Design of Ultra Compact 4:2 Encoder using Two Dimensional Photonic Crystals

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Abstract

In this paper all optical ultra compact 4:2 encoder is proposed and designed using two dimensional photonic crystals. The proposed structure has silicon rods of refractive index of 3.4 embedded in air host by creating line defects in hexagonal lattice platform. PWE method is used to determine the photonic band gaps and structure is analyzed using FDTD method. Further, the proposed 4:2 encoder is operated at 1550 nm and it provides a high contrast ratio of 9.25dB and foot print of the structure is 119.34 μm^2. Hence it is highly advisable for photonic integrated circuits and optical signal processing.

1. Introduction

In today's communication network the prime aim is to accomplish ultra-fast transmission speeds. Hence all epistle steps on the network that is data transferring and processing information, should be executed in a full optical form [1–2]. Photonic crystal (PC) is chosen as the suitable platform for designing optical devices because of its features such as lifetime, flexible design, good temperature resilient, low radiation loss and low group velocity [3]. The other platforms that are highly suitable for photonic integrated circuits are Planar Light wave Circuits (PLC), Plasmonics, Micro Electro-Optical-Mechanical- systems (MEOMS) [4].

Photonic crystal is nano optical composition with two different materials combined in a single substrate to direct the signal of light into a nanostructure [4]. Photonic crystal basic characteristic is its Photonic Band Gap (PBG) concept by which the light property can be changed at an optical wavelength. The types of photonic crystals based on fabrication, are 1D, 2D and 3D among which 2D PC is highly attractive because other optical devices can be easily integrated with it. Hence can be used efficiently to build various photonic devices such as logic gates [5], sensors [6, 7], flip flops [8], filters [9] and encoders [10–19].

The designing mechanism of photonic crystal based devices can be of three types. The first type is interference effect method. The second method is making use of materials having non-linear properties in nano resonators and ring resonators. The third method is self collimation effect. In a communication network the encoder is used to generate the binary code in analog to digital convertor. In literature all optical encoders are realized by using 2 dimensional photonic crystals with various techniques such as self- collimation [10], the interference [16, 18] and nonlinear effect [5, 6]. The encoders designed by self – collimation method requires phase shifters which results in to large foot prints so the cost of the device will be more. The encoder designed by using nonlinear materials occupies less area which in turn reduces the cost of the devices. In 2015 Moniem designed a optical 4 to 2 encoder by combining a T waveguide with four resonant rings and the designed encoder has a 1225μm^2 of foot print and switching speed is 500GHZ [20]. In the year of 2017 all optical 4 to 2 encoder was designed which is capable of working at mutual wavelengths by using nonlinear materials whose dimension is 240.5 μm^2 and Logic one power is 45% and logic zero power is 5% [21]. In 2018, 4 to 2 encoder was realized by designing a buffer and OR gate [22] which is capable of generating 2 bit binary code and overall footprint is 800 μm^2.

Different optical encoders are designed by using different platforms like square lattice and hexagonal lattice by using photonic crystal ring resonators PCRR till date. The designed resonators are in the form of square, hexagon, ellipse and quasi square [23–30]. These designed encoders need high input power to operate and resulted in to large footprints. In the present work a novel all optical encoder is proposed and designed with 2 nano resonators in the photonic crystal waveguides to reduce the radius of the rods to get all ultra- compact size and to obtain a equal output power in all states.

2. Basic 4:2 Encoder

The encoder executes the reverse operation of a decoder. It has 2^N inputs and N outputs as shown in Fig. 1. Only two values it can have at a time either on/off or 1/0. In a 4:2 encoder only one input is activated (logic 1) at a time and other inputs are inactivated (logic 0) and the equivalent binary coded output is received at the output ports depending upon selected active input line. The four binary inputs of an 4: 2 encoder are [1000], [0100], [0010] and [0001] and its respective binary outputs are [00], [10], [11] and [01] which is clearly presented in the Table.1

Table 1: Truth table of 4:2 encoder

Inputs				Outputs	
I_1	I_2	I_3	I_4	O_1	O_2
1	0	0	0	0	0
0	1	0	0	1	0
0	0	1	0	1	1
0	0	0	1	0	1

3. Structure Of Proposed Optical 4:2 Encoder

The proposed 4:2 optical encoder structure consists of 18x18 arrays that is 18 dielectric rods in x axis and 18 dielectric rods in z axis are used. The Si rods having refractive index n = 3.4 in the air host with refractive index n = 1 and designed in a hexagonal lattice. The proposed design consists of four inputs I_1, I_2, I_3 and I_4 ports, two outputs O_1 and O2 ports and two nano resonators as shown in Fig. 2.

