



# Factsheet 6: Applications of Germanium Photonics

Germanium photonics is a rapidly advancing field with diverse applications across multiple industries. As a semiconductor with unique optical and electronic properties, germanium is a critical material in various cutting-edge technologies. It is being increasingly utilized in fields ranging from telecommunications and healthcare to renewable energy and quantum computing. Below are some of the key real-world applications of germanium photonics and their potential to transform industries.

## 1. Sensing, Imaging, and Autonomous Systems

Germanium's sensitivity to infrared (IR) light makes it indispensable in the field of sensing, imaging, and autonomous systems. These applications span environmental monitoring, industrial process control, biomedical diagnostics, smart agriculture, and advanced navigation technologies.

- **LiDAR and 3D Cameras for Autonomous Vehicles:** Germanium-based infrared sensors play a crucial role in LiDAR (Light Detection and Ranging) and 3D camera systems. These technologies are essential for autonomous vehicles, drones, and robotics, enabling real-time depth perception, spatial awareness, and high-resolution 3D mapping. They allow self-driving cars to detect obstacles and navigate safely in low-light or adverse weather conditions.\*
- **Environmental Monitoring:** Germanium-based IR sensors can detect and measure gases, including carbon dioxide, methane, and pollutants, ensuring air quality in urban environments and monitoring greenhouse gas emissions.
- **Biomedical Applications:** Germanium photonics is used in non-invasive glucose monitoring devices, which employ IR spectroscopy to measure glucose levels in a patient's blood without the need for blood samples. Germanium-based sensors also contribute to medical imaging, wearable health technologies, and high-resolution thermal imaging, crucial for diagnostics and early disease detection.
- **Smart Agriculture:** In precision agriculture, germanium IR sensors provide valuable data on irrigation needs, pest infestations, and nutrient deficiencies, optimizing crop yields and reducing environmental impact.
- **Astronomy and Space Exploration:** Germanium-based infrared imaging systems are

used in space exploration to observe celestial objects emitting radiation in the mid-infrared spectrum, aiding in the detection of distant stars, galaxies, and exoplanets.

## 2. Data Communication

The demand for faster, more efficient data transmission is skyrocketing with the rise of cloud computing, artificial intelligence (AI), and the internet of things (IoT). Germanium-based photodetectors and modulators are critical components of high-speed optical communication systems. In silicon photonics platforms, germanium is used to enable efficient light detection and modulation, significantly boosting data transfer speeds in fiber-optic networks.

Germanium photonics is especially pivotal in the development of next-generation data centres, which are expected to manage unprecedented volumes of data. Additionally, as 5G and beyond become more widespread, germanium-based photonics will continue to play a key role in reducing signal loss and enabling ultra-low latency communications for applications like autonomous vehicles, remote surgeries, and real-time data processing.

## 3. Photovoltaics

Germanium plays a significant role in the renewable energy sector, particularly in solar energy technologies. Multi-junction solar cells often include germanium substrates due to their superior ability to convert sunlight into electricity.

- **Space-Based Solar Panels:** Germanium-based solar cells are commonly used in space applications, where high energy efficiency and durability are essential.
- **Next-Generation Solar Cells:** Researchers are exploring germanium to improve tandem solar cells, enhancing light absorption and energy conversion efficiency for broader solar power adoption.

## 4. Quantum and Computing Technologies

The future of computing lies in quantum technologies, and germanium is emerging as an essential material in this field.

- **Quantum Dots and Single-Photon Detectors:** Germanium-based quantum dots and single-photon detectors are being explored for use in quantum communication networks, promising ultra-secure communication via quantum key distribution (QKD).
- **Optoelectronic Circuits for AI:** Germanium's compatibility with silicon makes it ideal for next-generation optoelectronic circuits, crucial for improving the energy efficiency and computational power of AI and machine learning technologies.

## Conclusion

Germanium photonics continues to drive advancements in telecommunications, environmental sensing, imaging, renewable energy, and computing. With the increasing integration of germanium photonics into 3D cameras, LiDAR systems, and autonomous technologies, industries are poised for transformative innovations. The future of high-performance, energy-efficient photonic devices will see germanium playing a central role in enabling smarter, more advanced systems across multiple domains.

*\*PhotoGeNIC Work package 'WP5 – Automotive LiDAR and industrial camera demonstrator' aims to showcase the seamless integration and performance of Ge-based VCSELs in a LiDAR demonstrator for automotive applications such as assisted driving functions up until full autonomous driving as well as to demonstrate an improved characteristics of an industrial 3D camera in terms of image quality aspects. To meet lowest costs and the robustness level required by the automotive industry, a LiDAR without any moving component is desired.*