White Paper

Seeing beyond the visible – short-wave infrared (SWIR) cameras offer new application fields in machine vision

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Seeing beyond the visible – short-wave infrared (SWIR) cameras offer new application fields in machine vision

Short-wave infrared (SWIR) cameras open up numerous possibilities for machine vision solutions, since they detect invisible product flaws as well as desired characteristics: In contrast to mainstream machine vision cameras with CCD or CMOS sensors, most SWIR cameras have an InGaAs (Indium Gallium Arsenide) sensor and thus detect wavelengths between 900 nm and 1,700 nm. These wavelengths are invisible to the human eye and CCD or CMOS cameras. Thus, SWIR cameras detect the invisible, for example, water accumulations inside fruits or defects within silicon products.
This document gives examples of SWIR camera applications in several fields such as the semiconductor industry, recycling, metal and glass inspection, and airborne remote sensing. Since some SWIR cameras are mainly designed for use in research facilities, not only the image quality is crucial for industrial applications, but also an industrial rugged design as well as camera features commonly used in machine vision applications.

Semiconductor industry

The semiconductor industry has become one of the largest industries in the world and continues to expand. Manufacturing integrated circuits (ICs or chips) on thin silicon discs (wafers) is at the heart of this industry.

Cameras with InGaAs sensors typically operate in the SWIR spectral range between 900 nm and 1,700 nm and can image through semiconductor materials such as silicon (Si) at wavelengths around 1,150 nm. Thus, they are an essential part of the inspection process. The ability to image through Si provides a non-destructive inspection method with great benefits for the production process. Today, the semiconductor industry integrates InGaAs cameras into testing, inspection, and quality control systems.

Silicon crystal and ingot/brick inspection

Inspecting silicon crystals and ingots (also called bricks) is one of the classic applications for InGaAs cameras in the semiconductor industry. The ability to see through silicon at a wavelength range above 1,150 nm makes InGaAs cameras a well-suited solution for detecting inclusions such as impurities within a crystal or ingot, which can accumulate during the production process. The impurities are critcal when sawing the ingots into thin wafers with a special diamond chain. If the chain strikes an inclusion such as a small piece of metal, the extremely expensive chain can break. Not only does replacing a chain carry a cost, but also leads to a lower productivity and a reduced profit. An SWIR camera can prevent this situation and thus ensure a smooth production process.

Wafer inspection/packaging

Another important application for SWIR cameras is the wafer inspection. During the manufacturing process of wafers, particles may occur on the top, at the bottom, and even inside or between the wafers. Whereas CCD or CMOS cameras detect particles on the top and at the bottom, InGaAs cameras see through the silicon and therefore detect particles between two bonded wafers.

InGaAs cameras are also used for wafer packaging, where the alignment of the backside pattern to the front side of the wafer is conducted. The SWIR technology helps align layers of wafers as well as aligning other subproducts such as ICs, memory cells, or transistors along the entire supply chain.

Photovoltaics

SWIR cameras can cover the inspection process of the whole supply chain from the silicon crystal to the ingots/bricks, wafers, solar cells, and finally the solar modules. Since InGaAs cameras image through silicon, they are the most effective solution to detect physical defects within the silicon.

Besides SWIR imaging, which is a recent inspection technology, other important technologies and methods are common within the photovoltaics industry:

Photoluminescence (PL) and electroluminescence (EL) are the usual methods for inspection purposes.

PL imaging uses optical excitation (for example, laser illumination) to generate electron-hole pairs, which cause emissions by radiative recombination and thus can be detected by the camera. The band-to-band emission around 1,150 nm provides information on defects and dislocation clusters inside the silicon. Moreover, mapping the defect-band luminescence at around 1,550 nm delivers results regarding the limit of the final cell efficiency. Therefore, the detection sensitivity of the InGaAs camera from 900 nm to 1,700 nm suits the application perfectly.

In contrast, electroluminescence is the result of radiative recombination of electrons and holes in the silicon. Voltage is applied to the solar cell, which leads to a recombination with the available holes. The result is the emission of photons depending on the band-gap of the absorber material (silicon 1,150 nm).

Besides crystalline silicon, other types of solar cells or module materials (also called thin film solar) can be inspected:
Copper indium gallium diselenide (CIGS) is inspected at a wavelength of 700 nm to 1,330 nm (depending on the indium/gallium ratio) and copper indium diselenide (CIS) at a wavelength of 1,330 nm.

The main advantage of SWIR over CCD and CMOS cameras is the shorter exposure time with an excellent quantum efficiency (QE) at the prime silicon emission wavelengths ensuring a quick characterization during the manufacturing process. CCD or CMOS cameras need longer exposure times with up to 30 seconds. Even NIR enhanced CCD sensors need exposure times of up to 3 seconds or more. In contrast, SWIR cameras need only a few milliseconds and thus significantly accelerate the production.

