BULLETIN of Cherkasy State Technological University

Journal homepage: https://bulletin-chstu.com.ua/en

Vol. 31 No. 3. 2026

UDC 621.39:004.7
DOI: 10.62660/bcstu/3.2026.125

Review of trends and prospects in the development of infocommunication system devices

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Abstract. The study was motivated by the need to develop high-speed infocommunication systems in connection with the growth of digital traffic volumes and the limitations of conventional electronic switching, which created the need to analyse optical switching technologies, nanophotonic structures and methods for manufacturing photonic components. The aim of the study was to systematically analyse optical switching technologies and nanophotonic components, evaluate their properties, advantages and disadvantages, and determine their possible applicatioxhing speed, implementation technology and level of integration. The analysis indicated that the development of infocommunication systems had driven a transition from electronic to optical switching, which could reduce switching latency to 1 ps-10 ns, increase single-channel capacity to 400 Gbit/s-1.6 Tbit/s or higher, and reduce energy consumption to 0.5-5 pJ/bit. Hybrid photonic-electronic architectures were particularly promising, with the photonic domain used for high-speed data transmission and the electronic domain for control and routing. Wavelength-division multiplexing technologies enabled transport networks to scale to tens and hundreds of terabits per second, while the development of all-optical networks remained constrained by the need for 3R signal regeneration and the complexity of routing and wavelength assignment. Nanophotonic and plasmonic technologies can overcome the diffraction limits of conventional photonics and support nanometre-scale components; plasmonic waveguides (20-200 nm) provide a substantially higher level of integration than dielectric waveguides, although they have greater propagation losses. Photonic integrated circuits have reached the highest technology readiness level (Technology Readiness Level 7-9), whereas plasmonic and terahertz technologies are predominantly at Technology Readiness Levels 3-6. Researchers, engineers, and telecommunications system developers may use these findings when designing optical networks and photonic components

Keywords: optical switch; optical networks; nanotechnology; nanoimprinting; molecular beam epitaxy; interaction between electronic and optical components

INTRODUCTION

The relevance of the study is determined by the need to develop high-speed infocommunication systems amid growing volumes of digital traffic and increasing network-capacity requirements. The limitations of conventional electronic switching, including rising energy consumption, transmission delays, and scaling complexity, drive the search for new approaches to processing information flows. In this context, research on optical switching technologies, nanophotonic structures, integrated photonics, and photonic-component fabrication methods is essential for identifying promising directions in the development of contemporary infocommunication networks. Current research on infocommunication systems increasingly focuses on faster data processing, improved network energy efficiency, and the transition to photonic technologies.

Article's History: Received: 27.04.2026; Revised: 20.08.2026; Accepted: 21.09.2026; Published: 07.10.2026

Suggested Citation:
Melnychok, O. (2026). Review of trends and prospects in the development of infocommunication system devices. *Bulletin of Cherkasy State Technological University*, 31(3), 125-140. doi: 10.62660/bcstu/3.2026.125.

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D. Karabanov & D. Chebotaryova (2024) examined contemporary approaches to the security and reliability of information systems and highlighted the importance of more efficient processing of large data flows in digital environments. Their results confirmed the need for high-performance hardware solutions capable of rapid information transmission and stable operation of network infrastructure. A. Yanko & S. Gorchanenko (2025) focused on methods for rapid and reliable data processing in computer systems and networks. The researchers emphasised that growing data volumes require optimisation of data-transmission and processing architectures and the use of technologies that reduce latency and improve system performance. These arguments are directly relevant to optical switching, where the transition from electronic to photonic signal processing is regarded as a means of overcoming the limitations of conventional network solutions.

C.-Y. Jin & O. Wada (2014) covered a more specialised area of optical switching systems and assessed high-speed optical switches based on photonic crystals. The researchers showed that photonic-crystal structures can support compact switching elements with high switching speeds and low energy requirements. The study also highlighted technological limitations associated with the complexity of fabricating these structures and the need for precise control of nanophotonic-component parameters.

S.J.B. Yoo (2023) analysed emerging trends in photonic switching and optical-network architectures for data centres and computing systems. The researcher showed that growing data traffic requires optical solutions capable of scaling bandwidth without a proportional increase in energy consumption. The research was devoted to the integration of optical switches in next generation network architectures, where photonic technologies are the basis of high performance infocommunication systems. D. Al-Saffar & N. Jihad (2024) studied the design and implementation of an Optical Switching Network. The researchers investigated the construction of optical switches and, in particular, the effect of the network architecture and the parameters of the switching element on the efficiency of information transmission. Their results confirmed optical switching can reduce latency and improve network performance over electronic counterparts but control and scaling mechanisms require further improvement.

F. Li *et al.* (2025) showed that photonic technologies could be used to achieve high-speed data transmission with little electronic conversion. They pointed out the main challenges as stable optical routing, signal loss compensation, and reliable operation of photonic components under demanding operating conditions. D. Nandi *et al.* (2022) conducted a systematic review on optical switching technologies, their architectural solutions, and applications in modern networks. The researchers saw a shift from single photonic components to integrated network platforms, with switching speed, energy consumption and scalability as key performance indicators. The study further highlighted the fact that the selection of switching technology is dependent on the network environment requirements as different types of optical switches have their own limitations in terms of speed, signal loss and complexity of implementation.

D.M. Marom *et al.* (2022) examined prospects for optical switching in future fibre-optic networks using spectral and spatial degrees of freedom. The researchers demonstrated that further increases in optical-system capacity depend not only on improvements to conventional Wavelength Division Multiplexing (WDM) solutions but also on spatial multiplexing and new approaches to optical-resource management. K.I. Sato *et al.* (2022) analysed the prospects and challenges of implementing optical switching technologies in intra-data-centre networks. The researchers showed that photonic switches can reduce energy consumption and latency compared with conventional electronic solutions, an important requirement for large-scale computing systems. They also identified dynamic traffic management, high reliability, and integration of optical components with existing network architecture as the main challenges. A. Jukan *et al.* (2026) emphasised that photonic technologies have the potential to support high-speed communication in environments with demanding bandwidth and transmission-latency requirements. The researchers also noted that implementing such systems requires improvements in optical-channel stability, adaptive route management, and compensation for changing network conditions.

Previous research focused mainly on individual aspects of optical switching development, including photonic-switch architecture, higher network speeds, photonic crystals, plasmonic structures, and integrated photonic platforms. However, this body of research did not comprehensively examine how these stages of infocommunication-system development are interconnected, from the principles of optical switching and all-optical networks to nanophotonic components and their fabrication methods. The purpose of the present study was to conduct a comprehensive analysis of optical switching technologies and nanophotonic solutions relevant to the development of infocommunication systems, determine their functional characteristics and technological limitations, and assess their prospects for use in high-speed data-transmission networks.

