Toward Quantum Photonic Computers; Thinking May Not be Realized by Digital Computers

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Abstract. Experts at the forefront of Artificial Intelligence (AI) have dreamed for more than half a century of autonomous thinking machines. But there's no hope that scientists can develop digital machines, capable of thinking process. They will never replace human mind in thinking. Simply we, ourselves are not logic machines. "I'm not a robot"! Human being have an intuitive intelligence cognition and consciousness that reasoning digital machines can not match. We should abandon some dogmas both in physics and computer technology. "Duality" in physics and "Digital Hardware" for High Performance Computing (HPC), both have failed when being applied in this area, no matter how many billions of dollars, world governments, invest in them. In this paper, at first, basic features for possible realization of thinking HPC machine using Quantum Optical Computer (QOC) versus classical digital computer will be discussed. Then we'll propose quantum optical processors work according to Quantum Photonic (QP) treatment which is based on corpuscular nature of light. Photons refraction phenomenon when travel through the interface between two different transparent solids will be simulated according to QP. Results, follow successfully from experimental measurements. If photons, as signal carriers in QOC be tracked by controlling Short Range Interatomic Forces (SRIF) in solids, then realization of QP computers (QPC), will be possible. It means QPC or QOC, will be accessible for HPC. Since QPC behaves in physics principle, more similarly to human brain in comparison with classical digital computers.

Keywords: Quantum Photonic computers (QPC), Thinking Machine. Cognition, Consciousness, Artificial Intelligence (AI), Bohm Theory, Hidden variables.

1 Introduction

Every two years for the past several decades, computers have become twice as fast while their components have become twice as small. we're now at the age of Ultra Large Scale Integration (ULSI) electronic integrated circuits. Because of this explosive progress, today's machines are millions of times more powerful than their ancestors [1]. Advanced lithographic techniques can yield parts many hundred times smaller than even recently available [2]. So, computers are also to become much smaller. Then in the future, a new technology must replace or supplement what we now have. In spite of such a vast amounts of progress both in hardware techniques and software manipulations specifically in Artificial Intelligence (AI) domain, digital computers still can not think!

As, late Marvin Minsky, a well known AI professor at MIT and other AI entrepreneurs believed in talking about "intelligent systems", that will perform better than we can do in home, in class and at work.: Expert Systems. After nearly a quarter of a century, Hubert and Stuart Dreyfus challenged above idea and for the first time admitted why computers may never think like people [3]. Now after more than half a century and in spite of more huge progress still in computer manufacturing technology and software techniques, we're again should admit, digital computers may never think like human being. They are logic machines based on Boolean algebra. A logic physical hardware may not simulate "thinking" in brain. Since "thinking", does not necessarily works according to logic. We should have courage to admit the role of "wisdom" in this area, no matter we've never been able to define perfectly this notion, technically and no matter discussion at this domain seems to be very speculative!

It's more than several decades, pioneers in the world began investigating the physics of information processing circuits. Asking about how small can the components of circuits must be made in the course of computation? How much energy must be used? Because computers are physical devices, their basic operations are described by physics. But in very small scales, physical description must be given by Quantum theory, not Classic. Quantum computers should now be modeled and their differences with classical ones ought to be determined. In special, we should find out, whether quantum effects might be exploited to speed up computations or to perform calculations in novel ways. For example Hydrogen atoms could be used to store bits of information in a quantum computer [1,4]. An atom in it's ground state can represent a "zero" and the same atom at a higher excited energy level can represent a "one". Using a laser pulse with enough energy, atomic bit can change it's state between "zero" and "one".

In section 2, Quantum Optical Computer (QOC) versus digital computer for possible realization of thinking machine will be discussed. Quantum optical processors and how they work will be explained in section 3. We'll not limit our theoretical viewpoints only on Quantum mechanics and Copenhagen interpretation of quantum world. Since they seem to be incomplete for explanation of qubits (quantum bits), theoretically [5,6]. At this situation, Bohmian mechanics[7] and Hidden variables[8] must be taken into account. It's because we must know in theory (not in measurement), with exact certainty about photon's position and the time of it's interaction with qubits. This should be possible without violation of uncertainty in measuring process. Spintronics will also be mentioned in section 3. Finally in section 4, we'll introduce method of realization of Quantum Photonic computers (QPC) in continuation of QOC. Method of tracking light, at attosecond time scale theoretically, will be discussed at this section [9]. If we're able to control and track photons during their journeys between atomic layers, then QPC may be realized. We'll also have a conclusion section.

