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ADVANCED IMAGING

By Christopher Alexay, StingRay Optics

Working in the Infrared Bands

Matching optics to extended wavelengths can increase clarity, offer greater transmission and improve contrast

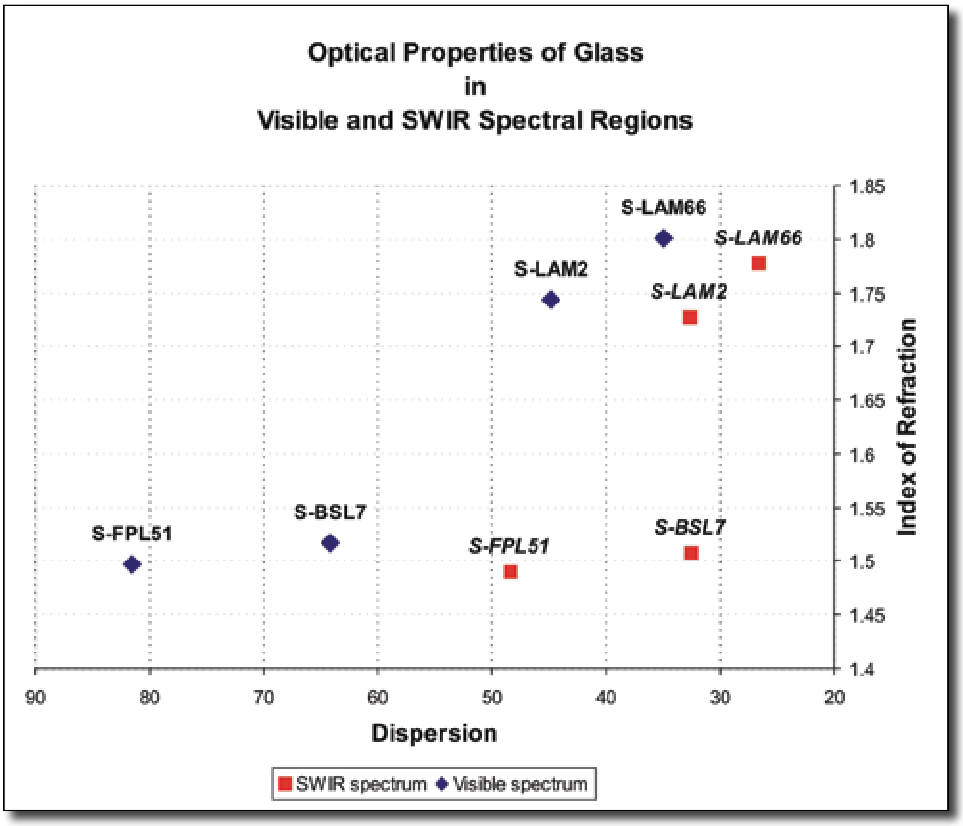

Figure 1: An optical designer will select suitable lens materials for a design based upon their locations on a chart like this one. (All images courtesy StingRay Optics)

- Optics
- Sensors
- Near infrared
- Visible near infrared
- Shortwave infrared

For the past several years sensor manufacturers in the photonics marketplace have met many technical challenges to yield new arrays, detectors and entire camera systems that expand our understanding of light and imaging. The latest technologies offer exciting advances that explore imaging using portions of the electromagnetic spectrum that go beyond the limits of human visual perception.

Newer detector technologies now offer the opportunity to produce images from light wavelengths that range from the visible region of the spectrum out to portions of the infrared. These wide spectral bands designated as shortwave infrared (SWIR), near infrared (NIR) and/or visible-near infrared (VNIR) will be the focus of our discussion on the important role optical design plays in achieving higher sensitivity and clearer imagery in these extended wavelengths.

