A Dissertation Report

On

Hybrid Silicon Microring Optical Switch

Submitted in the partial fulfilment of the requirements for the degree of
Master of Technology in Solid State Electronic Materials

By

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May 2018

Declaration

I hereby declare that the project entitled "**Hybrid Silicon Microring Optical Switch**" submitted by me to the Department of Physics, IIT Roorkee in partial fulfilment of the requirement for the award of the degree of Master of Technology in Solid State Electronic Material is a record of my own work carried out during the period Jan 2017 to May 2018 under the supervision of Dr. Rajesh Kumar.

Place: Roorkee (SAURABH KORANGLEKAR)

Date: M.Tech. SSEM

I.I.T. Roorkee

Certification

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Place: Roorkee

Date: (Dr. Rajesh Kumar)

Department of Physics

I.I.T. Roorkee

Acknowledgement

It is a matter of great pleasure to express my gratitude and veneration to Dr. Rajesh Kumar for his valuable supervision, convincing discussions, his constant inspiration throughout this work and for his valuable time he gave to me.

I also wish to thank Head of the Department of Physics for his help.

I am grateful to Mr. Nadir Ali and Mr. Shubham Singh (Research scholars) for their persistent help and discussions they made with me.

I would also like to express my gratitude and respect to my family and friends.

Abstract

This thesis reports the effects of parametric variations of hybrid silicon microring resonator for optical switching applications. Microring Resonator optical switch is a Silicon on Insulator (SOI) photonics contrivance utilized for developing photonic switch where waveguides are of Silicon with Silicon-diOxide substrate. It is an attempt for increasing the extinction ratio contrast of Amorphous and Crystalline GST cell transmission when placed in Microring resonating structure. To obtain the desired goal variation of certain parameters in the structure like radius, gap GST position and length was performed and observed its effects on transmission ratio. Summarization of results and analysis has led to categorization sensitive and non-sensitive parameters.

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Unit 1: Introduction

Si photonics is the study and application of photonic sys. which use Si as optical medium and is being used in the electronics circuitry for many years and now is becoming an emerging choice in photonics. In recent years we have witnessed been many breakthroughs and the increasing investments in international markets, and is becoming an integral discipline in integrated optics.

The motivation for silicon photonics:

Traditional reason: Silicon wafers have

- Lowest manufacturing cost
- Highest crystal quality

New Insight:

- The abundance of high-quality silicon-on-insulator (SOI) wafers, an ideal platform for creating planar waveguide circuits.
- The strong optical confinement due to high index contrast between silicon & its oxide helps in Size scaling

The application of silicon photonics isn't limited to only optical communication. It is kenned to possess linear as well as nonlinear optical properties in the infrared region. Also, the properties of thermal conductance and its threshold for optical damage have stirred inception of a niche class of mid Infrared based photonic devices.

These operate in infrared region, most commonly at the 1.55 µm λ.

The silicon typically lies on top of a layer of silica are known as silicon on insulator (SOI).

The light propagation through these devices is governed by a range of nonlinear optical phenomenon

- Kerr Effect,
- The Raman Effect,
- Interactions between Photons and Free Charge Carriers.
- Interactions between Photons and Free Charge Carriers.
- Two-Photon Absorption

Applications: -

- Spectral Filters and Switches.
- Optical Delay Lines.
- Sensing applications such as Strain Sensor, temperature change, refractive index change.
- Label Free Biosensors
- Using Active Ring Resonator, we can construct Modulator, Hybrid Silicon Rings.

Silicon on Insulator platform

Silicon on Insulator was chosen as the best solution to fit our purposes, for the considerations that follow.

The transparency range of Silicon extends from 1.1 um to the far infrared region, covering both the second and third bandwidth windows of optical communications. The R.I. contrast of Silicon ($n_{Si} = 3.5$) and Silica ($n_{SiO2} = 1.46$) is $\nabla n = 1.4$. The high mode confinement of the optical field, typical waveguide cross sections are 220 x 480 nm^2 and the minimum allowable bending radius is $R_{min} = 1.5$ um.

Sharp bends have two advantages, scaling of device area that enables higher density of integration on single chip, free spectral range $FSR_{max} = 7$ THz, that aids realization of filters with both large BW and high spectral selectivity. A few nm amplitude scale of roughness is sufficient to produce significant values of propagation losses. Silicon photonics has attracted a lot of interest in the last years for its compatibility with the CMOS industry. The fabrication process can be carried out in established industrial machines (exploiting consequent economy of scale to effective cost production).

The eventual integration with microelectronics and monolithic photonic integration with other platform would make it possible to realize, on the same substrate, all the optical functionalities and use it in a vision of optical interconnection.

A key limitation for Silicon is the scattering process due to sidewall roughness that becomes the dominant contribution to losses.

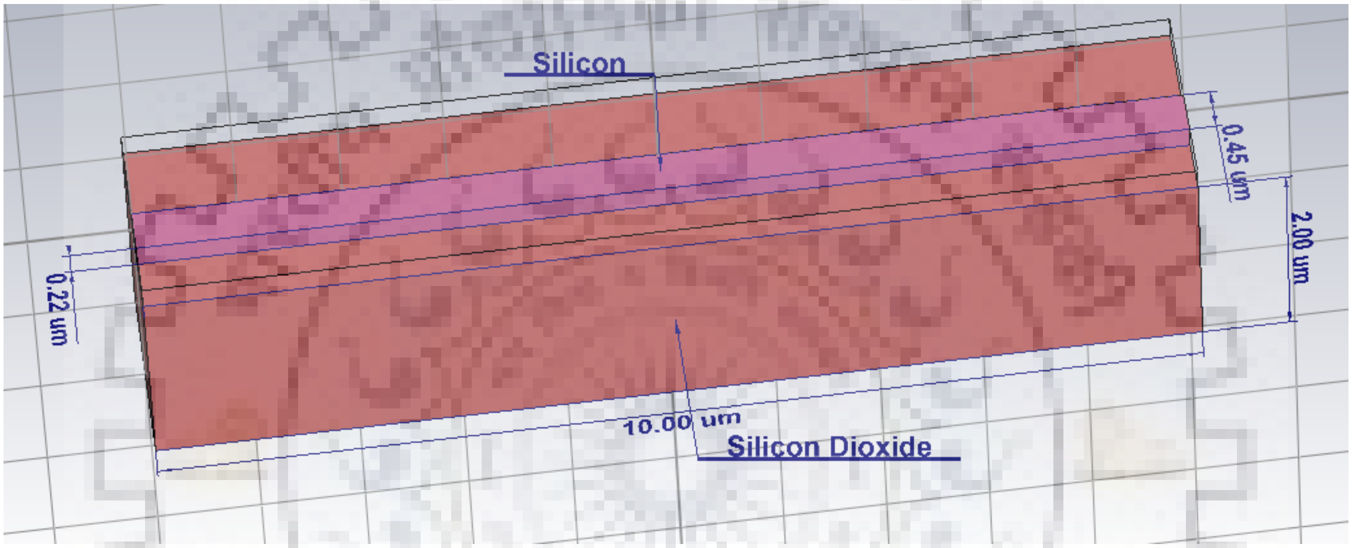


Figure 1

Unit 2: Ring Resonator

Introduction:-

Ring resonator is a optical waveguide in looped structure, resonance occurs when the optical path length is an integral multiple of wavelength.

$$m*\lambda_m = 2\pi r * n_{eff} = OPD$$

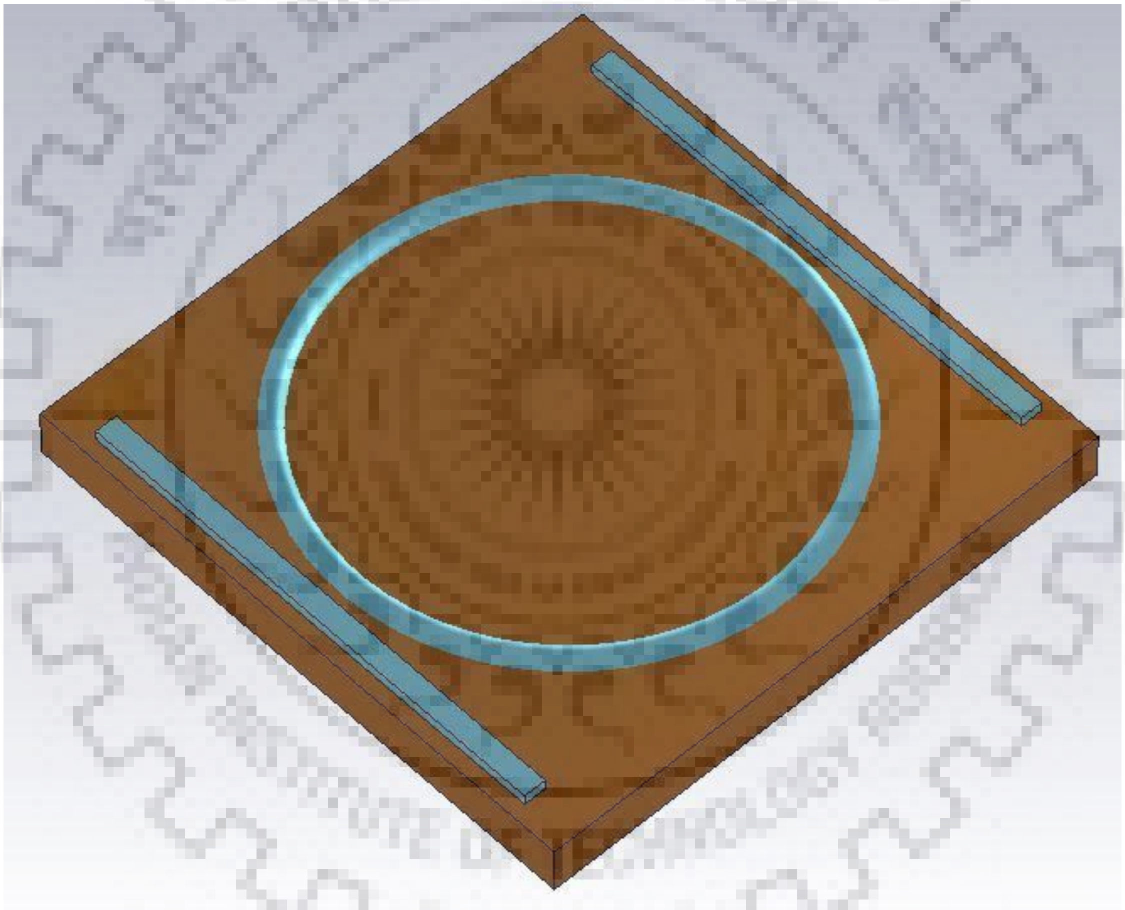


FIGURE 2: Generic Microring Structure

Definition and Short introduction of terms used:-

1. Optical path length

   It is the product of the R.I. of medium and path length covered by light in the system.

2. Co-directional coupling

   It occurs when two propagating modes couple in the same direction.

3. Free spectral range

   Frequency range between two resonating wavelength in ring resonator

4. WDM

   It is a technology which multiplexers and number of optical signal of different wavelengths in a single fibre cable

5. FWHM

   It is an expression of the part of a function depicting the difference between two extreme values of an independent variable for which the dependent variable becomes equal to half of its maximum value.

6. Finesse

   It can be defined as the ratio of free spectral range and full wave half maximum

7. Q factor

   It is ratio of resonant wavelength to full wave half maximum

8. Directional coupler

   An optical component is circuit with one port acting as an input port, one as a straight-through port, one as a coupled port and last one as an isolated port.

Due to the fact that it supports multiple resonances it can be used as wavelength filter.

Free spectral range is defined as spacing between these resonances, and is dependent of length of resonator. Only because of the high refractive index contrast between

silicon oxide and silicon, single mode waveguides can have bending radius around 0.005 mm. This facilitates fabrication of ultra-compact MRR, for FSR of about 0.020 um at wavelengths in near region of 1.550 um. This is a huge development in reducing the size dimension of rings which were made with materials of low refractive index difference. RR as an independent device becomes useful only when it is integrated with some circuit. One of the most prevalent mechanisms of coupling is utilizing coupling of two propagating modes are in the same direction, over a length, between an adjacent straight waveguide and ring.

MRR is becoming one of the extensively used photonic component. Range of Applications include laser cavity covering, WDM filters (wavelength division multiplexing), and sensors, Multiplexers, for processing of optical signals. Due to high refractive indices contrast along with its compatibility with CMOS, silicon photonics has become an ideal platform.

Applications:-

RR can be used to build circuits dealing with

- Optical Switches
- Intensity Modulators
- Sensors
- Spectral Filters
- Optical Delay Lines.
- Sensing applications such as Strain Sensor, temperature change, refractive index change.
- Label Free Biosensors

2.1 All pass ring resonator

The simplest form of ring resonator can be constructed by providing 1 Input and 1 output straight waveguide placed adjacent to microring.

