Photonics in Germany

Germany has established itself as a global leader in photonics, excelling in optical and laser technologies. This article examines the country's photonics industry, which accounted for €51.7 billion in 2023 and is essential to sectors such as healthcare, Industry 4.0 and, more recently, quantum technologies. Key contributors include companies such as ZEISS, TRUMPF and hundreds of SMEs, supported by robust educational institutions and research organizations such as the Fraunhofer Institutes. Government initiatives like "Photonik Forschung Deutschland" and the Research Program "Quantensysteme" have ensured continuous innovation. Emerging trends in quantum systems, laser fusion and ultrafast lasers further secure Germany's position at the forefront of global photonics advances.

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History of photonics in Germany

The history of optics and photonics in Germany dates back to the early 19th century, when pioneers like Joseph von Fraunhofer, a physicist and optician, laid the foundation for modern optical technology. Fraunhofer's advancements in spectroscopy and precision optics, including the invention of the diffraction grating, established Germany as a leader in optical research. In the late 19th and early 20th centuries, German companies like Carl Zeiss, founded in 1846, revolutionized optical instruments, particularly for scientific and medical applications. Zeiss's collaboration with Ernst Abbe and Otto Schott resulted in groundbreaking innovations in lens design and glass production.

After World War II, Germany's optics and photonics sectors experienced rapid growth, driven by advancements in industrial applications and scientific research. Research institutes like the Max Planck Institutes and the Fraunhofer Society became world leaders, fostering strong collaborations between academic research and industrial development. A key focus was laser technology, which became integral to the country's industrial and scientific progress. German companies such as Atlas Laser, Lambda Physics, TUI Laser, Rofin-Sinar - these and a number of others acquired by Coherent - and the family-owned machine manufacturer TRUMPF became pioneers in laser technologies, developing cutting-edge solutions for precision manufacturing, medical devices and scientific instrumentation. TRUMPF, in particular, gained prominence for its high-performance industrial lasers, which revolutionized manufacturing processes. This emphasis on laser innovation propelled Germany to the forefront of the global photonics industry.

German photonics market: current status and growth

Germany continues to lead Europe in photonics production, contributing to 39% of the continent's total photonics output (Fig. 1). Within Europe, Germany's photonics industry accounted for €51.7 billion in 2023, representing significant growth from €40.8 billion before the pandemic in 2019.

This industry is essential for the German economy, contributing 3% of Europe's total manufacturing output and employing more than 188,500 people across over 1,000 companies. These companies, ranging from large corporations like ZEISS and TRUMPF to dynamic SMEs, forming the backbone of the country's technological prowess in photonics.

Key industry segments in german photonics

Germany's photonics industry spans numerous sectors, but some key areas dominate in terms of both innovation and production (Fig. 2). According to the most recent market reports,

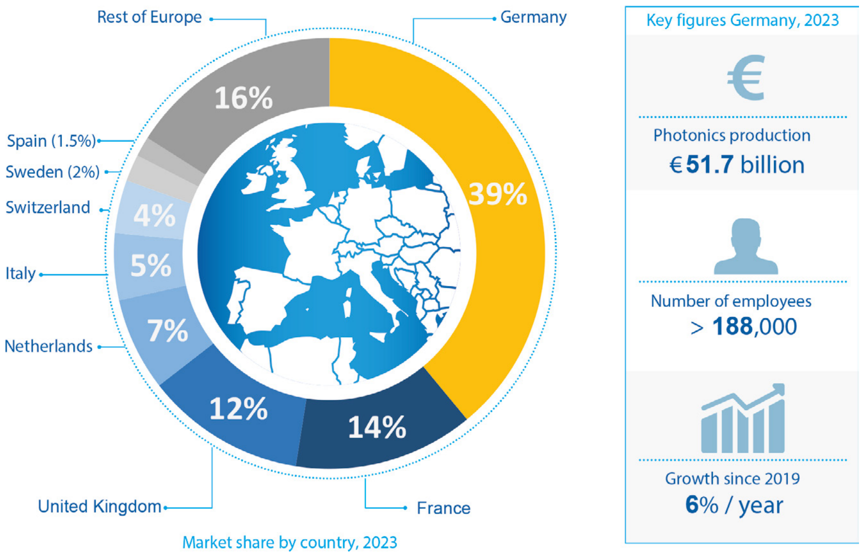


Figure 1. Germany in the European photonics market (Source: TEMATYS/SPECTARIS)

