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Design and implementation of All-Optical T-flip-flop using Photonic Crystals Waveguides

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ABSTRACT

High-speed communication has a lot of limitations because of slow electronic components. As a solution to these limitations, optical components will be used for high switching speed, low power consumption and large bandwidth, instead of electrical components. We have developed a photonic crystal T-shaped waveguide design to implement T flip-flop. Utilizing optimized parameters such as silicon rod radius and refractive index, this design has been analysed and examined. To implement this structure, the optical interference effect is utilized at a wavelength of 1550 nanometres. This design operates at the refractive index of 3.46 and silicon rod radius of 0.114, giving the best output value with an 14.78dB contrast ratio. Using Finite Difference Time Domain (FDTD) and plane wave expansion, the designed flipflop is simulated.

Keywords: *Photonic Crystal Waveguides, All-Optical T Flip-Flop, Beam Interference Principle, FDTD Method, T-Shaped Waveguides.*

1 INTRODUCTION

It is extremely challenging to scale electronic devices to greater transmission rates due to the increased demand for bandwidth, primarily because of their power consumption and dissipation problems. The advantage of optical devices is their fast switching, low power consumption and broad bandwidth, therefore overcoming the disadvantages of electronic devices. Mach-Zehnder interferometers (MZIs) [1-6], Photonic Crystal Ring Resonators (PCRRs) [7-9], Semiconductor Optical Amplifiers Mach-Zehnder interferometers (SOA-MZI) [10-13], and other techniques are used in the construction of the flipflop. They do, however, have significant flaws, such as their large size and lack of intricacy. That is why many people adopt photonic crystals, which employ beam interference techniques [14-21] and have advantages such as compact size, strong light confinement, and low power dissipation.

Photonic crystals are a nanostructure arrangement of materials with a wide range of refractive indices. Photonic Band Gap (PBG) crystals are formations that alter light in the same way that semiconductors do. Animal reflectors and structural colours are examples of photonic crystals found in nature. Line and point flaws regulate the amount of light that enters the room. Because of their structure, which may selectively reflect a given band of wavelength, these materials have a variety of colours. In one, two, or three dimensions, photonic crystals can be made. We created a two-dimensional lattice in this situation.

T-shaped waveguides are used in this design. The refractive index (RI) and silicon rod radius are tuned in this construction to minimise back reflection, resulting in less power loss. The T flipflop measures 10.4µm × 5.4µm in length. In waveguides, constructive or destructive interference occurs depending on the phase angle of the input signal and the path taken by the signals. Destructive interference occurs with odd integral multiples of the path difference or 180° phase difference dissipation, while constructive interference occurs with even integral multiples of the path difference and 0° phase difference dissipation.

2 DESIGN AND WORKING OF ALL-OPTICAL T FLIP-FLIP

The proposed structure is a two-dimensional Photonic Crystals with T-shaped waveguides that are made up of arrays of silica dielectric rods on an air substrate. Here, a T flip-flop is implemented utilising beam interference. Silicon rods with a radius of 0.19a are used, with ‘a’ equalling the 0.6 µm lattice constant (distance between two dielectric rods) and the refractive index of the silicon rods being 3.46.

The wavelength of operation for this structure is 1.55 µm. In this design, the junction rods of refractive rods are controlled to transmit maximum power to the output port with minimal back reflections. With T-shaped waveguides, this design has an array size of 17a × 9a (10.2 µm × 5.4 µm). The junction rod is a silicon rod with radius of 0.33a and a refractive index of 3.42 is utilised at the output junction. The planned T flip-flop has a 14.782dB contrast ratio.