The wafer size of the structure is 11.7μm x10.0μm. PWE method is used to calculate the photonic band gaps (PBG), in order to analyze the optical behavior of the structure. PBG is obtained to be $0.379 \leq a/\lambda \leq 0.599$ which wavelength range is $1065nm \leq \lambda \leq 1683nm$. 1550nm the selected wavelength falls in this range. The Band Gap diagram is exploited for different values of r/a and suitable values of a and r are selected. The value of lattice constant a = 638nm, r (radius of the rod) = 112nm and radius of nano resonators are chosen (r_1 and r_2) to be 58nm and used to conjoin the light into the required output. The area of the proposed structure is 119.34μm^2. In order to get the high and equal power at output the nano resonators are chosen with a value of 58nm. The following Fig. 3 is the refractive index profile of the designed encoder.

The band diagram of design is shown in above Fig. 4.The (PWE) Plane Wave Expansion method is used to determine the band gap of the design.

4. Operating Principle Of 4 To 2 Optical Encoder

All optical encoders are realized by using Gaussian continuous signals with an operating wavelength of 1550 nm. As the ports I_1 to I_4 are used to input the light to the structure, we stimulate the structure by passing the light through one of the port at a time and examine the ports O_1 and O_2 as they are used to obtain the light out from the structure.

Case 1: I_1 port is active.

The input power is applied to port I_1, and power applied in the other input ports are zero as shown in Fig. 5.a. In this case both the output must be zero. Hence in case 1 according to the proposed structure the input does not find the way to the output ports O_1 and O_2 as the port I_1 waveguide is not connected to the output ports. Hence obtained output is almost equal to zero as shown in Fig. 5.b and Fig. 5.c. In order to reduce the size of the structure, the port I_1 is chosen as a short-waveguide.

Figure 5.b and 5.c shows the output at observation point O_1 and $O_2$are 0.03 and 0.06 respectively, which is almost equal to zero as shown in below table.

	I_1	I_2	I_3	I_4	O_1	O_2
Output	Pin	0	0	0	0.03	0.06

Case 2: I_2 port is active

In this case I_2 port power is Pin and the power applied to the other ports are zero as shown in the Fig. 6.a.When the input is applied, the maximum amount of the input power reaches the O_1 output port through the Nano resonator 1 as shown in Fig. 6.b and a small percentage of power passes to the O_2 output port as shown in Fig. 6.c.

	I_1	I_2	I_3	I_4	O_1	O_2
output	0	Pin	0	0	0.473	0.059

The above table shows the simulation results when I_2 is active.

Case 3: I3 port is active

In this case I_3 port power is P_{in} and other ports power are zero as shown in Fig. 7.a. When the input power is applied to the I_3 port, it reaches the O_1 and O_2 output ports through the Nano resonator 1 and Nano resonator 2 as shown in the Fig. 7.b. and 7.c. respectively.

The below table shows the simulation results when I_3 is active.

	I_1	I_2	I_3	I_4	O_1	O_2
output	0	0	0	P_{in}	0.461	0.461

Case 4: I_4 port is active

In this case I_4 port power is P_{in} and other ports power is zero as shown in Fig. 8.a.When the input is applied, the maximum amount of the input power reaches the O_2 output port through the Nano resonator 2 and a small percentage of power passes to the O_1 output port as shown in the Fig. 8.b and 8.c.

	I_1	I_2	I_3	I_4	O_1	O_2
output	0	0	Pin	0	0.060	0.515

Table 2
Truth table of all-optical 4 to 2 encoder.

	I_1	I_2	I_3	I_4	O_1	O_2
Output1	P_{in}	0	0	0	0	0
Output1	0	P_{in}	0	0	0.473	0.059
Output1	0	0	P_{in}	0	0.461	0.461
Output1	0	0	0	P_{in}	0.060	0.515

Table 2 represents the summary of output obtained in all the four cases. As shown in the above table, we can cross verify the values with the table 1.