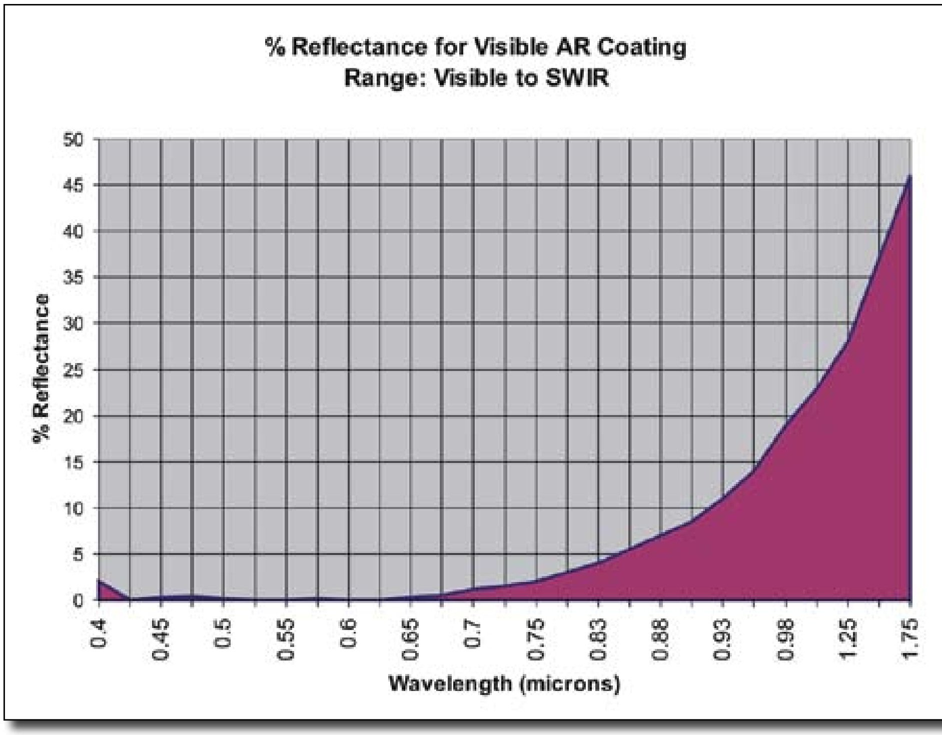

Figure 2: The anti-reflectance coating charted here is optimized to keep the reflectance of light between 425nm to 680nm below 1 percent per surface.

APPLICATION-SPECIFIC OPTICS

Work at StingRay Optics has been conducted with a variety of end users whose research involves these spectral ranges. The company has discovered a common grievance among end users regarding the image quality of some of the VNIR/NIR and SWIR imaging systems. The customer expects and requires a camera system to work in these extended wavelengths with optimal sensitivity and image clarity. However, many of these specialized camera systems are configured with optics or lenses that are not well-suited for rendering quality imaging in these spectral ranges.

Until very recently, integrators and, in some cases camera manufactures, have indicated that their VNIR/NIR/SWIR imaging products are capable of using the wide variety of lenses designed for use in visible photography or similar applications whereby the designed region of operation rarely extends beyond the visible wavelengths. These lenses offer an attractive option in that they are abundant, off-the-shelf and available at low cost. Produced in high volumes, the lens cost is only a small fraction of the camera package price, an appealing marketing feature, indeed.

However, the shortcomings in these inexpensive and often inadequate lenses for the VNIR/NIR/SWIR wavelengths, and the subsequent frustration voiced from customers, has prompted StingRay to develop alternative solutions—namely lenses that optimize performance at these wavelengths with enhanced resolution and sensitivity.

LENSES FOR VISIBLE VS. LENSES FOR INFRARED

A photographic, mass-produced lens assembly is typically comprised of multiple lens elements, specifically blended for their complementary optical properties. An easy way to understand the role of an optical design in a familiar arena is to compare the design to a cooking recipe. To ensure that the dish is prepared favorably, the cook combines specific amounts of certain complementary ingredients to produce the desired flavor. For most recipes, there is a window of give and take, so when the dish has a pinch too much of this or a little less of that, the desired result still is acceptable. The end result will be flavorful but not necessarily the level of perfection that the recipe intended. Following this same analogy, consider the case where the recipe calls for one cup of sugar and the chef instead substitutes one-quarter that amount. At the same time, the single cup of flour is supplanted by six cups. Even a novice chef quickly can appreciate that this dish will likely be unpalatable.