MATERIALS AND METHODS

This study is theoretical and analytical. The sources comprised academic publications, review papers, conference proceedings, and monographs on optical switches, all-optical networks, integrated photonics, plasmonic technologies, and methods for fabricating

nanoscale elements for infocommunication systems. The literature search was conducted in the Scopus, Web of Science, IEEE Xplore, ScienceDirect, and SpringerLink databases. Publications were included if they: (1) reported theoretical or experimental research on optical switching and photonic technologies; (2) described the architectures, characteristics, or operating principles of optical switches; (3) addressed fabrication technologies for nanoscale photonic and plasmonic structures; (4) were published in peer-reviewed academic publications; and (5) provided quantitative performance indicators for the solutions examined. Publications that had not undergone peer review, duplicate studies, short abstracts without full text, patents without experimental validation, and sources lacking descriptions of technical characteristics or implementation methods were excluded. The study covered publications from 2014 to 2026, enabling analysis of major trends in optical switches, nanophotonic devices, and promising technologies for manufacturing infocommunication-system components.

A set of complementary analytical methods was applied to synthesise research approaches to the development of optical switches and determine promising directions for infocommunication-system devices. Bibliographic analysis was used to identify, select, and synthesise research on optical switching, all-optical networks, nanophotonics, and nanoscale-structure fabrication technologies. This method provided the theoretical basis of the study and outlined key trends in the field. Comparative analysis of optical switching technologies was used to assess mechanical-optical, electro-optic, optoelectronic, and liquid-crystal switches by operating principle, switching speed, scalability, energy efficiency, and operational characteristics. Particular attention was paid to the advantages and limitations of each technology. Systematisation and synthesis were used to organise data on optical-switch parameters, including switching time, bandwidth, signal loss, crosstalk, polarisation sensitivity, and scalability. The analysis focused on relationships between device design features and functional capabilities and produced a generalised profile of the main classes of optical switches. Technological analysis of nanostructure fabrication methods assessed the capabilities of optical lithography, nanoimprinting, scanning probe microscopy, molecular beam epitaxy, ion bombardment, and vacuum deposition. The potential of each technology was evaluated according to attainable spatial resolution, process throughput, equipment complexity and cost, production scalability, compatibility with photonic integrated-circuit fabrication, and suitability for nanophotonic and plasmonic structures. This comparison clarified the advantages, limitations, and appropriate applications of the technologies and highlighted those with the greatest potential for high-speed, high-density photonic devices. The combined use of these methods provided a comprehensive analysis of optical switching technologies, nanophotonic components, and manufacturing processes and defined promising directions for infocommunication-system devices. The main types of optical switches were compared with the help of technical criteria that define their performance in infocommunication systems. The evaluation criteria included switching time (a measure of switch speed), insertion loss (a measure of signal attenuation through the device), scalability (a measure of the ability to increase the number of switching ports without significant degradation of performance) and operational advantages and technological limitations (such as energy consumption, polarisation sensitivity, channel isolation, implementation complexity and suitability for integration into photonic systems). The comparison was done on aggregate data from recent academic publications.

We have classified existing solutions for optical switching by grouping devices by their technical and functional characteristics. The main criteria were the principle of operation of the switching element, the parameters of switching speeds, the technology of implementation and the level of integration of components. Thus, the variety of architectural solutions was systematised, and their role in the development of infocommunication systems was clarified. The classification by switching principle allowed to classify devices according to the physical mechanism used to control the optical signal. Mechanical-optical, electro-optic, optoelectronic and liquid-crystal switches were distinguished. Such a criterion made it possible to analyse the operating characteristics of various switching devices, the relationship between the operating principle and technical performance. Classification by switching speed classifies devices by signal switching time. The analysis included systems operating in the millisecond, microsecond, nanosecond and picosecond switching ranges, and discussed the applicability of different technologies for switching, data packet switching and ultrafast optical information processing. The devices were classified by component base and materials, by implementation technology. This category comprises devices based on waveguide structures, photonic crystals, semiconductor optical amplifiers, liquid-crystal matrices, plasmonic elements and photonic integrated circuits. Specification of the technological advantages and limitations of individual optical-switching approaches. The degree of integration was categorised based on the combination of functional elements into a single device and identified discrete, hybrid and integrated photonic solutions. This classification reflected the transition from discrete components to sophisticated, integrated photonic platforms able to perform multiple signal processing functions on a single chip. Together the criteria formed a coherent model for classification of devices of the infocommunication system, which allowed to carry out a comparative analysis and to determine the most promising

directions of technological development. The main limitation of plasmonic structures is still large ohmic losses and further development is directed toward new materials and hybrid architectures.

RESULTS AND DISCUSSION

Development of optical switching in infocommunication systems. The development of infocommunication systems has been accompanied by the constant growth of data transmission volumes, the increase in the complexity of network services and the tightening of requirements for transmission latency. New demands on network transport infrastructure have been generated by the growth of cloud computing, virtualisation technologies, data centers, artificial intelligence systems and multimedia streaming services. Under these conditions, the conventional electronic switching systems have reached their limits, both physically and technologically, in scaling up, due to increasing energy consumption, heat generation and delays caused by the repeated conversion between optical and electrical signals. Backbone fibre-optic links are almost entirely transmitted in the optical domain, but routing, switching and data-flow management have traditionally been performed by electronic devices. This type of arrangement requires opto-electronic conversion at network nodes via a cascade of Optical-Electrical-Optical (OEO) conversions. Despite the high functional flexibility of this approach, each conversion introduced further delay, increased energy use, and constrained the maximum information-processing rate. The development of optical switching has therefore focused on transferring as many information-flow processing operations as possible directly to the optical domain without intermediate electronic conversion. G. Gayvoronska & B. Rybalov (2015) reached similar conclusions, showing that repeated OEO conversion was one of the main factors constraining further scaling of electronic switching in ultra-high-capacity networks. The researchers noted that the transition to photonic switching could reduce energy consumption and mitigate some limitations associated with the electronic bottleneck.

Optical switching allows light to serve not only as a medium for information transmission but also as a signal that can be controlled directly. This led to a new approach to transport-network architecture in which routing, multiplexing, demultiplexing, and channel switching are performed by varying the parameters of the optical signal. Wavelength-division multiplexing technologies are particularly important because they support simultaneous transmission of many independent information flows through a single optical fibre. Combining WDM technologies with high-speed optical switches can substantially increase network-infrastructure capacity without requiring further communication lines. Requirements for optical switching devices differ across levels of network infrastructure. Channel protection and network-topology reconfiguration generally require switching times in the millisecond range, while switching between alternative routes requires switching times in the microsecond range. Packet switching in high-speed transport networks requires switching times in the nanosecond range. Further increases in information-transmission rates to hundreds of gigabits per second and terabit speeds require switching elements with picosecond response times. C. Feng *et al.* (2020) noted that the combination of WDM and optical switching was regarded as one of the key prerequisites for all-optical data centres and next-generation networks. S. Okamoto *et al.* (2020) expressed a similar view and emphasised the importance of semiconductor optical amplifiers for high-speed switching in WDM environments.

