By Austin Richards, Ph.D., Oculus Photonics

Across the UV Spectrum

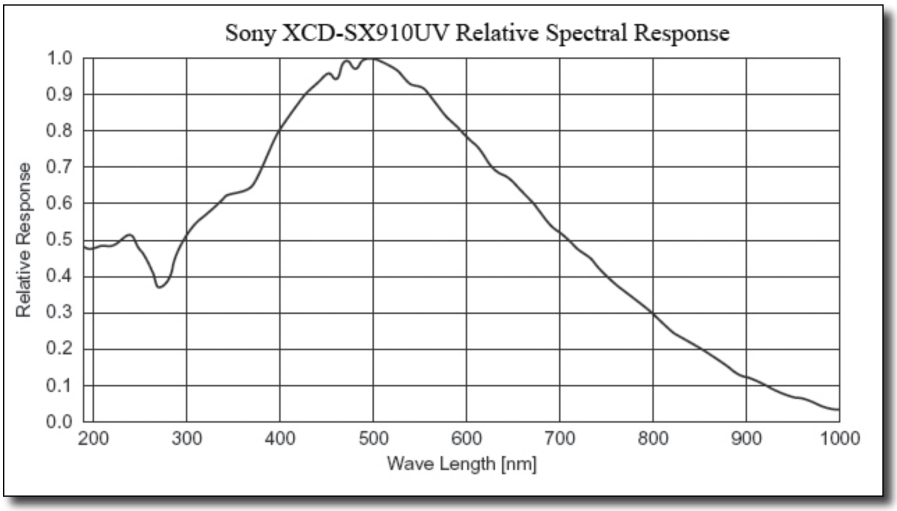


Figure 1 shows the relative spectral response for the Sony XCD-SX910UV camera, which is a two megapixel machine vision camera with enhanced UV response.

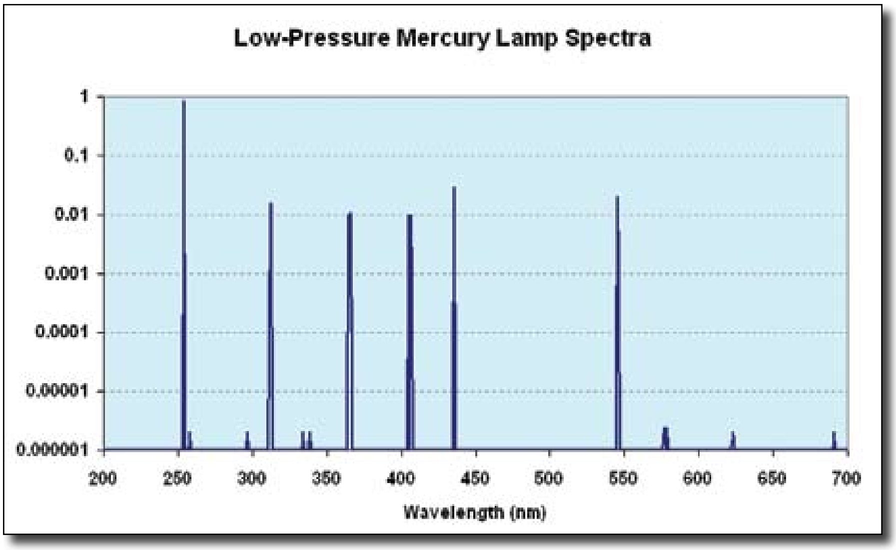
Digital imaging from near-ultraviolet to deep-ultraviolet

- Digital imaging
- UV
- UV fluorescence
- Cameras
- Spectral response

There are many interesting and diverse applications for ultraviolet imaging, a technology that is now over a century old. These include imaging tiny scratches and imperfections in surfaces, the visualization of sun-induced skin damage and faded bruises, and the detection of trace evidence and residue on surfaces. I am referring specifically to reflected UV imaging, where a UV illumination source is used in conjunction with a UV-sensitive camera to produce a pure UV image. This technique is different from UV-fluorescence imaging, where a UV excitation source is used to stimulate visible-light emissions from a fluorescent surface, which can then be visualized either by human eyes or color cameras equipped with barrier filters that block the UV excitation.

