Quantum Computing

***Abstract*—Quantum physics, also known as quantum mechanics, is the branch of physics that describes the behavior of particles at the quantum level. Quantum physics provides a framework for understanding the fundamental properties and behaviors of particles, including photons.All forms of light, processing of light, and detection of light are fundamentally governed by quantum physics because light, at its most fundamental level, consists of individual packets of energy called photons.since light is quantized energy levels and quantum physics explains that energy is quantized, meaning it can only exist in discrete values. In the case of light, energy is carried by photons, and the energy of a photon is directly proportional to its frequency or inversely proportional to its wavelength. Quantum computing represents a paradigm shift in computation, offering the potential to solve complex problems that are currently intractable for classical computers.By using Mach-Zehnder device, we notice the change of arm's length of MZI by changing in thermo optic and elecrtro optic coefficient.**

I. INTRODUCTION

QUANTUM computing represents a paradigm shift in computation, offering the potential to solve complex problems that are currently intractable for classical computers. Unlike classical computers that use bits to represent information as either a 0 or a 1, quantum computers utilize quantum bits, or qubits, which can exist in a superposition of both 0 and 1 states simultaneously[1]. This unique property allows quantum computers to perform computations in parallel, leading to exponential speedup for certain algorithms compared to classical systems. The need for qubits in quantum computing arises from the fundamental principles of quantum mechanics, such as superposition and entanglement. Superposition allows qubits to exist in multiple states simultaneously, increasing computational capacity exponentially. Entanglement enables the correlation of qubits, regardless of distance. Quantum computing aims to solve computationally difficult problems in fields like cryptography, drug discovery, and optimization, which are challenging for classical computers. Qubits are the building blocks of quantum information processing, representing and manipulating quantum information. They have unique properties that make quantum computers potentially revolutionary in solving previously unsolvable problems. However, qubits are vulnerable to noise and decoherence, posing challenges for reliable and scalable qubit platforms. Different physical systems, including photons, atoms, ions, and superconducting circuits, are being explored as qubit candidates, each with its own advantages and challenges.Photonics offers several advantages as a platform for qubit implementation in quantum computing. Some of these advantages include[2]: High-speed operations: Photons can transmit and process quantum information at the speed of light, enabling faster computations compared to other qubit platforms. Long-distance transmission: Photons can travel long distances through optical fibers with minimal loss or decoherence, making them well-suited for quantum communication and networks over large physical scales. Scalability: Integrated photonics allows miniaturization and integration of multiple quantum components on a chip, providing a scalable platform for building large quantum systems with many qubits. Low decoherence and errors: Photons are relatively robust against environmental noise and interactions, resulting in high coherence times and lower error rates for quantum information encoded in photonic qubits. Versatile qubit encoding and manipulation: Photons can be encoded in different degrees of freedom like polarization and time-bins, enabling efficient qubit manipulation using optical elements[3]. Compatibility with existing infrastructure: Photonic qubits can leverage optical communication networks and infrastructure already in place for classical signals. Potential for photonic quantum networks: The ability to transmit photons over long distances at high speeds makes photonics promising for building interconnected quantum networks for applications like secure communication and distributed computing. In the mid-1980s, silicon photonics emerged as a promising technology, marked by the study of single-crystal silicon waveguides. The introduction of silicon-on-insulator (SOI) substrates in 1988 popularized silicon waveguides, known for low propagation loss and polarization independence. Ongoing research optimized waveguide configurations, yielding submicrometer rib, strip, and photonic crystal waveguides on diverse SOI platforms. Integration with complementary metal-oxide-semiconductor (CMOS) technology facilitated compact, high-speed modulators for optical communication systems[4]. Simultaneously, photonic quantum computing, evolving over decades, achieved pivotal milestones. In 1995, entangled photons enabled the implementation of a controlled-NOT (CNOT) gate, showcasing photonics' potential for quantum logic operations. The KLM scheme proposed in 2007 marked progress towards universal quantum computing using photonic qubits. Photonic qubits played a vital role in quantum communication, evidenced by the implementation of quantum key distribution (QKD) protocols for secure communication. From 2012 to 2021, the field witnessed substantial developments: 2012-2017: Foundational Concepts and Quantum Supremacy Boson Sampling (2012): Researchers introduced boson sampling, leveraging photon behavior for quantum computing[5]. Photonic Quantum Supremacy (2017): Google's breakthrough demonstrated the superior computational capabilities of photonic quantum processors. 2018-2019: Architectural Advancements and Error Correction Scalable Quantum Architectures (2018): Integrated photonic circuits advanced scalable designs for large-scale quantum processing. Quantum Error Correction (2019): Specialized techniques addressed error correction, crucial for maintaining quantum information integrity in photonic qubits. 2020-2021: Long-Distance Communication and Quantum Networks Quantum Repeaters (2020): Quantum repeaters were a focus for overcoming challenges in long-distance quantum communication[7]. Quantum Networks and Internet (2021): Photonic qubits were instrumental in establishing entanglement distribution between distant nodes, a key step toward realizing a quantum internet. This period marked a transformative shift from foundational concepts to practical applications, encompassing quantum computational supremacy, scalable architectures, error correction, and the establishment of quantum communication over extended distances. The progress reflects the significant strides made in leveraging the potential of photonic qubits for quantum technologies[8].

