BLACK SILICON 4-QUADRANT DETECTOR

ELFYS

Introduction

Detecting and measuring NIR radiation with high sensitivity is essential for many modern defense and security technologies. Applications deploying laser-guided systems, as well as range-finding and night vision devices, require efficient photodetection to ensure precise operation under varying conditions. Another requirement for these applications is the high speed of photodetection. Speed is vital to enable instantaneous reaction to rapid changes in the light signal.

Achieving both high sensitivity and fast photodetection speed within the NIR band presents a significant technical challenge. At the component level, conventional photodiodes fabricated from silicon face several performance limitations for NIR applications. Given these drawbacks, there is opportunity for innovative alternate solutions to overcome these hurdles. The use of nanostructured black silicon for the photodiode is one such approach.

ElFys Black Silicon 4-Quadrant Detector (Figure 1). delivers a significant advancement in near-infrared (NIR) detection, achieving >30% higher responsivity compared to other state-of-the-art detectors. With a responsivity of 0.64 A/W at 1064 nm, it combines high sensitivity, low dark current, and precise positional information, making it ideal for demanding applications.

Challenges in NIR photodetection

In photodetection, silicon photodiodes are commonly used due to their compatibility with existing semiconductor fabrication processes, plus their wide availability and overall cost-effectiveness. Although silicon is an excellent material for visible light detection, the absorption of NIR radiation in silicon is weak due to the decreasing absorption coefficient with increasing wavelength, which causes the photodetector response to drop. Silicon's limitations for the NIR wavelength range — which become especially apparent beyond 950 nm — pose a significant challenge to the defense and security industries, where the 1064 nm wavelength is of considerable importance. Several applications in the field, such as missile target designation, laser warning systems, and laser rangefinders commonly use the neodymium-doped yttrium aluminum garnet (Nd:YAG) laser at this wavelength.

Responsivity gains via efficient anti-reflection

When light hits the photodetector surface, a portion of it is reflected away due to the difference in the refractive index between air and the photodetector material. This reflection loss can significantly reduce the amount of light entering the device: For a bare silicon surface, reflectivity is typically as high as 30% for normal incidence at NIR. This means that 30% of the light is lost before it reaches the active region, resulting in an equally large drop in the responsivity.

A commonly used technique to reduce the optical losses is to introduce an anti-reflection (AR) coating on the detector surface. AR coatings have an intermediate refractive index between air and the photodetector material, and use of the coating on the surface minimizes reflections by creating destructive interference for reflected light waves. More light is enabled to enter the silicon material, and more photons are absorbed as a result. The material and thickness of the AR coating are optimized so that the reflection minimum occurs at the wavelength range of interest.

As an alternative to the AR coating, the approach of texturizing the photodetector surface opens the possibility to leverage additional (and often very distinctive) optical properties. An advanced version of the technique of texturization of the photodetector surface uses nanostructured black silicon

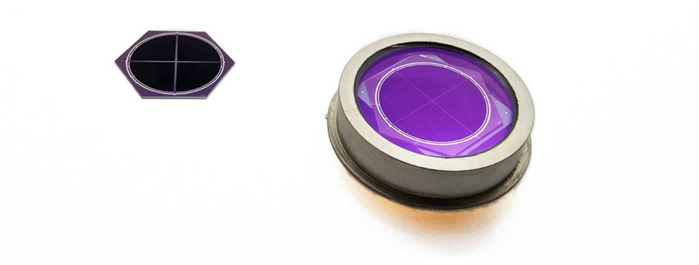

Figure 1: ElFys Black Silicon 4-Quadrant Detector

Black silicon consists of nanostructures smaller than the wavelength of light and acts as an effective medium with a gradual refractive index transition from air to silicon. Since the nanostructures eliminate the optical interface between these two materials, they efficiently suppress reflections across a broad range of wavelengths and incident angles from the ultraviolet to the visible and extending to the NIR (Figure 2).