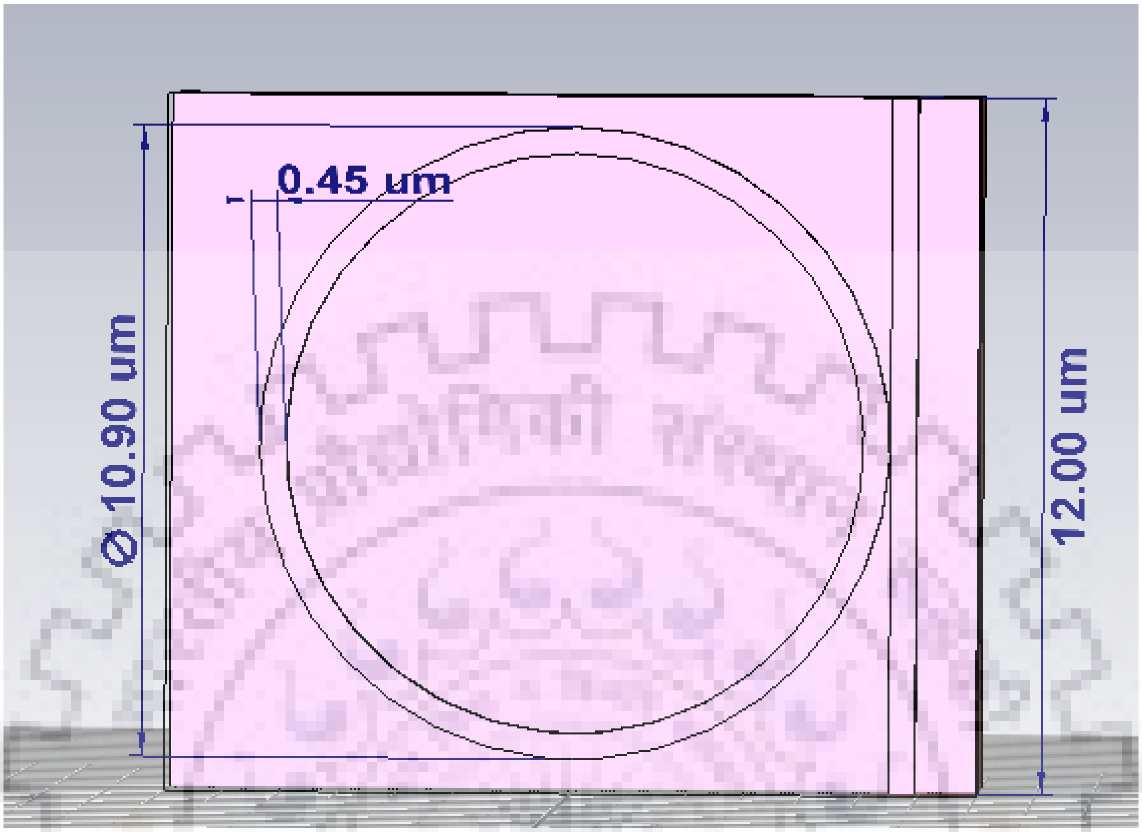


Figure 3 All Pass filter

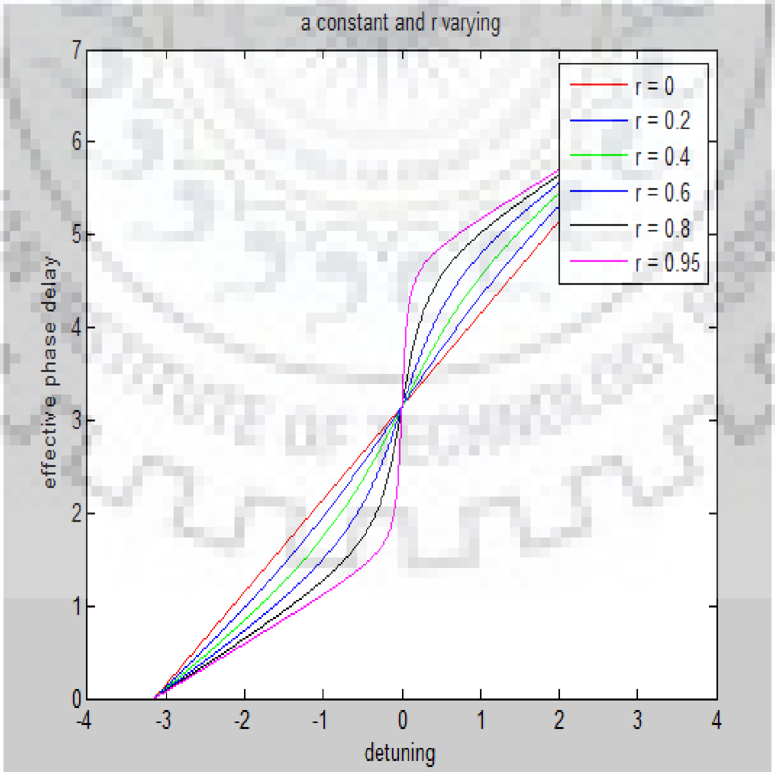


Figure 4 : Effective phase delay of an all pass filter as a function of single pass phase shift

2.2 Add Drop ring resonator

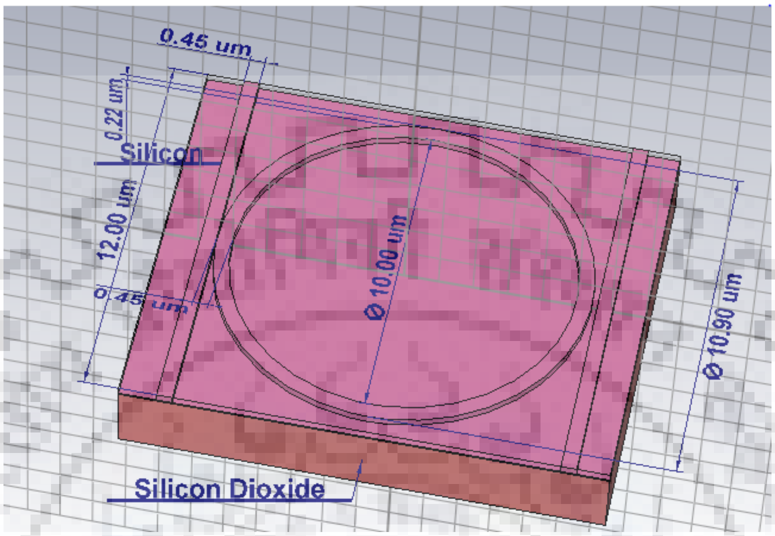


Figure 5

The ring structure that is coupled to two waveguides, the incident field is partly transmitted to the drop port is known as Add drop ring resonator. The transmission to the pass and the drop port can also be derived from CW operation and matching the fields.

$$T_p = \frac{I_{\text{pass}}}{I_{\text{input}}} = \frac{r_2^2 a^2 - 2 r_1 r_2 a \cos\phi + r_1^2}{1 - 2 r_1 r_2 a \cos\phi + (r_1 r_2 a)^2}$$

$$T_d = \frac{I_{\text{drop}}}{I_{\text{input}}} = \frac{(1 - r_1^2)(1 - r_2^2) a}{1 - 2 r_1 r_2 a \cos\phi + (r_1 r_2 a)^2}$$

If the attenuation is negligible (a=1), critical coupling occurs at symmetric coupling (k1=k2). For lossy resonator, critical coupling occurs when the losses match the coupling as $a = r_1./\, r_2$.

2.3 Spectral characteristics

$$\text{FWHM} = (1-r_1*r_2*a).*(\lambda_{res})^2./((\pi*ng*L)(r_1*r_2*a).\text{^}(0.5))$$

$$FSR = \lambda^2./n_g L$$

$$n_g = n_{eff} - \lambda_0.*((dn_{eff})./(d\lambda)$$

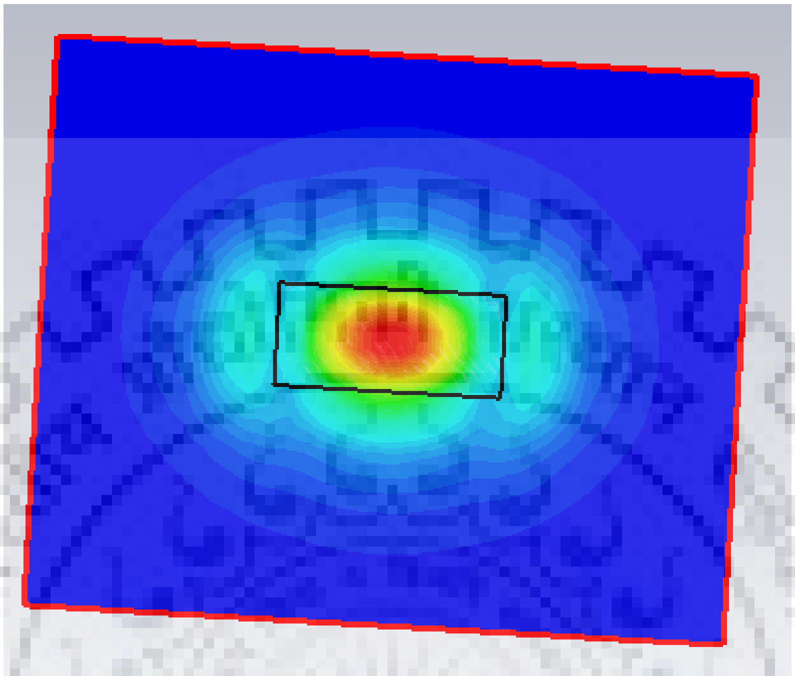
2.4 Silicon waveguides

SOI waveguides channel the light through a transverse and lateral confinements in silicon core (n=3.47) which is surrounded by its oxide as bottom cladding (n=1.44) and low index top cladding. Usually, silicon waveguides are being fabricated using e-beam also by reactive ion etching, on CMOS manufacturing tools. To abide by the condition of single-mode (at 1550 nm communication wavelength) the CSA (cross section area) dimensions need to be in sub-micro meter range, with decreasing thicknesses for increasing widths. The cross section area may vary from 0.6 x 0.100 um to square 0.300 x 0.300 um. The commonly used dimensions for the waveguides are 400 nm to 500 nm for width, and 200 nm to 250 nm for height. The index contrast between core and cladding is very high, this gives rise to very strong confinement which enables light guiding in bends with very small radii without radiation losses. At the core/cladding interface, the normal component of displacement $D = \varepsilon * E$ must be continuous. Therefore, the field amplitude at the cladding side of the interface will be stronger for a mode with the dominant E-field polarized normal to the interface. If waveguide height is smaller than its width (which is the most commonly applied geometry), the ground mode will have a T. E. polarization, with strong discontinuity on sidewall surface. Likewise, the T.M. mode will have discontinuity on the bottom top and surface.

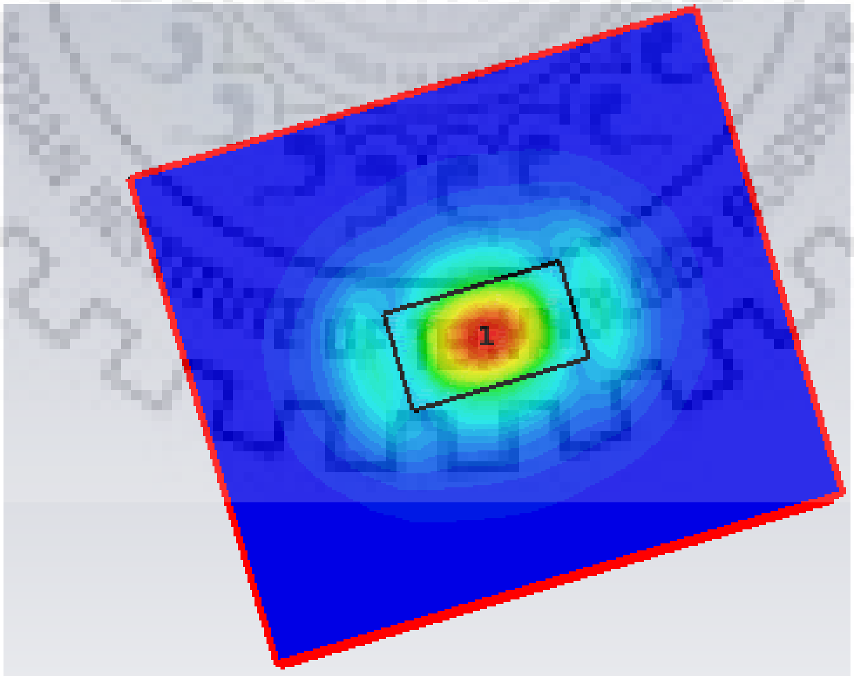
Propagation losses in silicon wires originate from multiple sources, and recent advances in process technology (in various groups) have brought the losses down to 2–3dB /cm with air cladding and less than 2dB/cm with oxide cladding. This difference can be explained by looking at different loss contributions. A lot of effort is put into the optimization of fabrication processes to minimize the surface-roughness. The losses are correlated with the periodicity of the roughness as well as its dimensions, and scale dramatically with the index contrast.

