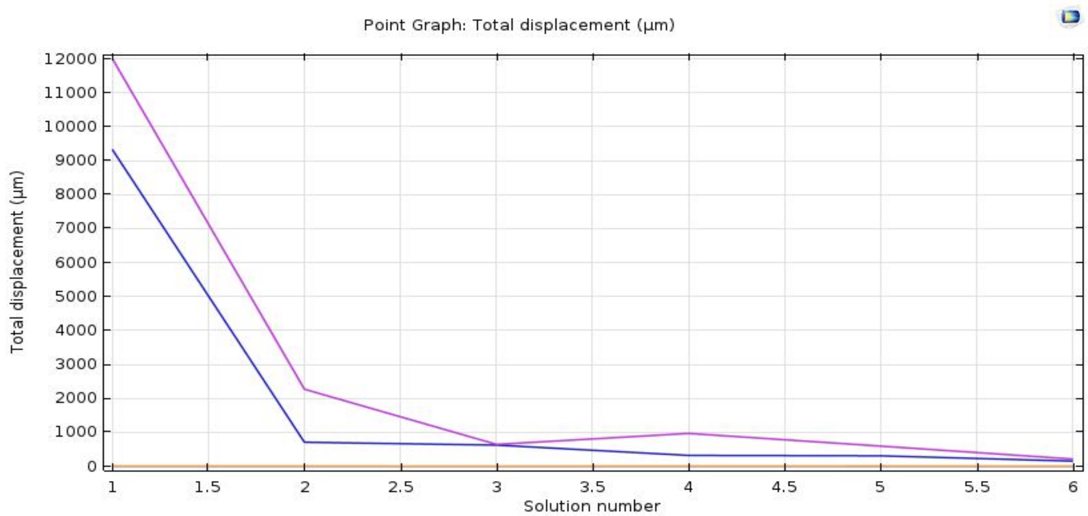

Fig 16: Total displacement vs. solution number

IV. CONCLUSIONS

With increasing network of communication in entire world, demand of networks with higher data rate is increasing. Optical networks can work seamlessly with existing telephone and wired networks can provide faster and more efficient data exchange. Like older technologies optical networks also needs equipments like multiplexer, demultiplexers, filters etc. This work developed a body of knowledge essential for the design and optimization of micro structured optical filters. The basics and theory concerning optical filters is studied. MEMS, its definition types, characterizes has been studied and how they can be used efficiently along with ring resonator to design and simulate a high quality optical filter is presented. A particular attention has been given to ring resonator and its characteristics. Ring resonator and MEMS shows compatibility with existing CMOS and FET technology.

A multilayered optical filter which is constructed over a cantilever beam of silicon is designed and simulated. This filter consists of 6 channel, these channels has been designed using Arrays of micro ring resonators. For actuation piezoelectric material PZT-5A has been used. Piezoelectric material is buried between upper and lower beams of silicon. After simulation and analysis of results, some observations about the filter has been outlined and relationship between various parameters has been studied. The conclusions are as the followings:

A. We have achieved tunability for each channel which has the values ranging from 45.21 to 45.53.
B. Filter response is studied for various Eigen frequencies we have found that higher the value of Eigen frequency causes the beam to expand and distort more which is not desirable.
C. Effects of stress and strain of the beam have been analyzed.
D. Various parameters such as total elastic energy, total displacement of the beam, bias applied on the cantilever has been observed.
E. Relationship between various parameters has been plotted.
F. Mathematical as well as Electrical, Optical and mechanical aspects has been calculated and plotted.

V. FUTURE SCOPE AND RECOMMENDATIONS

Optical filter is going to play a revolutionary role in various aspects in life in near future. These filters are used in the field of medical diagnostics. Optical filters of exceptional quality are being manufactured, which not only deliver accurate results but also open up a completely new avenue of applications in wearable light weight diagnostics. Optical filters are used to control the spectral properties of an incident light beam, attenuate unwanted waves and pass the desirable signals. Optical filter is important for monitoring blood glucose, testing hemoglobin levels, detecting infectious diseases and also checking of cardiac and cancer related checkups.

