Understanding Camera–Based Ultraviolet Imaging And Applications

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Numerous applications, from wafer inspection to elemental analysis and combustion imaging, stand to benefit from the use of camera-based ultraviolet (UV) imaging. However, misconceptions about UV imaging technologies persist: they lack the capability to meet some user needs, are too costly to acquire, or are too complicated to operate. Recent advances in UV imaging technology and technique have shattered these outdated notions, offering manufacturers, researchers, and various engineers a single, versatile option to accomplish their differing goals. This article discusses recent technological leaps in camera-based UV imaging, starting with a look at the differences between UV and visible light imaging, as well as the equipment used in each. It also describes how predecessor technologies and direct input from users have fueled the development of a new generation of advanced UV imaging cameras.

UV vs. visible light imaging: principles, technologies, and methodologies

UV imaging is fundamentally different from visible light imaging in that it captures images and video at wavelengths between 150 and 400 nm; humans cannot see light below 340 nm. Further, UV imaging is more technically challenging than visible light imaging.

It's inherently difficult to capture incoming, high-energy UV light because UV light tends to react with pretty much every material, and it does not transmit well through the atmosphere. Because UV light is absorbed by so many different materials, care must be taken in the selection of optics and sensor technologies used for camera-based UV imaging. In image sensors, most of the UV radiation is either absorbed in the upper layers and doesn't reach the light-sensitive areas, or it is absorbed in the micro lenses.

Optics differ largely by the material choice required for a given application. For example, commercial cameras traditionally have used glass lenses; cell phone cameras ordinarily use plastic lenses, which are inexpensive to produce, lightweight, and have good optical characteristics in the visible range, including very low distortion.

However, plastic absorbs almost all incoming UV light, so UV cameras demand materials that have high UV transmission — like fused silica or calcium fluoride — as a base material. Ultraviolet-grade fused silica is designed specifically to allow the UV range of wavelengths to pass through, and it is used in camera-based UV imaging for both lenses and windows for the sensors. Ultimately, for users, this means UV imaging technologies will cost slightly more than visible light-capturing cameras. Specialized optics are more expensive to implement than standard lenses usable for visible light cameras, due both to the materials necessary and the manufacturing process (i.e., UV optics are molded to start with, but then have to be polished and finished using more traditional lens-making techniques). Additionally, the market for UV cameras is a fraction of that for visible cameras and less production volume can lead to increased manufacturing costs.

Noting these considerations, it must be acknowledged that UV cameras are not fundamentally different from those used to capture visible light. Indeed, recent advances have brought UV cameras' appearance and functionality closer to those of visible light consumer cameras. Principally, this is because UV cameras are an extension of visible light cameras — not a daunting new technology — built on what a traditional camera does and modified to allow imaging in a dif ferent wavelength region.

Rather than a standard visible light image, UV imaging cameras present information as a map of UV intensities over an area, the meaning of which differs depending on the application. When interpreting such images, emission usually is represented as light-colored, versus absorption, which presents as dark. Thus, if you're looking for how much energy is being absorbed in a particular area, you will focus on darker parts of the image, where that absorption is taking place; if you're looking for something like electrical coronal discharge, you'll focus on bright regions, where significant UV emission is coming off the subject of study.

Advances in UV camera technology

As stated above, traditionally, sensor technology has not been very UV sensitive — at least, not to the point where it has been feasible for diverse applications. Hybrid solutions, built on charge coupled device (CCD) technology, have been more widely used than direct UV sensors.

Hybrid solutions place a phosphorous screen in front of a sensor; the screen essentially converts incoming light from UV wavelengths to visible wavelengths. A sensor then picks up the visible light portion. Thus, a UV imaging application might use, for example, a single-stage phosphor that would glow visibly when the light hits it and that, in turn, would be imaged.

Additionally, if an application is working at very low UV intensities, the setup would require an image intensifier to amplify the UV signal — for example, an electron multiplier. That said, each added technology adds complexity (specialized components) to a setup and, therefore, additional cost and user burden. Fortunately, the newest generation of UV cameras is more sensitive and less costly than previous iterations. New sensors are directly UV sensitive and, therefore, do not require image intensifiers and phosphors, driving the cost down. Further, this generation of UV sensors boasts significantly higher quantum efficiency: while previous generation sensors had a ceiling of about 10 percent QE below 300 nm, the current generation can achieve between 30 percent and 60 percent QE in that same range.

One of the driving forces behind new UV sensors' enhanced sensitivity is back illumination (bi). Specifically, the sensors can be illuminated from the back of the silicon chip, where no electronic structures block access to the light-sensitive silicon. UV is much more likely to be absorbed near the surface of the silicon, so by exposing as much of the surface as possible, you increase the probability of its absorbing a UV photon — thus increasing the overall system's UV sensitivity.