Recent developments in digital ultraviolet imaging technology have made reflected-UV imaging much more affordable and accessible to a diverse user group. Various systems now are commercially available that allow one to take UV digital stills and video with a live preview mode that makes it simple to dynamically adjust shot composition, exposure and focus. These advances have been a great boon to forensics and medical workers who have been trained in frustrating and slow methods of reflected-UV film photography. Consider that methods using SLR film cameras equipped with black glass UV pass filters will require bracketing the exposures, high f/numbers which increase depth of field to compensate for focus shifts, and severe challenges in correctly framing a shot of a moving target, since the eye cannot see an image through the barrier filter. There also is a mythology that one MUST use very expensive fused silica lenses for UV imaging[1]. For these reasons, many technical people decided years ago that reflected-UV imaging is too difficult and clumsy and have stopped trying to use it, which is one of the reasons

1 Fused silica lenses are often incorrectly referred to as being the same as fused quartz lenses. They are chemically identical, but fused silica is superior in purity and optical homogeneity.



In Figure 2, you can see that the spectral purity of low-pressure Hg lamps is quite high. Note that the 254nm line is almost 100 times more intense than the next most intense line at 436nm.

that most photographic filter companies have discontinued manufacturing black glass UV pass filters.

There are many ways to divide the ultraviolet portion of the UV spectrum into sub-bands, and every field of science has its own nomenclature, which I will not attempt to catalog here. The two main wavebands considered in this article are the near-UV band (generally considered to be 300-400nm) and the deep UV, which is roughly 200-300nm. 300nm is a convenient dividing point, since both the atmosphere and standard optical glass both cut off rather sharply around this wavelength.

A reflected-UV imaging system consists of the following components:

- A detector that is sensitive to UV light in the desired waveband
- A lens that transmits the desired waveband of UV light and focuses it correctly on the detector
- A filter that passes the desired UV waveband while simultaneously blocking out-of-band light to the required extent for the lighting conditions
- Sufficient UV illumination in the desired waveband

For digital UV imaging systems, the most common detector is a silicon CCD array, though there are other technologies (such as gallium nitride) that show promise. The CCD may be back-thinned to increase its response to UV light below 300nm. Figure 1 shows the relative spectral response for the Sony XCD-SX910UV camera, which is a two megapixel machine vision camera with enhanced UV response. As is the case with the SX910UV, silicon CCDs are generally more responsive to visible and near-infrared light than they are to UV. In order to image under lighting conditions that include visible or near-IR light (such as in sunlight), the imaging system must have a filter or filter stack that blocks this undesired light so that the desired UV band will dominate the images' spectral content.

In my experience, conventional color video or SLR lenses seem to work fairly well for near-UV imaging (330-400nm), but fail to transmit well below about 320nm, which is where the BK-7 lens glass material becomes highly absorbing. If the bandpass is narrow, as is the case with near-UV LED illumination, the chromatic aberration of color lenses used in the UV is quite tolerable. Imaging in the deep-UV band below the glass cutoff wavelength requires expensive optics made of fused silica or calcium fluoride. These lenses are commercially available but the selection of focal lengths is quite limited, and I know of no commercially available deep-UV zoom lenses. Many of these lenses are not achromatic, requiring refocusing if the bandpass is varied.

The solar spectrum at sea level has significant levels of near-UV light, particularly above 330nm, making it possible to take UV images in direct sunlight down to around 330nm. A UV bandpass filter with good out-of-band blocking is required to maintain the purity of the image. Below

330nm, it is necessary to use artificial illumination, as the solar spectrum is steeply falling to begin with and absorption by the ozone layer becomes increasingly strong. To put it another way, it is very dark outside in the deep-UV band below about 300nm, even at high noon!