Growth in traffic volumes has increased the number of channels and wavelengths that must be served simultaneously. As network technologies have developed, scalable switching architectures have become necessary to support tens, hundreds, or thousands of independent optical connections. Switch performance depends not only on the number of ports but also on insertion loss, crosstalk, polarisation dependence, and long-term stability. Table 1 presents the main requirements for optical switching devices.

Table 1. Main requirements for optical switching devices

Parameter	Characteristic
Switching time	From milliseconds to picoseconds depending on the application
Bandwidth	From tens of Gbit/s to several Tbit/s
Scalability	Support for multiport architectures
Signal loss	Minimisation of attenuation through the switch
Crosstalk	Channel isolation
Polarisation stability	Parameter independence from polarisation state
Energy consumption	Reduced energy use for switching
Reliability	Stable operation over long periods

Source: compiled by the author based on G. Gayvoronska & B. Rybalov (2015), C. Feng *et al.* (2020), S. Okamoto *et al.* (2020)

Table 1 shows that the performance of optical switching devices depends on a combination of switching speed, signal quality, scalability, and energy efficiency. Growth in network traffic requires higher performance without compromising system stability. This indicates a shift from improving individual

components towards comprehensive optimisation of switching-device architecture. The ongoing development of the field is centred on integrated photonics and nanophotonic technologies that provide a high bandwidth but are compact and energy efficient. In terms of technology, the evolution of switching systems from electronic to optical information processing was rather slow. Electronic switching enables flexible routing and advanced traffic-management mechanisms. The performance of such switches is limited by the speed of electronic components. Data rates are growing and so is energy consumption for information processing and heat dissipation. Optical switching, in contrast, enables the transmission and switching of information flows without intermediate electrical conversion, thus decreasing latency and increasing the energy efficiency of the network. Similarly, N. Starodubtsev *et al.* (2023) observed that electronic switching constraints become more pronounced at higher data rates, while photonic switching elements hold more promise for scalability. T.J. Seok *et al.* (2016) and X. Chen *et al.* (2023) have demonstrated that integrated silicon photonic switches can achieve a large energy saving for traffic processing compared to conventional electronic solutions. Table 2 Electronic versus optical switching comparison.

Table 2. Comparison of electronic and optical switching

Criterion	Electronic switching	Optical switching
Processing medium	Electrical signals	Optical signals
Need for optoelectronic conversion	Required at every switching node	Absent or performed only at end nodes
Switching speed	1-100 ns	1 ps-10 ns (depending on technology)
Energy consumption	5-20 pJ/bit	0.5-5 pJ/bit
Switching latency	10-100 ns	1 ps-10 ns
Single-channel capacity	Up to 100-400 Gbit/s	400 Gbit/s-1.6 Tbit/s and above
Scalability	Limited by the performance of electronic processors and interconnects	Supports wavelength-division multiplexing and high integration density
Control flexibility	High; supports complex routing algorithms	Requires an electronic control plane or software-controlled mechanisms
Implementation complexity	Mature industrial technology	Requires photonic integrated circuits and specialised manufacturing

Source: compiled by the author based on T.J. Seok *et al.* (2016), X. Chen *et al.* (2023)

Table 2 lists the basic differences between electronic and optical switching which influence the design of infocommunication systems. Optical switching has a higher capacity to transmit large volumes of data with less latency and energy consumption, while electronic switching is a mature technology with sophisticated control mechanisms. V. Sasikala & K. Chitra (2018) came to similar conclusions, noting that a gradual transfer of switching functions to the optical domain is necessary for further increases in the capacity of data centers and backbone networks. The researchers also stressed that completely dumping electronic processing is problematic, since it is complex to implement logic operations, buffering, and traffic management solely by photonic means. Thus, further development of network infrastructure assumes a gradual transition to hybrid photonic-electronic architectures, combining the advantages of both approaches.

Comparative analysis of the main types of optical switches. The development of optical data-transmission networks has produced a broad range of switching devices that differ in operating principles, architectural features, switching speed, scalability, and implementation complexity. The choice of optical switch depends on network-capacity requirements, acceptable data-transmission latency, energy consumption, and the required level of integration with other elements of infocommunication infrastructure. Mechanical-optical, electro-optic, optoelectronic, and liquid-crystal switching systems have become the most widespread approaches in photonic networks. Each technology has a distinct role in optical switching and a specific combination of advantages and limitations.

Mechanical-optical switches were among the earliest technical solutions used to control optical flows in telecommunications networks. They operate by physically moving an optical element that redirects light between input and output ports. Mirrors, prisms, rotating waveguides, micromechanical reflectors, or optical focusing systems can serve as switching elements. Switching occurs by changing the spatial position of these elements relative to the optical axis of the transmitted signal. Mechanical switching provides a high level of optical isolation between channels and extremely low signal loss. In many implementations, insertion loss does not exceed 0.5–1 dB, which is among the lowest insertion-loss values for optical switches. Mechanical systems are also largely independent of the wavelength of the transmitted signal, making them compatible with multichannel WDM systems. Their main disadvantage is low switching speed caused by the inertia of moving components. Switching times typically range from several milliseconds to hundreds of milliseconds. These characteristics are insufficient

for packet switching of high-speed traffic and restrict the use of such devices mainly to network reconfiguration, channel protection, and optical cross-connects. Mechanical-optical technology nevertheless offers a high degree of scalability. Microelectromechanical systems (MEMS) have enabled switching matrices with hundreds or even thousands of optical ports, allowing these devices to be used in backbone transport-network nodes and data centres. Further advances in mechanical switches focus on miniaturising MEMS components, although fundamental speed limitations prevent them from serving as a universal solution for high-speed optical switching. These characteristics are consistent with the research of K. Biswas & A. Sarkar (2022), who reported that MEMS technologies enabled large-port optical cross-connects with low signal loss and high operational reliability. The researchers also emphasised that mechanical switching constrained the use of such devices in packet-switching systems where nanosecond response times are critical. M. Liu *et al*. (2022) reached similar conclusions and identified MEMS switches as most suitable for backbone transport networks and optical-connection reconfiguration systems.

Electro-optic switches operate by changing the optical properties of a material under an external electric field. The most common mechanism is the Pockels electro-optic effect, whereby the refractive index of a crystal changes in proportion to the applied voltage. This alters light-wave propagation and redirects the optical signal between output channels. Such switches are commonly implemented using directional waveguide couplers or Mach-Zehnder interferometers. An applied control voltage changes the phase difference between waves propagating through different interferometer arms, redistributes optical power between the output ports, and switches the optical signal. One of the main advantages of electro-optical switches is their speed. The switching speeds are from several picoseconds to tens of picoseconds and can be used in ultrafast telecommunications systems. No moving parts means greater reliability and longer service life. But it is hard to scale electro-optic switches. The complexity of the waveguide architecture increases with the number of ports, and at the same time signal losses and fabrication tolerances of photonic components become more demanding. Another limitation is the polarisation sensitivity of some electro-optic materials. The promise of this technology moving forward is tied to progress in integrated photonics and silicon photonics platforms that allow high-speed switching circuits to be built on a single chip.

