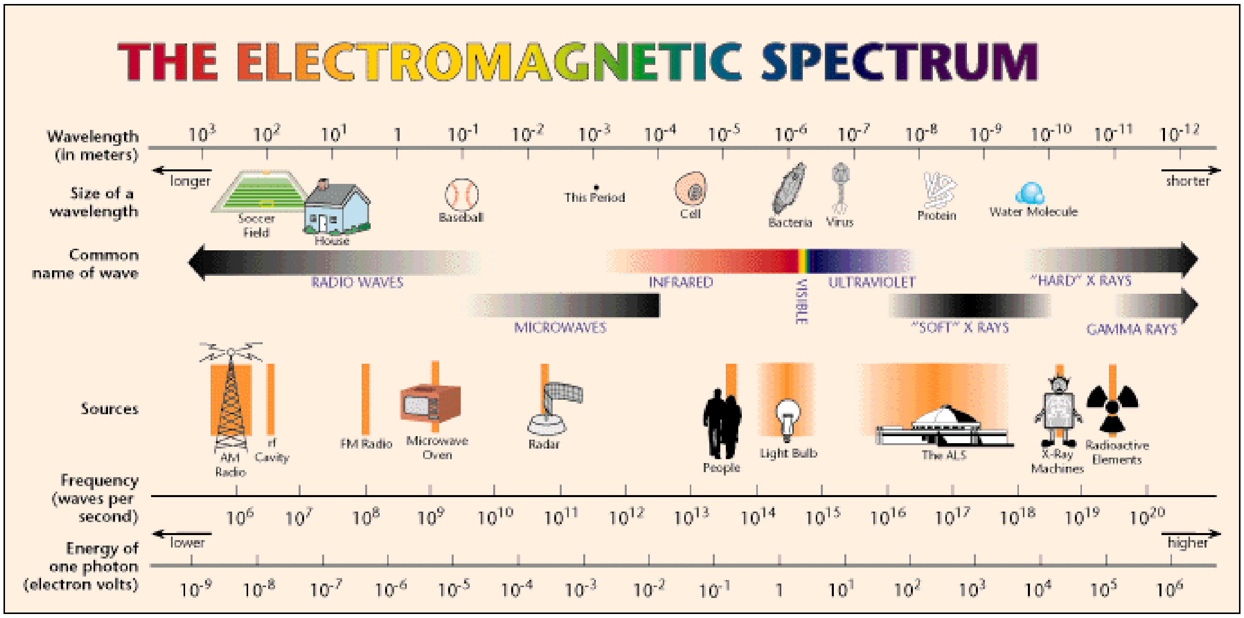
DALSA Application Note September 2001

ULTRAVIOLET IMAGING 101



INTRODUCTION

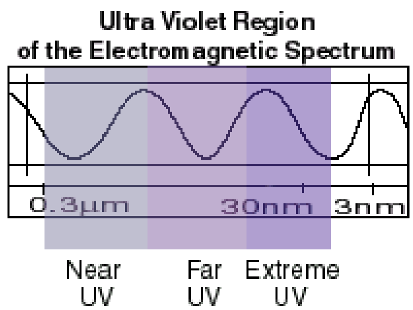
With the shrinking of semiconductor device geometry, critical dimension requirements are pushing the industry's imaging technique to its resolution limits.

Standard techniques using visible light make it possible to recognize and resolve features down to approx. 0.25µm. However, to visualize the shrinking features of 0.10µm resolution inspection, operating within the visible spectrum is no longer sufficient. The sole use of visible light is also insufficient to comply with the Nyquist sampling criterion, which states that an original signal can be recovered without any loss if the samples are no larger than half the size of the finest detail in the signal.

To resolve smaller structures, the reduction of the wavelength is the most practical and effective solution. The solution is ultraviolet imaging. Ultraviolet technology opens up a promising and challenging future for microscopy imaging, micro-defect inspection, astronomy, and others.

WHAT ARE ULTRAVIOLET RAYS?

Ultraviolet (UV) rays are an invisible form of light which lie slightly beyond the violet end of the visible spectrum. The sun is the major natural source of ultraviolet rays. Lightning and other electrical sparks in the air also emit ultraviolet rays. The UV rays can also be produced artificially by passing an electric current through a gas or vapor, such as mercury vapor.



UV rays have shorter wavelengths than visible light. A wavelength, defined as the distance between the crests of two waves, is often measured in units called *nanometers (nm)* for UV description. A nanometer is a billionth of a meter, or about 1/25,000,000 inch. UV wavelengths are sometimes quoted in Angstroms - an Angstrom is a unit length equal to 10^{-10} meters. Typically UV wavelengths range from about 10 to 390nm. UV wavelengths are comparable to the size of molecules and travel at about 2.99 x 10^{8} meters per second.