2. Quantum Optical Computer versus digital machine

A conventional digital computing system, requires first of all a Central Processing Unit (CPU). It may consist of sequential (Von Neuman) or parallel (non-Von Neuman) architectures. All of the processing procedures on data signals for many different applications will be executed by clock pulses in CPU. For example, speech and image processing for pattern recognition or pattern generation are all in domain of CPU and it's coprocessors. Artificial Intelligence (AI) and developing advanced deduction systems are all in this domain too (see Fig.1: Iranian first pedagogical robot PARS-1)[10].

Fig.1. First Iranian pedagogic Robot called "**PARS-1B**", with AI Graph Search Algorithm to track and find barriers and targets. Developed by Author, in Sharif University of Technology, E.E. Dept, year 1986.

Basically, it's not still obvious whether we'll finally be able to make a thinking machine, but proposing a quantum CPU, will be a step more toward realization possibility of it. Cognition and consciousness happens in human brain. So, brain's physical shape, materials made from, methods of interconnections, all should be taken into account. Bio-photonic, bio-electric and bio-chemical methods of interconnections between nervous cells in human brain, work very differently in comparison with a logical CPU, which behaves intelligently, but not with cognition and consciousness [11,12,13]. Even Robot called "Sophia", revealed two years ago in United Nations (UN), can not think unless it's supervisor hints it. Although it's owners might claim it could think and will have consciousness soon, only for business considerations [14].

AI procedure in conventional computers is done symbolically, not physically. But nature consists of real matters (atoms). Where atoms interact physically with each other. They behave according to rules of quantum theory not symbolically. So, simulation of brain's behaviors for making an advanced machine, requires quantum CPU [15,16]. It also requires optic and photonic interconnections[17], for development of fast image recognition systems based on Vander lugt optical filters and optical correlators for pattern recognition[18].

2.1. Memories in QOC

Memory in QOC should be able to save both magnitude and phase of input signals in 3-dimensional volume made from photo-refractive materials[19,20,21,22]. Data signals can be saved in 3D space domain in these materials, where we call them Holograms.

Data may also be saved in spatial frequency domain, where we call them optical Vander lugt filters (see Fig. 2), phase only optical filters, etc. These kinds of memories both Holographic[20,21] and Vander lugt[18], are able to store vast amounts of data, voice or images in physical volume of materials.

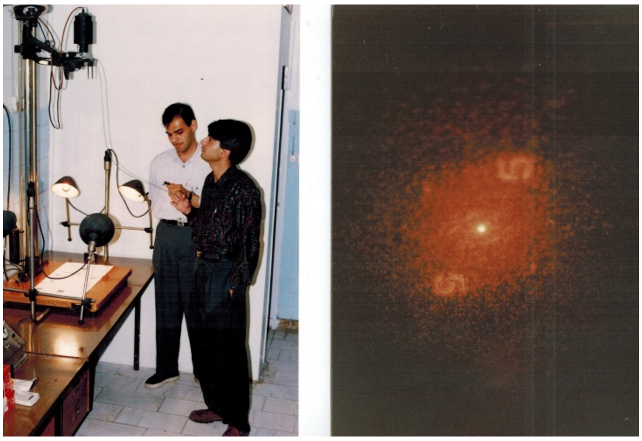

Fig.2. First development and reconstruction of Spatial Optical Vander lugt filter for number "**5**". Developed for optical pattern recognition in machine vision, by A.H. Majedi and M.R. Chaharmir in PRL-E.E.Dept., Amirkabir University of Technology, year 1995 [18].

