PHOTONICS21

Tematys
Exploration of photonics markets

Photonics – an essential technology for defence

Published by:
Photonics21 – European Technology Platform

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Brussels / Düsseldorf / Paris 2024

Photonics21 has received financial support from the European Commission in the scope of the Coordination and Support Actions "Boosting Europe's Sovereignty in Technology by driving Photonics from Research to Market – Photonics21" – Grant Number 101016520 and „Photonics from Research to Market – Empowering Europe's strategic autonomy, supporting the Green Deal and securing resilience – Grant Number 101134961.

Photonics – an essential technology for defence

Contents

1. Introduction – brief overview of the defence sector

Introduction

The purpose of this report is to analyse the role, potential, and opportunities of photonics technologies in defence applications (also known as Optronics) and demonstrate their impact on current and future defence systems.

Optics and photonics have an impact on virtually every aspect of modern defence systems.

Optics and photonics have an impact on virtually every aspect of modern defence systems, even those that are not optically based.

The trend towards optically based imaging, remote sensing, communications, and weapons in modern defence systems highlights the importance of maintaining leadership in optics and photonics for the EU to retain its position in the military and industrial defence sectors.

The defence industry is crucial for the EU due to its technological, economic, and sovereignty-related aspects. The competitiveness of the European defence industry is vital to the credibility of the Common Security and Defence Policy (CSDP).

Military expenditures

The figure below presents the military expenditures for a selection of countries.

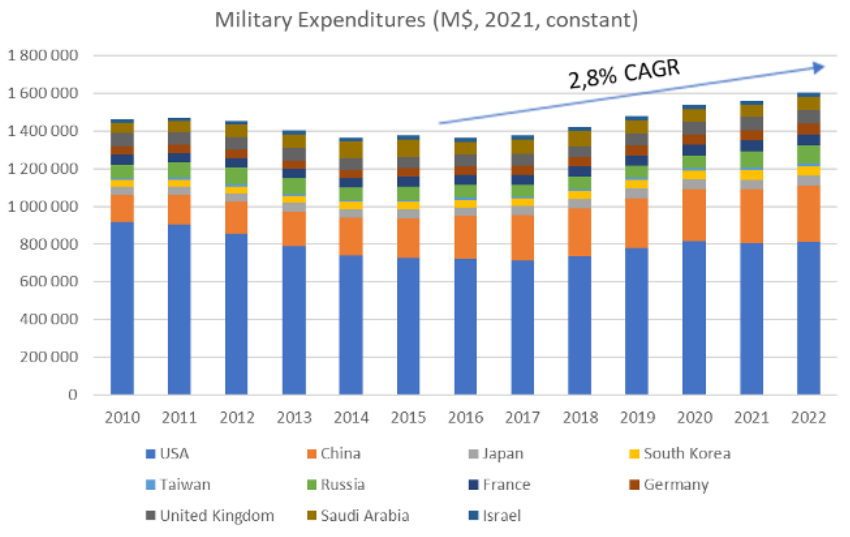


Figure 1: Military expenditures from 2021 to 2022 for a selection of countries ($ million) Source of data: SIPRI Military Expenditure Database 2023, https://www.sipri.org/databases/milex

The dynamics of global military spending are complex and are influenced by both regional and international political landscapes. Although there was a decrease in military spending from 2010 to 2015, expenditures have started to rise again in recent years, albeit with a CAGR of only 3% (in constant dollars).

Various factors, such as geopolitical tensions, the development of new military technologies, and changing global alliances, have significantly influenced defence budgets worldwide. Some countries have increased military spending to modernise their armed forces and counter perceived threats, while others have done so as part of broader strategic objectives. This rise in spending has been particularly notable in regions with heightened security concerns.

There has been a sudden increase in military spending, especially in Europe, following the conflict in Ukraine. So, a significant rise is predicted for military budgets in Europe: an increase of more than 25% on average forecasted for 2030. Some countries, such as Germany, have adopted a more ambitious defence policy.