UV imaging indoors almost always requires artificial sources, since conventional home and office lighting and exterior windows are specifically designed to maintain low levels of UV. Standard “blacklight” fluorescent bulbs generate near-UV light using a mercury vapor discharge, predominately at the 365nm line. These bulbs are coated inside with a dark purple filter that greatly reduces visible light emissions. Inexpensive germicidal mercury-vapor discharge lamps are readily available that generate either 254nm or 306nm radiation depending on the vapor pressure. The spectral purity of low-pressure Hg lamps is quite high, as shown in Figure 2. Note that the 254nm line is almost 100 times more intense than the next most intense line at 436nm. Since the SX910UV camera’s spectral response is roughly the same at 254nm as it is at 436nm, the resulting images have a spectral content that is almost completely deep-UV at 254nm. The medium pressure Hg lamps that peak at 306nm have similar spectra but with pressure-broadened lines. Both of these lamps can be dangerous and protective eyewear should be worn when working with them to avoid “welder’s eye.”

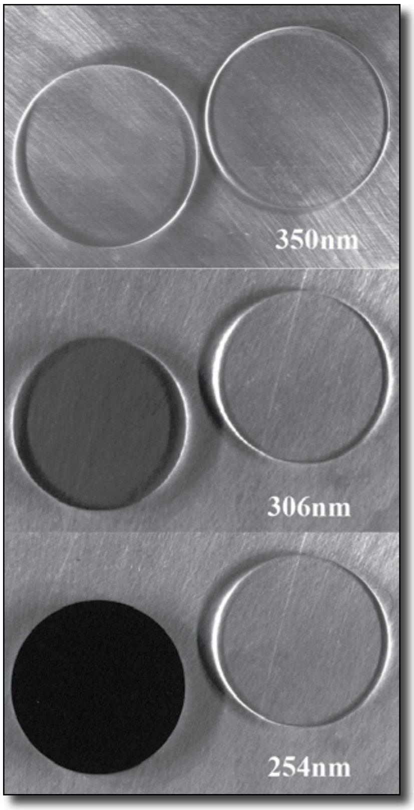


Figure 3: These images show the expected absorption behavior: the BK7 glass becomes progressively more absorbing as the wavelength is decreased, with a very steep drop off below 300nm. (Courtesy David Hayes)

I have found that a UV bandpass filter is not required to create very pure 254nm images with the Sony SX910UV camera, provided that the only light source present is the mercury lamp and that the target is not fluorescent. Figure 3 shows a series of three images taken at 350nm, 306nm and 254nm of 2-inch circular windows made of BK7 glass and fused silica. The background material is sheet aluminum that has been lightly sanded to make the surface a diffuse reflector.

These images show the expected absorption behavior: the BK7 glass on the left become progressively more absorbing as the wavelength is decreased, with a very steep drop off below 300nm. Test targets like this serve as an excellent test of the spectral purity of a UV imaging system: camera, lens, optics and bandpass filters (if any). The camera used was the SX910UV. The 350nm image was taken through a Hoya U-350 filter with a blacklight bulb for illumination. The 306nm and 254nm images were taken with medium-pressure and low-pressure mercury lamps and special Barr Associates UV bandpass filters, respectively. Note that the BK7 is just as transparent at 350nm as the fused silica – it is certainly not necessary to use fused silica lenses for near-UV imaging, especially above 330nm.

Figure 4 shows an example of one of the effects one can see with near-UV and deep UV imaging. The substrate material is a marble tile, which simulates a marble statue with traces of whole-egg-based paint on it. Archaeologists have used shortwave reflected-UV imaging to look at ancient Greek statues to determine how they were painted.

The dots are from left to right, egg yolk, egg white and scrambled egg. The second row of dots is the same as the first row, but with a much thinner layer applied. Inorganic crystalline materials tend to reflect UV down to quite short wavelengths, which is why the tile looks fairly “white” in the three wavebands. The egg proteins, however, are highly absorbing in the UV, especially at 254nm. Imaging at 254nm makes it possible to detect faint traces of many organic substances when all other imaging methods fail.