II. Preliminaries & Theories

A. *Quantum processing of information is powerful*

Due to several key properties and computational advantages offered by quantum systems. Here are some reasons why quantum processing is believed to have greater computational power:

*1) **Superposition**:[10] It is a fundamental principle in quantum mechanics that describes the ability of quantum systems to exist in multiple states simultaneously. The concept of superposition forms the basis for understanding quantum interference and the behavior of particles at the quantum level. Quantum systems can exist in superposition states, meaning they can simultaneously represent multiple states or values. This property allows quantum processors to perform computations on all possible combinations of states in parallel, providing exponential computational speedup for certain algorithms and many crucial aspect of quantum computing. Quantum bits, or qubits, can exist in a superposition of both 0 and 1 states, allowing for parallel processing and exponential computational power. The superposition of states is represented using Dirac notation or ket notation. A state vector is represented by a ket symbol*($|\ \boldsymbol{\Psi}>$)*and a superposition is expressed by adding or subtracting multiple state vectors. For instance, a superposition of two states* $|\alpha>and|\beta>$*can be written as* ($|\ \boldsymbol{\Psi}>$) $= a|\alpha> + b|\beta>$ *where 'a' and 'b' are complex coefficients.*

for example, horizontal and vertical photon polarizations: $|\ 0> =\leftrightarrow, |\ 1> =\updownarrow$) *and for the two states* $|\ 0>and\ |\ 1>$ *at the superposition*$\alpha|0>+\beta|1>$ *behaves like* $|\ 0>$ *with probability*$|$ $\alpha|2$ *and like* $|\ 1>$ *with probability* $|\ \beta|2$ *A pair of qubits (for example, two photons in different locations) is capable of existing in four Boolean states,* $|\ 00>, |\ 01>, |\ 10>and\ |\ 11>$ *as well as all possible superpositions of them. These include states such as shown in (1):*

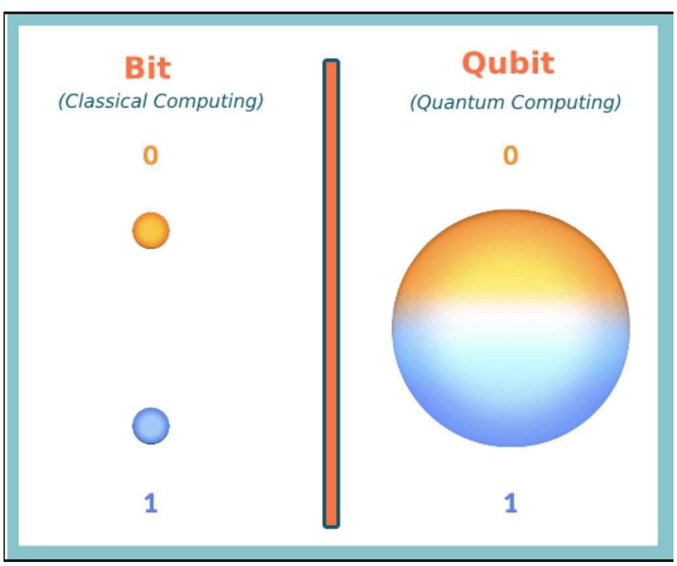

Fig. 1: Superposition

(1) $\sqrt{((1/2)\ (\ |00\rangle\ \ +|01\rangle\ \ ))} = \ \ |0\rangle\ \otimes \sqrt{((1/2)\ (|0\rangle\ \ +|1\rangle\ \ ))} = \cdots$