Here is a comparison of different cross section area dimensions

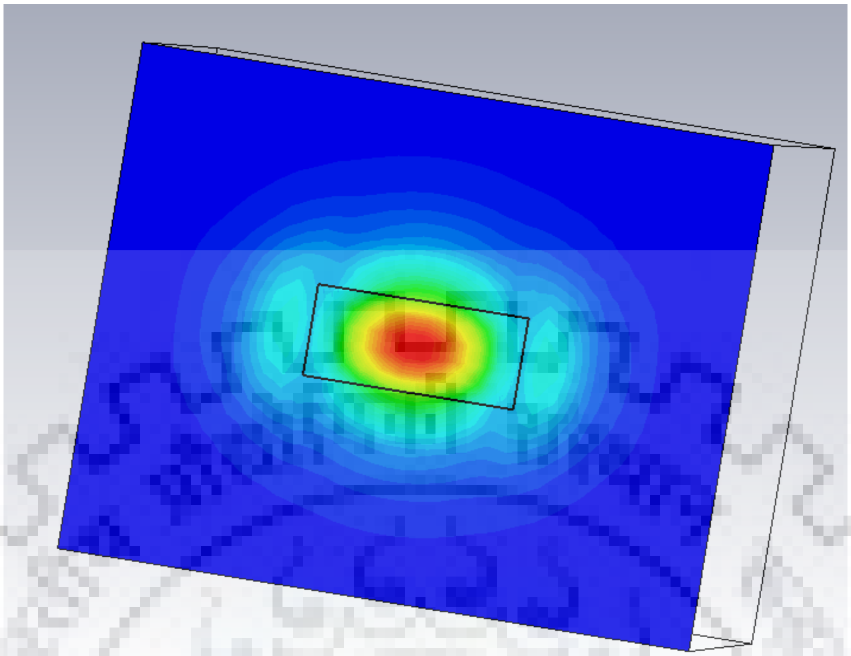
- 220 nm X 480 nm



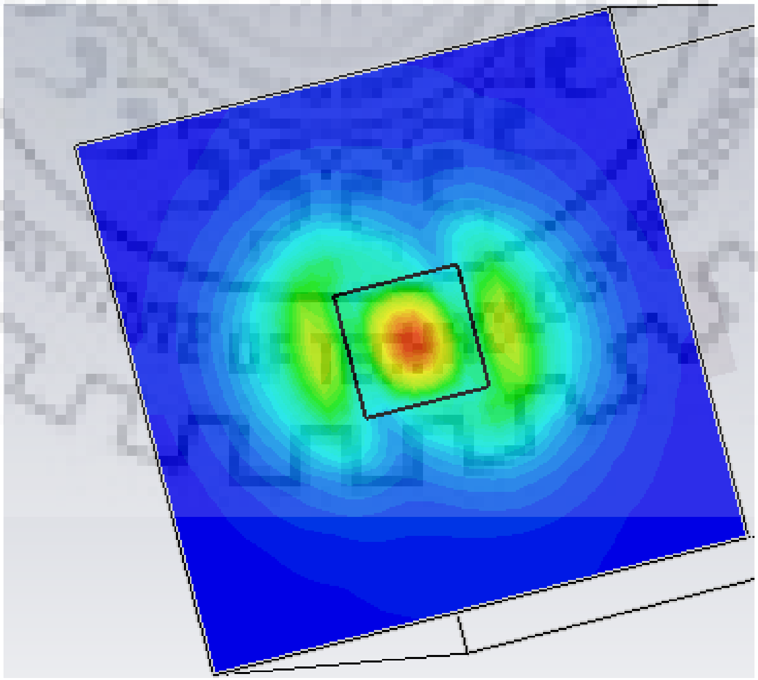
- 250 nm X 450 nm



- 250 nm X 500 nm



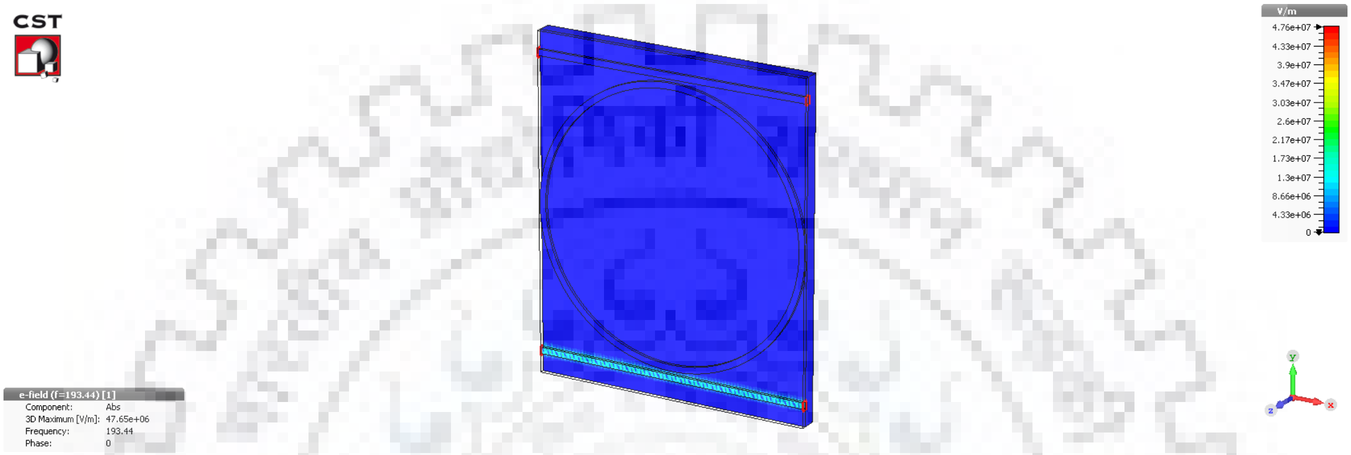
- 300 nm X 300 nm



2.5 Structure simulation

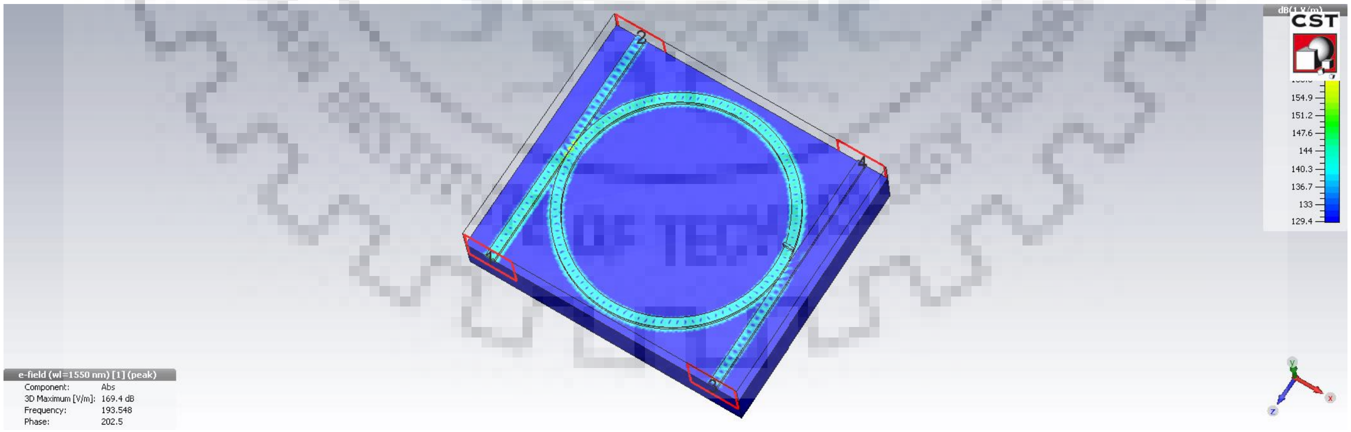
In order to have a clear understanding, here are set of two images to show straight through and coupling effect

- Straight Through



e-field (f=193.44) [1]
Component: Abs
3D Maximum [V/m]: 47.65e+06
Frequency: 193.44
Phase: 0

- Coupled / Cross



e-field (wl=1550 nm) [1] (peak)
Component: Abs
3D Maximum [V/m]: 169.4 dB
Frequency: 193.548
Phase: 202.5

Unit 3: Phase Change Material

3.1 Introduction: -

What is phase change material?

Phase change materials are those materials that change phase from one phase to other phase at a particular temperature. The phases can be two or more than two and the material can be switched among these phases. A large amount of heat is required to melt PCMs and large amount of heat is released when it freezes.

The different phases have different physical properties such as thermal conductivity, electrical resistivity etc. There is a large resistance contrast between the amorphous and crystalline phases of PCMs. The amorphous phase is highly electrically resistive, while the crystalline phase exhibits low electrical resistivity.

Examples of PCMs are $Ge_2Sb_2Te_5$, Sb_2Te, In doped Sb_2Te etc.

Scalability of phase change materials

Since 1960s, the idea of applying phase change materials to electronic memory got its way. But the interest in PCM technology was triggered after the discovery of fast (<100 ns) crystalizing materials such as $Ge_2Sb_2Te_5$. The physical properties of nanoscale materials is different from those of bulk materials and is a function of size. The ratio of surface atoms to volume atoms is greater in nanoscale matter than that in bulk matter. Therefore, the nanoparticles have a lower melting point. The parameters of phase change materials are of great importance for PCM applications. The optical properties are also functions of film thickness. Crystallization temperature is one of the most important parameters of PCMs. It is the temperature at which crystallization is fast. It varies as a function of material composition and thickness of film. Melting temperature is another parameter that varies with material composition and thickness of film. For very thin films, reduction in melting temperature has been observed. This is beneficial for device applications because lower melting temperature needs less power. The thermal conductivity of PCMs reflects the thermal response of a PCM device to an optical/electrical pulse. So it is also an important parameter. The materials which have been studied so far (GST-225, Sb2Te, Ag and In doped Sb2Te), however, show only a slight variation in thermal conductivity values (between 0.14 and 0.17 W/mK for as deposited amorphous state and between 0.25 and 2.47 W/mK for crystalline state) In summary, it has been observed experimentally that

- The crystallization temperature increases as the dimensions are reduced.
- The melting point is reduced as the dimensions are reduced.
- The resistivity increases as the dimensions are reduced.
- The thermal conductivity reduces slowly with the reduction in film thickness.

3.2: $Ge_2Sb_2Te_5$

$Ge_2Sb_2Te_5$ (GST- 225 or GST) is a compound of germanium, antimony and tellurium. It is a phase change material from the family of chalcogenide glasses. GST is found in two states- crystalline and amorphous. The crystalline phase has rock-salt structure. The Ge and Sb atoms occupy Na sites while the Te atoms occupy the Cl sites. GST is used in electrical phase change memory, Rewritable optical discs and DVDs etc.

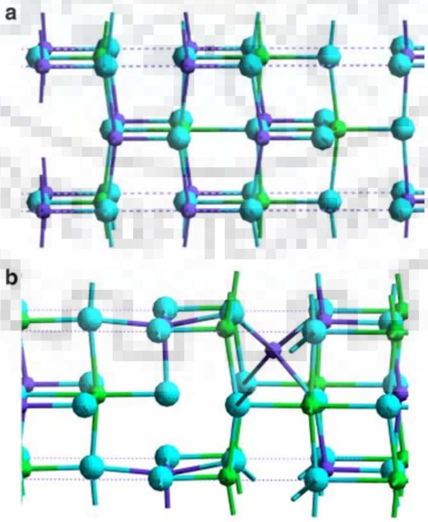


Fig 6 Relaxed rock–salt-like structure of crystalline phase of $Ge_2Sb_2Te_5$.

(b) Relaxed structure of glassy phase of $Ge_2Sb_2T_{e5}$

Unit 4: Simulation Software

Cst studio suite is one of the effective idea implementation stage for a wide range of electromagnetic field issues and related applications. The program gives us an easy to understand interface for dealing with plethora of ventures and perspectives.

The CST STUDIO Suite software package provides the following simulation modules;

- **CST MICROWAVE STUDIO**
- CST EM STUDIO
- CST PARTICLE STUDIO
- CST DESIGN STUDIO
- CST PCB STUDIO
- CST CABLE STUDIO
- **CST MPHYSICS STUDIO**

Structure Modelling: -

CST MICROWAVE STUDIO, CST EM STUDIO, CST PARTICLE STUDIO, CST MPHYSICS STUDIO share a typical structure simulating tool. The primary reason for this part is to give an outline of the structure modeller's numerous abilities.

Postprocessing: -

Once a simulation is completed, result information will appear in the navigation tree. CST STUDIO SUITE contains good postprocessing abilities which incorporate different alternatives for visualising the outcomes and computing auxiliary amounts. It would be ideal if you refer to module particular documentation and the online help framework for more data.

Result Navigator window:

The result window offers a processed data plots to visualise the quantity of showed results and wanted parameter ranges or plot where 0D comes about. Changing the choice in the route tree enables you to review different outcomes process of the dynamic parameter mix determination.

The parametric plotting aid allows for easy access of particular parametric results without need for further complex steps of more advanced post-processing operations. The automatically recorded parametric results can be used directly for optimization.

The solvers enlisted in CST EMC STUDIO are selected to allow a wide range of E.M.C. workflows to be carried out in straight forward fashion.

- The TLM (transmission line matrix) solver is time domain method which especially is well suited to E.M.C. simulations. The TLM solver may use octree gridding to reduce simulation time on extremely complex structures, and supports analytical compact model representation of fine detail.
- Transient solver, which is an application of the Finite Integration technique (FIT),it is general purpose time domain solver (TDS) and is used for performing broadband simulations related to radiated emissions.
- The frequency domain solver is based on the finite element method (FEM), and is often used to simulate conducted emission. The frequency domain solver includes a special meshing engine specially optimized for Printed circuit boards, which allows complex boards for faster simulation than conventional methods.
- Cable harness solver is specialized solver for simulating cables in complex environments. There is bidirectional coupling between cable harness solver and time domain solver, allowing cable harness for integration in a 3D model and analyzed using bidirectional simulation.

Cst microwave studio (CST MWS) is a specialized tool for the 3D Electro-Magnetic simulation of high frequency components. CST MWS’ unparalleled performance making it the first choice in the leading R&D departments.

C.S.T M.W.S. empowers us to perform a faster and more accurate analysis of high frequency (H.F.) simulating structures such as filter, planar and multilayer structures, antenna, coupler, and S.I. and

E.M.C. effects. Exceptionally user friendly, C.S.T M.W.S. quickly gives you an insight into the E.M. behavior of your high frequency designs.

C.S.T. promotes Complete Technology for 3D E.M. Software users are given great deal of flexibility in tackling a wide range of application through a variety of options available in solver technology. Besides this, the broadly applicable Time Domain and the Frequency Domain solver, C.S.T. M.W.S. offers further solver modules for specific applications. Filters for importing specific C.A.D. files and also extraction of S.P.IC.E. parameters enhance design possibilities and save time. In addition, C.S.T. M.W.S. can be utilized in various industry standard workflows through the CST .