Research and development policy in the EU

EU research funding is primarily directed towards civilian objectives. However, the implementation of EU research policy should also consider the needs of the defence industry whenever possible. In 2015, the Member States decided to shift from research that exclusively focused on civilian and dual-use to a single, dedicated European defence research program. The Commission, in collaboration with the European Defence Agency (EDA), developed proposals to increase investment in defence research and innovation.

The European Defence Fund (EDF) supports cooperation among companies and research actors in the Union to develop state-of-the-art and interoperable defence technology and equipment, complementing and amplifying Member States' efforts. A budget of nearly €8 billion for 2021–2027 has been allocated to the EDF.

Requirements and needs for defence systems

Modern warfare requires consideration of various aspects such as ISR (Intelligence, Surveillance & Reconnaissance), mobility, survivability & lethality, autonomy, adaptability, and connectivity at both tactical and strategic levels.

Additionally, military systems and components prioritise reliability, mission performance, environments, and SWaP (Size, Weight and Power) over commercial/industrial ones.

2. Review of photonics for defence

2.1 Infrared cameras and night vision goggles

nfrared cameras have been a crucial component of defence night vision systems for over 50 years. They are also utilised in commercial products, such as thermography and satellites.

While most IR photodetectors require cooling through cryogenic devices to achieve operating temperature, uncooled thermal detectors, particularly microbolometers, are suitable for low to medium-performance applications in long-wafe infrared (LWIR). Microbolometers can significantly reduce the size and cost of thermal imaging cameras compared to those based on cooled detectors.

Figure 2: Example of IR camera with laser rangefinder (left) and infrared image (right) – Source iStock

Infrared cameras are crucial in defence as they can detect thermal radiation emitted by objects, enabling surveillance, target acquisition, and situational awareness in various scenarios. Their main applications in defence include:

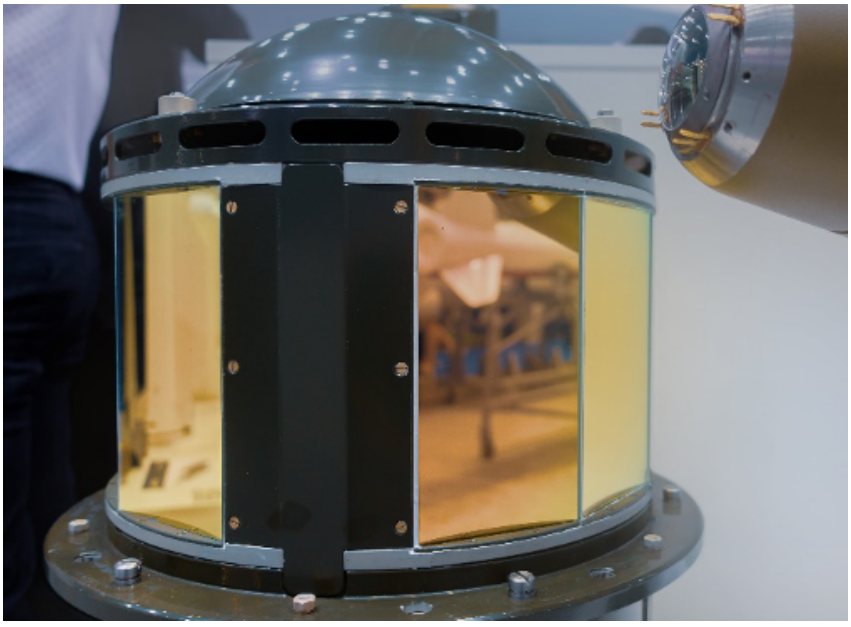
- **Intelligence, Surveillance, and Reconnaissance (ISR):** Infrared cameras are utilised in surveillance drones and other reconnaissance platforms. They detect heat signatures emitted by objects, enabling military personnel to identify potential threats, observe movements, and monitor areas of interest. They can detect and identify objects from great distances, even through light fog and smoke or in urban environments where visual detection might be challenging.
- **Target Acquisition:** Infrared cameras are utilised in targeting systems for airborne, naval, and ground platforms. They detect the heat signatures of an enemy vehicle, ship, or aircraft and provide images of the target. This capability is especially valuable for identifying targets in low-visibility situations or camouflage, improving targeting accuracy.
- **Night Vision:** Infrared technology allows military forces to operate effectively during nighttime or in environments with poor visibility, enhancing their ability to conduct missions covertly and maintain operational effectiveness 24/7. Ground forces also use intensified cameras for night operations.
- **Missile Guidance Systems:** Infrared sensors are crucial components in missile guidance systems. Infrared guidance allows missiles to lock onto heat sources emitted by targets, enabling precise targeting and tracking, especially against moving objects.
- **Integration with other systems:** Infrared cameras are frequently combined with different sensors, such as rangefinders, LIDAR (Light Detection and Ranging) systems, and visible light cameras, to create a comprehensive surveillance and targeting system. This integration enhances the accuracy of threat detection and identification.