(2) $|\Psi 1\rangle = 1/\sqrt{2}\ |0\rangle + 1/\sqrt{2}\ |1\rangle$

(3) $|\Psi 2\rangle = 1/\sqrt{2}|0\rangle - 1/\sqrt{2}\ |1\rangle$

*2) **Quantum entanglement**: Entanglement is a phenomenon in which two or more quantum particles become correlated in a way that the state of one particle is instantly related to the state of another, regardless of the distance between them. This property allows for the creation of highly interconnected quantum systems, enabling efficient communication and information processing.*

State of two qubits: qubit A and Qubit B Consider ($|\ \boldsymbol{\Psi}>$)*when* $\alpha = 1/\sqrt{2}$ *and* $\beta = 1/\sqrt{2}$ *Since* $|\ \alpha\ |\ 2$ *and* $|\ \beta\ |\ 2$ *both equal 1 then if we have two states: (2) and (3) Now We quantify entanglement by concurrence **C**, which implies for the state* $|\ X>$ *that. For* ω *in equal to zero or one, the state's entanglement and hence its concurrence vanishes;* $\omega = 1/2$ *implies*$|\ X> =|\ \phi+>$*for a pure state* $|\ X>$ *with* $0 \leq \omega \leq 1$ *; that is for values of* ω *between zero and one the particles are in a coherent superposition of both being in state* $|\ 0>$*and both being in state*$|\ 1>$.

It's important to note that entanglement is a fragile phenomenon. Interactions with the environment can disrupt or destroy entanglement, a process known as decoherence. Therefore, maintaining and preserving entanglement is a significant challenge in practical quantum systems.:

*3) **Quantum algorithms**: Quantum computing algorithms, such as Shor's algorithm for factoring large numbers and Grover's algorithm for unstructured search, exploit the unique properties of quantum systems to solve specific problems significantly faster than classical algorithms. These algorithms have the potential to revolutionize fields such as cryptography and optimization.:*

*4) **Quantum error correction**: Quantum systems are susceptible to errors caused by noise and decoherence. However, quantum error correction techniques have been developed to combat these errors and preserve the integrity of quantum information. By using redundant quantum bits and error-correcting codes, quantum processors can perform reliable computations despite the presence of noise:*

B. *Quantum enhanced photonic information processing*

I) Communications: Higher capacity communications for deep space lasercom with quantum enabled receivers Quantum networking: Communicating classical bits and quantum bits (qubits) reliably, generating shared entangled bits (Qubits), which enhance the networked communications.

II) Imaging and sensing Active imaging and sensing: Quantum enhanced ranging, metrology, velocimetry, vibrometry, atomic force microscopy, spectroscopy, reading.
III) Passive imaging and sensing: Super resolution passive imaging, hyperspectral imaging.
IV) Computing: Quantum computing like Factoring, Discrete Log Search (e.g., on graphs), Simulations, chemistry.
V) Special purpose computing like Quantum annealing, Boson sampling, Quantum receivers (communication, sensing).

C. *Optical modes and quantum computing.*

An optical mode is the "shape" of a confined electromagnetic field in space, time and polarization (the three independent degrees of freedom of the photon).[11]
In simple terms, an optical mode describes the spatial and polarization characteristics of light within an optical device or medium. It defines the possible ways in which light can exist and propagate, and it is determined by the geometry, refractive index profile, and boundary conditions of the optical system. Optical modes play a significant role in several aspects of quantum computing, particularly in the field of photonic quantum computing. The following structure represents a few key areas where optical modes are relevant:

III. STRUCTURE

The structure of qubits (quantum bits) based on silicon photonics can vary depending on the specific implementation and approach. Here, we will discuss some of this common structures used for qubits in silicon photonics: linear optics-based qubits and integrated waveguide-based qubits. Linear Optics-Based Qubits: Linear optics-based qubits, also known as cluster state qubits, utilize passive linear optical components to manipulate single photons for quantum information processing. These components include beam splitters, phase shifters, and wave plates. Unlike other qubit implementations, linear optics-based qubits do not require active elements like modulators or detectors. In this approach, the qubit information is encoded in the quantum state of single photons, which can be represented by various properties such as polarization, path, or time-bin. These properties serve as the basis for performing quantum operations and measurements. The key principle behind linear optics-based qubits is quantum interference, which allows for the implementation of quantum gates using the behavior of photons in linear optical circuits. By manipulating the interactions between photons at beam splitters and introducing phase shifts, quantum gates such as controlled-NOT (CNOT) gates can be realized. The CNOT gate is a fundamental gate in quantum computing that flips the target qubit's state if and only if the control qubit is in the "1" state. In linear optics-based qubits, CNOT gates can be implemented by exploiting the phenomenon of quantum interference. Entangled qubit pairs are generated using beam splitters and phase shifters, and measurements on these entangled photons are used to perform computations through the technique known as measurement-based quantum computing (MBQC). In MBQC, a large cluster state, which is a highly entangled state of multiple qubits, is generated by applying a series of quantum gates to an initial set of photons. Measurements are then performed on specific qubits in the cluster state, utilizing the principle of entanglement to perform computational operations. The measurement outcomes effectively "program" the remaining qubits in the cluster state, enabling the execution of quantum algorithms. Linear optics-based qubits offer advantages such as simplicity, scalability, and compatibility with existing optical communication technologies. However, they also face challenges, such as the probabilistic nature of photon sources and the difficulty of implementing non-linear operations. Overcoming these challenges is an active area of research in the field of quantum optics. Despite their limitations, linear optics-based qubits have demonstrated the feasibility of performing quantum computations using photons and have contributed to the development of quantum algorithms, quantum communication protocols, and quantum simulations. Further advancements in linear optics-based qubits are anticipated as researchers continue to explore their potential and address the technical challenges involved[9]

IV. BASIC IDEA

A. *Qubits:*

photonic qubits: In photonic quantum computing, information is typically encoded in the quantum states of individual photons, which serve as qubits. Optical modes, such as different modes of light propagation in waveguides or optical fibers, can be used to encode and manipulate these photonic qubits. Optical modes can represent different degrees of freedom of photons, such as polarization, spatial mode, or frequency.
Also for the quantum state generation and manipulation: Optical modes are utilized to generate and manipulate quantum states of light. Techniques such as single-photon sources, photon detectors, and quantum state manipulation using devices like beam splitters, wave plates, and phase shifters rely on controlling and manipulating different optical modes to prepare and operate on quantum states. Quantum bits—or qubits—are the fundamental building block of most quantum technologies. By harnessing the power of quantum-mechanical properties via qubits, quantum technologies can accomplish things that their classical counterparts could never match. For example, quantum technologies will help enable much more robust cybersecurity and more powerful computing.

B. *Computing with 0's and 1's: Classical bits*

The essential components of classical computers are known as classical bits. One item of information can be stored in a bit. Its value is either 1 or 0. Classical gates can be used to modify the value of a bit. The NOT gate, for example, sends bit values 0 to bit values 1 and 1 to bit values 0.

C. *How do qubits work?*

Qubits are the quantum analog to classical bits. Where as classical bits can either have value 0 or 1, qubits can be in a combination of the $|0>$ state and the $|1>$ state. So, what is the state? The state is the probability to happen, to be either 0 or 1 or combination of them. To capture all the possible combination states for a qubit, we give an arbitrary qubit state $| \mathbf{\Psi}>$ by an equation of the form $| \mathbf{\Psi}> = \alpha \mid 0> + \beta \mid 1>$, where $|\alpha>$ and $|\beta>$ are complex numbers such that the sum of the squares of the magnitudes $\mid \alpha|^2 + \mid \beta|^2 = 1$. There are infinitely many such pairs of $|\alpha|$ and $|\beta|$. What do these $|\alpha|$ and $|\beta|$ values represent? They are known as amplitudes, and we can use them to find the probability that the qubit will be measured in each state. Specifically, $|\alpha|^2$ gives the probability that when we measure $| \mathbf{\Psi}>$ the resulting state is $| 0>$ and $|\beta|^2$ gives the probability that when we measure $| \mathbf{\Psi}>$ the resulting state is $| 1>$. [12]