Optoelectronic switches are in between the conventional electronic and all-optical switching systems. They consist of active photonic elements, mainly semiconductor optical amplifiers, and electronic control circuitry. Switching is realised due to the change of the gain or the refractive index of the active medium. A commonly used architecture is the Mach-Zehnder interferometer with integrated semiconductor optical amplifiers in the interferometer arms. Changes in the parameters of the amplifier induce the phase shift of the optical waves and the switching of the output channel. The main advantage of optoelectronic switches is the combination of high photonic switching speed and the functional flexibility of electronic control systems. The switching time is about one nanosecond on average, which is much faster than that of mechanical switches. Their disadvantages are high power consumption, complex thermal management and relatively high cost of semiconductors optical amplifiers. Noise accumulation in cascaded structures can degrade the signal quality of large switching matrices. Optoelectronic switches are an important step toward the transition from OEO architectures to all-optical networks as they enable a large number of control functions to be performed without a complete conversion of the signal into electrical form. Signal switching in picosecond and sub-nanosecond ranges were reported by Z. Ghanaatian *et al*. (2025) using Mach-Zehnder interferometers and silicon photonic platforms. L. Laplatine *et al*. (2022) also noted that using electro-optic elements on silicon substrates enabled the development of scalable photonic processors and high-performance switching matrices. The researchers also highlighted that the number of switching elements should be increased to decrease losses and simplify the topology of photonic circuits, which remains a major technological challenge.

Another area of optical switching is multilayer liquid crystal matrices. Their operating principle is based on the variation of the orientation of liquid crystal molecules under an electric field. Such molecular reorientation changes the optical properties, e.g., the transmission, reflection or refraction of light. Liquid-crystal matrices can implement multiport switching directly, whereas most other switching technologies cannot. The required signal route is established by programmatically controlling many elementary switching cells. This makes it possible to realise spatial switching structures with complex topologies without using a large number of individual optical switches. The main advantage is the possibility of building very high-capacity switches. The matrix layout results in a quadratic increase in the number of possible input-output combinations with the number of ports. Liquid-crystal technologies also consume low energy and are relatively easy to manufacture. The principal disadvantages are a relatively low speed, typically in the range of milliseconds, and the dependence of the device parameters on the ambient temperature. Another limitation is the long-term stability of the properties of the liquid crystal material. These characteristics are in agreement with the study of R. Zhang *et al*. (2023), who demonstrated that liquid-crystal matrices based spatial optical switches could support high switching

connection density, as well as efficient multiport architectures. The researchers noted that the electronic control of many switching cells is amenable to scalable optical cross-connects. Similar conclusions were reached by L. Zhou & S. Liu (2022), who proposed that liquid-crystal matrices are a promising solution for reconfigurable optical networks due to their combination of large switching capacity and low energy consumption. The researchers also emphasised that, relative to other systems, long switching times and sensitivity to outside conditions limit use in applications where response on the order of nanoseconds is critical. The main types of optical switches are summarised in Table 3 for comparison.

Table 3. Comparative characteristics of the main types of optical switches

Switch type	Switching time	Signal loss	Scalability	Main advantages	Main disadvantages
Mechanical-optical	10-500 ms	0.2-1 dB	Up to 1,000×1,000 ports	Low loss, high isolation (>60 dB)	Low switching speed
Electro-optic	10-100 ps	2-5 dB	Up to 32×32 or 64×64 ports	Ultrahigh switching speed	Polarisation dependence, scaling complexity
Optoelectronic	≈1 ns	3-6 dB	Up to 128×128 ports	Flexible control, compatibility with electronics	High energy consumption, need for optoelectronic conversion
Liquid-crystal	1-100 ms	1-3 dB	Up to several thousand ports	High port density, low energy consumption	Slow switching, temperature sensitivity

Source: compiled by the author based on O. Singh & R. Paulus (2024), A. Sinha *et al.* (2025)

The comparative analysis shows that none of the technologies considered simultaneously provides maximum switching speed, high scalability, low loss, and minimum energy consumption. Research has therefore increasingly focused on hybrid photonic architectures, plasmonic switching structures, and nanophotonic elements that combine the advantages of different technological approaches within a single infocommunication platform. The comparison confirms that no universal switching technology can simultaneously provide ultrahigh speed, low signal loss, a large number of ports, and straightforward implementation. Each switch type serves a distinct functional role in infocommunication infrastructure. Mechanical-optical solutions are advantageous in large-port systems with modest switching-speed requirements; electro-optic devices provide the fastest switching; optoelectronic switches combine high speed with integration of active elements; and liquid-crystal matrices offer substantial scaling potential. O. Singh & R. Paulus (2024) described a similar distribution of functional advantages and proposed that future switching systems would combine different technological approaches within integrated photonic platforms.

Development of all-optical network technologies. Growth in information exchange, higher data-transmission rates, and increasing complexity of telecommunications traffic have contributed to a new approach to transport-network architecture based on extensive use of optical technologies throughout information transmission and switching. Within this approach, the concept of all-optical networks (AONs) has emerged, in which information flows are transmitted, routed, multiplexed, and switched without intermediate conversion of the optical signal into electrical form. The principal aim of these networks is to remove bottlenecks associated with electronic switching nodes, which are approaching physical performance limits because of semiconductor-component speed constraints, high energy consumption, and rising heat generation.

The concept of all-optical networks envisaged an end-to-end photonic environment in which the light signal remained in optical form from transmitter to receiver. Unlike conventional optoelectronic networks, where information underwent repeated optical-to-electrical and electrical-to-optical conversion, AON architecture was designed around network transparency. Switching nodes therefore routed and switched optical flows without decoding the information payload, which could substantially reduce transmission latency and improve the use of network resources.Wavelength Division Multiplexing is a fundamental technology underlying the development of all-optical networks. Its introduction enabled a single optical fibre to carry many independent information flows simultaneously, with each transmitted on a separate wavelength. Several WDM implementations have emerged as the technology has developed, most notably Coarse Wavelength Division Multiplexing and Dense Wavelength Division Multiplexing. Coarse Wavelength Division Multiplexing uses relatively wide spacing between adjacent channels, whereas Dense Wavelength Division Multiplexing supports very dense spectral-channel placement with spacing of 50, 25, or even 12.5 GHz (Deng *et al.*, 2022).