Post-processing Formats: -

The post-processing Formats take into account adaptable handling of 2D/3D Fields, 1D Signs, or scalar qualities. All characterized post processing Layouts are assessed after each count amid parametric scopes and enhancements. The ascertained information is then put away parametrically to take into account adaptable access to the whole informational collection.

Unit 5: Methodology

To start with the hybrid silicon ring resonator structure I considered following steps as mentioned chronologically

To construct Add drop ring resonator I started with simulation of straight waveguide of standard dimensions with a set of few other dimension changes relating to cross section area and the length of the waveguide.

This was followed by learning to simulate a simple All Pass Filter learning what are the results how to interpret and assuming and simulating certain set of parametric changes in order to qualitatively increase intended results.

This was followed by experimentation with Add and Drop Ring Resonator with a wide range of parametric changes and constant monitoring of results with the change in parameter.

Next step was introduction of G.S.T. material its two states a little background reading, with the guide's insight I assumed G.S.T. physical dimensions and obtaining standard optical properties.

G.S.T. cell's position and physical dimensions were altered in specific range and result was monitored.

Further paper reading and insights from research scholars I experimented with silicon waveguide cross section area dimensions. It helped me with filtering of specific wavelength, which is a big step in quality improvement over past.

After performing all the simulations result plotting and observation and analysis was performed.

Task Performed	**Variation performed**	**Simulation performed / Time required**
Straight waveguide	Cross section area (220-300nm)x(300-500nm)	4 / 1 hour
All Pass ring	gap variation (10-160 nm)	15 / (15 * 4 hrs)
Add and Drop ring	gap variation (10-250 nm)	30 / (30*4 hrs)
Add and Drop ring	GST length (60 – 160nm)	9 *2*30 / (540*4 hrs)
Add and Drop ring	Ring radius (5um to 15 um)	16*2 / (2*720 hrs)
Add and Drop ring	GST angle (0-315(in degree))	17*2 / (34 * 4 hrs)
GST position change	gap variation (10-160 nm)	15*2 / (15 *2* 4 hrs)
GST position change	GST length (60 – 160nm)	9*2*15 / (15 * 2*9*5 hrs)
GST position change	GST width (50nm – 3um)	6*9*2*15 / (6*15 * 2*9*5 hrs)
Result Analysis		5 days

Table 1 Task performed

Simulations performed 2575

Time required for simulations 14837 hours

Unit 6: Results

Results under this section are for structural dimensions

- **Straight Waveguide (220 nm) x (450 nm) x (12 um)**
- **Ring 5 um to 15 um (parameter variation)**
- **GST (60 to 140 nm) x (220 nm) x (450 nm)**

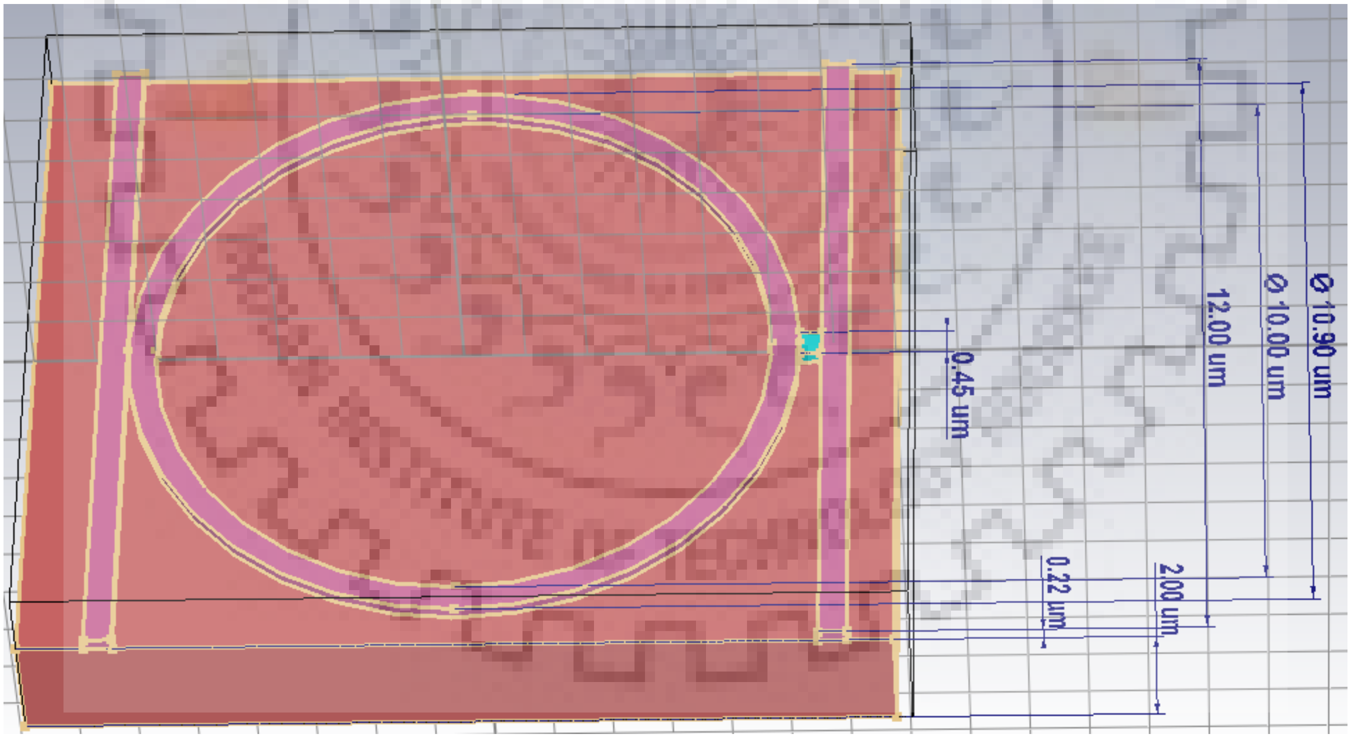


Figure 7 Experimental MRR structure with dimensions

Extinction Ratio at Add port for different lengths of GST.

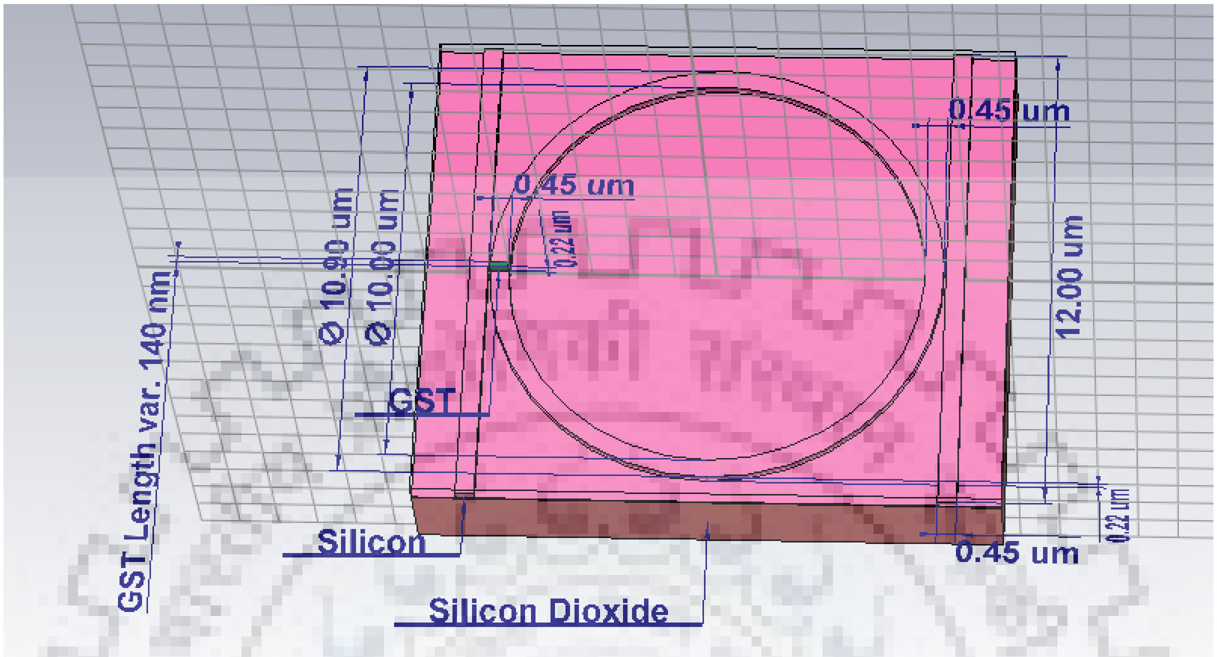
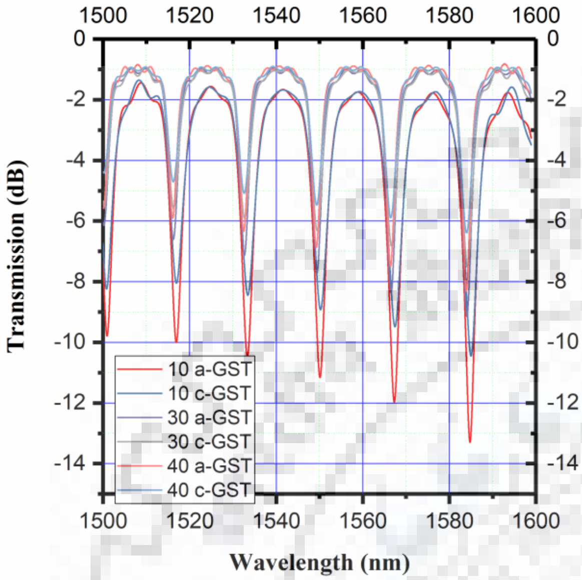
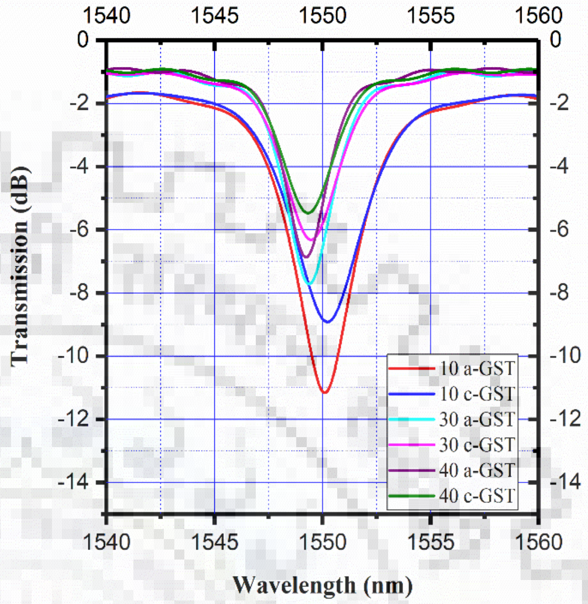


Figure 8 Extinction Ratio at add port for different GST length

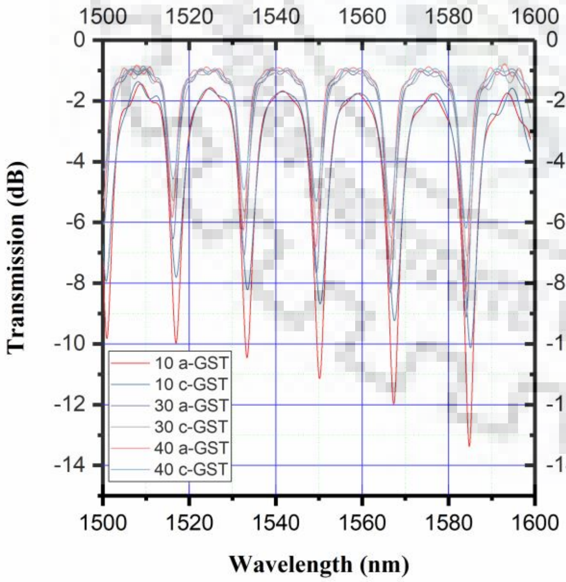
Parameter GST length (nm)	Parameter varied with GST length Variation (nm)
60	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
70	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
80	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
90	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
100	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
110	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
120	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
130	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
140	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
150	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
160	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160

