FRESNEL SAPPHIRE PRISM SPECTROMETER FOR ENGINE EMISSIONS DIAGNOSTICS – PHASE I SUMMARY

Under an EPA Phase I SBIR contract, OPTRA designed, built, and tested a mid-IR (3 to 5.5 μm), low resolution ($\Delta\lambda$ = 20 nm) Fresnel sapphire prism spectrometer specifically tailored to onboard vehicle emissions measurements. While a stationary spectrometer is ideal for many field-ruggedized applications, the prism spectrometer has been traditionally overlooked because of its generally low throughput (i.e. poor sensitivity). The primary reason for this deficiency is a lack of availability of exotic optical materials with sufficient chromatic dispersion. As discussed in this report, the dispersiveness of this prism material translates directly into the required focal length of the optical system which ultimately dictates the practical f-number, and, thus, throughput. OPTRA has addressed this historical shortcoming by employing highly-dispersive sapphire as the prism material. Sapphire has never been used as a dispersive prism due to two factors: the birefringence and the difficulty with which it is machined. Through careful optical modeling, we have demonstrated that the effects of the birefringence actually become negligible (for our spectral resolution) when the crystal axis of the sapphire is adequately aligned with the optical axis of the spectrometer. We have successfully fabricated the prisms with this orientation and verified the effects.

The second key innovation to this spectrometer system is the realization of a Fresnel prism. In the tradition of the well-known Fresnel lens, we have collapsed the angular surfaces of a large, full-bodied prism into linear zones which could be fabricated from a single thin plate. For the Phase I feasibility demonstration, we fabricated eight individual prisms with a roughly 0.25" base and 1.875" in length. We stacked the prisms in a mount and actively aligned them using a polarized helium neon laser. The Fresnel configuration allows for a significantly more compact package in comparison to a full-bodied prism and also eliminates a substantial amount of the bulk absorption, allowing for sensitivity into the longer wavelength regions near 5.5 μm.

The final key innovation is the use of an uncooled microbolometer focal plane array (FPA) as the detector. These infrared imagers have recently gained wide commercial interest for thermal vision systems in non-military, consumer applications such as options for passenger cars along with widespread use by public safety personnel for search and rescue and fire fighting. In our system, we coadded pixels in the non dispersive spatial dimension to increase the sensitivity. To the best of our knowledge, this is the first use of the uncooled microbolometer in a prism spectrometer. Typically, most prism spectrometer either employ a scanning detector or a more traditional IR linear array such as indium antimonide (InSb) or a more common pyroelectric or other thermal detector.

Fresnel Sapphire Prism Prototype