Features of the construction of photonic integrated circuits for communication systems

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Abstract. The article discusses the main methods of signal processing in a coherent optical transport network based on a photonic integrated circuit to increase the speed and the onset of the terabit era in optical transport networks, cloud and high-performance computing systems. The properties and operational characteristics of the main material platforms of photonic integrated circuits and their future technological units are considered.

1. Introduction
In modern human life, communication systems play an important role [1-10]. The volume of information and the requirements for its transfer are increasing every year [5-7, 11-18]. For different areas of human activity, different areas of communication are developing [3, 4, 6-8, 17-24]. A special place among communication systems is occupied by fiber-optic communication lines, which have found application in almost all areas of information transmission [16, 18, 22, 24-35]. Optical transport network at development of technology is stimulated by new services, such as cloud connection services of data centers, high-bandwidth video services and mobile 5G network services will drive future optical communications industry development and architecture transformation [5, 6, 13, 34, 36-40]. Service providers have driven higher speed Ethernet solutions for decades. Router connections, client side optics for optical transport networks (OTN) equipment, and wireless backhaul have continually pushed Ethernet to higher rates and distances to meet the demands for wireless connectivity [36-41]. And with global demand by consumers for video, this shows no signs of changing.

The main task of the network is to deliver traffic from one subscriber to another [34-41]. And do it as quickly as possible, both in terms of bandwidth and latency. Accordingly, the main task of the node is to transfer the incoming packet to the correct output interface as quickly as possible, having time to change its headers and apply policies. Therefore, there are pre-populated packet transmission tables - switching tables, routing tables, label tables, and neighborhood tables [36, 38, 40, 41].

The electrical or optical signal, getting to the device through the input physical port, is restored to the bit stream, separate Ethernet frames are isolated from it, then based on the headers (Ethernet, IP, MPLS), a decision is made about which output port this packet should be sent to and with which set of
headers. On its way from the input port to the output port, the packet still passes through the Traffic Manager module, where the following things can happen to it: buffering, policing, shaping, priority processing.

2. Optical Communication Systems

In connection with the increase in video traffic on the Internet and with an increase on the transmission speed over fiber-optic data transmission systems up to 100 Gbps, and in the future up to 400 Gbps per channel, there is a problem of packet processing on switches and routers of the aggregation and core levels telecom operators, since the speed there is limited by electronic components, where the maximum frequency is 50 GHz. Photonic integrated circuits can meet this growing demand. Super channels allow you to increase the DWDM bandwidth in terabits in one cycle without any loss in terms of spectral efficiency and with the same optical range as the current generation of coherent transponders.

All major optical functions on all 10 100G line cards are bundled into one PIC pair - one for transmit and one for receive. All 10 carriers can now be brought into service in a single duty cycle, consuming much less power than 10 discrete transponders, and the result is significantly improved service reliability. PICs bring the same engineering usability to super channels that electronic integration brings to multi-core processors or graphics engines.

Within reasonable limits, the more carriers there are in the superchannel, the simpler the electronics and the better the optical performance. PICs remove the complexity limitation of optical components and allow you to choose the right engineering balance. As PIC technology advances, new circuits will emerge that will either allow new applications to reliably combine different technologies or continue to scale the component density for photonic VLSI systems.

![Examples of the platform on PIC](image)

**Figure 1.** Examples of the platform on PIC are implemented. (a) Configurable discrete laser with nanosecond switching speed based on AWG; (b) Multi-stage SOA switching circuit with a speed of 320 GB/s; (c) multifunctional delay interferometer; (d) 4×4 cross-selective coupling of space and wavelength; (e) 16×16 photon switch for broadband photon packet routing; (f) wide frequency comb laser.

