Acousto-optic (AO) devices are electronically controlled RF-driven devices related either to optical processing, or spectroscopy, including spectral imaging. These devices have been used throughout the visible and infrared regions. Optical processing is almost exclusively done in the visible, where an AO material such as TeO₂ exists, whereas spectroscopy must often be done in the mid- and far-infrared due to the vibrational spectra of molecules. The performance of these filters depends on the diffraction figure of merit of acousto-optical materials. Northrop Grumman has been developing materials, designs, and a fabrication process for near-IR, mid-IR and LWIR wavelength regions.

AOTFs (acousto-optic tunable filters) are excellent sensors for passive detection of military objects of interest, such as chemical warfare agents and/or military vehicles in high clutter. The advantages of AOTF imagers include ruggedness (all solid state), versatility (computer controlled), covertness (passive operation), adaptability (variable bandwidths and capability of taking spectral derivatives), agility (quickly and randomly tuned to any wavelength), selectivity (accurately tunable to any spectral characteristic of the target), efficiency (high optical throughput), and easy interpretation (entire images). One of the most unique features of an AOTF is the capability to simultaneously select several spectral bands and to vary the spectral resolution of the instrument. This feature greatly enhances its capability for target recognition in the usual case that objects and backgrounds have complex spectral signatures where one spectral band is not adequate for accurate identification.

The implementation of a low cost, compact hyperspectral imaging system has won the 2010 ASM Engineering Materials Achievement Award for Northrop Grumman Corp. The implementation of a low cost, compact hyperspectral imaging system is enabled by new LWIR AOTF thallium arsenic selenide Tl₃AsSe₃ (TAS) crystals for operation to 18 mm. TAS was identified in Northrop Grumman’s lab as a unique material having outstanding acousto-optic properties. It is an excellent choice for AOTFs because it has a large transparency range (1.5 to 18 mm), a high AOTF figure of merit (2,800 times better than quartz) needed for high efficiency, and is easily designed to have the near optimum resolution (2 to 8 cm⁻¹) for high selectivity.

The materials technology, fabrication, and implementation for the hyperspectral imaging applications are crucial components of the technology. The development work

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**Fig. 1 — Schematic of a system that uses angular beam separation with the AOTF located in front of a camera (a) and acoustic field propagation at 21.9 degrees (b).**
involved sound knowledge of chemistry of materials, thermodynamics, fluid flow, X-ray analysis, spectroscopy, and excellent crystal growth and fabrication skills. For these reasons, the investigators were granted many patents and several trade secrets on this subject.

The devices based on TAS enable:
- Long wavelength large aperture imaging
- Simultaneous, multiple wavelength filtering for spectrally complex filtering
- Complex polarimetric signature analysis
- Rapid filter response times

Successful development and implementation of TAS in devices enhanced the abilities of a wide range of electro-optical systems that will address needs in target detection/discrimination, chem-bio, explosive and aerosol detection, foliage penetration, explosive atmospheric, and farm monitoring from ground airborne and high altitude platforms.

A TAS AOTF with 10.6 degree crystal orientation and 8 cm⁻¹ resolution was fabricated by using a Bridgman grown single crystal (40 mm diameter). The AOTF was mated to a microbolometer for thermal and SF6 imaging. This is the first reported use of imaging with a microbolometer camera and an AOTF. The passband at 8 cm⁻¹ is as wide as possible for many applications including identification of other chemical species. The efficiency of the TAS AOTF improved with crystal quality and fabrication process. It can be easily improved to more than 50% by increasing the aperture size and further refinement of growth and fabrication parameters.

The AOTF design for the current system is based on Tl₃AsSe₃ (TAS), which has the properties of transmission throughout the 8 to 12 mm LWIR region, high acousto-optic efficiency, and high index of refraction. The angular orientations of the crystal axes and acoustic field directly follow from design equations once the incidence design angle is decided. This is due to operating under the parallel tangents condition for AOTFs, which produces the largest field of view for a given resolution. This field-of-view is designated as Δθ in Fig. 1a. It is clear from Fig. 1b that for the 21.9° design, the acoustic field propagates at −78.40° to the crystal c-axis, and the acoustic phase propagation direction is perpendicular to the transducer surface, which then defines the preferred crystal growth direction as 10.6° to the c-axis. This optimizes the possible device size and simplifies the fabrication process. Note that the angle between the transducer plane and the optic axis is not identical to Δθ, the angle between the input optical beam direction and the optic axis. In addition, the power flow, or acoustic ray direction is not necessarily parallel to the phase propagation direction due to the nonisotropic nature of the acoustic velocity in TAS.

**Crystal Growth and Fabrication of AOTF**

The crystal growth of TAS involved purification of parent components, synthesis, directional freezing of the charge material and crystal growth by the Bridgman method. The crystal was accurately (±0.1 degree) oriented to locate the c-axis.

To achieve the high purity crystal after the synthesis, the charge was directionally solidified at the speed of 2.5 cm/day and at a temperature gradient higher than 40 K/cm to further consolidate and purify it. The directionally solidified charge was used for growing the crystal. The first and last part of the charge to freeze were rejected and not used for crystal growth. The TAS crystals are grown from the directionally solidified charge in a sealed quartz tube using the Bridgman technique. Figure 2 shows an as-grown TAS crystal, and Fig. 3 shows different stages of TAS fabrication into an AOTF. To ensure achieving the correct transducer thickness, the resonant frequency was checked several times during the grinding process. Figure 4 shows the AOTF in its RF mount.

![As-grown TAS crystal](image1)

![Different stages of TAS fabrication into an AOTF](image2)
For assembling the imager and testing, the AOTF was housed in an aluminum box fabricated to match the dimensions of the AOTF. It is mounted on a rail through a series of aluminum plates that allow sliding movements to center the AOTF on the optical center-line. Acoustic power is fed to the AOTF through a BNC connector in the top of the housing, and the center terminal of the BNC is connected directly to the transducer using silver paint. The larger face of the AOTF is the input aperture, and the diffracted beam propagates straight through the AOTF without bending.

The test setup consisted of an LWIR camera (microbolometer), the AOTF, and a blackbody radiative source (hot filament). The filament was placed ~50 cm in front of the AOTF. The camera was aligned to the first order diffracted beam of the AOTF, and the AOTF was tuned to the 10.6 mm wavelength by applying a 13.9 MHz RF signal on the transducer. The test setup is shown in Fig. 5. The ability to image room temperature SF₆ gas (in ppm range) was carried out with a gas-filled cell. Figure 6a shows the image of the first order diffracted beam of the CO₂ laser with no SF₆ present and Fig. 6b shows the diffracted beam being blocked by the gas cell filled with SF₆ showing the absorption at 10.6 μm. Similar images were taken for hot filaments and other objects. The performance of the current imager was better than previous imagers and indicated a sensitivity improvement due to improvements in efficiency of the AOTF.

Reference


Fig. 4 — As-fabricated TAS AOTF.

Fig. 5 — TAS AOTF based imager used in planar configuration; LWIR camera to the left, and AOTF in the center

Fig. 6 — Imaging of SF₆ gas: (a) image of the CO₂ laser beam with no SF₆ present (first order diffracted signal of the beam), and (b) image of laser beam blocked by a cell filled with SF₆, showing the absorption at 10.6 μm.