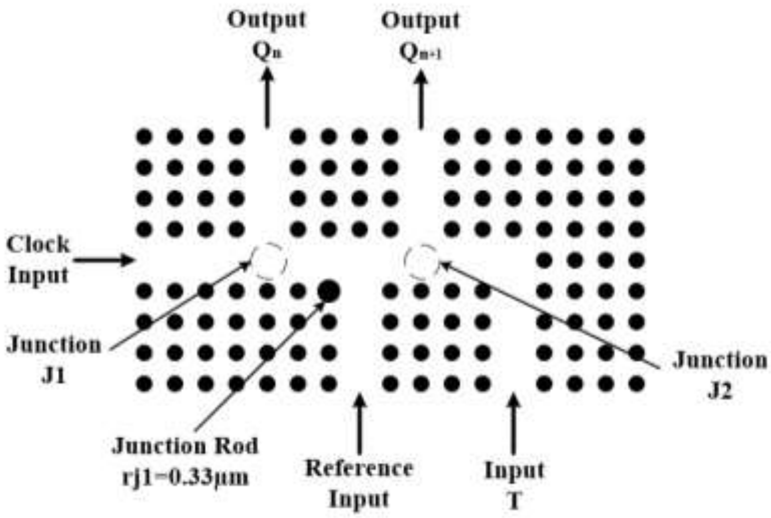

Figure 1: Layout of proposed all-optical T FLIP-FLOP

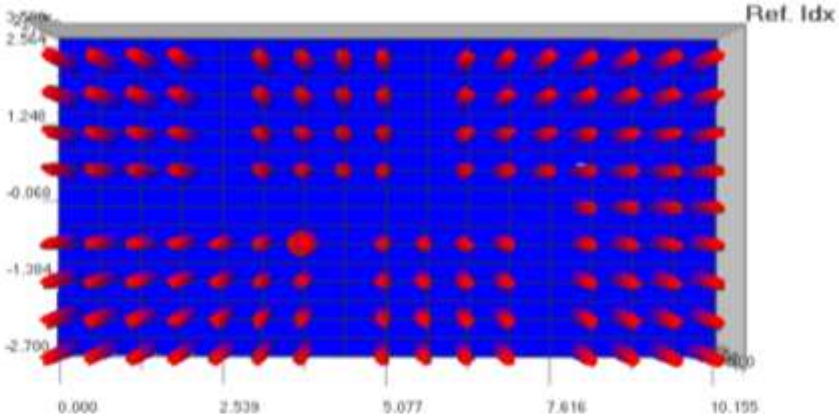

Figure 2: 2-D Refractive Index of all-optical T FLIP-FLOP

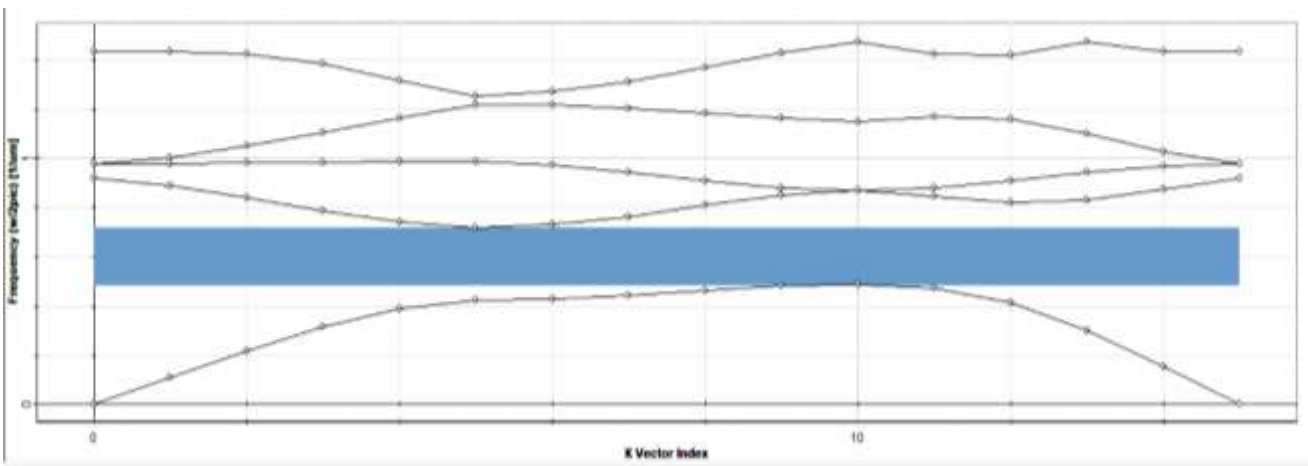

Figure 3: FDTD photonic band gap diagram for T FLIP-FLOP

The Band gap of T flip-flop is shown in the above figure. This can be determined by using the Planar Wave Expansion (PWE). There is a photonic band gap similar to the electronic band gap that exists between the conduction band and the valence band. The spectral ranges of T flip-flop are (0.489, 0.719) and the total photonic band gap is 0.2. “a/lambda” is the wavelength through which light can't propagate, where lambda is the continuous wavelength.

3 SIMULATION RESULTS AND DISCUSSION

Case 1: (Input port T is '0', CLK is '0'; LOGIC '00')

In this input condition, both input planes exhibit an inactive signal, and reference is always high. The weak signal at the output Qn+1 can be observed due to