The ultraviolet bandwidth of the electromagnetic spectrum is divided into three regions: the Near Ultraviolet (NUV), the Far Ultraviolet (FUV), and the Extreme Ultraviolet (EUV). The regions are sometimes designated as A, B, and C. The three regions are distinguished by the energy level of the ultraviolet radiation and the "wavelength" of the ultraviolet light, which is related to energy. The NUV region is closest to optical or visible light band. EUV is closest to X-rays and is the most energetic of the three types. The FUV region lies between the near and extreme ultraviolet regions.

UV IMAGING APPLICATIONS

- Semiconductor/Wafer Inspections
- Biological, such as phosphor fluorescent technology
- Biomedical, such as DNA analysis
- Astronomical, such as planetary objects
- Environmental monitoring, such as oil spills
- HV electrical transmission lines monitoring, such as corona effects
- Navigation, such as landing aid for aircraft in fog
- Imaging of invisible flames (e.g. hydrogen and alcohol flames)

ULTRAVIOLET CCD

Conventional high-end imaging applications utilise large format full-frame and frame-transfer style CCD image sensors. The benefits of using this architecture are high sensitivity, high charge capacity and low dark currents resulting in very large dynamic ranges. These CCDs are typically front-side illuminated and tend to have lower sensitivity or Quantum Efficiency (QE) for wavelengths less than 500nm(UV). The major contributor to this sensitivity loss is the overlying polysilicon gate electrode structures, which tend to absorb or reflect light depending on the wavelength. As well, a very small absorption depth results in the generation of electrons in the gates of CCDs rather than in the buried channels.

The window material used in the CCD also contributes to the difficulty in achieving high UV sensitivity. The commonly used glass inhibits UV rays. Alternatives, including quartz, calcium fluoride, gel, magnesium fluoride, and sodium chloride, have been explored with varying degrees of success.

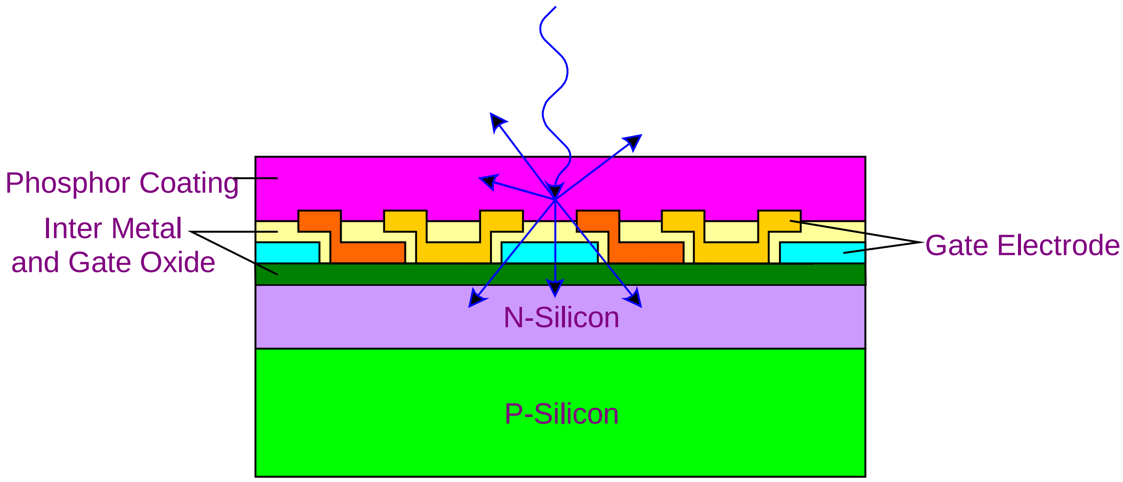
Most line scan cameras are already UV sensitive with a quantum efficiency of about 40–50% at 248nm. These sensors use Pinned Photo Diode (PPD) technology where there is no photogate to absorb or reflect the UV rays. Fill factor is normally at 100% and the cost is considered economical. The only major disadvantage to this technology is the sensor's window, which requires a UV transmittance material such as quartz or calcium fluoride.

There are several methods to increase or enhance area scan CCD sensors for UV imaging applications. Current technologies include:

- Phosphor coating
- Backside thinned / Illuminated
- Open pinned phase
- Indium tin oxide
- "Reticulation"
- Interline

PHOSPHOR COATING

The most common way to make a CCD “see” in the UV region is to coat the element surface with a layer of phosphor. The UV sensitive phosphorus coating can be deposited directly onto the CCD surface. The phosphor tends to degrade uniformity, cosmetic quality and to some extent Modulation Transfer Function (MTF). These coatings also tend to suffer photodecomposition and degrade over time from bright UV exposure.

