A set of methods was developed for implementing an InGaAs photocathode whereby the dark current can be reduced by lowering the temperature to the ultralow target level, while at the same time, exhibiting QE that is high enough to perform the astrophysical measurements.

This innovation features a thin, n-type InP cap layer that is etched during final cleaning between the grid lines. Along with an n-type InP layer at the heterointerface and a p-type InP emitting surface layer, the extra degree-of-freedom provided by the n-type InP cap layer enables independent tailoring of the electric field at 3 key locations in the device: beneath the grid lines, at the emitting InP surface between grid lines, and at the p-type InGaAs absorber/n-type InP heterointerface. This enables minimization of the field beneath the grid lines while the emitting surface and heterointerface fields are balanced such that the onset of high escape probability and turn-on completion of the heterointerface occur at the same reduced device bias. The resulting effect is that dark current components are minimized, including those due to undue extension of the depletion region into the low bandgap absorber and premature emitting surface field development with bias, while maintaining high QE and minimal grid line leakage.

The innovation features an InP:Zn emitting surface layer doped below the onset of Zn diffusion (thus minimizing epitaxy and process variability), absence of an undoped InP drift layer (along with the avalanche-current-inducing voltage drop across it), and an InGaAsP step grade layer introduced at the InGaAs absorber/InP:Si layer heterointerface (further reducing dark current components associated with the depleted low bandgap absorber). Employment of a SiON dielectric beneath the grid line promotes device stability and the absence of fixed mobile charge in the metal/dielectric/InP stack.

This work was done by Michael Jurkovic of Intevac Photonics for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16044-1

Integrated Optics Achromatic Nuller for Stellar Interferometry

Nuller allows faint off-axis light to be much more easily seen.

NASA's Jet Propulsion Laboratory, Pasadena, California

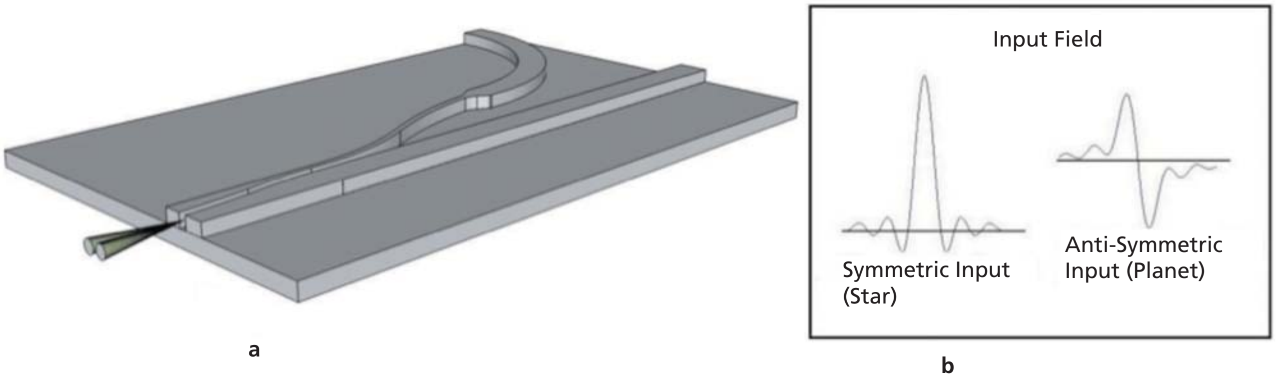
This innovation will replace a beam combiner, a phase shifter, and a mode conditioner, thus simplifying the system design and alignment, and saving weight and space in future missions. This nuller is a dielectric-waveguide-based, four-port asymmetric coupler. Its nulling performance is based on the mode-sorting property of adiabatic asymmetric couplers that are intrinsically achromatic. This nuller has been designed, and its performance modeled, in the 6.5-micrometer to 9.25-micrometer spectral interval (36% bandwidth). The calculated suppression of starlight for this 15-cm-long device is 10^{-5} or better through the whole bandwidth. This is enough to satisfy requirements of a flagship exoplanet-characterization mission.

Nulling interferometry is an approach to starlight suppression that will allow the detection and spectral characterization of Earth-like exoplanets. Nulling interferometers separate the light originating from a dim planet from the bright starlight by placing the star at the bottom of a deep, destructive interference fringe, where the starlight is effectively cancelled, or nulled, thus allowing the faint off-axis light to be much more easily seen. This process is referred to as nulling of the starlight.

Achromatic nulling technology is a critical component that provides the starlight suppression in interferometer-based observatories. Previously considered space-based interferometers are aimed at approximately 6-to-20-micrometer spectral range. While containing the spectral features of many gases that are considered to be signatures of life, it also offers better planet-to-star brightness ratio than shorter wavelengths.