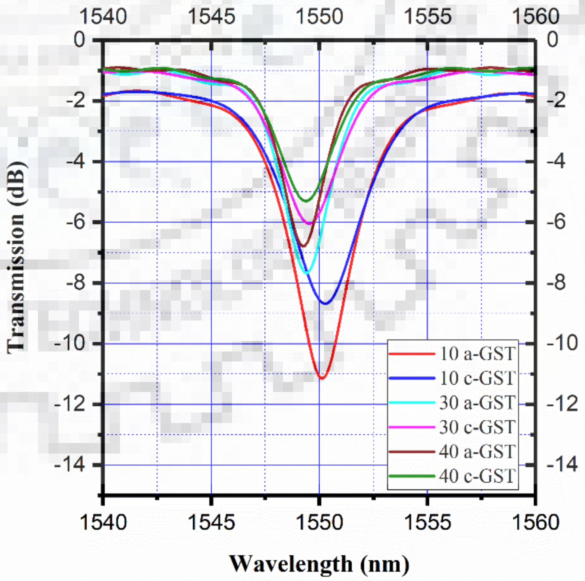
- GST LENGTH = 90 nm



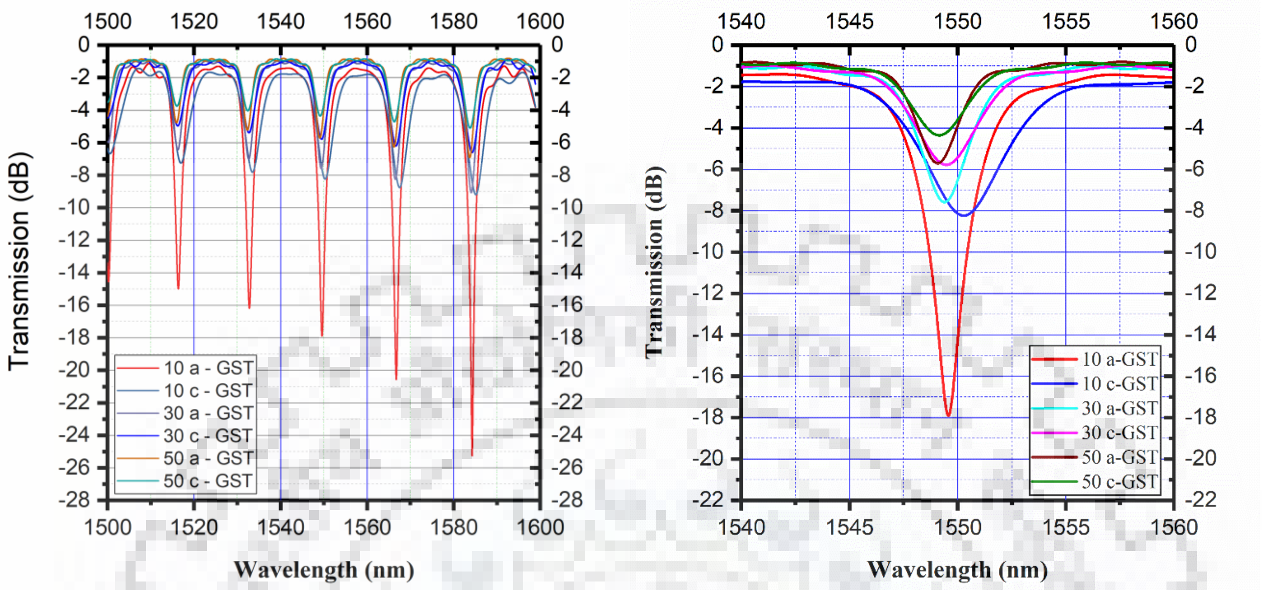


- GST LENGTH = 100 nm

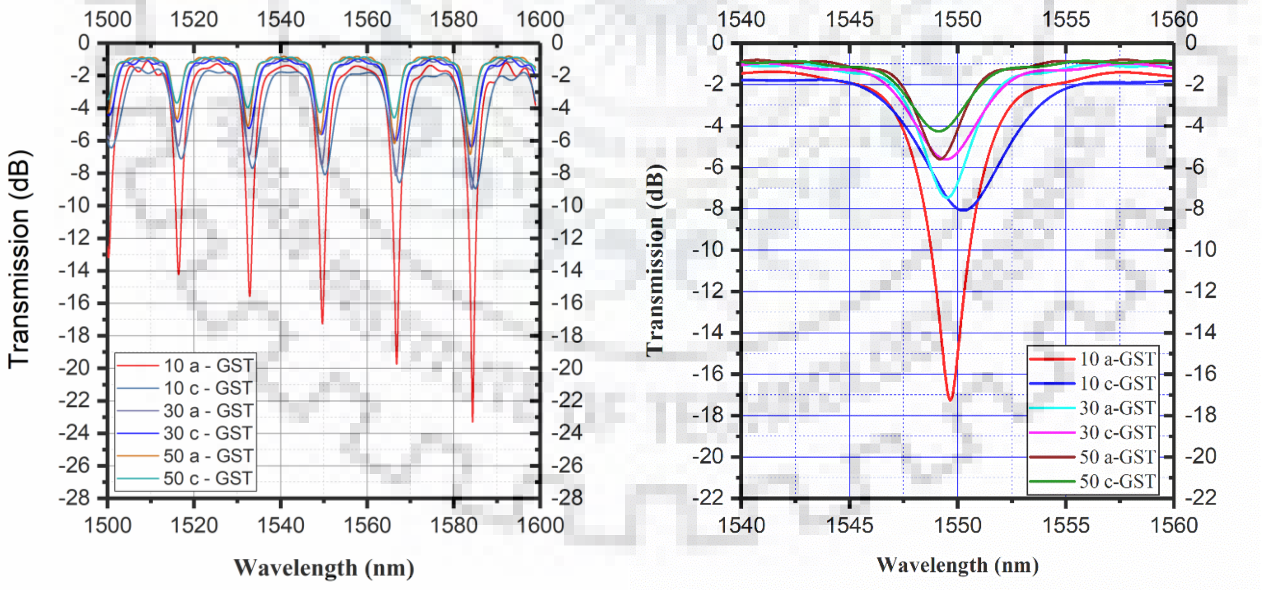




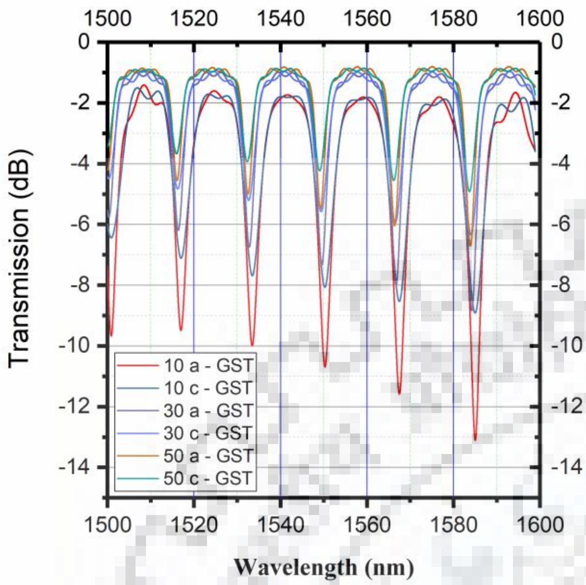
- GST LENGTH = 110 nm

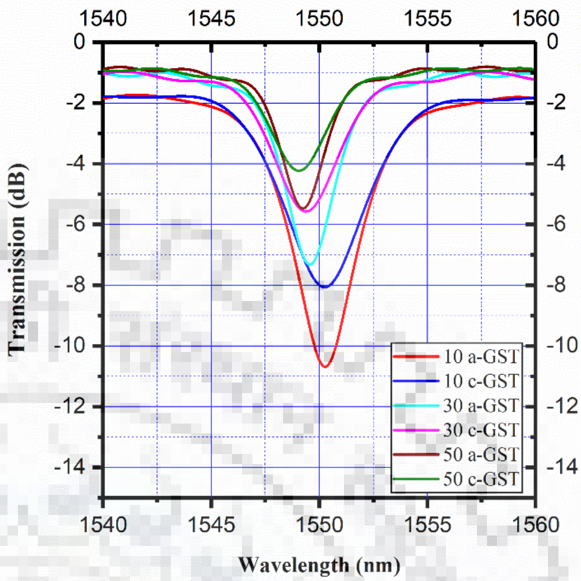


- GST LENGTH = 120 nm

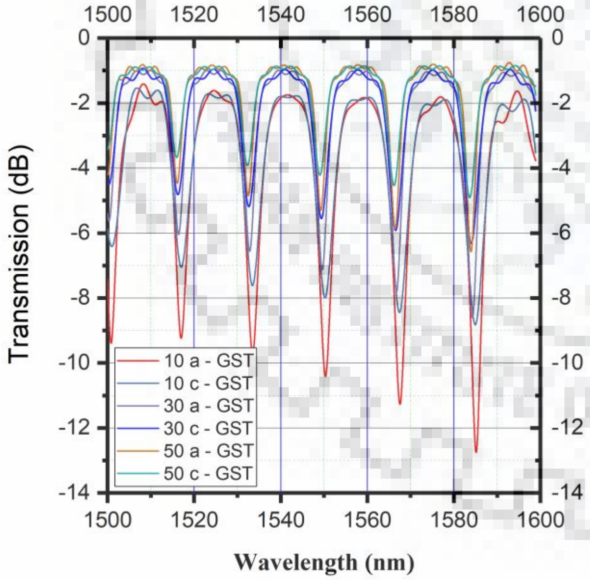


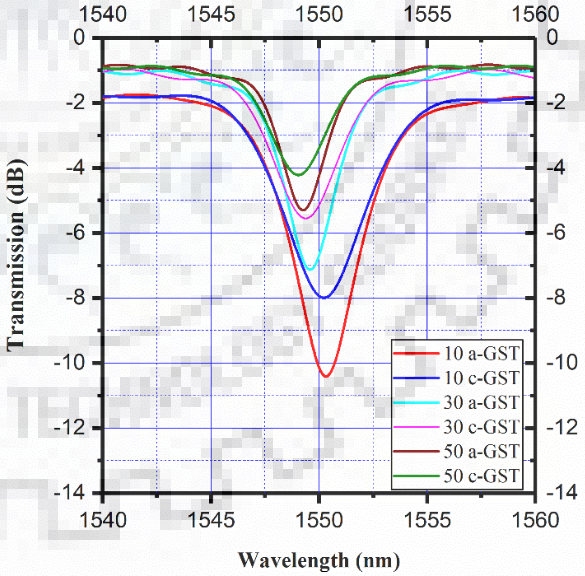
- GST LENGTH = 130 nm



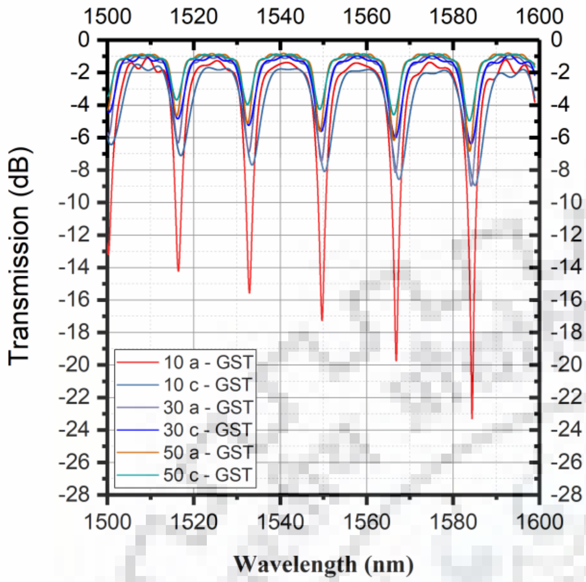


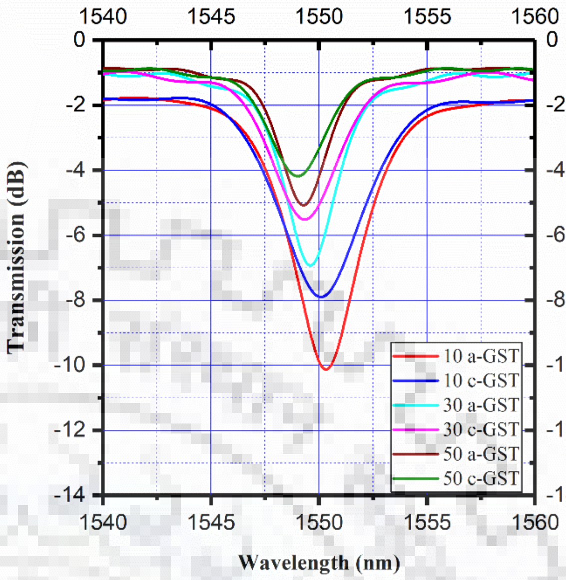
- GST LENGTH = 140 nm



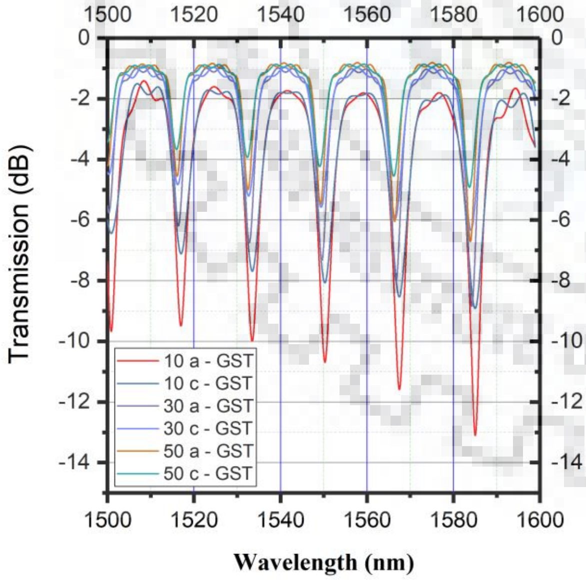


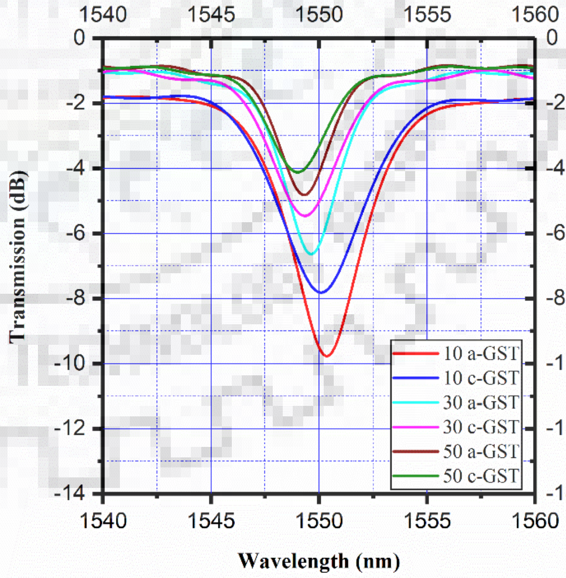
- GST LENGTH = 150 nm





- GST LENGTH = 160 nm





Numerical Interpretation

Parameter variation For highest extinction ratio difference		**Wavelength corresponding to highest extinction ratio difference (in nm)**	**extinction ratio (in dB)**	**extinction ratio at 1550 nm (in dB)**
GST Length (in nm)	**Best gap (in nm)**			
60	10	1584.4535	-3.06387	-2.31488
70	10	1584.4429	-3.14716	-2.30068
80	10	1584.5268	-2.96226	-2.22828
90	10	1584.5895	-3.09578	-2.29576
100	10	1584.6524	-3.52364	-2.5217
110	10	**1584.2651**	**-16.88778**	-6.25521
120	10	1584.3907	-14.77219	**-7.13922**
130	10	1585.0399	-4.19016	-2.46194
140	10	1585.1866	-3.97533	-2.18673
150	10	1585.3123	-3.8247	-1.97751
160	10	1585.5009	-3.38966	-1.67853

Table 2

Extinction Ratio at Drop port for different lengths of GST.