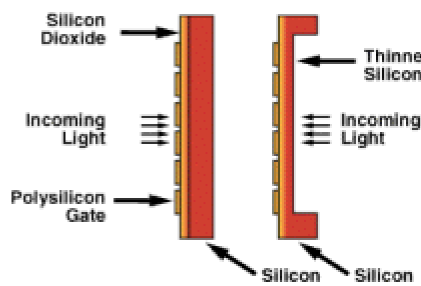


When using phosphor coating, parameters such as conversion efficiency, decay time, absorption and emission peak, particle size, and photo-stability must be taken into consideration to ensure that the application is both effective in light conversion and CCD operation. A high conversion efficiency is required because phosphor emission is isotropic and about 50% of the emitted radiation is immediately lost. The decay time must be short if the coating is to be used with high-speed sensors. Smearing of the image occurs if the phosphor continues to emit light after the signal charge is shifted out of the sensing area. As a result, the decay time must be shorter than the integration time.

Anti-Reflective (AR) coatings can be used to reduce reflection losses at surfaces and in very thin layers, thereby increasing quantum efficiency. Silicon coating has a high refractive index and this normally produces large reflection losses of up to 30% or more, resulting in lower QE. These coatings can be "tuned" or optimized (tailored by adjusting the thickness of the coating) for certain wavelength and can be applied to the glass or fused silica lenses or windows to reduce reflection losses. The AR coating contributes to the sensor’s surface undulation (topography), is susceptible to water, and will degrade over time.

BACKSIDE THINNED/ILLUMINATED

Light normally enters the CCD through gates on the parallel register (front-illuminated CCD). These gates are made of very thin polysilicon, which is reasonably transparent at long wavelengths, but becomes opaque at wavelengths shorter than 400nm. Thus, at short wavelengths, the gate structure attenuates incoming light. It is possible, using acid-etching techniques, to uniformly thin a CCD to a thickness of approximately 10μm and focus an image on the backside of the CCD register where there is no gate structure (back-illuminated CCD). To further improve the sensitivity in the ultraviolet wavelengths, the CCD can be coated with an antireflective chemical such as phosphor. This results in larger signals and therefore, improved signal-to-noise performance. In low-light applications, this feature can be used to generate superior-quality data and / or to increase frame rates.



Backside thinning technology provides for a very high fill factor, close to 100%. Major disadvantages to this process are increased Photo Response Non-Uniformity (PRNU) and crosstalk. The difficulty in thinning the device to such depths normally leads to lower yields and higher costs. Also, the handling of the CCD becomes extremely difficult.

OPEN PINNED PHASE

Open Pinned Phase (OPP) architecture is another technology that presents significant challenges. It is a method of fabricating a two-phase CCD with an N-type region between two electrodes on a P-type substrate.

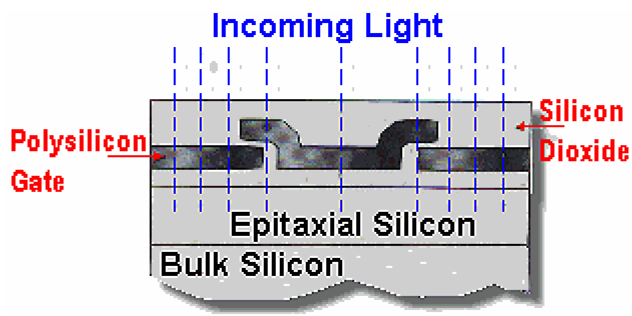
The first attempt to produce a front-illuminated CCD with a thin electrode structure was the *virtual phase technology*. In this case, two of the electrode phases were removed, and the potential well in that area defined by a surface implant. Charge transfer was effected by pulsing the voltages on the remaining electrode alternately above and below the potential necessary to form the same surface potential as in the implanted phase. The implant was made symmetric to ensure uni-directional charge transfer.

OPP technology uses the implanted structure concept of the virtual phase device, but requires a less complex implant because only one out of three electrodes is replaced with an implant.

The layout requirements are much simpler for this approach, but performance is not expected to be as good as the ILT in TDI structure. The OPP structure may have hold promise for designs without the metal mask for different customers requiring high UV sensitivity in a TDI sensor. The OPP provides 100% full factor.