the presence of a high reference since T is low and CLK is low with a phase of zero. This condition satisfied the truth table of the T flip-flop we designed.

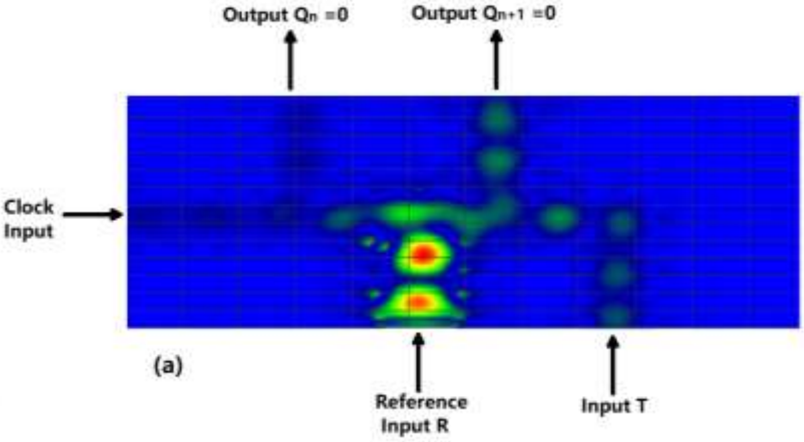

Fig 4: T flip-flop - '00' Condition

Case 2: (Input port A is '0', B is '1'; LOGIC '01')

The input T and the reference are set high in the '01' condition, whereas the input CLK is set low. According to the beam interference phenome, we can see constructive interference at J2 and destructive interference at J1. As a result, there is no output at Qn, but output is visible at Qn+1.

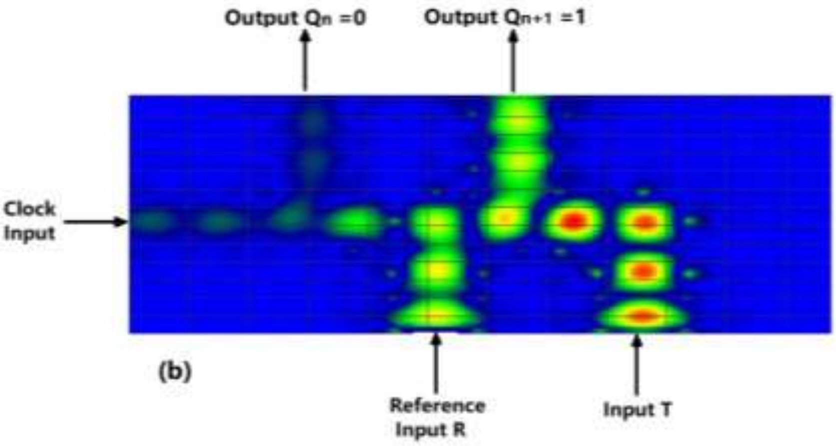

Fig 5: T flip-flop -'01' Condition

Case 3: (Input port A is '1', B is '0'; LOGIC '10')

An active signal incident from port CLK, as well as a reference signal and an inactive signal present from port T, make up the input '10' condition. There is constructive interference at junctions J1 and J2, where the outputs Qn and Qn+1 are both high and the T flip-flop is satisfied.