Additionally, the latest generation of UV sensors is inherently less noisy. Previous generation sensors would produce a background signal in the 10-electron range for an uncooled sensor; the current generation can achieve a single electron of baseline readout noise.The cameras' sensors aren't the only dramatic improvement. Previous UV cameras could produce 1-megapixel resolution. Using wafer inspection as an example, consider that previous-generation UV cameras would require a large number of images to examine a given wafer; the images then would be "tiled up" to allow the desired level of inspection. Current-generation cameras render images in 4-megapixel resolution, leading to crisper images and more identifiable features that can be picked out from a single image.

Sticking with that same example, fewer images to work with means higher throughput. Typically, to inspect a larger area with higher resolution, you would have to move the wafer around underneath the camera: take a picture of it, and then move the wafer … take another picture. Move it again. This laborious process eats into your cycle time for the full inspection. The ideal inspection situation is to take one image of that one wafer and have enough information in that single image to do the job (i.e., inspect all features you need to inspect). Even if a single image doesn't provide sufficient resolution, the overall higher resolution will lead to fewer steps and, thus, higher throughput. The implications for time and cost savings, as well as the opportunity to inspect more volume with greater precision, are obvious.

UV cameras' physical size also should be considered. In some applications, where the camera must be crammed into a small enclosure, or must work in tandem with a microscope, an unwieldy UV camera could prove difficult — if not impossible — to work with. These concerns have been addressed in the design of the newest generation of UV cameras by greatly reducing the cameras' size, even as performance improves; for example, the pco.panda 4.2 bi UV is about one-tenth the size of a traditionally intensified camera.

Finally, it's critical to dispel the myth that you need two cameras to image in both the visible light and ultraviolet spectrums. The latest generation of cameras is envisioned as a single solution to meet multiple needs. Consider the aforementioned pco.panda 4.2 bi UV, which can operate between 190 and 1,100 nm. Such utility is great for a multitude of situations — for example, a life-science application wherein you have multiple fluorescence.You might have something that's in the deep blue, or close to UV fluorescence, as well as a visible or near-infrared fluorophore all within the same sample. State-of-the-art camera-based UV imaging now enables you to pick out each of these fluorescent sources using a single sensor.

If your application calls for longer exposure times at lower light levels, you can decrease thermal noise by cooling the sensor down, accomplished using a cooled UV camera. One such option — also capable of operating between 190 to 1,100 nm — is the pco.edge 4.2 bi UV. These attributes add up to comprise a generation of UV cameras that enables component inspection, elemental analysis, cutting-edge scientific research, UV lithography, combustion imaging (i.e., oxidized fuel elements vs. unoxidized), and countless other applications with never-before-seen versatility and high resolution. Where it may have been difficult to justify the expense of a more complicated hybrid system or a low-efficiency UV-sensitive system in the past, there now exist smaller, less expensive solutions. And, as stated earlier, because these new cameras are much smaller and more sensitive, they're substantially easier to implement experimentally, all while producing much higher-quality images at both visible light and UV wavelengths.

Use PCO's expertise

PCO was among the developers of scientific complementary metal oxide semiconductor (sCMOS) technology — which enables low-noise, high-resolution, and high frame-rate systems — and was one of the first companies to release an sCMOS-based camera. Prior to that, PCO gained experience in UV applications, developing intensified cameras based on CCD technology. The company laid the groundwork for this current generation of UV cameras more than a decade ago, when it took one of its uncooled, low-noise CCD cameras and crafted a UV version. While limited by its sensor's low quantum efficiency, that camera provided some UV capability in a small, inexpensive package that worked well in applications where a strong signal could be produced. PCO has continued along that path of innovation, combining the company's experience in camera-based UV imaging with direct feedback from

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users. This has resulted in priority being placed on quantum efficiency – meaning, for most users, actual sensitivity between 200 and 300 nm. Inc. excels by offering that sensitivity at costs that remain competitive with traditional solutions, with simple-to-use USB interfaces and OEM optimization out of the box — encompassing not just the sensor spec, but all electr onics that surround it. Additionally, all cameras come with a free software package that allows you to acquire images and perform evaluation. For custom needs, a full-featured software development kit is available to allow users to control all aspects of the camera on various platforms; PCO also offers MATLAB and LabVIEW support.

Finally, PCO offers free, comprehensive user support, from its North America-based service and repair depot to the Germany-based design engineers available for consultation. The company's experts can help you to better understand how camera-based UV imaging fits your application's needs — and your budget — as well as dispel misconceptions about UV imaging and cameras that may be driving your decisions. Let us advance your understanding and, in turn, propel your knowledge, operations, and products into the future.

About the author

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