The use of WDM has greatly increased the information capacity of optical communication lines without requiring further fibres. Each wavelength can effectively be treated as a separate logical data-transmission channel, supporting high-performance transport networks with capacities of tens or hundreds of terabits per second. This development led to the concept of optical paths, under which end-to-end optical channels are established between network nodes without intermediate electronic information processing. These principles of all-optical network architecture are

consistent with the research of J. Lorincz *et al.* (2025), who were among the first to substantiate optical paths as a basis for photonic transport networks. The researchers showed that WDM could provide end-to-end optical connections between network nodes without intermediate electronic traffic processing, substantially improving use of fibre-optic infrastructure capacity. L. Tunesi (2025) reached similar conclusions and noted that the transition to photonic switching enabled transport networks to scale to terabit and petabit rates. The researcher also stressed that implementing all-optical networks requires solutions to fundamental problems involving signal regeneration, optical-channel routing, and sufficient network controllability. Figure 1 presents a schematic of an all-optical network.

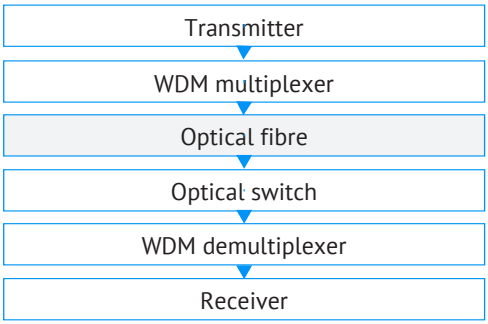


Figure 1. Schematic of an all-optical network
Source: compiled by the author based on D. Uzunidis *et al.* (2022)

Although progress has been made in photonic technologies, the full implementation of the AON concept is still a complex scientific and technical challenge. A big problem is non-universal methods of optical-signal regeneration. Light travelling down fibre-optic lines accumulates noise and the signal being transmitted gradually deteriorates through non-linear distortion, chromatic dispersion and polarisation-mode dispersion. This problem is solved in conventional networks with electronic regeneration. This restores the amplitude and shape and timing of the signal. All-optical networks require specialised photonic regenerators capable of performing equivalent 3R regeneration without conversion to the electronic domain.

Restoring the temporal structure of optical pulses without conversion to the electronic domain remains particularly challenging. Although laboratory demonstrations of all-optical regenerators have produced promising results, practical deployment is constrained by design complexity, high cost, and limited scalability. Signal regeneration therefore remains one of the main barriers to widespread deployment of all-optical networks. Routing information flows presents a comparable challenge. Electronic networks can analyse packet headers and make routing decisions with considerable functional flexibility, whereas photonic environments require fundamentally different approaches. Consequently, many logical control functions continue to be performed by electronic controllers even in networks with a high degree of optical integration. Wavelength allocation among information flows creates further difficulties. Routing and Wavelength Assignment (RWA) is a complex optimisation problem whose effective solution requires consideration of network topology, current load, spectral-resource availability, and characteristics of the physical transmission medium. In large networks, the computational complexity of these procedures increases substantially, requiring specialised optimisation algorithms and artificial-intelligence techniques. These limitations are consistent with the conclusions of M. Matuszewski *et al.* (2024), who identified optical regeneration as one of the main factors affecting the scalability of photonic transport systems. The researchers showed that optical amplifiers could compensate for signal-power loss but did not fully restore timing and structural information, so more sophisticated regeneration mechanisms remained necessary. A. Majumdar & I. Toselli (2024) similarly confirmed that the development of transparent optical networks depends substantially on improved 3R-regeneration technologies capable of operating without conversion of the signal into electrical form.

Further development of all-optical network technologies is increasingly linked to advances in integrated photonics, silicon photonics, nanophotonic structures, and plasmonics. Photonic integrated circuits have substantially reduced the size of switching nodes and increased the level of functional integration. Research has also explored nanoscale plasmonic waveguides, photonic crystals, and metasurfaces for ultrafast switching without conventional electronic components. Spatial Division Multiplexing (SDM) is another promising direction and complements WDM through multicore and multimode optical fibres. Combining SDM and WDM creates the potential to increase network-infrastructure capacity to petabit levels. The development of machine learning also offers opportunities for automated photonic-network resource management and routing optimisation under dynamic loads. M. Daryalal & M. Bodur (2022) examined optical-flow routing in detail and identified RWA as one of the key mechanisms for resource management in WDM networks. The researchers noted that the performance of photonic infrastructure depended not only on the physical parameters of channels but also on the ability of control algorithms to adapt wavelength allocation to changing network loads. This approach was developed further in research on intelligent optical-network management, in which machine-learning methods were used to predict load, optimise routes, and reduce the probability of optical-connection blocking. Overall, the analysis indicates that end-to-end photonic transmission has become one of the key directions in

the evolution of infocommunication systems. Despite several technological constraints, advances in photonic integration, nanophotonics, and optical switching support a gradual transition towards network architectures in which most information-processing and transmission operations are performed directly in the optical domain.

Nanophotonic and plasmonic technologies in infocommunication system devices. Further increases in the speed and functional density of infocommunication systems require overcoming fundamental limitations of conventional photonics. Despite substantial progress in fibre-optic technologies and integrated photonics, the dimensions of most optical components remain constrained by the diffraction limit of electromagnetic-wave propagation. Consequently, miniaturisation of optical devices has progressed more slowly than developments in microelectronics. Nanophotonics and plasmonics address this problem by combining principles of quantum physics, electrodynamics, materials science, and nanotechnology to create functional elements with characteristic dimensions ranging from several to hundreds of nanometres. Nanophotonic technologies exploit physical phenomena that arise at interfaces between materials with different electromagnetic properties. Unlike conventional optical systems, where light propagates predominantly through dielectric media, nanophotonic structures localise the electromagnetic field within extremely small volumes. This supports mechanisms for controlling light that are unavailable to conventional photonic components (Chou Chau, 2025).

Surface plasmon polaritons provide the basis for many plasmonic technologies. These quasiparticles arise from the interaction between an electromagnetic wave and collective oscillations of free electrons at a metal-dielectric interface. The interaction produces a bound electromagnetic state whose energy is concentrated near the metal surface and decays exponentially with distance from it. Surface plasmon polaritons can localise optical energy within volumes substantially smaller than the radiation wavelength. Such localisation overcomes the diffraction limits of conventional optics and supports ultradense integration of functional elements on photonic chips. Surface plasmon polaritons can therefore be used to create ultracompact photonic components for modulation, switching, filtering, and signal multiplexing at scales unattainable by conventional optical systems. These properties are consistent with the research of J. Khan *et al.* (2025), who showed that plasmonic structures enabled control of electromagnetic radiation at scales substantially smaller than the wavelength of light. The researchers noted that the main advantage of plasmonics is its ability to concentrate the optical field near a metal surface, creating opportunities for ultracompact photonic-system elements.