Figure 3: Example of an infrared seeker for missile guidance – Source iStock

The use of infrared (IR) cameras in defence is constantly evolving due to advancements in technology, particularly new IR detectors. These advancements allow for increased precision, longer-range detection, and integration with other defence systems. IR cameras provide real-time, reliable information in various operational environments, making them invaluable assets for military applications. Intensified cameras, especially night vision goggles, complement IR cameras for use on land, particularly by soldiers.

2.2 Laser device applications in defence

Figure 4: Laser countermeasures for active protection of helicopters against missiles with IR seeker – Source iStock



Lasers are widely used in defence due to their unique properties, precision, and versatility. Below is an overview of their applications:

- **Laser Rangefinders:** Laser rangefinders are used to measure the distance between an observer and a target. This information is valuable for enhancing accuracy in artillery, snipers, and precision-guided weapon systems. Rangefinders are often integrated with other sensors, particularly infrared cameras, to complement the information with distance to target.
- **Laser-Based Imaging and Sensing:** Lasers are used in imaging and sensing technologies for reconnaissance and surveillance. LIDAR systems, based on laser technology, provide three-dimensional mapping and target identification.
- **Laser Designation for Guided Munitions:** Lasers are used for target designation. Laser designators emit a beam that can be identified by precision-guided munitions such as laser-guided bombs or missiles, increasing accuracy and reducing collateral damage.
- **Communication and Data Transmission:** Lasers are used for secure communication and data transmission in free-space optical communication systems. These systems offer high bandwidth and secure transmissions, especially in situations where radio frequency communications are compromised. Optical communications based on lasers minimise the probability of interception, jamming, and detection while requiring less power.
- **Laser Countermeasures:** Lasers are used in countermeasure systems to detect and disrupt incoming threats like laser-guided munitions. They can be employed to deflect or disrupt the guidance systems of these munitions or to disrupt or damage sensors on enemy platforms, such as Unmanned Aerial Vehicles (UAVs) or surveillance equipment. Additionally, they can counter incoming threats by blinding sensors or disrupting guidance systems.
- **Laser Weapons Systems:** High-energy lasers are being developed and deployed as Directed Energy Weapons (DEWs). These lasers can generate intense beams of focused energy capable of damaging or destroying targets, such as UAVs, rockets, mortar rounds, missiles, or even small boats. They offer the potential for precise and rapid engagement against threats. These weapons provide precision targeting with minimal collateral damage and are increasingly being developed for both defensive and offensive operations.

The advancements in laser technology, including improvements in power, efficiency, and miniaturisation, have expanded their utility in defence applications. Their versatility makes them an increasingly vital component of modern military arsenals. However, deploying them often involves complex technical challenges, safety considerations, and international regulations that govern their use in military contexts.