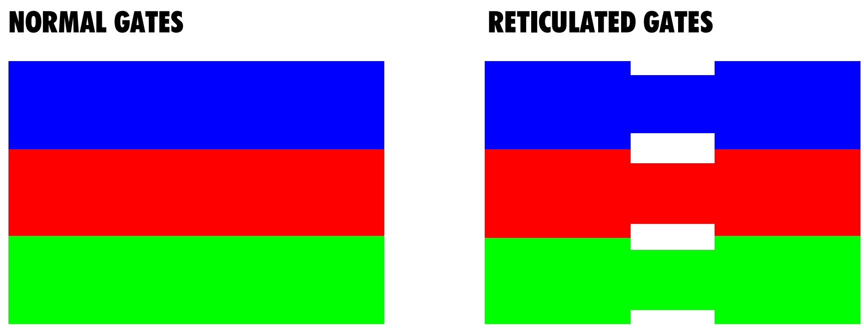
INDIUM TIN OXIDE

A new gate structure based on Indium Tin Oxide (ITO) was recently developed to boost the sensitivity of front-side illuminated CCDs. ITO is a transparent conductive coating that is used as the gate material for the CCD. These gates are more transparent to light than the regular polysilicon gates. The ITO gates provide higher light throughput into the photoconversion layer of the CCD. The resultant imaging devices have higher QE levels than those attainable with conventional front-side illuminated CCDs. This technology allows approximately two and a half times more blue light to reach the CCD, improving color accuracy and reducing image noise (increased dynamic range). The main disadvantage to this technology is the less than 100% fill factor.



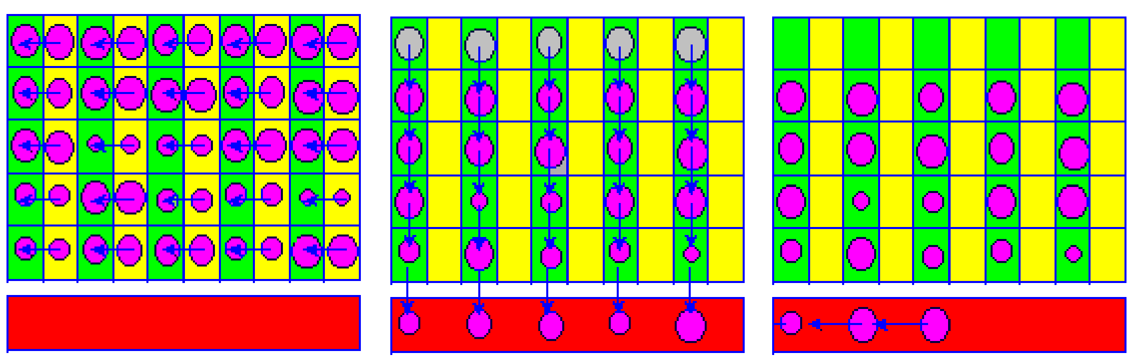
RETICULATION

"Reticulation" is a term that describes a CCD design architecture whereby windows are formed in the polysilicon gates to allow for an enhanced blue response. This design approach is only used in front-side illuminated CCDs. Fill factor is usually less than 100%. This design compromises spatial resolution and modulation transfer function (resulting in less than expected).



INTERLINE

The Interline CCD is a hybrid sensor with photosensitive diodes on one part of the pixel, which are electrically coupled to a CCD type storage region residing under a mask structure. The masks are long structures running along the vertical axis of the CCD alternating with the open regions, hence the name interline CCD. The diode portion of the pixel has very good QE properties, but the diode only takes up approximately 25% of the pixel area (25 % fill factor), thereby reducing the number of photons converted per unit area.



Summary

All of the discussed technologies (phosphor coating, backside thinned, open pinned phased, indium tin oxide, reticulation, and interline) are practical and feasible. However, the backside thinned / illuminated method outperforms the others in terms of quantum efficiency. In the final analysis, economics and availability may be the most important factors when considering a UV imaging CCD.

APPENDIX: ULTRAVIOLET SOURCES AND DANGER

ULTRAVIOLET SOURCES

To image in the UV spectrum, a UV source is required. Some sources are:

- High speed lamps (500-1000W)
- Low-pressure mercury steam fluorescent tubes
- Mercury steam high-pressure lamps
- Halogen metal steam high-pressure lamps
- Arc lamps (xenon high-pressure lamps)
- Photo-flash lamps
- Lasers

ULTRAVIOULET DANGER

- A UV light source emits strong, hazardous, and invisible UV-A, UV-B, and UV-C radiation. It also generates ozone, which is a strong oxidizer that is dangerous to the lungs in high concentrations. Ozone is heavier than air and accumulates along the floor. Floor level extraction vents can help to minimize this accumulation. Ozone concentrations as low as 0.1 ppm are dangerous to the lungs. Fortunately, ozone chemically transforms itself into oxygen in a very short time after the source is disabled, and radiation normally travels only a few meters through air before it is absorbed.
- Always use special UV designated gloves for skin protection.
- UV radiation can permanently damage the cornea, lens, and retina of the eye. And can even cause blindness. **Never** look directly into the output beam from a UV source. **Always** wear special UV eye protection.