3. Photonic Integrated Circuit

The most productive commercial chip today produces 25.6 Tb/s. This is a major engineering challenge for developers. And there is no reason to believe that hyperscalers and examscalers will moderate their appetites and decide to stop there. The speed will increase. The PHY chip is on the transceivers, and the SerDes chip is on the network chip chip. The signal between them goes through an electrically
conductive medium - along a metal track. As the speeds increase, so does the design complexity and the electricity consumed. Sooner or later (rather, sooner) we'll hit something. In the case of silicon photonics, the PHY chip is transferred inside the switching chip itself. Photonic ports are “embedded” in the crystal, allowing communication between chips at the speed of light through the optical medium.

The idea is not new, and only waiting for its time, namely, when the technology will reach the desired level of maturity. The problem was that the materials and processes used to make the photonic chips were fundamentally incompatible with the silicon chip manufacturing process - CMOS. Possible alternative solutions: installing a separate chip on the board that converts the electrical signal into an optical one, or installing it inside the network chip, but not on the crystal itself (still requires converting the medium). But this technological dam is washed away by persistent developments in this direction, and in the near future, microelectronics is waiting for big changes.

Figure 2. Silicon photonics chip-on-chip layout options.

Figure 3 (a) shows a number of components that we can manufacture using passive waveguides. MMI connectors and AWG demultiplexers are the most important of them. Deeply embedded waveguides allow you to create MMIRE reflectors and compact ring filters. The polarization converter is building block that can be created using a passive waveguide. It is possible to make polarization splitters and unifiers by placing a polarization converter in a Mach-Zehnder interferometer (MZI), placing it half in a polarization-dependent component, its response is independent of polarization. A wide range of functionality is offered by SOA on combination of passive devices. As shown in Figure 3 (b): Fabry-Perot lasers (FP), multiwave lasers, ring lasers and tunable lasers. It is possible to create picosecond pulsed lasers using a short SOA section with a reverse offset as a protected absorber. Figure 3 (c) shows the functionality will be implemented by a block of phase modules with passive devices: amplitude modulators, spatial switches, switches with wavelength selection, such as WDM cross-connections and multiplexers with addition and reset. It is also possible to create ultrafast switches using the nonlinear properties of SOA integrated into MZI.

4. Conclusion
The paper discusses the main ways to help the onset of the terabit era in optical transport networks, in the clouds, as well as in high-performance computing systems. New signal processing technologies using photonic integrated circuits in coherent optical networks are considered. Three main platforms of photonic integrated circuits, their technological components, properties and performance characteristics are considered.
Figure 3. Examples of implementing devices using (a) passive waveguide devices (b) passive waveguide devices in combination with optical amplifiers (c) passive waveguide devices in combination with phase modulators.