The aforementioned exercise is intended

to emulate a critical stage in the design of achromatic or "spectrally corrected" optics. Keeping the recipe analogy in mind we can envision an optical designer selecting various lens materials for a design based upon their ability to both direct and disperse light. These two critical aspects of an optical material will dictate the precision with which light of a particular range of wavelengths is shaped to form a clear image. When properly mated, two or more dissimilar materials can achieve impressive results. Conversely, when improperly employed they can all but degrade a system to the point of uselessness.

To better understand this principle, Figure 1 indicates the strength and dispersive nature of four common optical glasses in both the visible (blue) and the shortwave infrared or SWIR (red) portions of the electromagnetic spectrum.

An optical designer will select suitable lens materials for a design based upon their locations on this type of chart. The designer then will optimize the "recipe" based on the properties of these chosen materials to produce a design carefully tuned for the specific application and some bounded portion of the spectrum.

If the behaviors of these optical materials or ingredients were to change or shift from their previous location, the design would, as with the error-filled recipe above, no longer behave properly. In the case of visible optics employed over SWIR wavelengths, these changes can be considerable and as a result, produce images with disappointing contrast and clarity.

Figure 3: This image and that in Figure 4 were taken in series in series. Figure 3 was taken with a visible lens and Figure 4 with a specialized SWIR lens.

Figure 4: The same image as Figure 3, but taken with a specialized SWIR lens.

TRANSMISSION AND LENS EFFICIENCY

A further limitation of many of the most common commercial lenses designed for visible imaging is that they utilize anti-reflection (AR) optical coatings intended to enhance visible light transmission by controlling the reflectivity of a given surface. In so doing, these coatings prevent reflected light in the lens from becoming unwanted misdirected or scattered light. Scattered light in an optical design leads to a proportional loss in contrast of the image, which is an undesired characteristic in any lens where image quality is of importance.

An optical coating that is capable of reducing the reflectance over a particular band of energy will, at the same time, increase the amount of light outside the band (in this case wavelengths other than visible) that is reflected by the optics. Therefore when light falls past the range for which a coating is designed, it will by nature inhibit, scatter or totally block the transmission of this unwanted light to the detector, rather than utilize and enhance it.

The anti-reflectance coating shown in Figure 2 demonstrates one that is optimized to keep the reflectance of light between 425nm to 680nm below 1 percent per surface and, in fact, does so quite well.

Unfortunately, beyond this point the amount of light per surface that is reflected continues to increase. The actual transmission in the shortwave infrared is calculated by doubling this reflected contribution for each and every element with this coating. Therefore a lens comprised of three elements with a coating of similar properties as those seen in Figure 2 would have an average transmission in the visible portion of the spectrum of approximately 94 percent whereas this same lens could see as little as 30 percent transmission over the SWIR portion of the spectrum.

ENHANCED SWIR IMAGERY WITH SPECIALIZED OPTICS

Noting the limitations of visible optics when pressed into SWIR service, the images of the wolf in Figures 3 and 4 illustrate the total impact. When comparing images produced by both a standard, high-quality visible-imaging lens with one specifically designed for SWIR band imaging, the difference is striking. These two images (Figure 3 with a visible lens, Figure 4 with a specialized SWIR lens) when observed in series demonstrate both the image clarity as well as the transmission issues described above.

> **"When comparing images produced by both a standard, high-quality visible-imaging lens with one specifically designed for SWIR band imaging, the difference is striking."**

VNIR/NIR/SWIR imaging has progressed a great distance in recent years. The technology is entering a frontier in optical science where unique wavelengths are being employed to improve and enhance a wide variety of medical, industrial and military applications. Optimized imaging systems are enabling scientific breakthroughs in medical instrumentation that are improving and saving lives. In machine vision, process control, security, homeland defense and many more, advances in these regions of imaging are helping to protect us all from harm.

To do so however, one needs to understand that a critical factor in the exotic imaging train is the lens. An optimized imaging system is only as strong as its weakest link and in the case of visible optics for SWIR imaging; the weak link may just be the lens. Properly designed optics that operate in specific wavelengths can increase clarity, offer greater transmission and improve contrast in the imagery, thereby opening doors to new possibilities in imaging for the near-infrared and the SWIR portions of the electromagnetic spectrum. ***AI***

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