D. *Superposition:*

When neither α nor β is a 0, we say that the qubit is in a superposition of the states $| 0>$ and $| 1>$. As there are infinitely many appropriate pairs of α and β, this means that there are infinitely many possible different superpositions. Consider $| \mathbf{\Psi}>$ when $\alpha = \frac{1}{\sqrt{2}}$ and $\beta = \frac{1}{\sqrt{2}}$. Since $|\alpha|^2$ and $|\beta|^2$ both equal $\frac{1}{2}$, then this qubit has a 50 percent chance of being measured in the $| 0>$ state and a 50 percent chance of being measured in the $| 1>$ state. However, we cannot 100% confidently predict the result of a measurement due to the principles of quantum physics. Even if we prepared and measured two qubits in the same state separately, we might still obtain various states for every measurement.

E. *Representation of photonic qubit:*

Photons have several different two-level quantum-mechanical systems that can represent qubits, such as their horizontal polarization $|Hp>$ and vertical polarization $|Vp>$.

1) Representation1: Polarization: Classical intuition applies to single photon as well. Horizontally-polarize state $|H>$, Vertically-polarization $|V>$ Then photonic state will be $| \mathbf{\Psi}> = \alpha|H> + \beta|V>$,

Another basis: Diagonal / anti-diagonal: $|D> = \frac{1}{\sqrt{2}}(|H> + |V>), |A> = \frac{1}{\sqrt{2}}(|H> - |V>)$.

Right / left-circular: $|R> = \frac{1}{\sqrt{2}}(|H> + i|V>), |L> = \frac{1}{\sqrt{2}}(|H> - i|V>)$ [13].

*Measurement on a single polarization qubit:*1- Using polarizer: α^2 is referred to the probability of the horizontal polarization, $\beta^2$is referred to the probability of vertical polarization.2- Using polarizing beam splitter: It is a beam which splits the wave in two directions. [13][14]

2) Representation2: time-bin encoding: In this way we are using the arrival time of photon. If the photon arrives early, it is called $|e>$ represents a logical $| 0>$, on the other hand if the photon arrives late it is called $|L>$ represents a logical $| 1>$. The two bins must be well separated in time to ensure distinguishability of the two states (T sep > T coh).

Encoding superposition using an unbalanced interferometer: It is unbalanced because the lower arm is shorter than the upper arm. The (variable coupler) controls how much is transmitted and how much of the photon is reflected, and in upper arm there is phase “phi” a phase shifter , then the two arms are combined back together at the switch.

F. *Silicon photonics qubits:*

Silicon photonics qubits offer a promising avenue for realizing practical quantum computing. Their compatibility with existing technologies, scalability, and integration capabilities makes them a compelling platform for building large-scale quantum systems. Ongoing research and development in this field aims to address challenges related to qubit coherence, gate fidelity, and scalability, with the ultimate goal of realizing fault-tolerant quantum computers based on silicon photonics. [15][16][17]

V. PRACTICAL APPLICATIONS

Photonic integration opens the path towards miniaturized quantum communication systems with increasing complexity and enhanced functionality.[18] there is a lot of examples that is using photonics qubits like: (Quantum memories [19], Quantum repeaters, Chip packaging and system integration, Quantum secure communication systems [18], DV-QKD systems, Quantum computers) there is a mach zender device, A Mach-Zehnder interferometer is an optical device that utilizes the principles of interference to manipulate and measure light.The primary function of a Mach-Zehnder interferometer is to split an input light beam into two separate paths, recombine them, and observe the resulting interference pattern .

VI. CHARACTERSTICS

A. *MAch zender device*

There are many uses for the Mach-Zehnder Interferometer (MZI) in optical communication systems. The basic idea is that you have a pair of matching waveguides connecting a balanced arrangement of a splitter and a combiner. interference in the recombination process results in variations in the amplitudes of the output signals when something is done to produce a phase difference between the signals in the two matched waveguides, such as a difference in the two-waveguide lengths and/or a variation in the refractive indices between the two waveguides.