components and materials, smart factories/Industry 4.0 and healthcare are particularly strong segments.

Components and Materials: Germany plays a crucial role in the development and production of high-performance photonic components and materials. These include optical lenses, lasers, fiber optics, and photonics integrated circuits (PICs). German companies are at the forefront of precision optical components for industrial, medical, and scientific applications. Additionally, advanced materials such as semiconductors and specialized glass used in photonic applications are areas where Germany excels.

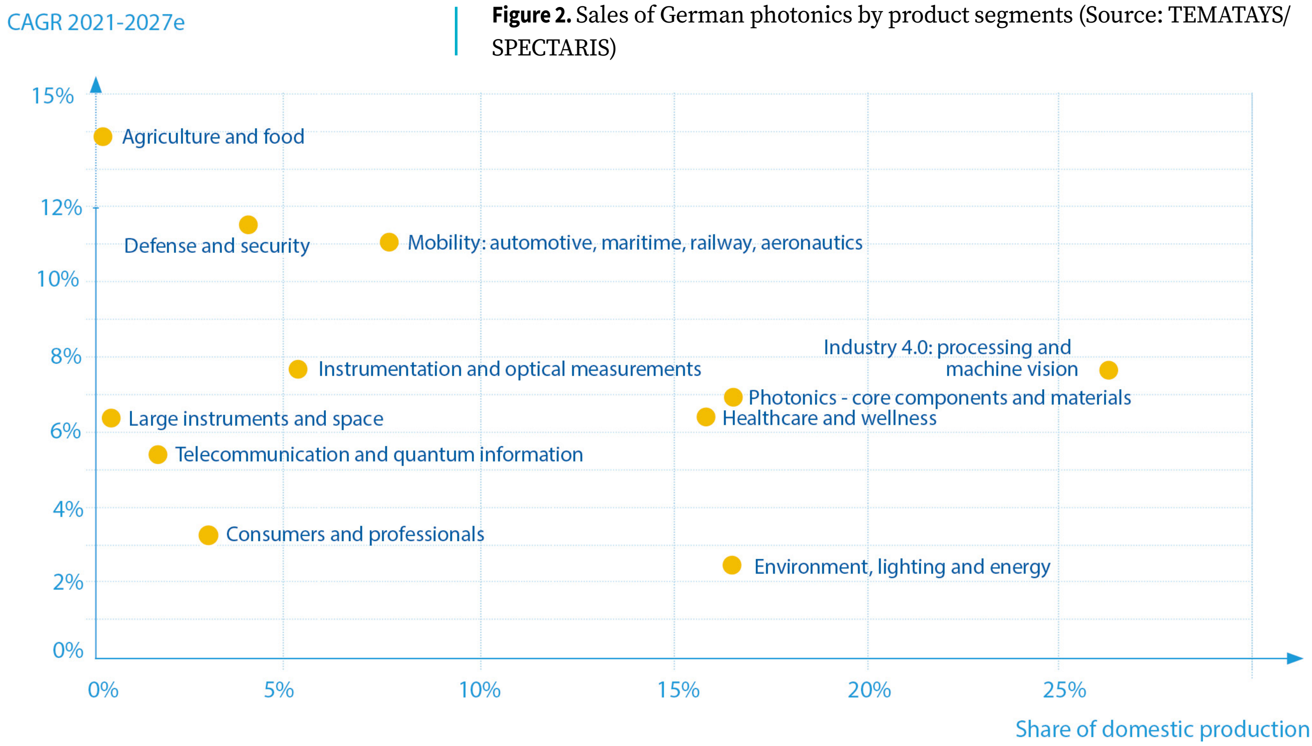
Photonics for Industry 4.0: Germany leads the global market in industrial photonics, with a 38% share of the world's photonics technologies for manufacturing. This includes laser-based precision systems used in production, optical metrology, and machine vision technologies, which are essential for smart factories and automated processes in the context of Industry 4.0.