Plasmonic waveguides are one important direction in the development of plasmonics. Unlike conventional dielectric waveguides, where light propagates within a high-refractive-index material, plasmonic structures transmit energy through surface plasmon polaritons. Their development has enabled optical-signal transmission through structures only several tens of nanometres wide. The most common architectures include metal-dielectric-metal, dielectric-metal-dielectric, slot, and nanowire waveguides. Strong electromagnetic-field localisation enables extremely high photonic-component integration density. However, plasmonic waveguides also have substantial ohmic losses caused by energy absorption in the metal. Research therefore focuses on new materials and optimised waveguide geometries that balance field localisation against signal-propagation distance. V.E. Babicheva (2023) confirmed that nanoscale optical-signal channels with strong electromagnetic-field confinement could be implemented. The study showed that metal-dielectric structures could substantially reduce waveguide dimensions compared with conventional photonic components. The researcher also identified propagation loss as the principal limiting factor determining the maximum optical-channel length. Further advances in plasmonic waveguides therefore focus on low-loss metals, hybrid dielectric structures, and active media that compensate for losses. Table 4 compares dielectric and plasmonic waveguides.

Table 4. Comparison of dielectric and plasmonic waveguides

Characteristic	Dielectric waveguide	Plasmonic waveguide
Characteristic transverse dimension	0.5-10 μm	20-200 nm
Minimum bend radius	10-100 μm	0.1-5 μm
Electromagnetic-field localisation	≈ 0.5-1 λ	< 0.1 λ
Propagation loss	0.13 dB/cm	100-1,000 dB/cm*
Maximum transmission length	cm–-m	10-1,000 μm
Level of integration	Medium	Very high

Source: compiled by the author based on V.E. Babicheva (2023), and A. Sanchez-Ramirez *et al.* (2024), J. Khan *et al.* (2025)

Analysis of the two waveguide types shows that the choice of technological platform depends on the balance between compactness and signal-transmission efficiency. Dielectric waveguides remain the standard solution for backbone optical systems because of their low losses, whereas plasmonic structures provide a

fundamentally greater degree of miniaturisation and integration. Plasmonic technologies therefore do not completely replace conventional photonics but offer a complementary approach to developing nanoscale switching elements, photonic integrated circuits, and high-density optical-signal processing systems.

One application of plasmonic structures is nanophotonic multiplexers designed to combine and separate signals of different wavelengths in ultracompact photonic systems. These devices use the resonant properties of nanostructures to enable selective interaction with individual spectral components of radiation. Research on nanophotonic multiplexers actively explores photonic crystals, plasmonic resonators, metasurfaces, and hybrid photonic-plasmonic structures. Multichannel multiplexers based on surface plasmon polaritons are of particular interest because they can process several independent information flows simultaneously while retaining extremely small dimensions. Such devices support integrated spectral-multiplexing systems for ultradense next-generation photonic networks. Nanophotonic multiplexers are also regarded as key components of future all-optical switching systems.

The development of nanophotonic technologies led to the concept of photonic integrated circuits. Just as electronic integrated circuits brought thousands of transistors together on a single chip, photonic integrated circuits combine waveguides, switches, modulators, multiplexers, photodetectors, and laser sources within one platform. Silicon photonics enables fabrication processes compatible with microelectronics manufacturing, reducing photonic-component costs and increasing integration density. This development has produced photonic processors, switching matrices, and high-speed interconnects for data centres. Figure 2 presents a schematic of an integrated photonic platform.

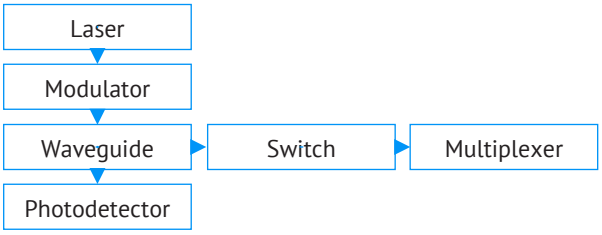


Figure 2. Schematic of an integrated photonic platform
Source: compiled by the author based on T. Sharma *et al.* (2024)

Figure 2 illustrates the transition to a high level of functional integration, in which the main processes of optical-signal generation, transmission, switching, and reception are combined within a single technological architecture. This approach reduces the number of intercomponent connections, thereby lowering aggregate losses and improving system efficiency. The architecture also reflects the continuing shift of information-processing operations into the photonic domain. Fewer intermediate signal conversions improve data-transmission speed and overall network-infrastructure performance. Integrated photonics is therefore one of the main directions for further development of infocommunication systems because it combines the high speed of photonic technologies with the compactness and scalability of semiconductor manufacturing.

Continued growth in information-transmission volumes has brought conventional radio-frequency and optical systems closer to the limits of efficient operation. This has increased interest in the terahertz frequency range, which lies between the microwave and infrared spectral regions. Terahertz technologies support wireless data-transmission rates of hundreds of gigabits or terabits per second. Implementing these systems, however, requires new radiation sources, receivers, waveguide structures, and multiplexers capable of operating at ultrahigh frequencies. Plasmonic and nanophotonic components play an important role in terahertz systems because they support effective localisation and control of ultrahigh-frequency electromagnetic waves. Combining terahertz technologies with photonic integration represents a promising approach to developing networks with ultrahigh capacity. These observations are consistent with the findings of A. Shekari *et al.* (2025), who identified the terahertz range as a promising resource for high-speed communication systems but noted limitations associated with creating efficient sources and receivers. R. Guo *et al.* (2022) confirmed that integrating photonic technologies with terahertz components could improve signal-generation stability and extend communication-system capabilities.

Analysis reveals that nanophotonics and plasmonics alter not only the design of individual components, but also the architectural principles of infocommunication systems. Miniaturisation of waveguides, switches, multiplexers and photonic integrated circuits improves the integration density of functions in network equipment, shortens the internal connections and reduces the transmission delays. This allows for compact and high-performance switching nodes that can handle significantly larger information flows without a proportional increase in energy consumption. Photonic integration and plasmonic components also affect network control and packet-switching principles. Moving switching, multiplexing and routing functions straight to the optical domain decreases the number of intermediate optoelectronic conversions, thus reducing the packet-processing time and increasing the capacity of backbone and data-centre networks. This transition also makes the burden on algorithms for spectral resource management, wavelength assignment, optical path reconfiguration, and photonic integrated circuit coordination more severe. Further development of nanophotonic technologies is aimed at highly integrated, software-controlled photonic platforms that combine switching, routing, wavelength-division multiplexing

and information processing in a single architecture. This approach increases capacity, energy efficiency, and scalability, and offers a technological basis for next-generation infocommunication systems. Thus, terahertz systems in combination with nanophotonic technologies are a promising direction for infocommunication platforms for higher data rates and integration of photonic and wireless technologies (Table 5).