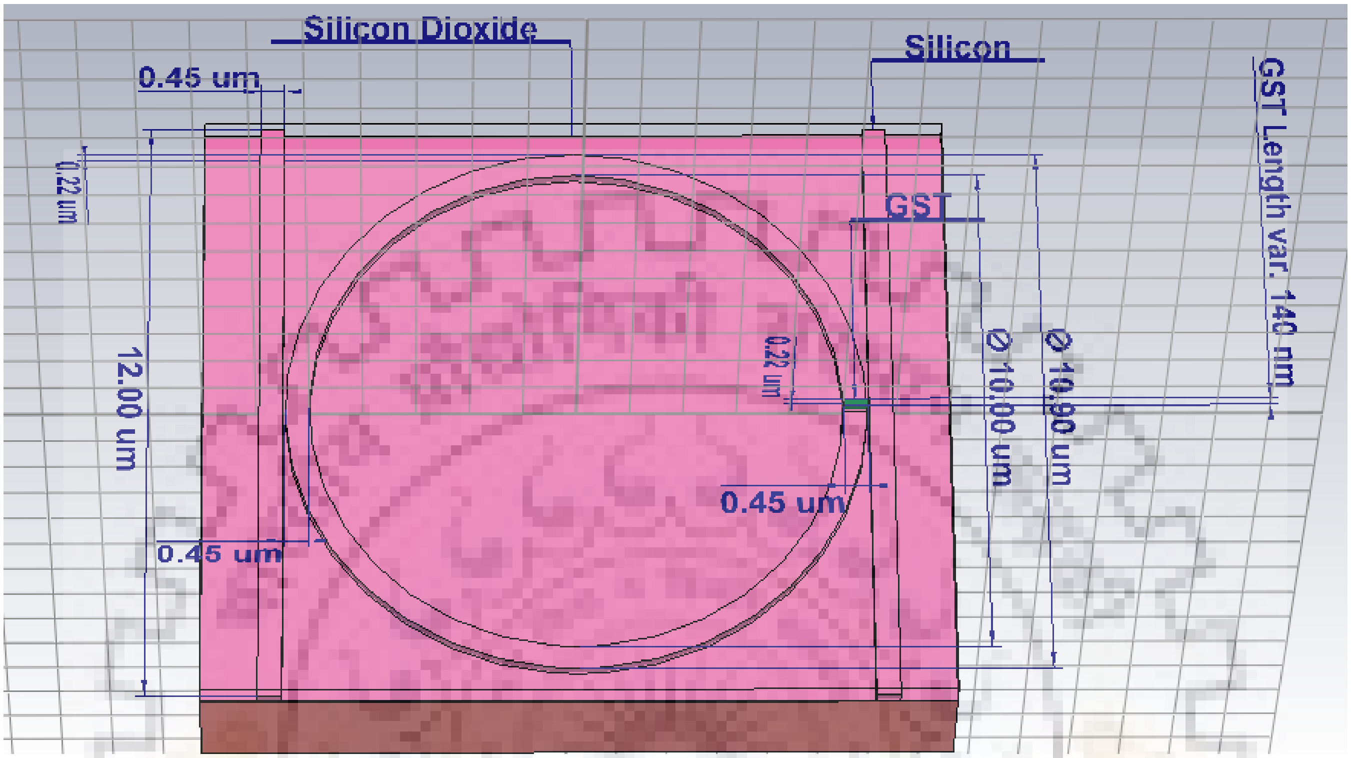
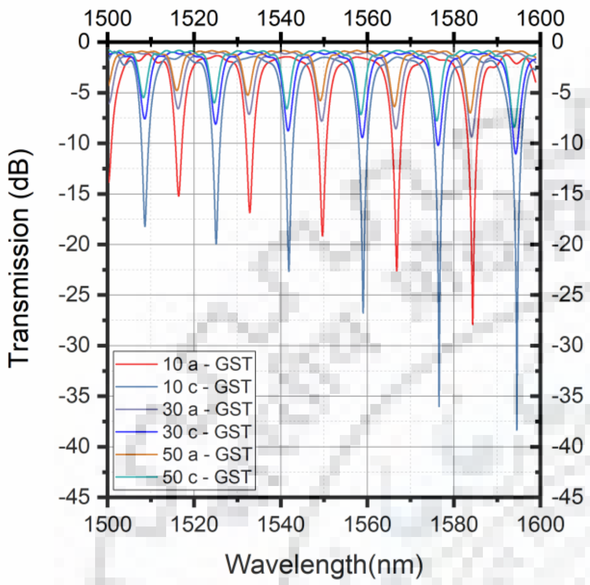


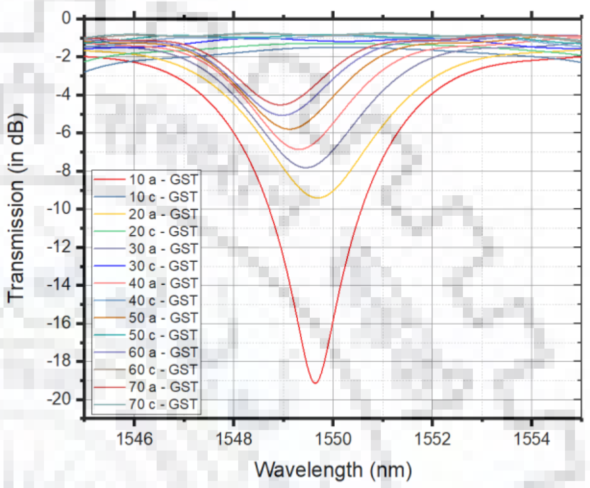
Figure 9

Parameter GST length (nm)	Parameter varied with GST length Variation (nm)
60	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
70	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
80	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
90	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
100	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
110	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
120	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
130	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
140	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160
150	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160

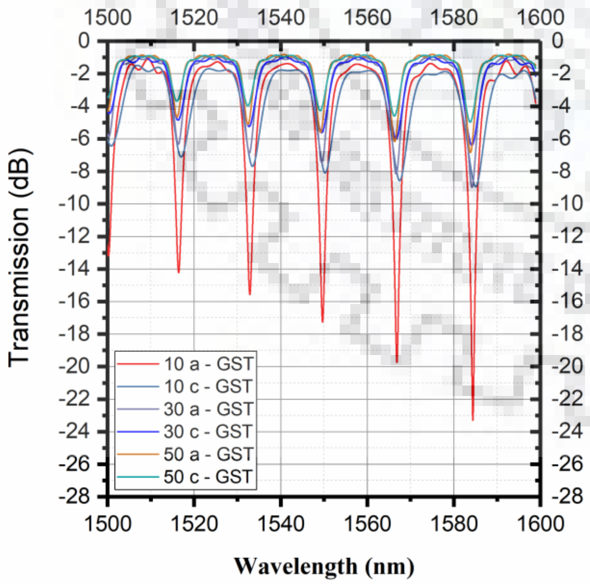
160	0,10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160