The Fig. 9 represents the contrast ratio of designed encoder by varying the lattice constant. Initially the material Si is considered and varied the lattice constant by keeping the rod radius and radius of nano resonators constant and calculated the contrast ratio for different lattice constants. Secondly the material Ge is considered and varied the lattice constant by keeping the rod radius and the radius of nano resonators constant and determined the contrast ratio. From the above it is clear that the proposed encoder gives good results with the Si material.

Table 3
comparison of the proposed optical 4 to 2 encoder results with previous work done so far.

References	Lattice structure	Encoder type	Material	Contrast ratio (dB)	Dimension in μm^2
9	Square	4 to 2	Si	7.84	3795
11	Triangular	4 to 2	Si	15	625
12	Rectangular	4 to 2	GaAs	-	1927
13	square	4 to 2	si		1225
14	square	4 to 2	si	-	240.5
15	Hexagonal	4 to 2	Si	5.7	218.2
16	Square	4 to 2	Si	9.2	795.6
17	square	4 to 2	BTO	7.11	174.24
19	Rectangular	4 to 2	si	-	800
20	Hexagonal	4 to 2	Si	6	132
Present work	Hexagonal	4 to 2	Si	9.25	119.34

From the above table, it is very clear that the proposed 4:2 encoder has high contrast ratio as well as small dimension.

5. Conclusion

In the proposed design of all optical 4:2 encoder, utilizes the low input power as non-linear material is not used. The overall foot print of all-optical encoder structure is stingy and equal to 119.34μm^2 and the contrast ratio obtained is 9.25 dB. The structure designed is very simple and compact. These amenities prompt it feasible to employ this 4 to 2 encoder in Photonic integrated circuits and optical computing.