References

[1] Grevtseva A S, Davydov R V, Dudkin V I and Rud' V Y 2019 Journal of Physics: Conference Series 1326(1) 012043
[2] Valov A P, Davydov R V, Rud V Y and Grevtseva A S 2019 Journal of Physics: Conference Series 1326(1) 012040
[3] Lukashev N A, Glinushkin A P and V. S. Lukyantsev V S 2019 Journal of Physics: Conference Series 1410(1) 012211
[4] Lukashev N A, Davydov R V and Glinushkin A P 2019 Journal of Physics: Conference Series 1326(1) 012046
[5] Andreeva E I and Potapov I A 2020 Journal of Physics: Conference Series 1695(1) 012125
[6] Andreeva E I and Potapov I A 2021 Springer Proceedings in Physics 255 241–245
[7] Davydov R V, Dmitrieva D S, Pilipova V M, Dudkin V I and Andreeva E I 2020 Proceedings of International conference of Laser Optics ICLO-2020 (Saint-Petersburg), vol. 9285820 (IEEE), p. 171
[8] Logunov S E, Vysoczyk M G and Titova O A 2018 International Conference on Electrical Engineering and Photonics EExPolytech-2018 (Saint-Petersburg), vol. 8564402 (IEEE), p. 282-284
[9] Davydov R V and Antonov V I 2018 Journal of Physics: Conference Series 1124(8) 081037
[10] Davydov R V and Antonov V I 2018 Journal of Physics: Conference Series 1135(1) 012087
[11] Kozlova E S, Kotlyar V V and Nalimov A G 2015 Computer Optics 39(5) 654-660
[12] Kozlova E S and Kotlyar V V 2014 Computer Optics 38(1) 132-138
[13] Kuzmin M S and Rogov S A 2019 Computer Optics 43(3) 391-396
[14] Skidanov R V, Blank V A and Morozov A A 2015 Computer Optics 39(3) 384-392
[15] Petrov A A, Grebenikova N M, Lukashev N A, Ivanova N V, Rodygina N S and Moroz A V 2018 Journal of Physics: Conference Series 1038(1) 012032
[16] Podstrigaev A S, Smolyakov A V, Myazin N S and Slobodyan M G 2018 Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11118 LNCS 509-515
[17] Valov A P 2019 Journal of Physics: Conference Series 1410(1) 012246
[18] Filatov D L, Galichina A A, Vysoczky M G and Yalunina T R 2017 Journal of Physics: Conference Series 917(8) 082005
[19] Petrov A A and N S Myazin 2017 Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 10531 LNCS 561-568
[20] Petrov A A, Vologdin V A and Zalyotov D V 2015 Journal of Physics: Conference Series 643(1) 012087
[21] Petrov A A, Zalyotov D V, Shabanov V E and Shapovalov D V 2018 Journal Physics: Conference Series 1124(1) 041004
[22] Davydov V V, Dudkin V I and Karseev A Yu 2014 Optical Memory & Neural Networks (Information Optics) 23(4) 259 – 264
[23] Petrov A A and Shapovalov D 2019 Journal of Physics: Conference Series 1400(4) 044008
[24] Petrov A A, Zalyotov D V, Shabanov V E and Podstrigaev A S 2019 Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11660 LNCS 744–756
[25] Davydov R, Antonov V and Moroz A 2019 IEEE International Conference on Electrical Engineering and Photonics (EEPolytech-2019), vol. 8906791, (IEEE), p. 295-297
[26] Davydov R V, Saveliev I V, Lenets V A and Tarasenko M Yu 2017 Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 10531 LNCS 177-183
[27] Moroz A V and Davydov R V 2019 Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11660 LNCS 710 – 718
[28] Fadeenko I, Fadeenko V, Reznik V, Moroz A, Popovskiy N and Nikolaev D 2019 IOP Conference Series: Earth and Environmental Science 390(1) 012022
[29] Davydov V, Fadeenko V, Fadeenko I., Popovskiy N and Rud V 2019 E3S Web of Conferences 140 07006
[30] Smirnov K J, Glagolev S F and Tushavin G V 2018 Journal of Physics: Conference Series 1124(1) 022014
[31] Fadeenko V B, Kuts V A and Vasiliev D A 2018 Journal Physics: Conference Series 1135(1) 012053
[32] Moroz A V 2019 Journal of Physics: Conference Series 1410(1) 012212
[33] Moroz A V, Davydov V V, Malanin K Y, Krasnov A A and Rud V Yu 2019 Journal of Physics: Conference Series 1400(4) 044009
[34] Fadeenko V B, Pchelkin G A and Beloshapkina O O 2019 Journal of Physics: Conference Series 1410(1) 012238
[35] Fadeenko V B and Pchelkin G A 2019 Journal of Physics: Conference Series 1400(4) 044010
[36] Makolkina M, Pham V, Kirichek R, Gogol A and Koucheryavy A 2018 Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 11118 LNCS 547-559
[37] Ermolet N L, Krishpents G P and Vysoczkiy M G 2016 Journal Physics: Conference Series 741(1) 012071
[38] Hoang T, Kirichek R, Paramonov A and Koucheryavy A 2016 Lecture Notes in Electrical Engineering 376 1249-1259
[39] Grebenikova N, Moroz A, Bylina M and Kuzmin M 2019 IOP Conference Series: Materials Science and Engineering 497(1) 012109
[40] Karanov B and Chagnon M 2018 J. Lightwave Technol 36 (20) 4843-4855
[41] Popovskiy N I and Davydov V V and Valiullin L R 2020 Journal of Physics: Conference Series 1695(1) 012120