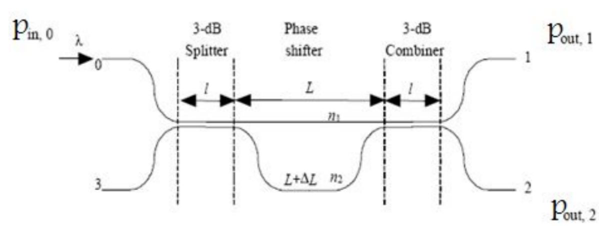

Fig. 2: Mach-Zehnder Interferometer with 3 dB Couplers: Output Power Variation with DeltaL.

A simple 2×2 Mach-Zehnder Interferometer (MZI) consists of a device where the input signal power from port 0 is split into two waveguides equally, each with a power of 50, using a 3-dB splitter.

$$\begin{bmatrix} E_1 \\ E_2 \end{bmatrix} = \begin{bmatrix} Cos(kl) & jSin(kl) \\ -jSin(kl) & Cos(kl) \end{bmatrix} \begin{bmatrix} E_0 \\ E_3 \end{bmatrix} \tag{1}$$

where the waveguide width and the refractive indices of the waveguide core determine the coupling length (l) and coupling coefficient (k), respectively. It is a measurement of the degree to which the input and output electric fields are dependent upon one another, or coupled .

output powers in the case of single input (port 0) are:

$$P_{out,1} = E_{out,1}E^{*}_{out,1} = Sin^2(kl)P_{in,1} \tag{2}$$

$$P_{out,2} = E_{out,2}E^{*}_{out,2} = Cos^2(kl)P_{in,2} \tag{3}$$

where z * is the same-magnitude electric field z's out-of-phase component.

$$\begin{bmatrix} T_{01} \\ T_{02} \end{bmatrix} = \begin{bmatrix} Cos^2(kl) \\ Sin^2(kl) \end{bmatrix} \tag{4}$$

From equation (4), it is clear that for a directional coupler to be 3-dB coupler, the coupling length satisfies the condition .

$$kl = (2u+1)\pi/4 \tag{5}$$

where u is an integer Therefore, by using Equations (1) and (5), the propagation matrix of each 3-dB coupler is:

$$M_{coupler} = \begin{bmatrix} Cos(kl) & jSin(kl) \\ -jSin(kl) & Cos(kl) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ -j & 1 \end{bmatrix} \tag{6}$$

As for the phase shifter which occupies the central region of MZI, the phase difference caused by the two waveguides is expressed as

$$\delta\phi = \frac{2\pi n_1}{\lambda}L - \frac{2\pi n_2}{\lambda}(L+\delta L) \tag{7}$$

where δ L is the length difference between the two MZI arms and L is

$$n_2 = n_1 + \delta n \tag{8}$$

the straight phase-shifter length. Because of the carrier injection in one of the two arms, the two have distinct refractive indices, n1 and n2. In specifics, where delta n represents the refractive index variation brought on by the insertion of carriers.

$$\delta\phi = -\frac{2\pi L}{\lambda}\delta n - \frac{2\pi n_2}{\lambda}\delta L \tag{9}$$

by either the refractive index difference or the difference in path length by (DL). The current work focuses on managing the change in the refractive indices of the two waveguides in order to induce a phase change. The two waveguides must have the same length in order to do this. This can be done through current injection using a forward voltage or carrier injection by doping [20]. As a result, Equation 9 becomes

$$\delta\phi = -\frac{2\pi L}{\lambda}\delta n \tag{10}$$

A 2x2 Jones matrix may fully describe the linear operation of any optical device, and a two-element Jones vector can represent any state of polarization . The phase modulator's Jones matrix should have the following shape:

$$M_{\delta\phi} = \begin{bmatrix} exp(j\delta\phi/2) & 0 \\ 0 & exp(-j\delta\phi/2) \end{bmatrix} \tag{11}$$

with obtained from Equation 9. It is assumed that the two waveguides in the phase shifter section are far distant enough to neglect any cross-interaction between them. Thus, the elements M12 and M21 in the matrix of Equation 11 are zeros. The general propagation matrix of the whole MZI is to be [22]

$$M = M_{coupler}M_{\delta\phi}M_{coupler} = j\begin{bmatrix} Sin(\delta\phi/2) & Cos(\delta\phi/2) \\ Cos(\delta\phi/2) & -Sin(\delta\phi/2) \end{bmatrix} \tag{12}$$

