Snapshot polarimetry enables new signature opportunities for remote sensing

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Polarization information can help classify materials and identify objects of interest for remote sensing and military applications.

Polarimetric imaging measures the polarization states of light from all points of the scene. There is interest in capturing and storing polarization images in the infrared, similar to the way intensity information is gathered using a pixelated focal plane array (FPA). The polarization information can help classify materials and identify objects of interest for remote sensing and military applications.

Multiple images of a static scene are taken with a combination of oriented polarizers and waveplates in the optical path. Differences between image-pairs quantify the distribution of (for example) right circularly-polarized light in the scene. A configuration that describes the linear polarization content of a scene only yields three of the four Stokes parameters. One that produces the complete Stokes vector requires a birefringent waveplate in addition to oriented polarizers. Several techniques apply, including the use of rotating polarizers\(^1,^2\) or waveplates,\(^3\) or a snapshot\(^4,^5\) that records data for three or four Stokes parameters in a single frame. Traditionally, sequential polarimetric imaging sensors, like the first and second methods, produce scenes with polarization information through a series of assembled images. Snapshot polarimetric imaging, see Figure 1, collects the spatial distribution of all four Stokes parameters simultaneously. In this way, any noise due to scene movement from one frame to the next is eliminated.

Since almost all the photodetectors available now are polarization insensitive, a combination of polarizing elements and photodetectors is needed to measure the polarization content of light. To obtain the complete Stokes vector, four independent measurements are desirable. These four pixels are collectively termed the ‘super pixel’. If the scene is divided into \(N\) pixels, \(4 \times N\) measurements are needed to obtain the complete polarimetric image. Thus, snapshot polarimetry becomes practical for FPAs with 20 micron pixels and pixel counts of 1024 x 1024.

At Sandia National Laboratories, we use our nano-fabrication facility to engineer material parameters on the subwavelength scale that can directly manipulate the optical fields. The principle behind linear micropolarizers for long wavelengths is based upon the strong anisotropic absorption of light in a subwavelength, metallic grid structure. The grid structures are patterned with different orientations, defining the micropolarizers’ polarization axes. Incident light polarized perpendicularly to the grid lines (transverse magnetic, TM) is transmitted efficiently, while transverse electric (TE) light is primarily absorbed and reflected.

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The extinction ratio, \( \frac{TM_{TRANSMITTED}}{TE_{TRANSMITTED}} \), quantifies performance, see Figure 2.

The extinction ratio of a polarizer degrades as the component aperture decreases toward wavelength dimensions. Even so, Figure 3 illustrates that single pixelated micropolarizers have measured extinction ratios larger than 100:1 for pixel sizes as small as 9 microns. That exceeds, by 7 times, previously reported measured extinction ratios for large area, 1cm apertures.\(^6,7\) Equally important, the transmitted signal in Figure 3 remains above 50%.

![Figure 2](image_url)  
**Figure 2.** Subwavelength, metallic grid structure for micropolarizers and corresponding extinction ratio. TM: transverse magnetic. TE: transverse electric.

![Figure 3](image_url)  
**Figure 3.** Measured extinction ratio of single, finite aperture micropolarizers at 3.39 microns wavelength with inset of a 4.8 micron pixel polarizer.

Most recently,\(^5,9\) we have been quantifying near-field and diffractive effects of the finite component apertures upon detection. We put together an experimental setup that isolates a pixel within an FPA and measures crosstalk from adjacent micropolarizers within the super pixel. This configuration models a snapshot polarization imaging device where the two substrates are stacked within the micropolarizer array substrate on top of an FPA. Crosstalk between adjacent pixels increases uncertainty in the measured polarization states in a scene of interest. Measured and simulated data indicate significant crosstalk between neighboring pixels within only a few microns of propagation after the polarizer plane. Figure 4 shows the measured irradiance pattern transmitted through an array of micropolarizer super pixels as the propagation distance is increased. Note the substantial change in the imaged pattern, and the corresponding drop in extinction ratio with the introduction of adjacent super pixels, resulting from increased propagation distance. These effects on extinction ratio are a real concern as typical glue separation can be ten microns.

Because of these findings, both simulated and measured, we are now recommending changes in the array assembly for separation between the FPA, micropolarizer array, and birefringent waveplate array, originally on the order of hundreds of microns (substrate thicknesses) to a few microns or less. This new requirement is leading us to investigate new approaches to fabricate an advanced, integrated FPA.

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Dr. Shanalyn Kemme designs, models, and coordinates fabrication of micro-optics and diffractive optics at Sandia National Laboratories. Her projects include diffractive optics for polarimetry and remote sensing, subwavelength structures for field parameter manipulation, resonant subwavelength grating arrays for narrowband mode selection, and optical modeling and measurement for micro electro-mechanical systems (MEMS).

References