Declarations

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Figures

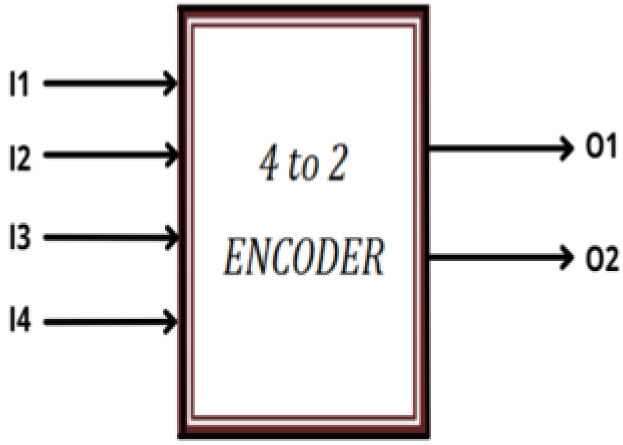

Figure 1

Logic representation of 4: 2 encoder

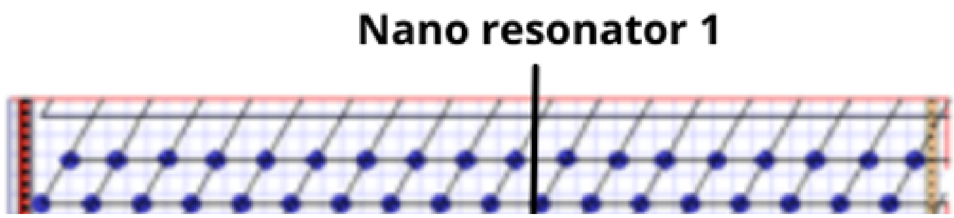

Figure 2

The proposed Optical 4 to 2 encoder structure

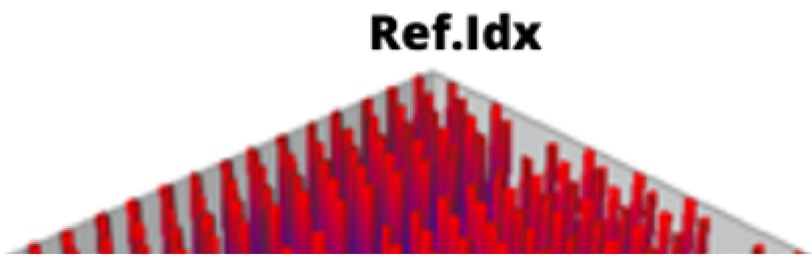

Figure 3