As a result of the lack of information about how to put together spectrally pure UV imaging systems and the perceived high cost, the application space for both near-UV and deep-UV digital imaging technology is still relatively undeveloped. It is hoped that users with challenging imaging applications that fail to yield to color, near-infrared, and fluorescent techniques will consider trying reflected-UV, particularly if the phenomena they seek

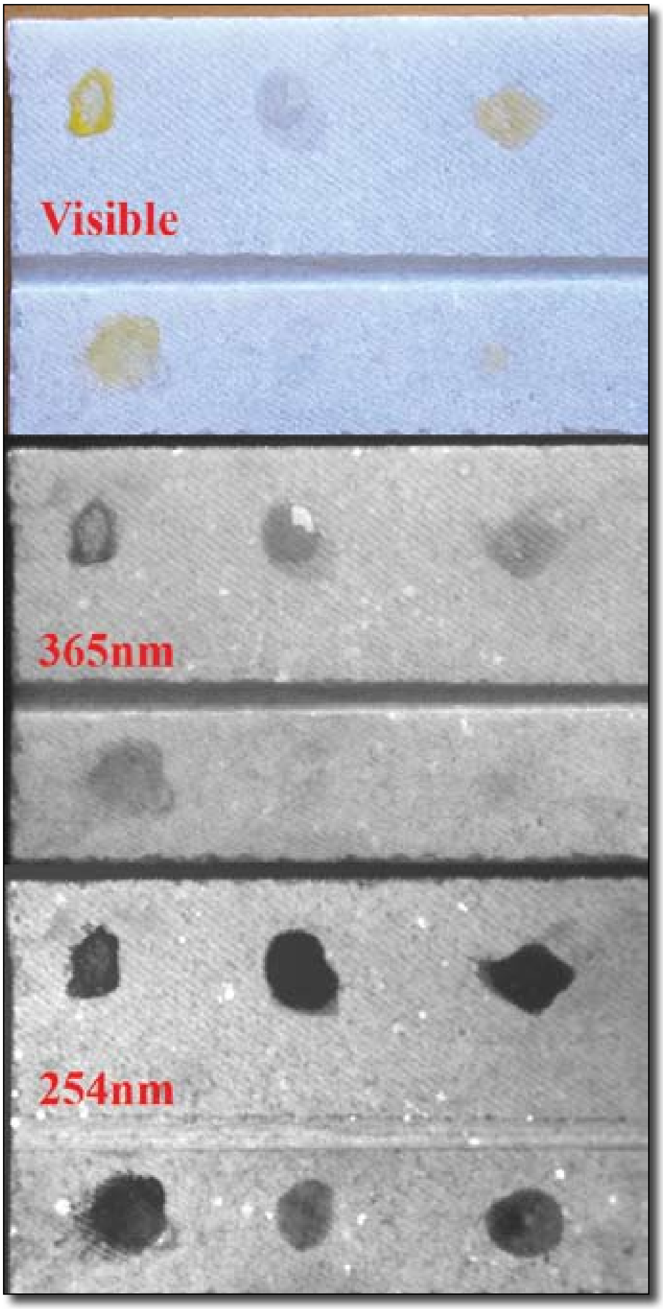


Figure 4 shows egg substances on marble imaged in 3 bands. It is an example of one of the effects one can see with near-UV and deep UV imaging. (Courtesy David Hayes)

involves enhancing contrast between various materials such as organics and inorganics, or the enhancement of tiny features or surface texture that don't record well at longer wavelengths. ***AI***

Dr. Austin Richards is Chief Technology Officer of Oculus Photonics, Santa Barbara Calif. He is a member of the Advanced Imaging Magazine Editorial Advisory Board and the author of "Alien Vision: Exploring the Electromagnetic Spectrum with Imaging Technology" (SPIE Press, 2001). Dr. Richards would like to acknowledge David Hayes for his contributions to this article.