So the power transfer function of MZI for single power input at port 0 and two outputs at ports 1 and 2 can be expressed as:

$$\begin{bmatrix} T_{01} \\ T_{02} \end{bmatrix} = \begin{bmatrix} Sin^2\delta\Phi/2) \\ Cos^2(\delta\phi/2) \end{bmatrix} \tag{13}$$

B. *electro optic effect*

The electro-optic effect refers to the phenomenon where the refractive index of a material changes in response to an applied electric field. This effect allows for the modulation or control of light using electric fields. It is commonly observed in certain crystalline materials, such as lithium niobate (LiNbO3) and potassium dihydrogen phosphate (KDP). . Due to its quicker response time, the electro-optic effect allows for significantly higher frequency modulation than other methods like mechanical shutters, moving mirrors, or acousto-optic equipment. Using an applied electric field to change a material's optical properties in a controlled manner is the basic idea behind electro-optic devices. A shift in phase, amplitude, frequency, polarization, or position during an optical signal's propagation through a device is referred to as its optical characteristics. We distinguish between the based on changes in attributes.Certain materials have the ability to alter their characteristics in response to an applied external force when an optical signal travels through them. The application of external forces, such as voltage, temperature, acoustic waves, etc., can alter the locations, orientations, or forms of the molecules that originate from the material. The electro-optic effect is the change in refractive index that results from applying an electrical dc or low frequency field .Lithium niobate : Lithium Niobate (LiNbO3) is a colourless. It is insoluble with water. LiNbO3 is a ferroelectric material. Waveguides which made of lithium niobate material can be manufactured using either in-diffusion of titanium or annealed proton exchange procedures to design switches and modulators. The entire LiNbO3 is subjected to the manufacture of planner waveguides while, with these procedures, the photolithography method is used to define masks for chosen areas on it. In some cases, to control optical damage, Mg oxide is doped with LiNbO3. The lithium niobate waveguides exchanged for protons are simple to manufacture and can function at low temperatures. For multiple communication, sensor systems and signal processing, Ti diffused lithium niobate waveguides are helpful. Ti doping in lithium niobate crystal increases refraction indexes, allowing both TE and TM modes to propagate along the wave guides, which fulfils the necessary optical signal processing requirements [21]. Following equation can be used to find out the corresponding phase change [23]

$$\delta\phi = \frac{2\pi}{\lambda}(\delta n)L \tag{14}$$

Where, L is substantial length of interferometer arm delta n is the change in refractive index due to applied voltage that is represented by [23]

$$\delta n = (\frac{n^3}{2})rE \tag{15}$$

r is electro-optic coefficient. For LiNbO3, r = 3.66× 10-10 m/V. And delta is shown below [23]

$$\delta\phi = (\frac{2\pi}{\lambda})[(\frac{n^3}{2}rE)L \tag{16}$$

Let the distance between the two electrodes in figure 1 is d and the voltage difference between them to be V, then find E approximately equal to V/d. Then eq. 16 can deduce to eq. 17.

$$\delta\phi = (\frac{2\pi}{\lambda})[(\frac{n^3}{2})\frac{V}{d}r]L \tag{17}$$

If $\delta\phi$ = zero, then it shows no voltage is applied. And when V is applied, then delta phi = . At this point, voltage is known as V and is represented by eq. 18 .