Refractive index profile of the proposed design

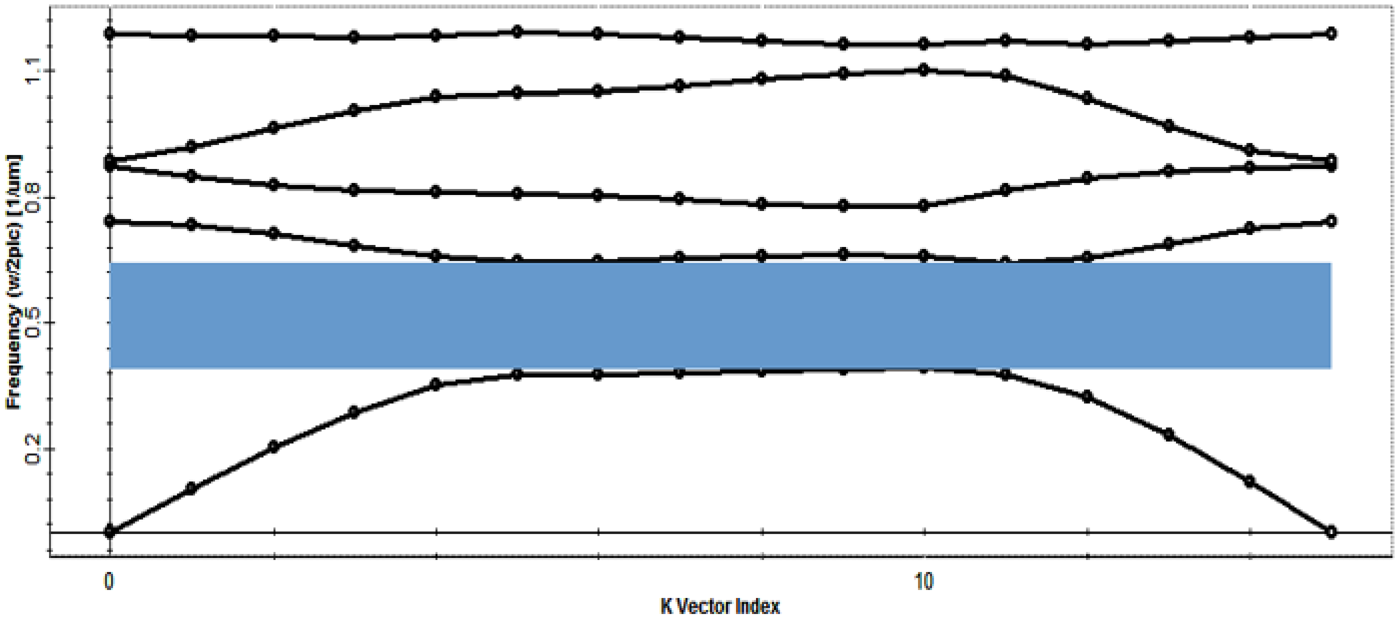

Figure 4

TE band diagram of the proposed design

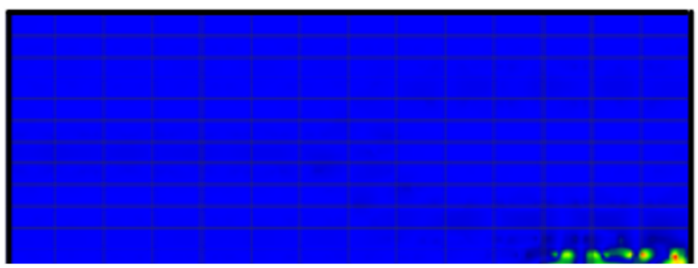

Figure 5

a: The electromagnetic field pattern when the input port I_1 is active

b and c: Output at observation point O_1 & O_2