Table 5. Potential of major technologies for the development of infocommunication systems

Technology	Main advantage	Main limitation	Approximate technology readiness level
Surface plasmon polaritons	Subwavelength field localisation	Ohmic losses	3-5
Plasmonic waveguides	Dimensions of 20-200 nm	Limited propagation length	3-5
Nanophotonic multiplexers	High spectral density	Fabrication complexity	4-6
Photonic integrated circuits	High level of integration	High development cost	7-9
Terahertz systems	Rates above 100 Gbit/s	Difficulty of signal generation and reception	3-6

Source: compiled by the author based on T.M. Christensen (2022), E. Albisetti *et al.* (2022), Z. Alnakhli *et al.* (2024), W. Hidayat & M. Usman (2024) P. Basu *et al.* (2025), J. Huang *et al.* (2026)

The comparison shows that the main technological challenges are shifting from achieving high speeds towards effective implementation, scaling, and stable operation of complex photonic structures. This indicates that the field is moving from proof-of-concept demonstrations of individual solutions towards practical integration into network infrastructure. The development of nanophotonics and plasmonics therefore provides a technological basis for the transition from microphotonic to nanophotonic infocommunication systems. Surface plasmon polaritons, plasmonic waveguides, photonic integrated circuits, and terahertz components support further increases in switching speed, integration density, and the functional capabilities of switching devices that can underpin future high-performance data-transmission networks.

Analysis of technologies for fabricating nanoscale elements. Miniaturisation of infocommunication-system components has become a key factor in improving switching speed, reducing energy consumption, and increasing the functional density of photonic devices. Fabricating optical switches, plasmonic waveguides, photonic crystals, resonators, multiplexers, and photonic integrated circuits requires structures with characteristic dimensions ranging from tens of nanometres to only a few nanometres. The development of nanophotonics has produced several technological platforms that differ in the physical principles used to create nanostructures, attainable resolution, throughput, and economic efficiency. Each platform has a distinct field of application and supports particular stages in the production of nanophotonic components. Table 6 compares the main technologies used to fabricate nanoscale structures.

Table 6. Comparative characteristics of technologies for fabricating nanoscale elements

Technology	Typical structure-size range	Throughput	Equipment complexity	Main applications
Optical lithography	20-100 nm	High	High	Photonic integrated circuits
Nanoimprinting	1-20 nm	Very high	Medium	Mass production of nanostructures
Scanning probe microscopy	0.1-10 nm	Low	Very high	Nanostructuring and research
Molecular beam epitaxy	0.3-1 nm	Low	Very high	Heterostructures and quantum systems
Ion bombardment	1-100 nm	High	High	Doping and property modification
Vacuum deposition	1-1,000 nm	High	Medium	Fabrication of functional films

Source: compiled by the author based on E. Albisetti *et al.* (2022), T.M. Christensen (2022), Z. Alnakhli *et al.* (2024), W. Hidayat and M. Usman (2024), P. Basu *et al.* (2025), M. Unutmaz *et al.* (2025), J. Huang *et al.* (2026)

Table 6 indicates that none of the available technologies simultaneously provides maximum structural precision, high production throughput, and low implementation cost. The technological process must therefore be selected according to the intended function of the device and its performance requirements. These approaches are complementary: some methods are used primarily to create and investigate nanoscale structures with the highest possible precision, while others support large-scale replication in manufacturing. This specialisation reflects the broader transition from laboratory experimentation to industrial production of nanophotonic components.

Optical lithography has been a fundamental technology for microelectronic and photonic component fabrication for a long time. The principle of photolithography is to transfer a pattern from a photomask onto the surface of a substrate using electromagnetic

radiation. The photosensitive layer experiences local physicochemical changes during the exposure of the photoresist, where the required spatial structure is obtained by removing the selected areas in the development stage. The progress made in projection lithography has significantly improved the accuracy of fabricating nanophotonic components. Advanced optical systems and short-wavelength ultraviolet radiation enable structures with characteristic dimensions less than 50 nm. The high throughput of optical lithography makes it widely used for the fabrication of waveguides, photonic crystals, microresonators and planar optical switches. A significant benefit of the approach lies in the simultaneous pattern formation of a large number of elements in a large area of a substrate with a high degree of process repeatability and cost-effectiveness in mass production. Diffraction effects gradually limit further size reductions of the structure. Also, the equipment needed to produce photomasks is expensive and complicated making the cost of the process extremely high. Optical lithography is used to fabricate optical waveguide structures, directional couplers, Mach-Zehnder interferometers and other integrated photonic devices in the production of optical switches. According to R. Gupta *et al.* (2025), diffraction-related limits necessitated combined technological approaches to further decrease the dimensions of photonic-components.

Nanoimprinting has emerged as a promising alternative to conventional lithography. Unlike photolithographic processes, the structure is produced by mechanically transferring the relief pattern of a stamp onto a polymer coating rather than by exposing a resist to radiation. During fabrication, a stamp with a nanoscale relief is pressed into the polymer layer, leaving an imprint of the required structure on the surface. Y. Cao *et al.* (2025) demonstrated the effectiveness of this method for producing nanoscale structures with high precision through mechanical pattern transfer. Compared with optical lithography, nanoimprinting reduces dependence on radiation wavelength and therefore supports further miniaturisation of photonic components. The present analysis indicates, however, that practical use of nanoimprinting in optical switches depends on stamp stability and accurate pattern replication. Y. Cao *et al.* therefore considered the method particularly promising for plasmonic structures, photonic crystals, and highly integrated components where the need for nanoscale features outweighs the complexity of tooling fabrication.

Scanning probe microscopy is a distinctive technology that combines investigation with direct fabrication of nanostructures. It operates through the interaction between an ultrasharp probe and the surface of the material under examination. Depending on the operating mode, tunnelling currents, interatomic forces, or other physical parameters are measured. This enables surface imaging at atomic resolution and precise control of the geometric parameters of individual nanostructures. A distinctive capability of the technology is the manipulation of individual atoms and molecules. Under ultrahigh-vacuum and cryogenic conditions, the probe can move atoms across the substrate surface and create structures with a predetermined configuration.

Molecular beam epitaxy is among the most precise technologies for fabricating semiconductor heterostructures. The process takes place under ultrahigh vacuum, where atoms or molecules are deposited on a crystalline substrate in narrowly directed beams. The growth rate is controlled with atomic-scale precision, enabling structures with specified doping profiles, layer thicknesses, and interface characteristics. It is typically only a few atomic layers per second. This exceptional precision provides atomically smooth surfaces and very high structural quality. The main disadvantages are high equipment costs, the need to maintain ultrahigh vacuum, and comparatively low throughput. Molecular beam epitaxy is widely used to produce active regions of semiconductor lasers, optical amplifiers, photodetectors, and integrated electro-optic switches. Ion bombardment is used for the controlled introduction of dopants into near-surface layers of materials. The technology accelerates ions to high energies and implants them into the crystal structure of the substrate. As the ions penetrate, they change the local composition of the material, creating regions with different electrical and optical properties, and providing the desired doping profile. The advantage is that the dopant concentration and implantation depth can be precisely controlled, enabling the formation of functional regions with pre-defined properties. A disadvantage is the formation of radiation defects in the crystal lattice. Thus, annealing is often carried out at high temperature after implantation. In optical-switch manufacturing, ion bombardment is employed to create active waveguide regions, to change refractive index, and to manufacture photonic integrated structures.