$$V_\pi = \frac{\lambda}{n^3}\frac{1}{r}\frac{d}{L} \tag{18}$$

C. Thermo optic effect

The field of optics has witnessed remarkable progress in the quest for faster and more efficient data communication systems. One key area of exploration involves the integration of the thermo-optic effect with devices such as the Mach-Zehnder interferometer. The thermo-optic effect, which refers to the change in refractive index of a material due to temperature variations, has emerged as a powerful tool for manipulating light. On the other hand, the Mach-Zehnder interferometer, a versatile optical device, exploits the interference of light waves to enable precise measurement and control of optical signals. By combining the thermo-optic effect with the Mach-Zehnder interferometer, researchers and engineers have harnessed the potential to create advanced all-optical devices with enhanced functionality and improved performance. In this paper, we will explore the fundamentals of the thermo-optic effect and the Mach-Zehnder interferometer, discuss their synergistic relationship, and highlight their applications in high-speed optical communication, sensing, and signal processing. The total phase shift introduced by a heater

$$\delta\phi = \beta.\delta L. \tag{19}$$

the change in arm length due to thermo optic effect ,can be represented by this equation

$$\delta L = \alpha.\delta T.L_0 \tag{20}$$

$$\delta L = L_{new} - L_0 \tag{21}$$

$$\delta L = L_{new} - \frac{\delta\phi}{\beta.\alpha.\delta T} \tag{22}$$

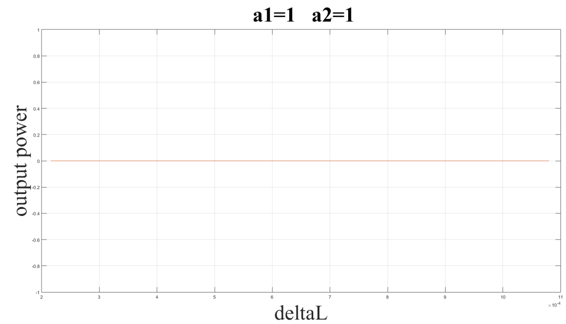

Fig. 3: Output Power Variation with Delta L for a1 = 0 and a2 = 0”

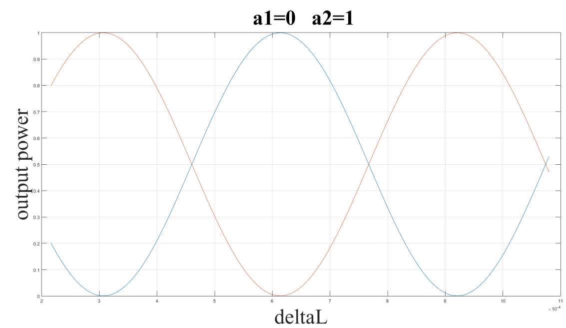

Fig. 4: Output Power Variation with Delta L for a1 = 0 and a2 = 1”

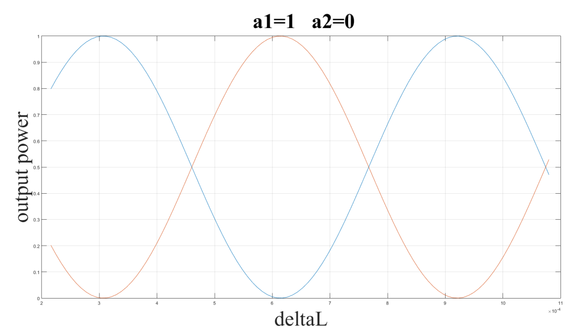

Fig. 5: Output Power Variation with Delta L for a1 = 1 and a2 = 0”

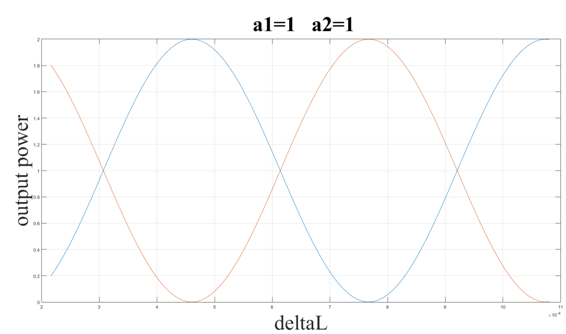

Fig. 6: Output Power Variation with Delta L for a1 = 1 and a2 = 1”

VII. CONCLUSION

Quantum computing presents a promising frontier in the field of computing, offering the potential to revolutionize various industries and solve complex problems,AS MZI device which can control the state with changing in refractive index or length of arm , we use electro optic effect and thermo optic effect and we deduce arelation betwwen change in length and output power using thermo optic effect.

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