Focus on Laser Weapons Systems

Figure 5: HELMA-P – The anti-drone laser developed by Cilas – Source: https://www.defense.gouv.fr/dga

Introduction
A few years after its invention, laser technology was already being considered for use in defence and weapons. In the late 1960s, the Excalibur project was proposed for destroying ballistic missiles, but it remained on paper and military R&D focused on laser-based systems for intercepting airborne threats. Prototype examples of these systems, such as THEL and YAL-1, saw limited use for demonstration purposes in the 1990s and early 2000s. With the advancements in optical fibre technology and laser pumping sources, continuous wave (CW) fibre lasers emitting in the kW range became widely available by the late 2000s. Given that the optical fibre gain medium provided a highly efficient and less costly alternative to solid-state counterparts, there was a renewed interest in the use of lasers in defence.

Laser weapon achievements in the US
Raytheon offers compact laser systems with 15kW or 50kW output power that can be mounted on various vehicles operating in air, land, and sea to attack UAVs, rockets, artillery, and mortars. They claim to have already destroyed over 400 targets.

Lockheed-Martin develops weapons systems that utilise 60kW+ output fibre lasers customised for each operational environment on land, sea, and air. These systems offer unique multi-mission capabilities that go beyond standard target neutralisation, including the integration of dazzlers and long-range intelligence, surveillance, and reconnaissance modes. In 2022, Lockheed-Martin delivered their most powerful tactically-relevant class laser with an output power of 300kW.

Laser weapon programs in Europe
Tactical Advanced Laser Optical System (TALOS) (France/EU): Led by CILAS and part of a European consortium, the TALOS program is developing a high-power laser effector capable of defending against various threats, including drones and mortar rounds.

Rheinmetall's Laser Weapon Demonstrator (Germany): Rheinmetall has been advancing its laser weapon technology with successful tests against mini drones aboard a German Navy frigate.

DragonFire (United Kingdom): The UK Ministry of Defence has been investing heavily in the DragonFire program, a high-energy laser weapon system. Recent trials have demonstrated its capability to neutralise aerial threats such as drones and missiles.

There are various collaborative efforts within the EU to develop laser weapons, leveraging pooled resources and expertise. Programs like the one led by CILAS are part of a broader strategy to ensure Europe remains at the forefront of DEW technology.

2.3 Optical fibre applications in defence

The defence and aerospace sectors have significantly adopted optical fibre technologies due to their light weight and immunity to electromagnetic interference. While initially used for telecommunications, their application is expanding into sensing.

Enhanced and secured communication
Optical fibres are widely used for secure communication systems in the military due to their high bandwidth, which enables the transmission of large amounts of data quickly and securely. Additionally, optical fibres are immune to electromagnetic interference, making them ideal for transmitting sensitive information in environments where electronic eavesdropping is a concern. The immunity to electromagnetic emissions also eliminates the risk of jamming or other forms of interference that can disrupt military communication systems.

Navigation and guidance systems
Fibre optic gyroscopes (FOGs) are utilised in military navigation and guidance systems for various vehicles, including aircraft and submarines. FOGs provide precision in measuring angular rates and acceleration, which is crucial for autonomous navigation and accurate targeting, particularly in situations where electronic interference affects satellite navigation. Additionally, FOGs are critical components in fire control systems, providing stability to aiming and firing lines of weapon systems, such as armed helicopters. This capability ensures that weapons can accurately perform search, aim, track, and shoot while in motion.

Avionics
Fibre optics are increasingly used in avionics for defence to address size, weight, and power (SWaP) challenges while enabling high-speed data transmission. They are essential for transmitting control signals and sensor data in advanced avionics systems, accommodating bandwidth-intensive applications due to their high data transmission rates and electromagnetic interference immunity. The use of fibre optics in avionics is revolutionary, allowing modern defence missions to be supported by next-generation avionics systems.