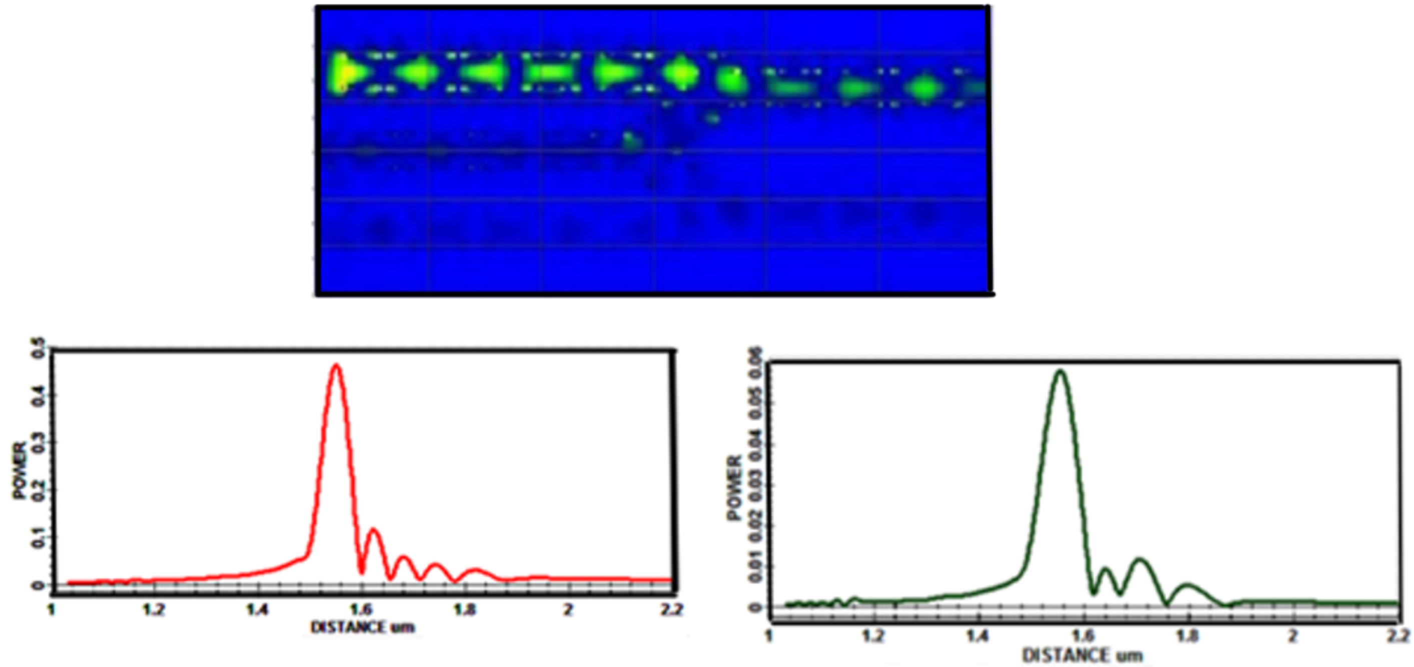

Figure 6

a: The electromagnetic field pattern when the input port I_2 is active

b & c: Output at observation point O_1 & O_2

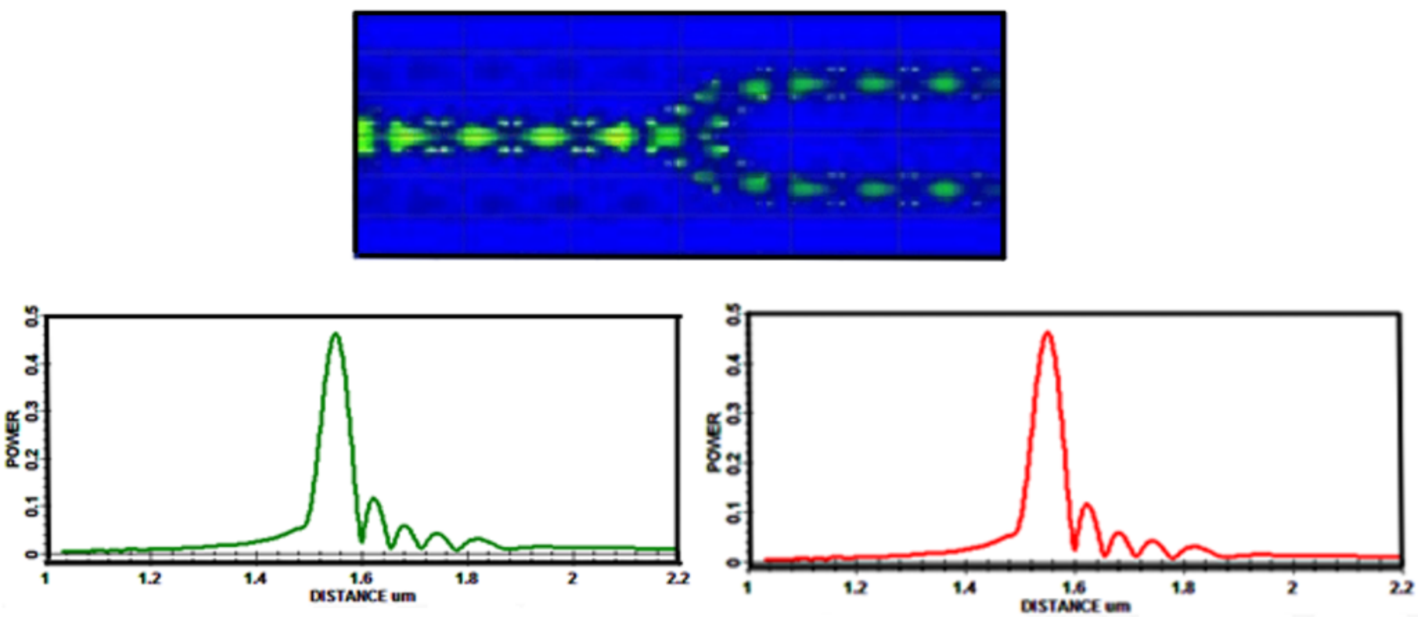

Figure 7

a: The electromagnetic field pattern when the input port I_3 is active