In photonics and microelectronics, vacuum deposition was one of the most common techniques for the fabrication of thin-film structures. The process involved vacuum evaporation of the material, followed by atom deposition on the surface of the substrate. It was able to produce uniform functional layers with controlled thicknesses from several angstroms to several micrometres and could produce conductive, dielectric or optical coatings. Its main advantage was that it was versatile on a large variety of materials including metals, oxides, nitrides and multi-component compounds. The main limitations were the difficulty of maintaining high uniformity on large areas and the need for hoover equipment. In optical-switch structures, vacuum deposition is used to produce metal electrodes, reflective coatings, plasmonic layers, waveguide structures, and multilayer photonic elements. The analysis indicates that no single technology provides a universal

solution for all nanophotonic manufacturing tasks. Combining lithographic, epitaxial, vacuum, and ion-beam methods enables the fabrication of complex multilayer structures required for next-generation high-speed optical switches, plasmonic components, and photonic integrated circuits. The study is limited to the analysis of academic sources and does not include experimental evaluation of specific optical switches or nanophotonic devices. A promising direction for future research is the integration of nanophotonic, plasmonic, and terahertz technologies in energy-efficient, high-speed next-generation networks.

CONCLUSIONS

The analysis of academic sources indicates that rapid growth in network traffic and the development of cloud services and data centres have driven the transition from conventional electronic switching towards optical switching as a key direction in the development of contemporary infocommunication systems. Optical switching minimises optoelectronic signal conversions, reduces switching latency from 10-100 ns to 1 ps-10 ns, increases single-channel capacity from 100-400 Gbit/s to 400 Gbit/s-1.6 Tbit/s and above, and reduces energy consumption from 5-20 to 0.5-5 pJ/bit. The choice of switching technology depends on the application: transport-network reconfiguration requires switching times of 10-500 ms, network switching requires 1-100 ms or approximately 1 ns, whereas packet switching requires picosecond operation (10-100 ps). The findings support hybrid photonic-electronic architectures in which the photonic domain provides data transmission and the electronic domain provides control and routing. Wavelength-division multiplexing technologies have become fundamental to scaling transport networks. WDM supports channel spacing of 50, 25, and 12.5 GHz and enables a single optical fibre to carry tens or hundreds of terabits of information. However, widespread deployment of all-optical networks remains constrained by the need for full 3R signal regeneration and the complexity of RWA. Combining spectral and spatial multiplexing creates the potential to reach petabit-level capacity.

Nanophotonic and plasmonic technologies have helped overcome the diffraction limits of conventional photonics and support elements ranging from several to hundreds of nanometres in size. Surface plasmon polaritons localise the electromagnetic field to scales below 0.1 of the wavelengths. Plasmonic waveguides measure 20-200 nm compared with 0.5-10 μm for dielectric waveguides, while the minimum bend radius decreases from 10-100 μm to 0.1-5 μm. These reductions in size are accompanied by propagation losses of 100-1,000 dB/cm compared with 0.1-3 dB/cm and a reduction in maximum transmission length to 10-1,000 μm, which reflects a necessary trade-off between integration density and signal-transmission efficiency. The development of nanophotonic multiplexers and photonic integrated circuits has created a new level of functional integration in infocommunication equipment. The technology readiness assessment shows that photonic integrated circuits are at TRL 7-9 and nanophotonic multiplexers are at TRL 4-6, while plasmonic technologies and terahertz systems are generally at TRL 3-6. Terahertz systems have already demonstrated potential transmission rates over 100 Gbit/sec but practical implementation is limited by the difficulty in producing efficient sources and receivers.

Modern methods of fabrication of nanostructures cover a range of dimensions from 0.1 nm (scanning probe microscopy) to 1,000 nm (vacuum deposition). 20-100 nm for optical lithography structures, 1-20 nm for nanoimprinting, 0.3-1 nm for molecular beam epitaxy and 1-100 nm for ion bombardment. No one technology is universal: high-throughput methods are useful for mass production, but scanning probe microscopy and molecular beam epitaxy are the highest precision, lowest throughput. This demonstrates the need to integrate technological platforms according to the demands of nanophotonic components. Future research should focus on high efficiency integrated nanophotonic and plasmonic platforms, optimisation of their fabrication technologies and implementation in high-speed next generation infocommunication systems.

ACKNOWLEDGEMENTS

None.

FUNDING

None.

CONFLICT OF INTEREST

None

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Огляд тенденцій та перспектив розвитку пристроїв інфокомунікаційних систем

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Анотація. Актуальність визначалася необхідністю розвитку високошвидкісних інфокомунікаційних систем в умовах зростання обсягів цифрового трафіку та обмежень традиційної електронної комутації, що зумовлювало потребу в аналізі оптичних комутаційних технологій, нанофотонних структур і методів створення фотонних компонентів. Метою було здійснити системний аналіз технологій оптичної комутації та нанофотонних компонентів, оцінювання їх характеристик, переваг і обмежень, а також визначення можливостей використання у сучасних високошвидкісних інфокомунікаційних мережах. У дослідженні проаналізовано наукові джерела із використанням бібліографічного, порівняльного, систематизаційного та технологічного аналізу для оцінювання оптичних комутаторів, нанофотонних технологій і методів їх виготовлення. Проведено класифікацію пристроїв за принципом роботи, швидкодією, технологією реалізації та рівнем інтеграції. Встановлено, що розвиток інфокомунікаційних систем зумовив перехід від електронної до оптичної комутації, яка забезпечує скорочення затримки комутації до 1 пс-10 нс, підвищення пропускної здатності одного каналу до 400 Гбіт/с – 1,6 Тбіт/с і більше та зниження енергоспоживання до 0,5-5 пДж/біт. Показано перспективність гібридних фотонно-електронних архітектур, у яких фотонний домен використовується для високошвидкісної передачі даних, а електронний – для керування й маршрутизації. Визначено, що технології спектрального ущільнення забезпечують масштабування транспортних мереж до десятків і сотень терабіт за секунду, тоді як розвиток повністю оптичних мереж стримується необхідністю 3R-регенерації сигналу та складністю задачі маршрутизації і призначення довжин хвиль. Показано, що нанофотонні та плазмонні технології дозволяють подолати дифракційні обмеження класичної фотоніки, забезпечуючи створення компонентів нанометрового масштабу, а плазмонні хвилеводи (20-200 нм) значно підвищують рівень інтеграції порівняно з діелектричними, хоча характеризуються більшими втратами поширення. Встановлено, що інтегральні фотонні схеми досягли найвищого рівня технологічної готовності (Technology Readiness Level 7-9), тоді як плазмонні та терагерцові технології перебувають переважно на рівнях Technology Readiness Level 3-6. Результати можуть використовуватися науковцями, інженерами та розробниками телекомунікаційних систем під час проєктування оптичних мереж і фотонних компонентів

Ключові слова: оптичний комутатор; оптичні мережі; нанотехнології; наноімпринтінг; молекулярно-променева епітаксія; взаємодія електронних та оптичних компонентів