Healthcare and Biophotonics: In the healthcare segment, Germany holds a 21% share of the global photonics market. Key innovations include biophotonics, which covers diagnostic equipment like imaging systems and laser surgery tools. Companies such as Carl Zeiss Meditec and Karl Storz are global leaders in this field, producing cutting-edge medical devices and systems.

The role of quantum systems in Photonics

A crucial aspect of Germany's leadership in photonics is its integration with quantum systems, a joint research initiative that combines quantum technologies and photonics to harness their synergies. The "Forschungsprogramm Quantensysteme" (Fig. 3), launched by the Federal Ministry of Education and Research BMBF, strategically • • •

Figure 2. Sales of German photonics by product segments (Source: TEMATAYS/SPECTARIS)



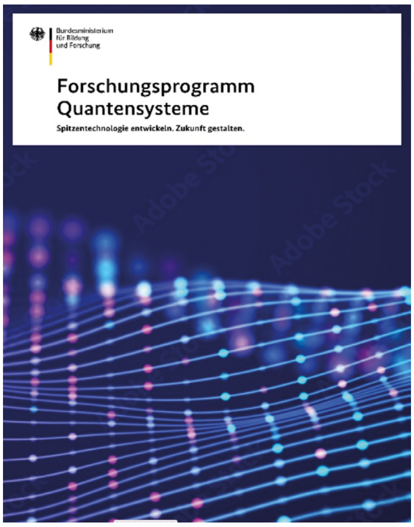


Figure 4. Germany's Quantum Systems Research Program.

unites these two fields to propel Germany to the forefront of quantum innovation.

Quantum systems utilize quantum mechanics' principles, such as superposition and entanglement, to create new technologies like quantum computers, quantum sensors, and quantum communication systems. Photonics is indispensable in this initiative, as it provides the foundational technology necessary for many quantum applications, such as photon-based qubits in quantum computing and quantum-enhanced optical sensors.

The goal of the quantum systems program is to make Germany a global leader in quantum computing and quantum sensing by 2030. The program fosters technological innovation across a range of industries, including healthcare, telecommunications, and manufacturing, where precise measurements, secure communications, and advanced computational capabilities are becoming increasingly essential.

Photonics acts as a critical enabler in these advancements, particularly in the development of quantum-enhanced imaging, sensors, and integrated photonic circuits. Through this joint program, Germany aims to unlock the potential of quantum technologies while expanding the applications of photonics in real-world scenarios, leading to significant technological breakthroughs.

Educational framework and research ecosystem

Germany's photonics excellence is supported by a robust education and research infrastructure. Universities such as RWTH Aachen, the Friedrich-Schiller University Jena, and the Karlsruhe Institute of Technology (KIT) and more than a dozen other educational institutions offer specialized programs in optics and photonics. These institutions collaborate with Germany's renowned Fraunhofer Institutes and the Max Planck School of Photonics (MPSP), ensuring that research and industry are closely linked.

Max Planck Institutes are focused on fundamental photonic research laying the foundation for an continues flow of discovery and inventions in photonics and quantum physics. The Nobel prize winners Theodor Hänsch and Stefan Hell are evidence for the highest standards of photonic research in the Max Planck Institutes.

Research institutes like the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena, the Fraunhofer Heinrich Hertz Institute HHI in Berlin and the Fraunhofer Institute for Laser Technologies ILT in Aachen are at the forefront of technological advancements, working closely with industry to translate research into commercial products. These collaborations foster innovation in emerging fields such as quantum optics, high-power lasers and biophotonics.