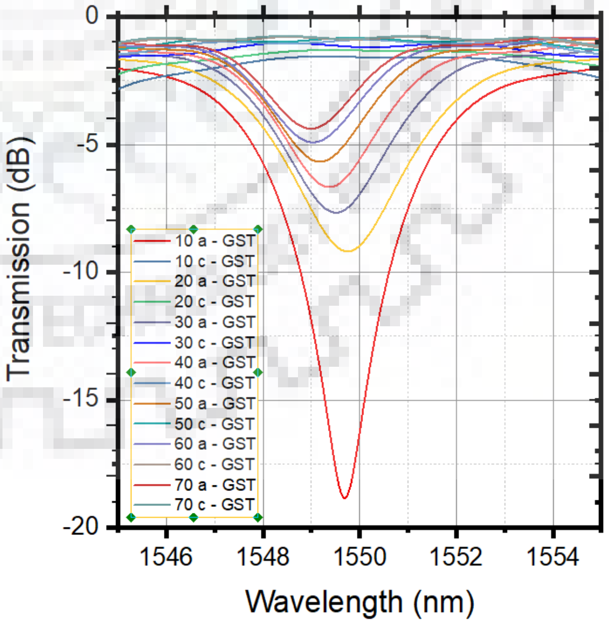
- GST LENGTH = 110 nm



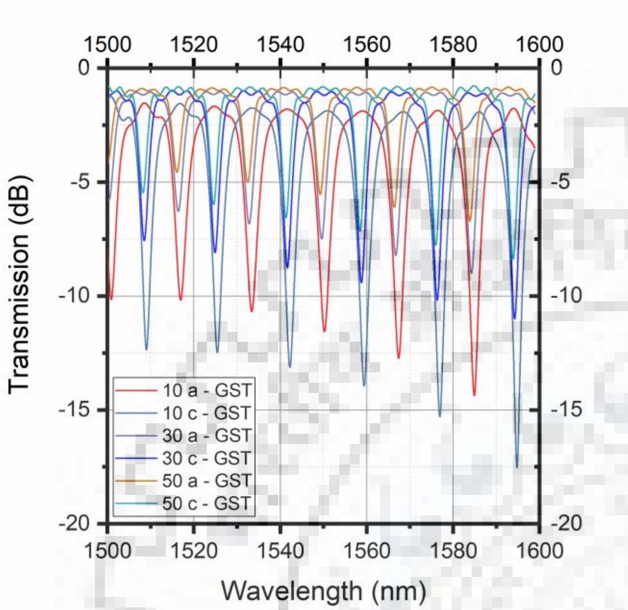


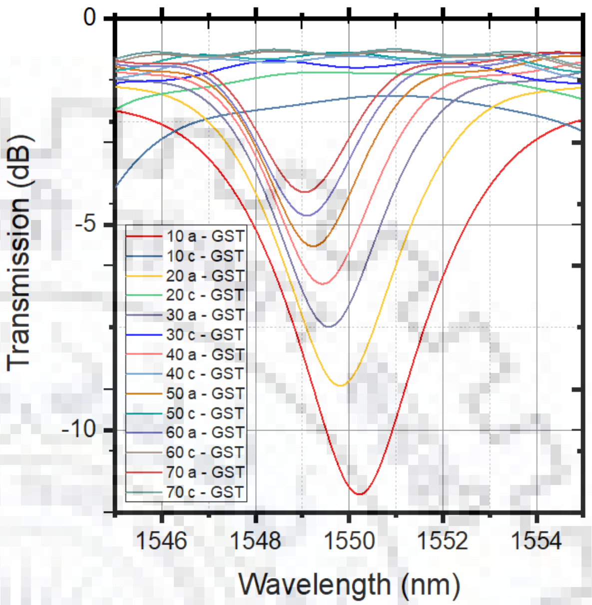
- GST LENGTH = 120 nm



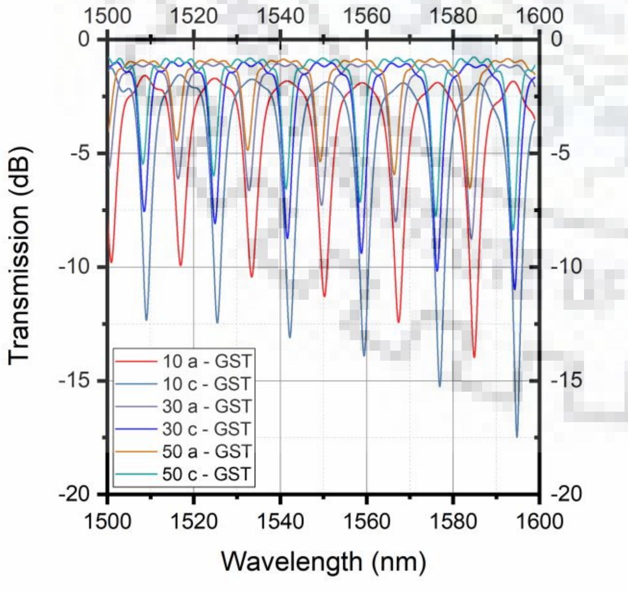


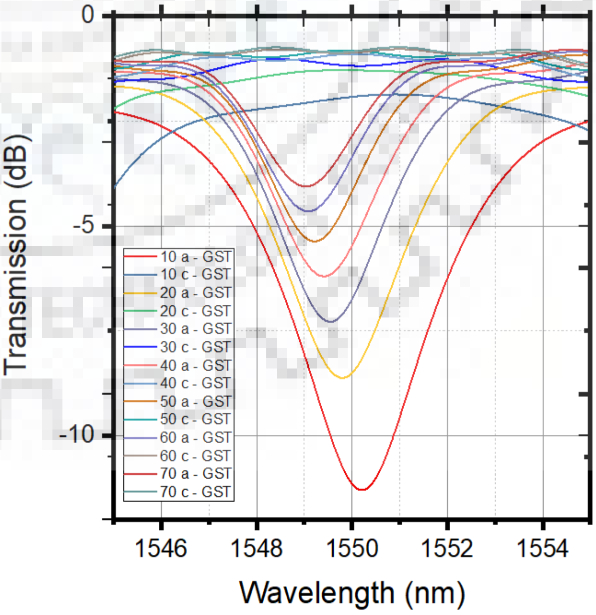
- GST LENGTH = 130 nm



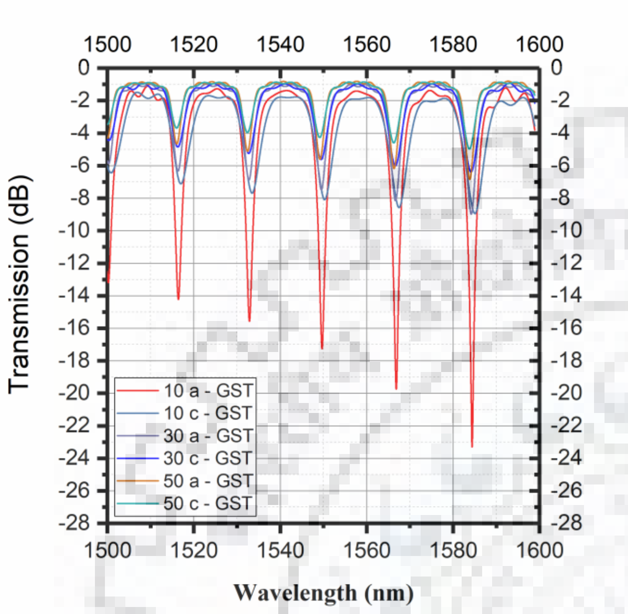


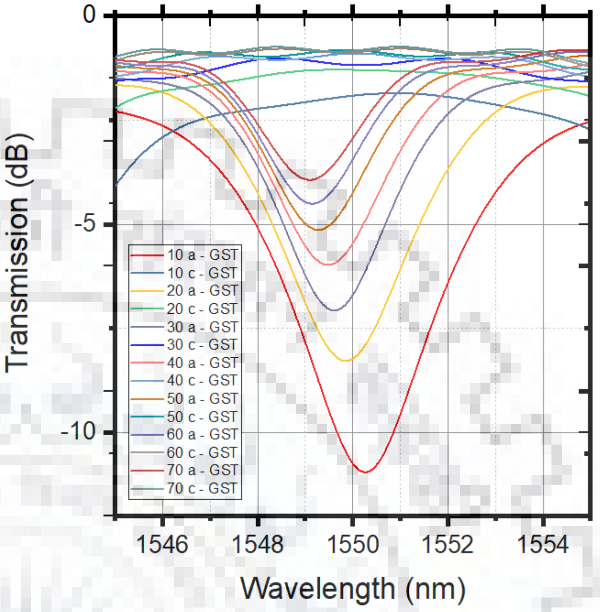
- GST LENGTH = 140 nm



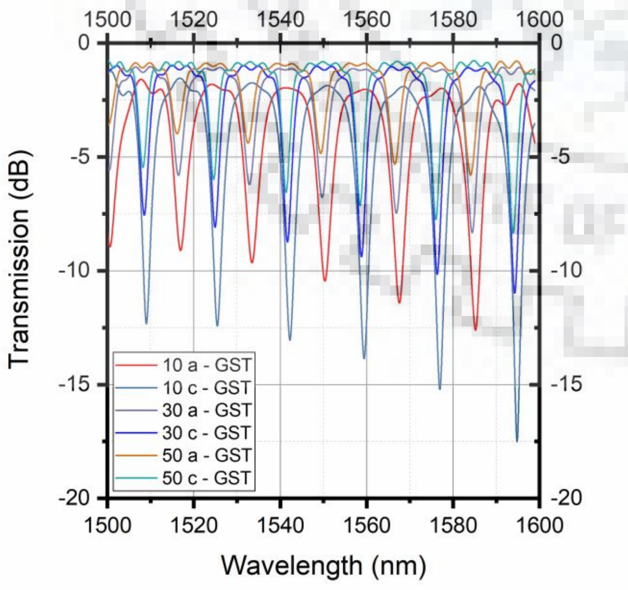


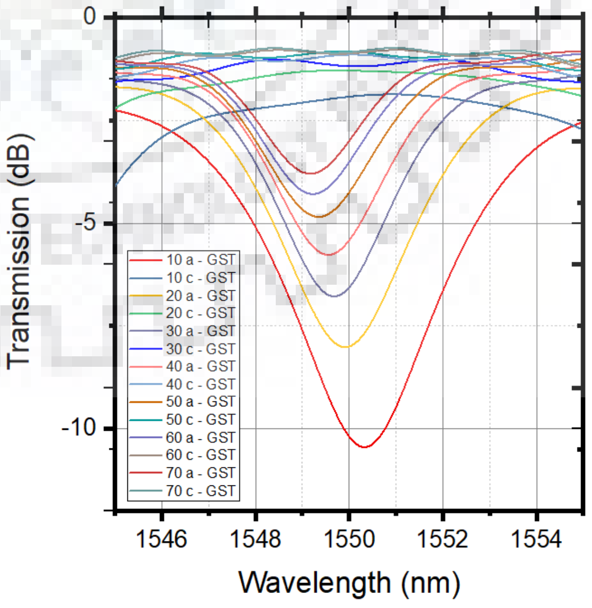
- GST LENGTH = 150 nm





- GST LENGTH = 160 nm





Parameter variation		Wavelength corresponding to highest extinction ratio difference (in nm)	Extinction Ratio difference (in dB)	Extinction Ratio around 1550 nm (in dB)
GST Length (in nm)	Best Gap (in nm)			
110	10	1584.3489	-26.47875	-14.43023
120	**10**	1584.3697	**-27.39165**	**-14.76539**
130	10	1584.9142	-12.27588	-9.45006
140	10	1584.9037	-11.87317	-9.21831
150	10	1585.0084	-11.50179	-8.82385
160	10	1585.2075	-10.57834	-8.265
170	20	1583.5328	-8.87427	-4.91577

Table 3

Extinction Ratio at Add port for different Radius of Ring, for 10 nm gap, and GST length of 60 nm.

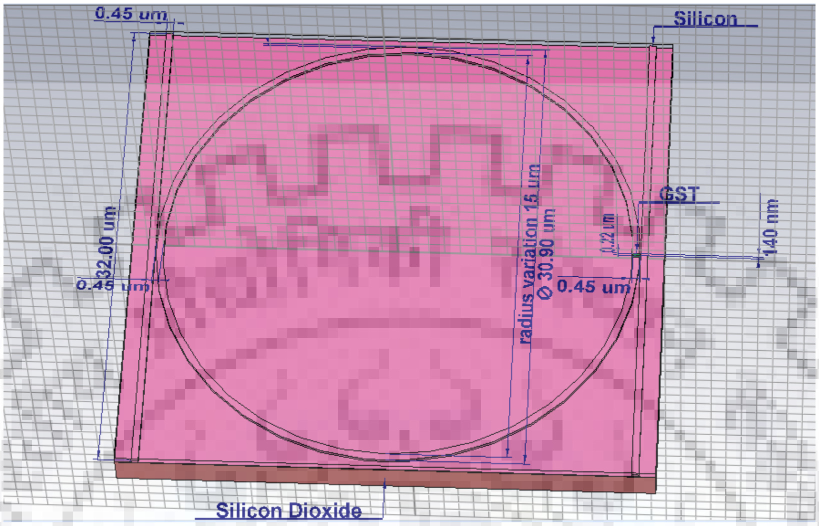
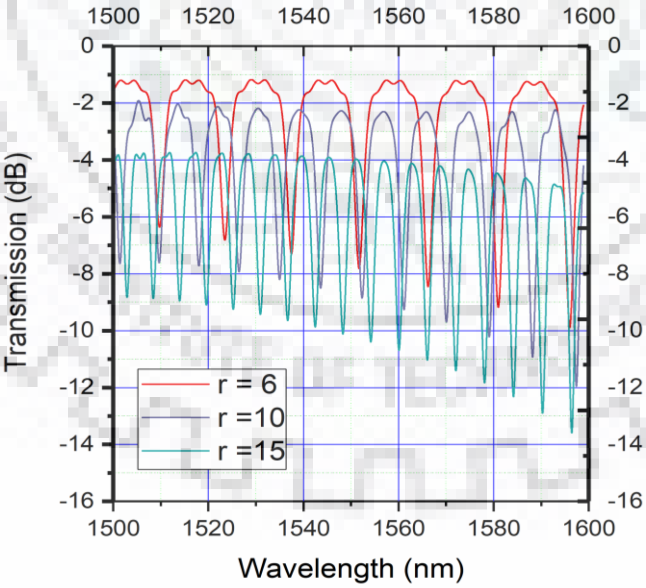


Figure 10 Radius Variation R= 5 um



Radius change (in nm)	**Wavelength corresponding to highest extinction ratio (in nm)**	**Extinction Ratio (in Db)**	**Extinction Ratio at 1550 nm(in dB)**
5	1595.9991	-9.88523	-2.98139
6	1593.3589	-9.83535	-1.54565
7	1591.0966	-10.05115	-2.02668
8	1589.4202	-10.36216	-8.28482
9	1597.4022	-11.95099	-2.83722
10	1595.4045	-10.93944	-2.70047
11	1593.7929	-11.24351	-5.38403
12	1592.4491	-11.61004	-6.62411
13	1597.8599	-12.23519	-3.68934
14	1596.4345	-13.59051	-4.64305
15	1595.2771	**-14.24121**	**-10.48658**

Table 4

Extinction Ratio at Different positions of GST material, for 60 nm length of GST.

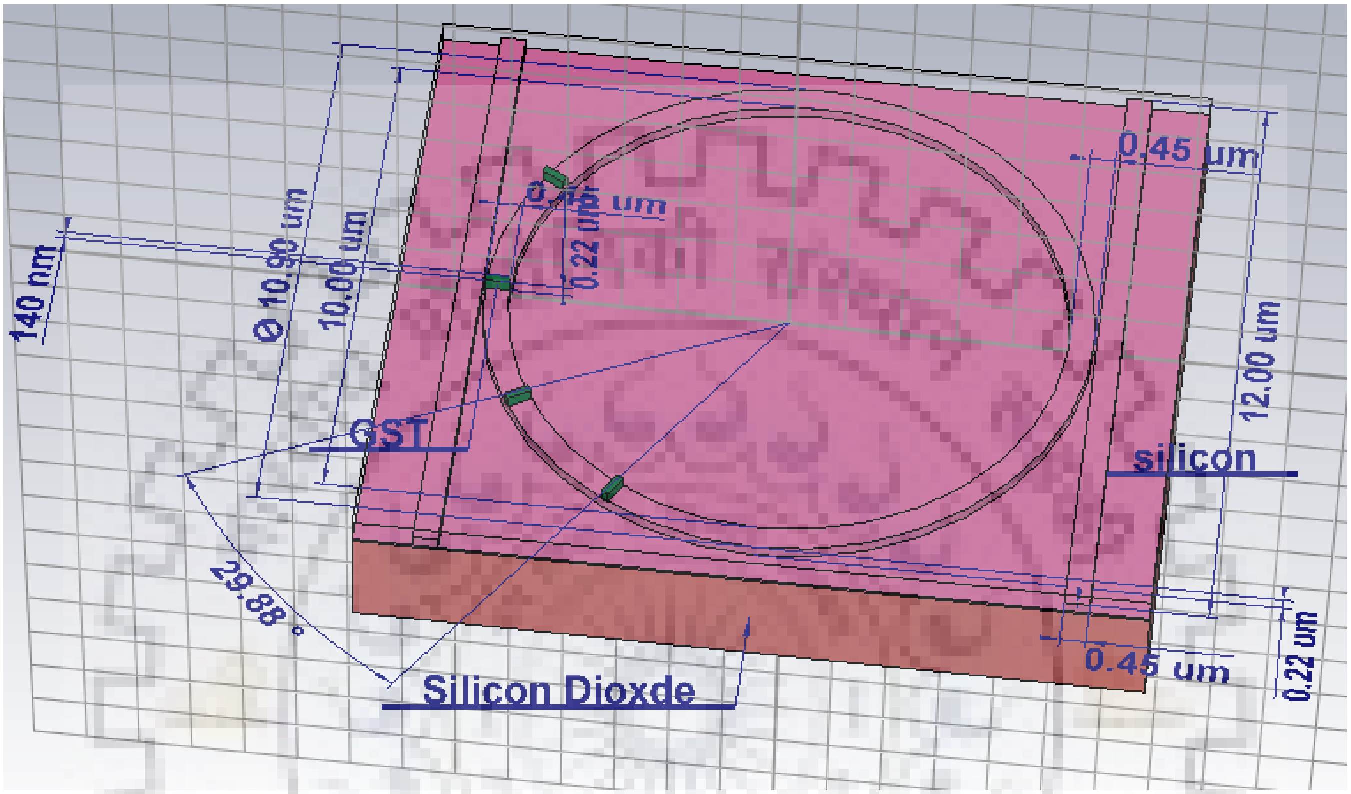
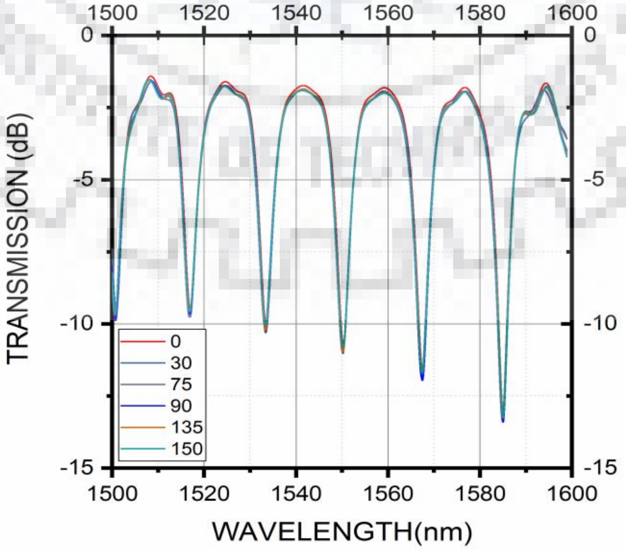


