EC601

Project 1: Literature and Product Review

Photonics Chips for Machine Learning

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I. Problem Statement

Based on my research review, photonics chips mainly use optical waveguides, beam couplers, electro-optic modulators, photodetectors and lasers to manipulate optical signals. They use semiconductor to emit light, combines the speed and bandwidth of light, and have the characteristics of anti-interference and fast propagation. Low power consumption and low cost are the biggest advantages of photonic technology in multiple applications. On the operating platform, a certain area can simultaneously complete a lot of wiener magnitude, take the photon as the carrier of information function branch, forming a whole, with large comprehensive computing capability of the photon chip. Due to the development of artificial intelligence big data in the information age, the data flow of each branch of photon carrier has reached a full load. Therefore, it is necessary to use integration technology to import micro-nano photons into the chip to become a Nano-level photon chip. They are mainly used for specific applications such as optical fiber communications, chemical, biological or spectral sensors, metrology, classical and quantum information processing, as well as programmable photonics chips that can be adapted to a wide variety of application scenarios.

As a part of artificial intelligence, machine learning covers a lot in the area of photonics chips. Photonics chips use light instead of electricity - and consumes relatively little power in the process. The chip could be used to process massive neural networks millions of times more efficiently than today’s classical computers do. Neural networks are machine-learning models that are widely used for such tasks as robotic object identification, natural language processing, drug development, medical imaging, and powering driverless cars. Novel optical neural networks, which use optical phenomena to accelerate computation, can run much faster and more efficiently than their electrical counterparts can. Simulations suggest photonic chip could run optical neural networks 10 million times more efficiently than its electrical counterparts could. [2] They are combined with the speed and bandwidth of light, it has the characteristics of anti-interference and fast propagation.  Low power consumption and low cost are the biggest advantages of photonic technology in multiple applications. Therefore, Photonics chips are vital for future industry and society.

II. Applications

1. Long-distance, high-speed moving target ranging, velocity measurement and high-resolution imaging laser radar.

2. Biomedicine, Nano devices and other internal structures to achieve high-resolution nondestructive detection of new computational microscopic correlation imaging equipment.

3. The main technical means to solve the bottleneck of current space transmission rate; Inter-satellite Internet, 6G communication, intelligent remote sensing mapping.

4. Key AI (machine learning) areas such as autonomous driving, security monitoring, voice recognition, image recognition, medical diagnosis, gaming, virtual reality, industrial Internet of Things, enterprise servers and data centers. [4]

Social Significance:

Photonics chips compute beyond the fundamental limits of energy consumption and improve the efficiency of social development.

III. An area of focus that interests me

Programmable Photonics Chips

IV. Literature review

1. Programmable photonic chip lights up quantum computing [5]

Computers are made of chips, and in the future, some of those chips might use light as their main ingredient. Scientists from the Ontario, Canada-based quantum computing firm Xanadu and the US National Institute of Standards and Technology have taken a big step towards that future by building a light-based chip that can be programmed through cloud access.

While conventional computers use electricity to create the ones and zeros that are their lifeblood, quantum computing experts have multiple options when developing their quantum bits (qubits). Some rely on superconductors, some start with extremely cold atoms, and some, like the researchers at Xanadu, use light.

But not just any light. The light that travels through the thumbnail-sized Xanadu chip, or circuit, has been “squeezed” – that is, its quantum uncertainty has been minimized. Squeezing light is possible because of the Heisenberg uncertainty relation that says that trying to make any microscopic object very narrow is like squashing a piece of clay: the narrower it gets in one direction, the more it bulges in another. Squeezing light produces precisely shaped photonic states that can be used for very accurate measurements in optical physics. Xanadu researchers, however, had other ideas: they used these squeezed states as qubits.

2. Programmable Photonic Circuits: a flexible way of manipulating light on chips [6]

Programmable Photonic integrated circuits are optical chips where the flow of light is configured through electronics. This provides a flexible way to explore new photonic functions, and a lower threshold for deployment in new applications.

3. Programmable photonic signal processor chip for radiofrequency applications

“Integrated microwave photonics, an emerging technology combining RF engineering and integrated photonics, has great potential to be adopted for wideband, flexible analog processing applications. However, realizing an application-specific photonic integrated circuit is expensive and time-consuming. Here, we introduce a disruptive approach to tackle this bottleneck, which is analogous to electronic field-programmable gate array (FPGA). We use a grid of tunable Mach-Zehnder couplers interconnected in a two-dimensional mesh network topology, each working as a photonic processing unit. Such a device is able to be programmed into many different circuit architectures and thereby provide a diversity of functions. This paper provides the first-ever demonstration of this concept and show that a programmable chip with a free spectral range of 14 GHz enables RF filters featuring continuous, over-two-octave frequency coverage, i.e. 1.6- -6 GHz, and variable passband shaping ranging from a 55-dB-extinction notch filter to a 1 .6-GHz-bandwidth flat-top filter.” [7]

4. MORPHIC: Programmable photonic circuits enabled by silicon photonic MEMS

“Photonic integrated circuits (PIC) are becoming ever more complex. This evolution is fueled by increasingly mature fabrication processes for silicon photonics and III-V PICs, as well as better photonic circuit design capabilities. Especially, technology platforms with a high refractive index contrast such as silicon can integrate thousands of building blocks on the same chip, boosting the level of complexity and functionality in a photonic circuit. Today, most PICs are custom designed with one particular application in mind. The optical waveguide connections on the chip are optimized at the design stage and implemented in physical paths on the chip. These so-called application-specific photonic integrated circuits (ASPIC) have similar benefits as electronic application specific ICs (ASIC) in terms of ultimate performance, efficiency and power consumption. But the development of a new ASPIC is a costly proposition, as it takes a year to design, fabricate and test a new circuit.” [8]

References:

1. Photonic integrated circuit - Wikipedia <https://en.wikipedia.org/wiki/Photonic_integrated_circuit>

2. Chip design drastically reduces energy needed to compute with light – MIT News <https://news.mit.edu/2019/ai-chip-light-computing-faster-0605>

3. Accelerating AI with Photonic Chips – OSA

<https://www.osa-opn.org/home/industry/2021/june/accelerating_ai_with_photonic_chips/>

4. The technical principle and application prospect of photonics chips <http://m.elecfans.com/article/1462469.html>

5. Programmable photonic chip lights up quantum computing <https://physicsworld.com/a/programmable-photonic-chip-lights-up-quantum-computing/>

6. Programmable Photonic Circuits: a flexible way of manipulating light on chips on YouTube, provided by prof. Wim Bogaerts (Ghent University - imec) <https://www.youtube.com/watch?v=eZSnJPDzyaI>

7. Programmable photonic signal processor chip for radiofrequency applications by Leimeng Zhuang etc. <https://arxiv.org/ftp/arxiv/papers/1505/1505.00094.pdf>

8. MORPHIC: Programmable photonic circuits enabled by silicon photonic MEMS by Wim Bogaerts etc. <https://biblio.ugent.be/publication/8660130/file/8660134.pdf>