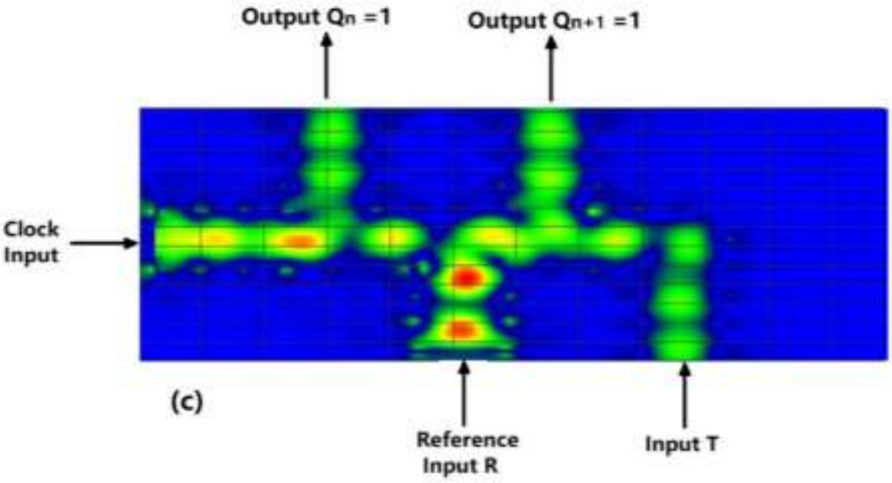

Fig 6: T flip-flop -'10' Condition

Case 4: (Input port A is ‘1’, B is ‘1’; LOGIC ‘11’)
The condition '11' is defined as an active signal from all input ports, including T, CLK, and reference. Constructive interference affects junction J1, whereas destructive interference affects junction J2, resulting in a low output at Qn+1 and a high output at Qn. The final requirement is likewise met by the T flip-flop.

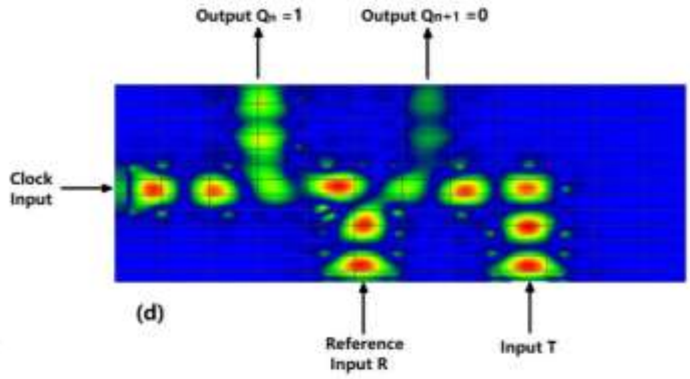

Fig 7: T flip-flop -'11' Condition

Table 1: Normalized output power with different input phase angles

Input Logic			Input Phase			Phase Difference	Type of Interference		Output	
T	Clock	R	T	Clock	R		Qn	Qn+1	Qn	Qn+1
0	0	1	-	-	0°	0°	Destructive	Destructive	0.034	0.140
1	0	1	180°	-	0°	180°	Destructive	Constructive	0.165	0.661
0	1	1	0°	0°	-	0°	Constructive	Constructive	0.760	0.845
1	1	1	0°	0°	180°	180°	Constructive	Destructive	0.589	0.159

Intensity of light at the output for different refractive index values of T flip-flop
The T flipflop has been confirmed and evaluated using a variety of refractive indexes, with the refractive index of 3.42 being found to be the best refractive index for concurrently satisfying all of the conditions of the T flipflop truth table with highest output.