They're made from photo-refractive materials. It means applying suitable external electric field, for example in visible region, may alter material's optical properties like index of refraction. In turn, they cause a kind of optical storage for a limited time, from fractions of second up to several minutes, hours, days or even months. Inorganic materials like GaAs, BaTio3, LiNbO3, KNbO3 ..… crystals or organic crystals like 2-cyclooctylamino-5-nitropyridine doped with 7-7-8-8-tetracyanoquinodimethan [19,22,23]. Photo-refractive effect formulation for QOC-3D memories, has already been explained theoretically using Kukhtarev equations[22,23]. Their applications are in high speed real time complex images correlations as in human face and alphanumeric symbols recognition. We've successfully developed hybrid optical computers for machine vision and recognition [18,22]. Dynamic data storage and retrieving optical bit storage signals are main features necessary for developing real time QOC. It's already been studied that brain in pattern storage, behaves very similar to holograms [3].

Other alternative for temporarily data storage in QOC is called Slow Light optical bit memory. Quantum storage of light in atomic sodium vapor at very low temperatures (even micro-Kelvin) has already been reported experimentally [24,26]. We've successfully explained this kind of storage theoretically according to Quantum Mechanics [25]. It's a kind of quantum entanglement of photons for example in Sodium or Robedium vapors at very low temperatures. QOC memory is also available in semiconductor solids [27,28]. Slow light devices can also be used as optical delay lines. Some known optical properties like Stimulated Brillouin Scattering (SBS), Stimulated Raman Scattering (SRS), Electromagnetically Induced Transparency (EIT), Coherent Population Oscillation (CPO) may be applied in some nonlinear- dispersive optical devices to realize light speed reduction. We've already successfully simulated and analyzed such devices for designing new optical bit memories [29,30].

2.2. Optical Keyboards and Display Devices as I/O in QOC

In QOC, man-machine interface must be more user friendly. Besides, computer size and it's hardware electronic components should be minimized or even be eliminated.

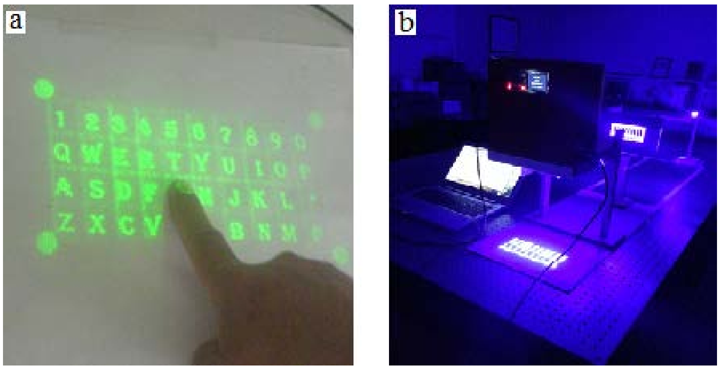

Fig.3.a A virtual optical keyboard illuminated by 550nm Green laser. Developed by M. Farhadi, in PRL-E.E.Dept., AUT, year 2009. **Fig.3.b** A virtual optical keyboard illuminated by Blue-Violet laser for Organ music instrument. Developed by M. Khalaj Babaie, in PRL-E.E.Dept., AUT, year 2017.

Limited reliability of a real keyboard causes to think about optical virtual keyboards illuminated by a laser beam as input device. As can be seen in Fig. 3.a and Fig.3.b, Schema of a keyboard pattern can be projected virtually by laser on table, wall or even in the air. On the other hand, display devices are used as output. In QOC, 3D display devices are suitable choices[31,32].

3. Quantum Optical Processors

Old quantum Theory announced for the first time in 1905 after Hertz's and Planck's experimental and Einstein's theoretical works. Quantum mechanics developed since 1928 by N. Bohr and V. Heisenberg with non-causal Copenhagen interpretation of Quantum Theory. Finally in 50's decade of 20'th century, Bohmian mechanics developed by D. Bohm with intuitive- causal interpretation of quantum theory. For realization of QOC, we need to know quantum theory:

3.1. Quantum Mechanics

Quantum mechanics, for better or worse, predicts a number of counter intuitive effect that have been verified experimentally. To appreciate the weirdness of which quantum computers are capable, we need to accept a single strange fact called wave-particle duality[1,15,16]. In some weird quantum sense, an electron can sometimes be both here and there simultaneously. It's location will remain unknown, until some interaction (such as photon bouncing off the electron) reveals it to be either here or there but not both. Two super imposed quantum waves behave like one wave. Atom is in a state equal to a superposition of a wave corresponding to zero and one, each having the same amplitudes. Such a quantum bit, is called qubit [5,6]. In contrast a classical bit will always read either zero or one. While 3-bits equal 8 sequential states, 3-qubits equals 8 simultaneous states. It means exponential growth of processing speed. There are 5 things every quantum computer needs: 1) reset all qubits into zero(start). 2) readable at the end of calculation. 3) qubits last long enough during run program. 4) carry out two fundamental operations: NOT and EXOR and 5) ability to handle large amounts of qubits[5].

3.2. Bohmian Mechanics

Albert Einstein noted that Copenhagen interpretation of quantum mechanics, would violate all classical intuition about causality. In such a superposition, neither bit is in a definite state, yet if you measure one bit, there by putting it in a definite state, the other bit also enters into a definite state. In contrast with Copenhagen counter intuitive viewpoint, there's also another interpretation for quantum world that we know it as Bohmian mechanics [36,37], based on viewpoints of late David Bohm[7,9]. It's based on intuitive physics and introduces hidden variables. Because of universal ignorance of such hidden variables, we deduce superposition and duality. According to Bohm theory, there's a kind of what's called:" Straight forward conditionalization" during light-matter interaction [7,8]. According to causality, it'll be possible to predict next position steps based on initial conditions. So, with certainty, we'll be able to trace information signals from starting point till to the end. Bohmian mechanics, has been deliberately ignored for most of the past six decades. It challenges the probabilistic, subjectivist picture of reality implicit in the standard formulation of quantum mechanics[7,33].

In this theory, chance plays no role and every material object invariably does occupy some particular region of space. All the mathematical operations in quantum mechanics occurs in Hilbert space. But it's noticeable that quantum phenomena do not occur in Hilbert space. They occur in laboratories. In real space.

3.3. Spintronics

A growing band of experiments think they have seen the future of electronics, and it is "spin". This fundamental property of electrons and other subatomic particles underlies permanent magnetism, and is often regarded as a strange form of nano-world angular momentum. Paul Dirac for the first time postulated spin existence in 1920. Spin, like charge and mass is an intrinsic subatomic particles property. Bosons- like photon or pion- have integer spin. Fermions-like electron, proton, neutron- have half-integer spins. Spin can be used as memory cell or processor instead of electron. Huge amount of non-volatile magnetics RAM and ultra-fast spin microprocessors will be available. This technology which is called “Spintronics”, requires special materials[34,35]: Ferromagnetic metals(Cr, Co, Fe,…), magnetic semiconductors-(InCr, …). Cryogenic temperature is needed. Or else spin scattering happens at room temperature. Moreover spin polarization (up-down) or (right-left) retains in microsecond orders. Spin field effect transistors have already been proposed in 90’s decade[34]. Spintronics microprocessor is one of modern proposals for realization of quantum computers [35]. But some experiments based on electron’s spin by researchers in physics, have demonstrated some kinds of violation of duality in quantum mechanics with Copenhagen interpretation of Niels Bohr[7]. Finally, Bohmian mechanics have found answer to this enigma.

4. Quantum Photonic Computer

Quantum Photonics(QP) revealed for the first time in 1994 [44] with the aim of finding intuitive description for atomic scale and attosecond time scale photon electron interactions. Annihilation and recreation mathematical operators in Hilbert space found intuitional meanings. If we want to realize Optical Photonic Computers (QPC), three dimensional space trajectory of photon when travelling inside a transparent material should be precisely tracked. For this reason, Short Range Interatomic Forces (SRIF), must be taken into account. For realization of QPC, duality will no more help us. Since QOC or QPC designer must know exactly the location of photon inside the matter. Moreover, straight forward conditionalization in Bohmian mechanics determines photon’s trajectory in next following steps. We must know with certainty[33], where’s the photon, and also the time of it’s interaction with matter at different atomic layers.