As we are seeing old and obsolete wired internet connections which extensively use metallic wires are being replaced by optical equipments. Because of their enormous bandwidth range and high speed they will soon make traditional network extinct. Optical filter is highly versatile device and can be used for enhancing the performance and efficiency of fiber based networks. [10][11]

Optical filters and optical networks in general are widely used in space technology because of their small size, light weight and durable structure. Because of these mentioned points their use is very likely to increase. [12][13][14]

Few recommendations for optical filter and related technology are

A. Although optical filters have been improving continuously for the past twenty or so years, and theoretically these are very precise when expected to deliver for a particular application, manufacturing technology is not yet up to delivering such exacting quality. This should be improved.
B. These filters are very accurate and quick but even than their significant room for improvement. Now high- performance filters are needed which have deeper blocking, higher transmission rate, steeper edges in spectrum and larger angles.
C. The fabrication tolerances of microring resonator based devices are quite low, and a improvements and works are needed to develop a less sensitive geometry that is more easily fabricated

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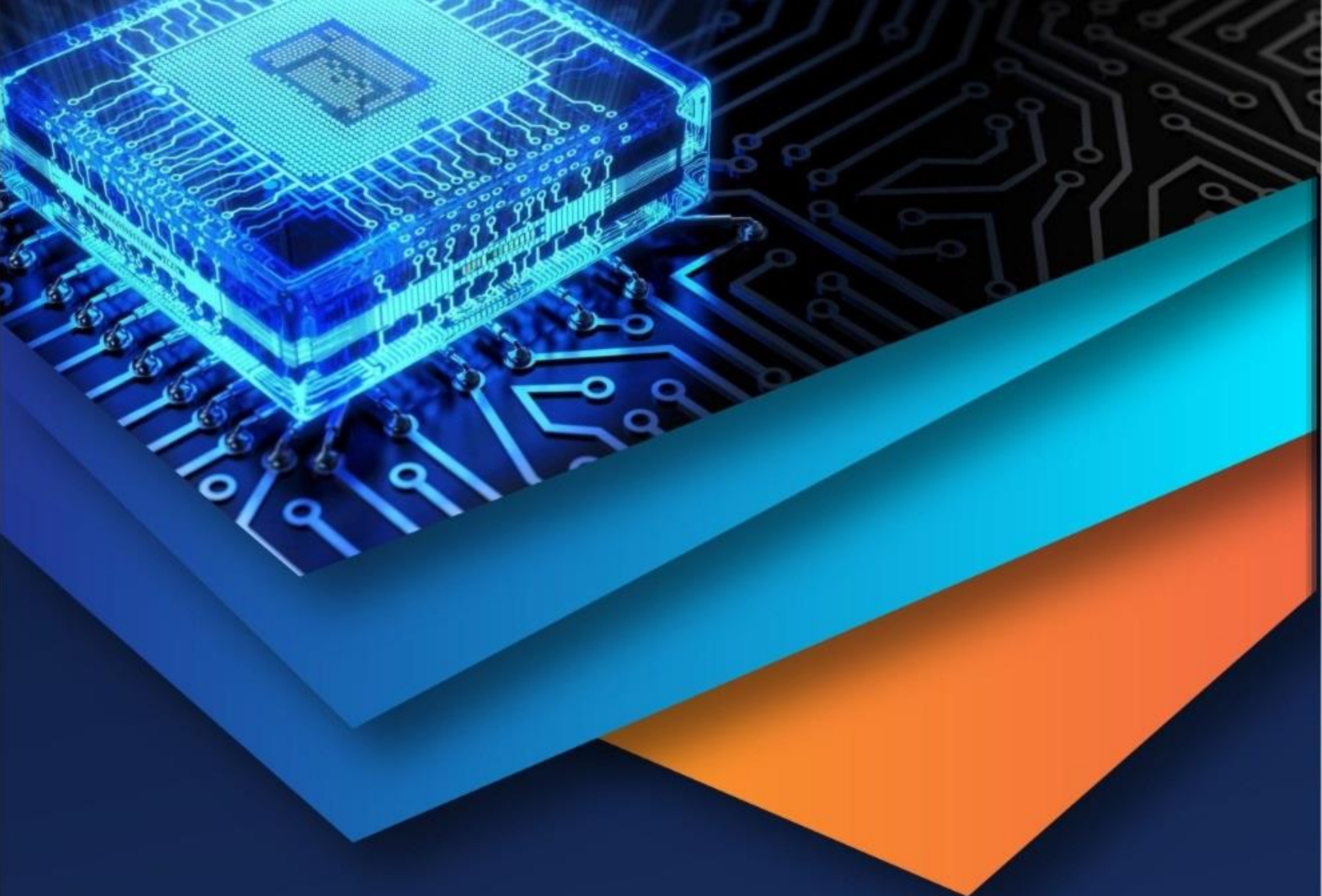

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