Government Support and Funding

The German government plays an active role in supporting the photonics industry through funding initiatives and innovation clusters. The photonics research program "Photonik Forschung Deutschland", launched by the Federal Ministry of Education and Research BMBF, has provided significant financial resource to support innovation in photonics for many years, focusing on areas such as healthcare, optical communication, and industrial technologies. Since 2017 the photonics program has been an essential part of the research program Quantum Systems.

Additionally, European programs like Horizon 2020 and Horizon Europe fund collaborative research projects in photonics, with Germany being a major beneficiary. Public and private investments in R&D are crucial for sustaining Germany's competitive edge in photonics and ensuring its global leadership in this key technology.

Photonics associations and quantum clusters in Germany

Germany's photonics sector is supported by a dense network of associations, innovation clusters, and research hubs that bring together industry, academia, and government institutions.

SPECTARIS
German Industry Association for Optics, Photonics, Analytical and Medical Technologies

SPECTARIS, the German Industry Association for Optics, Photonics, Analytical and Medical Technologies, is the representative of the German photonics industry. The photonics membership consists of large companies like ZEISS, Jenoptik and SCHOTT, but also of more than 100 SMEs that are often world-market leader in their specific photonic niche. Permanent topics of SPECTARIS are the support of its corporate members in the areas of international trade, governmental regulations, market research and attraction of young talents. Also outreach activities belong to the portfolio like the publishing the books "Photonics Infographics" to get students, politicians and the general public interested in photonics.

PHOTONICS GERMANY

Figure 5. Logo of the German photonics alliance

At the regional level, there are a number of vibrant photonics clusters such as OptecBB in Berlin and Optonet in Jena, as well as Bayern Photonics and Photonics BW in the southern federal states. They are all part of the umbrella organization OptecNet Deutschland, which represents some 600 companies, universities and other photonics stakeholders, making it the largest photonics network in Germany.

In 2020, SPECTARIS and OptecNet Deutschland have started the alliance PHOTONICS GERMANY (Fig. 4) to bundle their large membership and expertise for an even stronger voice of photonics in the German economic discourse.

Future trends in german photonics

The future of photonics in Germany is bright, driven by key emerging trends:

- Quantum Systems: As quantum technologies evolve, Germany is heavily invested in developing photonics for applications in secure communications, quantum computing and quantum sensing.

  A vibrant network of stakeholders in quantum technologies is growing with excellent interlinked regional clusters, and a growing number of startups are commercializing the latest inventions of academic research.
- New generation of powerful ultrafast laser systems: So far, ultrafast laser systems are limited in power. The goal of a large consortium of Fraunhofer institutes and collaborating German companies under the name CAPS is on the way to develop and industrialize new systems in the multi-kilowatt range offering a wide range of new applications in industry and research.
- Research on laser fusion has gained momentum in Germany, following fundamental advances in international basic research. New initiatives have been launched to develop and establish the necessary infrastructure, with particular emphasis on high-power lasers and precision optical components.
- Photonics in Agriculture and Food: A rapidly growing segment, photonics in agriculture is becoming more important for ensuring food security and enhancing sustainable farming practices. Although small (around 1% of the total market), this segment is growing at an impressive 11.8% CAGR. German specialists in optical sensors like the Nynomic corporation and dozens more German photonics companies benefit from this trend.

Conclusion

Germany's leadership in the global photonics industry is built on a strong foundation of research, innovation, industrial expertise and a unique network of all those photonics stakeholders. The country's photonics sector is expected to continue its growth trajectory, driven by advances in healthcare, Industry 4.0 technologies, and quantum systems. With a well-developed educational system, significant government support, and a dynamic industry (see Fig.5) , Germany is poised to remain a global powerhouse in photonics for years to come.

Figure 6. New headquarters of German photonics flagship ZEISS under construction in Jena (Source: ZEISS)