The Contrast Ratio (CR) is calculated as follows:

$$CR=10\log_{10}(P_1/P_0)$$

Where CR is the Contrast Ratio
P_1 indicates the output power at 1 logic value
P_0 indicates the output power at 0 logic value

Table 2: Output values of T flip-flop for different Silicon Rod Radius

Input Logic			Normalized Power					
			Silicon Rod Radius					
			0.18a		0.19a		0.2a	
T	Clock	R	Qn	Qn+1	Qn	Qn+1	Qn	Qn+1
0	0	1	0.040	0.109	0.034	0.140	0.049	0.176
1	0	1	0.197	0.547	0.165	0.661	0.123	0.534
0	1	1	0.710	0.812	0.760	0.845	0.731	0.798
1	1	1	0.604	0.151	0.589	0.159	0.539	0.153
Contrast Ratio			12.491	8.721	13.493	7.807	11.737	7.173

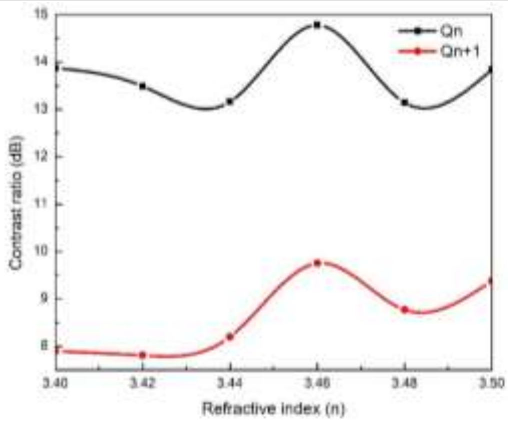

Fig 8: Contrast ratio for all-optical T flip-flop for different Silicon Rod Radius

Table 3: Output values of T flip-flop for different Refractive Index (RI) values

Input Logic			Normalized Power											
			Refractive Index (RI) Variations											
			3.40		3.42		3.44		3.46		3.48		3.50	
T	Clock	R	Qn	Qn+1	Qn	Qn+1	Qn	Qn+1	Qn	Qn+1	Qn	Qn+1	Qn	Qn+1
0	0	1	0.031	0.132	0.034	0.140	0.036	0.141	0.026	0.129	0.037	0.142	0.032	0.137
1	0	1	0.168	0.540	0.123	0.553	0.175	0.568	0.136	0.597	0.171	0.572	0.171	0.513
0	1	1	0.757	0.813	0.751	0.789	0.746	0.806	0.782	0.841	0.764	0.829	0.776	0.832
1	1	1	0.666	0.140	0.589	0.159	0.635	0.122	0.611	0.089	0.705	0.110	0.702	0.096
Contrast Ratio			13.877	7.895	13.493	7.807	13.164	8.199	14.782	9.754	13.148	8.771	13.841	9.378

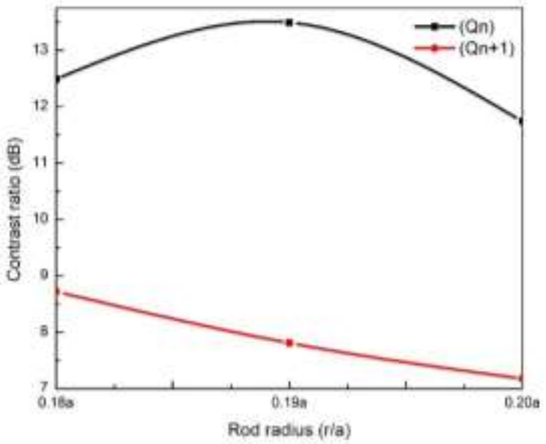

Fig 9: Contrast ratio for all-optical T flip-flop for different Refractive Index (RI) values

4. CONCLUSION

T flip-flops are implemented utilising Photonic Crystal Waveguides and square lattice silicon rods in this architecture. The FDTD Method is used to do simulations of the designs. The T flip-flop has a CR of 14.782 dB at 1550nm wavelength. In this design, T-shaped waveguides are used. As a result, it may be used to enable optical networking and computing.

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