Sensing and surveillance
Fibre optic sensors detect vibrations, temperature changes, pressure, and strain along the fibre, providing real-time information about potential threats or unauthorised access. They offer unparalleled benefits, such as immunity to electromagnetic interference, high voltage fields, and extreme environmental conditions. These features make them ideal for various applications where traditional sensors may fall short.

Fibre optic sensors are crucial for defence applications because of their versatility. They improve perimeter security by detecting unauthorised intrusions at borders, military bases, and sensitive sites. They can be seamlessly integrated into fences, walls, or underground for reliable, round-the-clock monitoring. In structural health monitoring, sensors detect changes in strain, temperature, and vibration, allowing for early identification of potential structural issues in assets such as aircraft and bridges. Fibre optic sensors are indispensable for coastal defence and anti-submarine warfare, offering durability in harsh underwater conditions for effective surveillance, including precision tracking of submarines and monitoring of marine ecosystems. The versatility of fibre optic sensors makes them crucial in modern defence strategies.

Conclusion
Fibre optics are essential in modern defence technology due to their reliability, high data transmission rates, and security features. They support critical functions within military operations and infrastructure. Ongoing advancements continue to expand their capabilities and applications in defence systems and equipment.

2.4 Other technologies

Head-up displays (HUDs) are transparent displays that present critical information without requiring users to shift their gaze from their usual viewpoints. They eliminate the need for pilots to refocus their eyes between the display and the outside view. HUDs show information such as speed, weapon status, and target range. In addition to fixed HUDs, helmet-mounted displays (HMDs) are also used, which move with the user's head orientation. Modern military aircraft, such as the F-16 and Eurofighter, commonly utilise both HUDs and HMDs.

Figure 6: Example of Head-Up Display (HUD) in a military aircraft – Source iStock

Opto-pyrotechnic systems are utilised in launchers and satellites to enable controlled explosions through laser-activated optical fibres. Some armoured vehicle protection systems utilise opto-pyrotechnic initiators to neutralise threats rapidly.

3. Manufacturers and position of Europe

Main players

The table below presents the main manufacturers of photonics systems for defence in Europe and the US.

Table 1: Main manufacturers of photonics systems for defence in Europe and the US
Source: TEMATYS/Photonics21, 2023

Type of systems	Ground systems	Airborne systems	Naval systems
Main players	Aselsan Controp Elbit Systems Hensoldt Leonardo Lockheed Martin L3 Technologies Raytheon Rheinmetall Safran Teledyne FLIR Thales	Aselsan Controp Elbit Systems Hensoldt Leonardo L3 Technologies Lockheed Martin Northrop Grumman Raytheon IAI Rafael Saab Safran Teledyne FLIR Thales	Elbit Systems Hensoldt Kollmorgen Leonardo Rafael Raytheon Rheinmetall Saab Safran Teledyne FLIR Thales Ultra Electronics

The market for photonic devices in defence and security is growing at around 7.5% per year, accounting for $48 billion in 2022.
The main sub-segments are as follows:

- Infrared and night vision cameras and related devices account for more than $18 billion (including infrared seekers for missiles).
- Cameras for visible surveillance systems represent a market of around $15 billion.
- Other sub-segments are fiber optics sensors, displays, rangefinders and Lidars. They account for about $5 billion.
- Optical telecommunications are not included as it is very difficult to separate them from civil telecommunication systems.

In the global market for photonic systems for defence and security, European production accounts for €10.2 billion in 2022, a market share of 24%. It represents about 8% of the total Photonics production in Europe. Europe has a significant market share in the sub-segment of infrared systems for defence.

The three main producing countries in Europe are France, Germany, and the UK (together accounting for >70% of European production), followed by Italy and Sweden.

