In Greek mythology, the hunter Narcissus was renowned for his beauty, and exceptionally proud of it: He displaced all who loved him. When Nemesis saw this, he attracted Narcissus to a pool where he saw his own reflection in the waters and, not realizing it was merely an image, fell in love with it. Every time he tried to drink water from the pool, the image vanished; unable to leave the beauty of his reflection, Narcissus died of thirst.

In IR cameras, the effect of a detector’s reflection on the detector itself is named after Narcissus. This reflection usually is related to the front surface of the lens assembly and is enhanced if the detector is cooled. In a fixed-focal-length assembly, the surface can be designed to eliminate this effect, but in a zoom-lens assembly, the effect is hard to eliminate.

Figure 1 shows the ray tracing of a zoom assembly in medium field of view (MFOV) compared with the assembly in wide field of view (WFOV) shown in Figure 2. In the first case, the aperture used is wide, and there is a small percentage of rays that are normal to the front surface. In the WFOV case, the aperture is much smaller and the number of rays that are normal to the surface is much greater.

The magnitude of the effect is directly influenced by the reflectance of the antireflection (AR) coating of the front lens. The front lens usually has to withstand the harsh environmental requirements of an external part. The most suitable coating is a hard carbon (HC) or diamondlike carbon (DLC) coating.

DLC coatings

The standard DLC coating is a single layer of carbon atoms with a mixture of \( \text{SP}^3 \) (diamond) and \( \text{SP}^2 \) (graphite) bonds. The \( \text{SP}^3 \) bonds are extremely hard, and the \( \text{SP}^2 \) bonds are soft. The combination of these bonds results in an extremely durable layer that adheres well to Si and Ge substrates. The index of refraction is about 1.9, which is a good optical match to these high-index substrates.

Reflection and transmittance graphs in the 3- to 5-\( \mu \)m region are shown in Figures 3 and 4. This coating has excellent durability, but the average reflection of 3.2 to 3.4 percent at the 3- to 5-\( \mu \)m region is too high, resulting in a noticeable Narcissus effect.

There are many ways to produce DLC coatings. In chemical vapor deposition (CVD), a chamber contains two electrodes, one connected to a radio frequency voltage source and the other grounded. When argon is introduced, plasma forms as a result of the high voltage. When a carbon-rich gas such as methane, butane or acetylene is introduced, the plasma process decomposes the gas and accelerates the carbon atoms toward the substrate, where the DLC layer is formed (see Figure 5). This is different from the standard...
physical vapor deposition (PVD) process of evaporation by direct heating.

A new type of coating – low-reflection hard carbon (LRHC) – from Ophir Optronics Ltd. is a multilayer coating with a DLC overcoat layer designed to have a low reflection. The design considerations were (see Figure 6):

1. A dielectric layer with either a Si or Ge top layer would be coated in a PVD coating chamber.

2. The DLC layer would be added in a plasma-enhanced CVD chamber.

3. The DLC layer thickness had to be minimized to reduce internal absorption but to maintain a minimal thickness to achieve the required durability.

Experimental results

For the 3- to 5-µm region, the preferred substrate for an external lens is usually Si, mainly because of its hardness and low price. With an LRHC coating on Si, shown in Figure 7, the average reflectance achieved in the 3.5- to 5-µm region was 0.26 percent. The average transmittance achieved was 98.5 percent, shown in Figure 8.

For the 8- to 12-µm region, several coatings on Ge, ZnS and ZnSe substrates were designed with an HC top layer to withstand severe durability requirements. The theorized performance of similar designs on these substrates is shown in Figure 9.

Experimental results for a Ge substrate are shown in Figures 10 and 11. The average reflectance in the 8- to 11.5-µm range was 0.62 percent, with average transmittance of 94 percent in the same region.

Reduction of Narcissus effect

Several AR coatings were applied on the front Si lens of a 15- to 300-mm zoom assembly.

A lens with a single-layer DLC and a typical average reflectance of 4.8 percent in the 3- to 5-µm region was compared with an LRHC coating with a typical average reflectance of 0.5 percent, both in the WFOV state.

In the first case, the effect was noticeable, while in the second case, the effect was not seen (see Figures 12 and 13).

The above designs show that a multilayer coating with a DLC top layer has
Diamondlike Coatings

Figure 12. Lens assembly with a single-layer HC front lens in wide field of view. The central circle and one ring are noise from the Narcissus effect.

Figure 13. Lens assembly with an LRHC coating having an average reflectance of 0.5 percent, with the same field of view as in Figure 10. The Narcissus effect is eliminated.

good potential for external surfaces. Several designs were demonstrated for a Si substrate in the spectral region of 3 to 5 µm and for a Ge substrate in the 8- to 11.5-µm spectral range.

Other designs show that this concept can be applied to ZnSe and ZnS substrates.

All the coatings passed the durability tests required of a DLC coating (humidity, severe abrasion, salt immersion, salt vapor and acid corrosivity), including the 5000 revolutions wiper sand test. They can be applied on lens assemblies for high external durability and low Narcissus effect.

Every system designer knows that in AR coatings, there is always the trade-off between the best optical performance and the highest durability. These coatings can substitute the system front surface coatings, while ensuring the required low reflection. They also will provide the highest known coating durability and could be developed for more than one spectral region for a variety of applications.

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