Figure 11 Angle variation



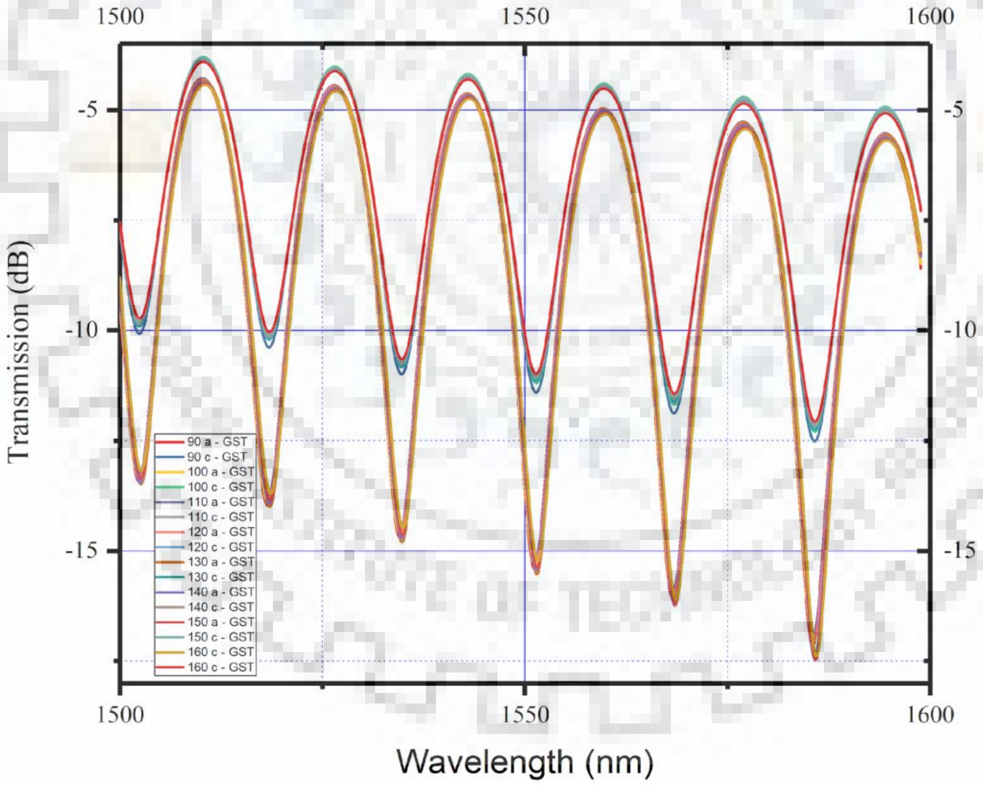
Angle variation (in nm)	**Wavelength corresponding to highest extinction difference(in nm)**	**Extinction Ratio (in dB)**	**Extinction Ratio around 1550 nm (in dB)**
0	1585.0293	-13.10559	-10.45198
30	1584.8827	-13.33	-10.92592
45	1584.8618	-13.36343	-10.91726
60	1584.9455	-13.46868	-10.85121
75	1584.8723	-13.27876	-10.93301
90	1585.0189	-13.40193	-10.77395
105	1584.9037	-13.45431	-10.95319
120	1585.0084	-13.17161	-10.75365
135	1584.9874	-13.26934	-10.82748
150	1585.0293	-13.23368	-10.67461
165	1584.8618	-13.37437	-10.93583
180	1584.9874	**-14.01456**	**-11.05945**
195	1584.9245	-13.70546	-11.02455
210	1584.8618	-13.33993	-10.91098
225	1584.9561	-13.2558	-10.87601
270	1585.0608	-13.285	-10.70656

315	1585.0189	-13.15736	-10.79704

Table 5

Results under this section are for structural dimensions

- **Straight Waveguide (220 nm) x (450 nm) x (12 um)**
- **Ring 5 um**
- **GST (90nm to 160 nm) x (220 nm) x (450 nm)**
- **Gap between the Ring and straight waveguides (0 nm)**



Parameter variation (in nm)	**Wavelength corresponding to highest extinction ratio difference (in dB)**	**extinction ratio difference (in dB)**	**extinction ratio around 1550 nm (in dB)**
90	1585.6581	-4.81219	-2.92489
100	1585.3857	-4.69859	-3.24822
110	1585.4695	-4.80782	-3.24673
120	1585.5533	-4.6396	-3.03099
130	1585.8259	-5.11519	-2.74479
140	1585.7734	-5.28413	-2.92162
150	1585.9098	-5.37729	-2.73112
160	1586.0672	-5.35826	-2.49837

Table 6

Results under this section are for structural dimensions

- **Straight Waveguide (220 nm) x (480 nm) x (12 um)**
- **Ring 5 um**
- **GST (60nm to 130 nm) x (220 nm) x (500 nm to 3 um)**

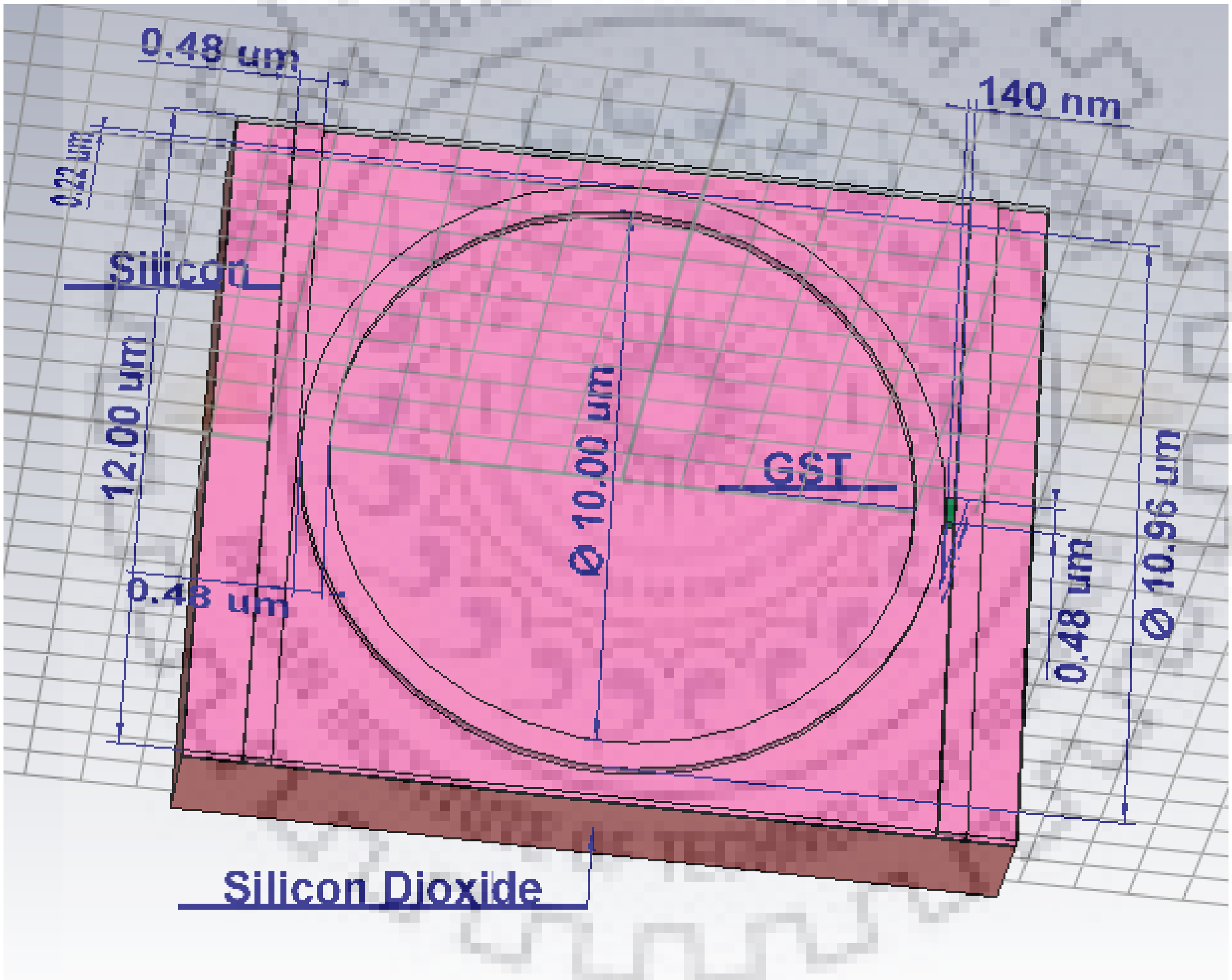
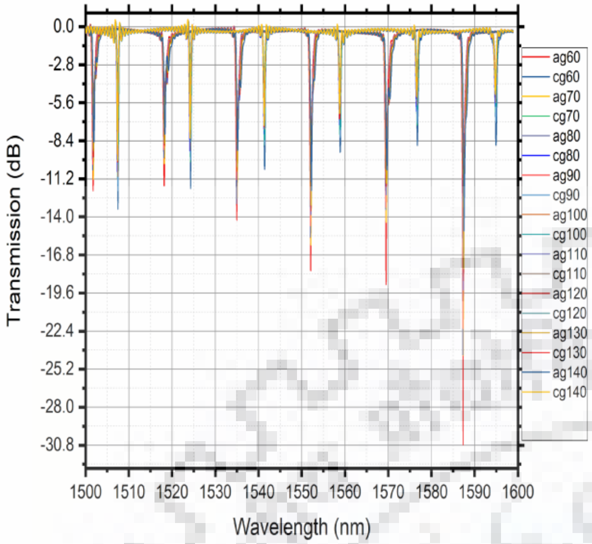
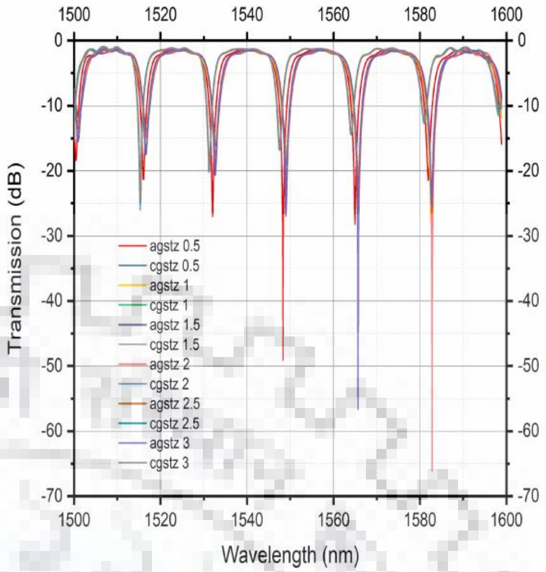


Figure 12 GST placed between Ring and bus WG





Parametric Variation (GST z) in (um)	Wavelength corresponding to Max Extinction ratio difference	Max Extinction ratio difference	Extinction ratio difference at 1550 nm wavelength
0.5	1584.3348	-39.97776	-2.78367
1.0	1582.5716	-23.07368	-6.94307
1.5	1582.7699	-24.39205	-8.22114
2.0	1582.8118	**-62.33957**	-7.95537
2.5	1565.7411	-40.71991	-7.29033
3.0	1565.6696	-51.9822	-6.65118

Table 7

Unit 7: Observation and Conclusion

The objective of this work was to optimize the dimensions of GST cell for switching application. Firstly, the propagation properties of silicon waveguide (rectangular) have been analysed without GST and then with GST. The dimensions of GST cell for amorphous and crystalline phases have been optimized considering the coupling of power between silicon waveguide and GST film.

Task Performed	**Variation performed**	**Best parameter observed**
Straight waveguide	Cross section area (220-300nm)x(300-500nm)	220 nm x 480 nm
All Pass ring	gap variation (10-160 nm)	10 nm
Add and Drop ring	gap variation (10-250 nm)	10 nm
Add and Drop ring	GST length (60 – 160nm)	110nm and 120nm
Add and Drop ring	Ring radius (5um to 15 um)	15um
Add and Drop ring	GST angle (0-315(in degree))	180 degree
GST position change	gap variation (10-160 nm)	10 nm
GST position change	GST length (60 – 160nm)	110nm and 120nm
GST position change	GST width (50nm – 3um)	2 um

Table 8

After performing 2575 Simulations I have observed sensitive and less sensitive parameters

Sensitive parameters	**Less sensitive parameters**
Cross section area	GST Angle Position (when GST is placed over the silicon waveguides)
Gap	GST length (apart from range of 90nm to 120 nm)
GST length (in range of 90nm to 120 nm)	
GST width (in range of 2um)	
Radius	

Table 9

From simulation results-

Maximum extinction ratio in amorphous phase = -64.79827 dB

Corresponding extinction ratio in crystalline phase = -2.4587 dB

So Maximum extinction ratio difference = $\text{ER}_{\text{amorphous}} - \text{ER}_{\text{crystalline}}$

$= -64.79827 \text{ dB} - (-2.4587 \text{ dB})$

$= -62.33957 \text{ dB}$

The maximum extinction ratio difference obtained is 62.33957 dB

Future Scope

If I continue this project further or anyone interested in continuing this work. I would like to suggest to work on following parameters

- Power calculation
- Wavelength filter improvement
- Thermal Simulations
- Radius Size reduction
- Circuit implementation
- Sequence generation of digital signals
- Fabrication

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