b & c: Output at observation point O_1 & O_2

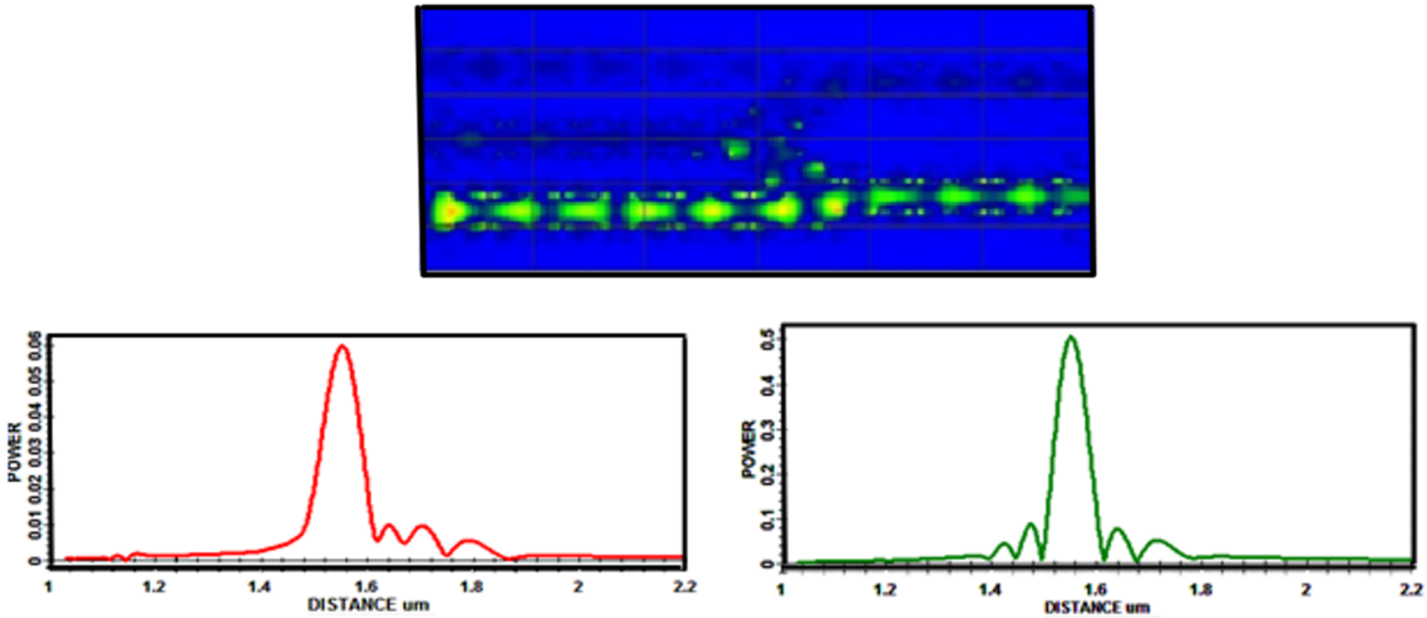

Figure 8

a: The electromagnetic field pattern when the input port I_4 is active

b & c Output at observation point O_1 & O_2

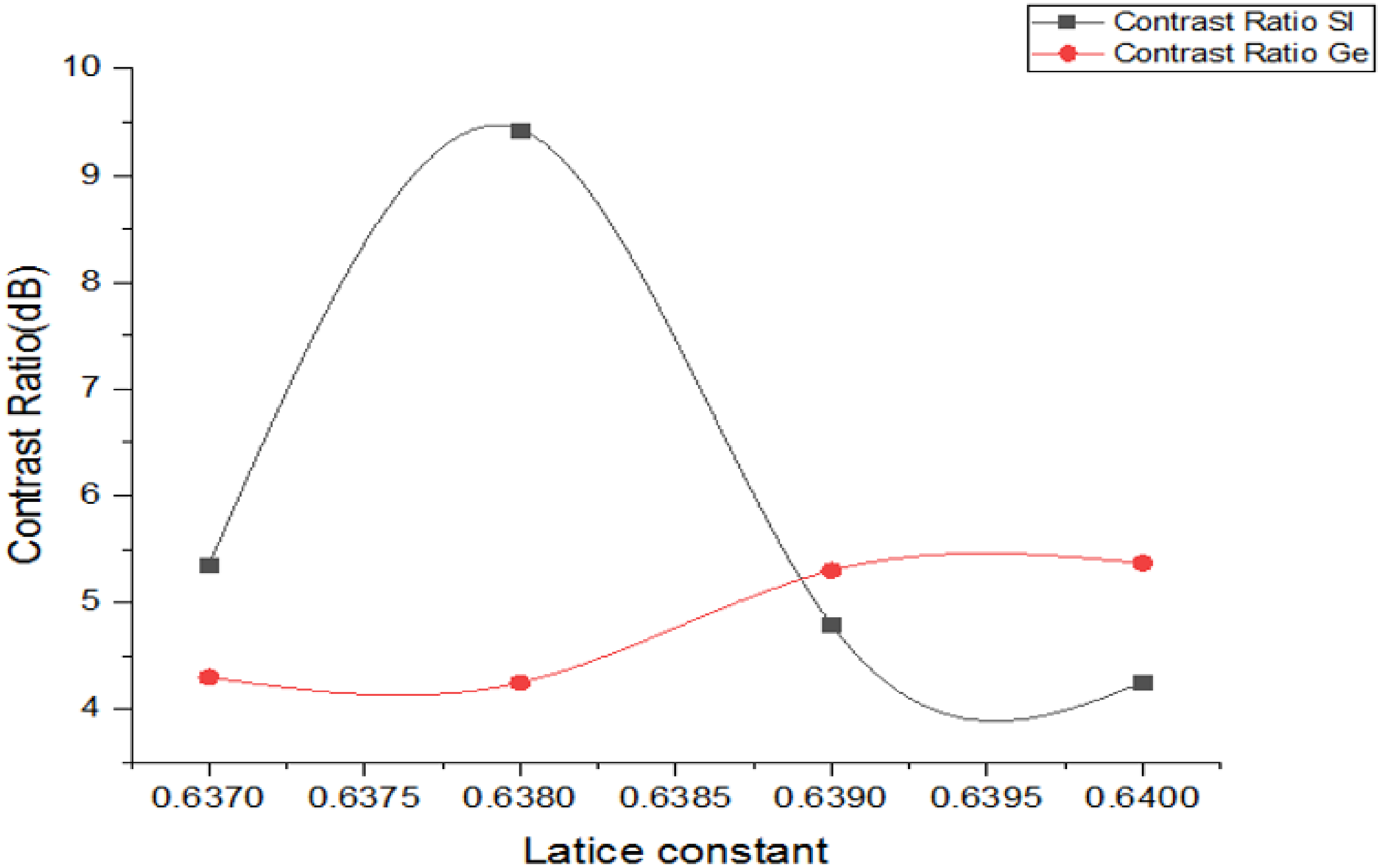

Figure 9

Contrast ratio of optical encoder with respect to lattice constant.