4.1 Main Features of QP

This theory as it’s called, is based on quantum theory. In addition, it delivers a “real”, instead of “virtual” description of photon-electron interaction inside a transparent solid material. It not only emphasizes on mathematical point of views similar to quantum mechanics, but in addition, it also emphasizes on intuitive physics about what’s really happening in space-time atomic world. In QP, we’ve four main postulates[9]: First, knowledge of real shape of molecules in 3D spatial coordinates. Second, knowledge of physical shape of materials lattice. Third, precise estimation of SRIF between molecules in a real material. Fourth, space-time analysis and simulation of electron-photon interaction and prediction of photon trajectory when travels inside the matter[38].

Moreover in QP, light itself is assumed to be a stream of billions of photons as particles. Each photon has quantized energy according to Planck’s formula ($E=h.\upsilon$). Photon has zero rest mass and potential energy. Carries momentum and has it’s own electric and magnetic fields. It’s electrical field has penetration depth on the order of it’s wavelength and travels in vaccum at speed of 300,000 km/s. But in transparent solids experiences some kinds of retardation in every molecular layer of material [39,40,41,42].

4.2. Nano-scopic interpretation of Refraction phenomenon in Q.P.

Equation (1), shows the total time, which takes for photon to travel through a transparent media [9,42]: (see also Fig.4)

$$T = \frac{L}{C_0} + \sum_{i=1}^{N} \tau_{di} \quad (1)$$

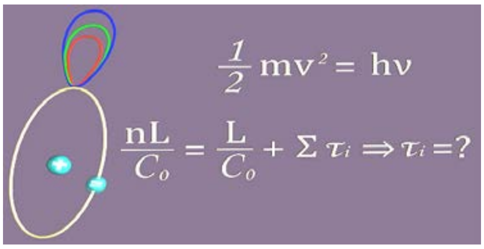

Fig. 4. During Photon-electron interaction, photon is Annihilated and it's energy as kinetic form will be transferred to electron for a short time. Then photon is recreated.

Where "L" is the material length. Travelling time of photon may be assumed as the sum of time that photon spends to pass through the intermolecular (inter-atomic) empty space ($\frac{L}{C_o}$) and photon- matter interactions ($\sum_{i=1}^{N} \tau_{di}$). The index of refraction is the ratio of C_o (vacuum velocity of the light) over the average velocity of light in the medium for large values of N (number of interactions), so:

$$n = \frac{C_o}{C} = 1 + \frac{C_o}{L} \sum_{i=1}^{N} \tau_{di} \qquad (2)$$

If now, we consider "τ_d" as the mean retardation time per interaction and "d", as the mean free pass between two successive interactions, we have:

$$n = 1 + \frac{C_o}{d} \tau_d \qquad (3)$$

(where: $\tau_d = \frac{\sum_{i=1}^{N} \tau_{di}}{N}$; and $d = \frac{L}{N}$)

During the interaction, as seen in fig. 5, at first, the photon, annihilates and gives it's energy to the electron in the lowest energy level and perturbs it. Since the energy of annihilated photon is not sufficient to transfer the electron to a higher allowed energy state, the perturbed electron returns to it's initial orbit after a transit time, which we call (τ_p), ultimately the photon recreates.

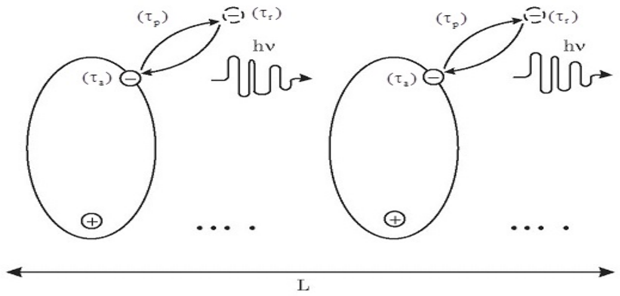

Fig. 5. Photon-Electron interaction with molecular layers of a transparent typical solid, based on Quantum Photonics and Bohm Theory.