Black silicon has other interesting optical properties. Notably, the irregular surface of black silicon scatters incoming light, effectively increasing the optical path length within the photodetector material. This in turn increases the likelihood of photon absorption, particularly for longer wavelengths in the NIR region (Figure 2). Therefore, black silicon enables thinner photodetector chips to achieve the same (or better) light absorption compared to thicker counterparts. This relaxes the tradeoff between the responsivity and speed of the detector and gives more freedom to optimize the performance of the device for a specific target application.

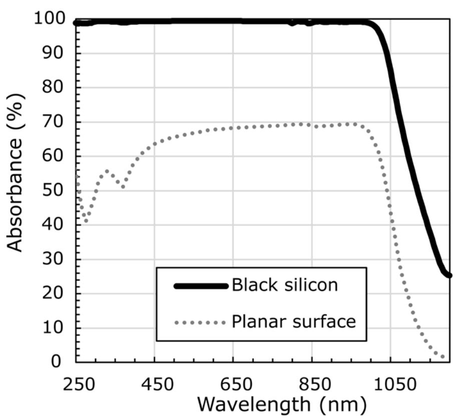

Figure 2

ElFys Black silicon 4-quadrant detectors

ElFys's Black Silicon 4-Quadrant Detector sets a new standard for NIR photodetection, delivering unmatched responsivity, speed, and positional accuracy. By overcoming the historic limitations of silicon photodiodes, this technology empowers defense, industrial, and scientific users to achieve greater precision, reliability, and operational range. As the demand for advanced NIR detection continues to grow, ElFys' innovation stands ready to meet and exceed the needs of tomorrow's most demanding applications.

Though not all precision munitions harness laser technology, laser-guided missiles represent one effective use of 1064 nm sources in defense and military applications. With laser-guided missiles, four-quadrant detectors are often used. These sensors divide the detection area into four equal segments. As a laser beam shines onto the surface of the photodetector, the position of the beam on the surface determines the amount of light received by each of the four quadrants.

One of the main challenges facing conventional four-quadrant detectors is the limited responsivity that can be provided at 1064 nm while still maintaining fast speed of operation. Conventional silicon photodiodes even with an optimized AR coating typically exhibit responsivity of < 0.5 A/W at this wavelength at room temperature.

By enhancing light absorption and minimizing losses due to reflection, black silicon photodiodes exhibit higher quantum efficiency, translating to improved responsivity. **Indeed, black silicon four-quadrant detectors can achieve responsivities > 0.6 A/W, representing an up-to-30% improvement compared to conventional technologies.** Higher responsivity combined with low dark current offers the capability to lock on to the target at longer distances, improving hit accuracy and circular error probable in application. It also makes the system more robust against any disturbances in the air that weaken the signal, such as smoke or dust. Furthermore, as a more sensitive detector can detect weaker signals at greater distances, it allows an operator to designate targets from farther away. This increases the stand-off distance, reducing the risk of the operator being within range of enemy fire or counterattacks.

Performance Highlights of ElFys Black Silicon 4-Quadrant Detector

High Responsivity: **Responsivity >0.6 A/W at 1064 nm**, an up-to-30% improvement over conventional silicon detectors.

Fast Rise Time: ElFys black silicon technology enables rapid operation without sacrificing photoresponse, maintaining fast rise times crucial for tracking fast-moving targets

Low Dark Current: Ensures high signal-to-noise ratio, allowing detection of faint signals at long distances.

Robustness: Enhanced sensitivity allows operation in adverse environments, withstanding atmospheric disturbances that would weaken the signal for less sensitive detectors.

Versatility: While optimized for defence and aerospace, black silicon quadrant detectors are also promising for industrial process control, medical imaging, and scientific instrumentation.

Beyond Defense: Industrial and Scientific Applications

The benefits of ElFys' black silicon technology extend far beyond the battlefield. In industrial laser systems, the detector's precision and speed enable accurate beam alignment and process control. In scientific research, its sensitivity opens new possibilities for NIR spectroscopy and analytical devices. Medical imaging technologies can also leverage the high quantum efficiency and low noise of black silicon detectors for improved diagnostic performance.

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