In the Integrated Optics Achromatic Nuller (IOAN) device, the two beams from the interferometer's collecting telescopes pass through the same focusing optic and are incident on the input of the nuller.

The dual-input waveguide structure accommodates two modes, while each of



A 3-dimensional view of the **Integrated Optics Achromatic Nuller** device. (a) The scales are distorted for visual clarity. The input from the two telescopes is incident on the device from the left. (b) The input field for the case of the two telescope beams arriving in-phase (starlight) and exactly out-of-phase (planet light).

the output waveguides accommodates one mode only. At the input, the waveguide structure is symmetric and, therefore, the fundamental mode of the structure at the input is symmetric and the other mode is anti-symmetric. At the output, one of the waveguides is wider than the other, and therefore has a higher effective refractive index. For the light originating from the star, if the interferometer is perfectly balanced, the input field in the focal plane of the focusing optic at the input of the device is symmetric, while for the light field originating from the planet (assuming the exact π phase shift) it is anti-symmetric. Thus, in the two-mode input waveguide the starlight excites the fundamental mode, while the planet light excites the second, anti-symmetric, mode.

This work was done by Alexander Ksendzov of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47834

High-Speed Digital Interferometry

Optical decoding eliminates the need for high-speed detectors and digital signal processing.

NASA's Jet Propulsion Laboratory, Pasadena, California

Digitally enhanced heterodyne interferometry (DI) is a laser metrology technique employing pseudo-random noise (PRN) codes phase-modulated onto an optical carrier. Combined with heterodyne interferometry, the PRN code is used to select individual signals, returning the inherent interferometric sensitivity determined by the optical wavelength. The signal isolation arises from the autocorrelation properties of the PRN code, enabling both rejection of spurious signals (e.g., from scattered light) and multiplexing capability using a single metrology system. The minimum separation of optical components is determined by the wavelength of the PRN code.

A variation of DI has 100 times reduction in the minimum component separation, allowing measurements of optical components only a few centimeters apart. Instead of the usual electronic decoding, the DI signal is interfered with an appropriately delayed, identically PRN-encoded, local oscillator beam. Optical decoding allows the use of a low-bandwidth signal processing chain with GHz codes, negating the need for high-speed detectors and digital signal processing. This reduced bandwidth also reduces the power consumption of the entire system.

The heterodyne signal is created by off-set phase-locking two lasers with a digital phase-locked loop. The error-point is monitored on a dedicated phase-locking photoreceiver. PRN codes are phase-modulated by waveguide modulators onto each laser beam. These are subsequently interfered via a fiber beamsplitter, thus optically demodulating the laser signals, before being detected on a signal photoreceiver. One PRN code is digitally delayed with respect to the other in order to align the codes with respect to the reflected light from an optic under interrogation, thus optically demodulating the signal for that specific mirror. The delay is altered (controlled digitally) to pick out any one of the optics under interrogation.

At the time of this reporting, this is the first known time that DI has been employed to measure optics separated by less than meters, down to a few centimeters. This was achieved by implementing, for the first time, optical demodulation of the encoded laser beams (as opposed to the more traditional/common electronic demodulation). This technique is entirely implemented in software via hardware that would already exist onboard a spacecraft. This reduces complexity, power consumption, volume, and risk of failure.

There are many proposed missions that will employ lasers and require extremely high-resolution metrology. Digital interferometry can be implemented and achieve sub-10-pm resolution. With this new technique, the metrology can be performed on optical components separated by centimeters. This allows measurements of optics on a single optical bench within a single spacecraft, in addition to inter-spacecraft metrology measurements.

This work was done by Glenn De Vine, Daniel A. Shaddock, Brent Ware, Robert E. Spero, Danielle M. Wuchenich, William M. Klipstein, and Kirk McKenzie of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47886

Ultra-Miniature Lidar Scanner for Launch Range Data Collection

New scanning technology promises at least a 10× performance improvement.

John F. Kennedy Space Center, Florida

The most critical component in lidar is its laser scanner, which delivers pulsed or CW laser to target with desirable field of view (FOV). Most existing lidars use a rotating or oscillating mirror for scanning, resulting in several drawbacks.

A lidar scanning technology was developed that could achieve very high scanning speed, with an ultra-miniature size and much lighter weight. This technology promises at least a 10× performance improvement in these areas over existing lidar scanners. Features of the proposed ultra-miniature lidar scanner include the ability to make the entire scanner <2 mm in diameter; very high scanning speed (e.g. 5–20 kHz, in contrast to several hundred Hz in existing scanners); structure design to meet stringent requirements on size, weight, power, and compactness for various applications; and the scanning speed and FOV can be altered for obtaining high image resolutions of targeted areas and for diversified uses.