Recycling industry

The quantities of waste produced throughout the developed countries are growing continuously while the available resources are becoming scarce; hence, it is necessary to develop efficient methods to separate quality recyclable materials from collected waste.

Plastic sorting

Since all plastic waste looks alike in the visible spectrum, it is impossible to separate the high quality material with conventional methods. In the short-wave infrared (SWIR) range, however, the absorption spectrum of different plastic materials shows different characteristics. Thus, the SWIR camera technology allows implementing automated separation systems to segregate material of similar quality and properties for recycling.

To efficiently realize an automated waste separation process, the material is shredded into small flakes of similar size. A conveyor belt transports the flakes to the inspection unit, which consists of an illumination system and an SWIR camera with an InGaAs sensor. Since each plastic material shows unique spectral characteristics within SWIR, the different materials can be distinguished from each other and the spectral characteristics can be assigned to the corresponding plastic type. The different plastic types are separated on the conveyor belt by an array of air jets. To reach a fine screening and thus a good recycling rate with a high quality outcome, this step can be repeated several times.

Food industry

Fruits and vegetables contain between 80 % and 90 % water. Therefore, their SWIR spectrum is primarily characterized by the water absorption band, which has a peak at around 1,450 nm. Due to its stronger absorption, the water appears darker in the SWIR band.

Food analysis and sorting

Each food product has a unique chemical composition and thus unique spectral characteristics in the visible as well as in the SWIR spectrum. SWIR cameras with InGaAs sensors are used for in-line food inspection via conveyor belts. One of the most common approaches for analyzing food is spectroscopy. However, the latest development in the food industry shows the trend towards hyperspectral imaging (HSI). This method combines digital imaging with spectroscopy to obtain detailed information across multiple ranges of the electromagnetic spectrum. The reflections and absorptions of certain wavelengths depend on the chemical composition and the molecular structure of the food.

SWIR cameras are typically used in push broom imaging systems in combination with a spectrograph. The full spectral data of the inspected food are collected simultaneously, with spatial line scanning over time. With their extended wavelength range from 900 nm to 1,700 nm, SWIR cameras can provide more spectral information than CCD or CMOS cameras. One example is the sorting of bruised apples. SWIR cameras can detect bruises, which are darker in the image because of their higher water content. This eases sorting them out for juicing and separating them from those with perfect characteristics to be sold to end customers.

Metal and glass industry

SWIR cameras can be used for thermal imaging of hot objects between 250 °C and 800 °C. The metal and glass industry integrates SWIR cameras into process and quality control systems.

Molten metal process monitoring and inspection

In contrast to CCD and CMOS cameras, the spectral range of a typical InGaAs camera of 900 nm to 1,700 nm enables the inspection of emission differences between hot metal and slag. The information is used to detect differences in the slag within the manufacturing process. This ensures a maximized yield without any contaminated material.

Glass bottle monitoring and inspection

During the manufacturing process of bottles, InGaAs cameras enable an inside and outside inspection of the glass bottles. Because of their ability to perform thermal imaging of hot objects between 250 °C and 800 °C, SWIR cameras can monitor the temperature uniformity and the cooling rate of the glass. Thus, manufacturers can continuously observe the production to maximize the yield and the quality.

Agriculture

Hyperspectral imaging is also used for agricultural purposes, especially in combination with an unmanned aerial vehicle (UAV). Farmers can inspect plants from the air, for example, their strawberry fields: Looking at the SWIR image, the farmers can recognize plants or areas that lack water, have an ideal water content, or too much water. The more water is detected, the higher the absorption peak at a wavelength of 1,450 nm and the darker the area appears in the image. Special band-pass filters can enhance this effect.

Airborne/remote sensing

UAVs are particularly popular in agriculture, but can also be used for many other purposes; numerous materials can be inspected from the air. Each inorganic material has a different chemical composition and crystalline structure resulting in a unique spectral response corresponding to its specific light absorption characteristics.

Geology and mineral inspection

The unique spectral response enables to perform a mineral mapping of every area in the world. Furthermore, forestry companies can map woodland from the air.

Hyperspectral imaging contributes to geology and mineral inspection by methods similar to food analysis: A push broom imaging system with an SWIR camera and a spectrograph is a common solution within the industry.

Conclusion

Thanks to their versatile capabilities, SWIR cameras with InGaAs sensors are moving into the machine vision market. However, not all SWIR cameras are made for industrial conditions under sustained operation, a hot environment, or vibrations. Thus, many industrial applications require a good image quality as well as a rugged camera design. SWIR cameras are already established in the semiconductor industry and are also gaining popularity in other fields.

As a leading machine vision camera manufacturer, Allied Vision Technologies (AVT) has over 25 years of experience in designing industrial cameras. Besides development, AVT advises customers to find the right camera for their application.