Therefore, the retardation time (τ_d) for a more precise estimation, may be considered as the sum of photon annihilation time (τ_a), electron perturbation time (τ_p) and photon recreation time (τ_r) (see Fig.5) and [42,46]:

$$\tau_d = \tau_a + \tau_p + \tau_r \qquad (4)$$

Generally these quantities can be considered as a function of wavelength but, for simplicity as a first- order approximation, we consider τ_a and τ_r as negligible constants on the order of zepto-seconds. Since according to Quantum Photonics assumptions, (τ_p) will be in the range of atto-seconds [9].

4.3. How to Obtain Hidden Variable: SRIF

When an atom is placed inside a crystal, the wave functions (or atomic orbits) of atoms are perturbed and altered because the neighboring atoms, exert electric field on the atomic electron, which results in the distortion of orbits and splitting of the energy levels. This electric field is known as crystal field. It's effect can be treated by Perturbation theory, a common approach in submicron scales related to quantum mechanics. In Perturbation theory, the potential in the presence of applied field becomes:

$$V = V_o(r) + V'(r) \qquad (5)$$

where $V_o(r)$, is the atomic potential and $V'(r)$, is the potential due to the field. The details of this method may be found in books of quantum mechanics like[45].

the results are:

$$E_n \cong E_n^{(o)} + \langle n|V'|n\rangle - \sum_m{}' \frac{\left|\langle m|V'|n\rangle\right|^2}{E_m^{(o)} - E_n^{(o)}} \qquad (6)$$

and:

$$\psi_n \approx \psi_n^{(o)} - \sum_m{}' \frac{\left|\langle m|V'|n\rangle\right|^2}{E_m^{(o)} - E_n^{(o)}} \qquad (7)$$

Here, $E_n^{(o)}$ and $\psi_n^{(o)}$ are energy and wave function for an arbitrary level "n" in the absence of field. These results show the wave function of atoms inside the crystal in a stable state. So, if one atom goes farther or closer to other atoms in crystal structure, a restoring force makes it go back to it's stable state.

For simplicity, we assume that electrons of atoms in a typical lattice structure, form a uniform, negatively charged sphere surrounding the nucleus of atoms. let F_o be the inter-atomic force between mother atom (which interacts with photon) and it's nearest neighbor at distance "a": constant lattice:

$$F_\circ = \frac{\text{Constant}}{a^r} \qquad (8)$$

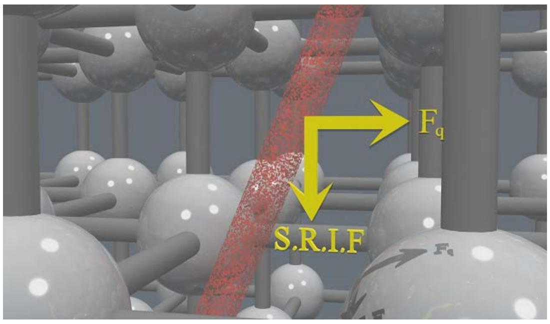

Fig.6. coulomb mother nucleus force and SRIF in a typical Orthorhombic or tetragonal crystal lattice.

The interatomic force, when photon interacts with i'th layer from the interface surface, will be obtained as follows [9]: See also Fig.6 and Fig.7:

$$F_{ii} = F_i + F_{i+1} + \ldots F_p + \ldots \qquad (9)$$

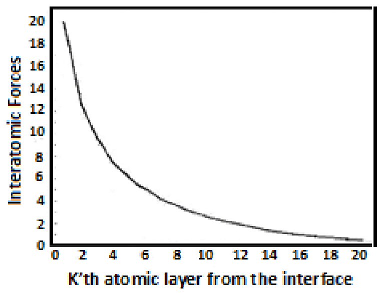

Fig.7. Interatomic force in K'th layer from the interface for a typical crystal lattice. As can be seen, it decreases exponentially to zero when "K" becomes enough large. These results can be extended easily to amorphous transparent solids too.