Thales is the European industry leader in multi-domain optronics solutions. For land and naval applications, the other primary European manufacturers are Rheinmetall, Safran and Hensoldt, while Leonardo, Hensoldt and SAAB lead the way in airborne applications. Their main competitors in the global market are North American firms such as Raytheon, Lockheed Martin, L3Harris, and Teledyne FLIR, as well as Israeli companies Elbit and Rafael.

According to a recent report, **McKinsey estimates that the global market size for defence photonics-enabled systems is approximately $300 billion.**[1]

[1] Imperatives for photonics companies in the next wave of growth, McKinsey & Company, 2023.

4. Summary and conclusions

Most modern warfare aspects involve at least one photonics device or piece of equipment. The table below provides an overview of the applications of photonics technologies.

Warfare domain	Intelligence, Surveillance, and Reconnaissance (ISR)	Survivability & lethality	Mobility	Connectivity
Photonics functions	**Observation & surveillance**	**Fire control & protection**	**Vision Enhancement**	**Communication**
Cameras & sensors	Night sights IR cameras on various platforms	Weapon sights Missile warning systems	Helmet sights Driver vision enhancement	N/A
Lasers	Laser Rangefinders and Lidars in turrets and pods	Pods for target designation	Lidars for enhanced vision	Free Space Optics communication
Fibers	Fiber sensors and monitoring systems	Fiber sensors for protection	Fibers for avionics systems	Secure communication for operations

Table 2: Overview of the applications of photonics technologies for defence Source: TEMATYS/Photonics21, 2023.

Photonics essential for defence

Photonics plays a crucial role in various defence applications due to its ability to manipulate and control light for a wide range of purposes. Here are some key applications of photonics in defence:

- **Night Vision and Imaging:** Photonics-based sensors, such as infrared cameras and night vision goggles, allow military personnel to operate effectively in low-light or no-light conditions. These devices are critical for surveillance, reconnaissance, and navigation.
- **Laser Targeting and Ranging:** Lasers are used in target designation, rangefinding, and guidance systems for missiles and artillery. They provide high precision in identifying and hitting targets.
- **Directed Energy Weapons:** High-energy lasers are being developed for various defence applications, including anti-drone systems, missile defence, and disabling enemy electronics. These lasers can deliver precise, high-energy beams over long distances.
- **Communication Systems:** Optical fibres are integral for secure and high-speed communication systems. Lasers enable free space optics communications.
- **Fiber Optic Sensors:** Fiber optic sensors are used to monitor structural integrity and detect changes in temperature, pressure, or chemical composition in military equipment, vehicles, and infrastructure. They are crucial for ensuring the safety and reliability of defence systems.
- **Fibre Optic Gyroscopes:** Fibre optic gyroscopes are used in military navigation and guidance systems across various vehicles.

These applications demonstrate how photonics plays a critical role in enhancing the capabilities of defence systems, from communication and sensing to targeting and protection. Advancements in photonics continue to drive innovation in defence technology, leading to more effective and efficient military operations.

Sovereignty and security at stake

When considering the sovereignty of a state or political entity, such as the European Union, several aspects must be taken into account. In addition to political and economic factors, defence is of utmost importance at both military and industrial levels.

Most advanced defence equipment cannot operate without at least one photonics device.

Photonics, as a key enabling technology, is undoubtedly connected to the sovereignty challenge faced by European institutions. Fibre optics, sensors, IR detectors, accelerometers, atomic clocks, and lasers are essential components for many high-tech equipment and systems, particularly in the defence industry. Mastering their design and manufacturing is crucial for maintaining sovereignty.

Photonics is crucial for the defence sector. No advanced equipment can operate without at least one photonics device or module, such as IR cameras, countermeasures, mobility sensors, head-up displays, advanced imaging cameras embedded in satellites or drones, LIDARS, rangefinders, inertial sensors, or surveillance systems.

As countries outside of Europe rapidly enhance their defence capabilities, it is imperative for Europe to advance and master photonics technologies. Embracing these innovations will ensure the continent remains secure and competitive on the global stage.

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