4.4. Quantum Photonic Physical Model

When incident light strikes at the interface between two dielectric media and interacts with the surface layer electrons of a medium, it causes a small perturbation in electron orbits. It's been assumed that these electrons bear a transient stage at this moment, and their flight routes are determined by result of the columbic nucleus force (F_{cn}) and the inter-atomic force (F_i), and also depend on the angle of the incident light (θ_i).

We have shown that photon, when traveling through k'th layer from the interface region, deviates in an angle with the amount of ($\Delta\theta$) and we can write [9]:

$$tg(\Delta\theta) = \frac{F_{ik}.\sin(\theta_i)}{F_{cn}.\cos(\alpha) + F_{sl}} \qquad (10)$$

and:

$$\cos(\alpha) = \cos(\beta).\cos(\theta_i) \qquad (11)$$

where F_{cn} is the columbic nucleus force, F_i is the inter-atomic force in the K'th layer from the interface region, and F_{sl} is the surface layer inter-atomic force.

Equation (10), is a nano-scopic refraction relation proposed by QP theory. It can predict the trajectory of photons, traveling through the first few atomic layers of the crystal- interface. When photons interact with atomic layers near the interface surface, the electrons of those atoms, bear rotational torque, because two main perpendicular forces exist: first, the inter-atomic force SRIF. Second: columbic nucleus force (Fq in Fig.8). QP predicts photon's refracts gradually at the first few atomic layers from the interface surface (see Fig.8).

Now, we may propose here a real scenario: since the nature of SRIF is columbic, with applying external electric field for example, it'll be possible to change SRIF and control the rate of photon deviation inside the crystal. This is a kind of photon multi

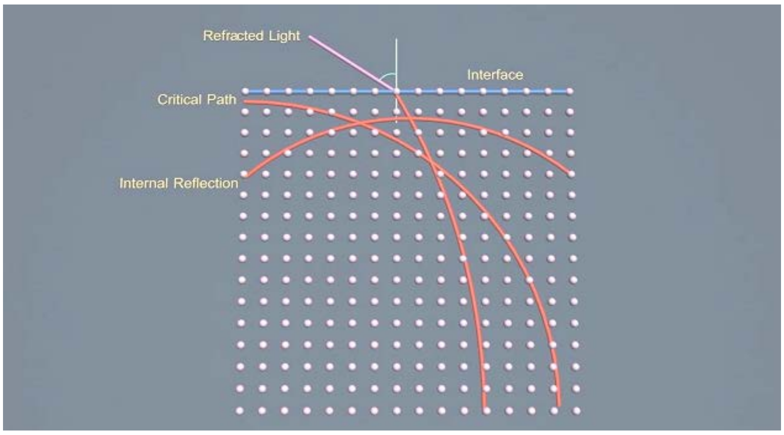

Fig. 8. According to predictions of QP, photon's flight route in first few atomic layers from the interface is not abruptly refracted as the case of macroscopic observation of Snell's law. But gradually refracts step by step and asymptotes to output angle value.

plexing or de-multiplexing through different atomic channels. Also in theory, it's also possible, when photon annihilates during interaction with bounded electron of an atom, it may recreate or may not: means a kind of photon atomic switch. Other photonic devices may also be realizable in atomic scales with switching times even on the order of attosecond. They all means realization of QP-CPU.

5 Conclusion

In QPC, photons assumed to be signal carriers. By controlling SRIF inside the material, computer is made from, we'll be able to track and interconnect optical signals even in attosecond time scales during single-photon interactions with electrons of matter.

This theoretical intuitive scenario, delivers a powerful tool for executing huge amount of mathematical calculations, but physically! This approach help us to claim that we're now one step more to realize QPC. Although using QP, we'll be able to track photons one by one inside brain, but it still does not mean we'll be able to realize thinking machine. Since we're not thinking machine, as some researchers claims [43]. We're not robots! However it seems emotional intelligence may be explained now in more details. AI will experience one more powerful step forward physically not symbolically. Human brain is a physical entity and is the container of thinking and intelligence processes. For understanding seriously about these processes we should abandoned duality dogma in world of physics. Although duality works well in Politics and in Cinema, but is not a suitable tool to find out the truth!

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