

single-mode emission from InGaAsSb/AlInGaAsSb multi-quantum well structures. The device fabrication utilizes etched index-coupled gratings in the top AlGaAsSb cladding of the laser chip along the ridge waveguide, whereas commercial lasers that emit close to this wavelength include loss-coupled metal gratings that limit the output power of the laser.

Semiconductor-laser-based spectrometers can be used to replace gas sensors currently used in industry and govern-

ment. With the availability of high-power laser sources at mid-infrared wavelengths, sensors can target strong fundamental gas absorption lines to maximize instrument sensitivity.

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## Optical Device for Converting a Laser Beam Into Two Co-aligned but Oppositely Directed Beams

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Optical systems consisting of a series of optical elements require alignment from the input end to the output end. The optical elements can be mirrors, lenses, sources, detectors, or other devices. Complex optical systems are often difficult to align from end-to-end because the alignment beam must be inserted at one end in order for the beam to traverse the entire optical path to the other end. The ends of the optical train may not be easily accessible to the alignment beam.

Typically, when a series of optical elements is to be aligned, an alignment laser beam is inserted into the optical path with a pick-off mirror at one end of the series of elements. But it may be impossible to insert the beam at an end-

point. It can be difficult to locate the pick-off mirror at the desired position because there is not enough space, there is no mounting surface, or the location is occupied by a source, detector, or other component. Alternatively, the laser beam might be inserted at an intermediate location (not at an end-point) and sent, first in one direction and then the other, to the opposite ends of the optical system for alignment. However, in this case, alignment must be performed in two directions and extra effort is required to co-align the two beams to make them parallel and coincident, i.e., to follow the same path as an end-to-end beam.

An optical device has been developed that accepts a laser beam as input and produces two co-aligned, but counter-

propagating beams. In contrast to a conventional alignment laser placed at one end of the optical path, this invention can be placed at a convenient position within the optical train and aligned to send its two beams simultaneously along precisely opposite paths that, taken together, trace out exactly the same path as the conventional alignment laser. This invention allows the user the freedom to choose locations within the optical train for placement of the alignment beam. It is also self-aligned by design and requires almost no adjustment.

*This work was done by Donald Jennings of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16610-1*

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## A Hybrid Fiber/Solid-State Regenerative Amplifier with Tunable Pulse Widths for Satellite Laser Ranging

**Applications include materials processing, remote detection, and high-resolution 3D image mapping.**

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A fiber/solid-state hybrid seeded regenerative amplifier, capable of achieving high output energy with tunable pulse widths, has been developed for satellite laser ranging applications. The regenerative amplifier cavity uses a pair of Nd:YAG zigzag slabs oriented orthogonally to one another in order to make thermal lensing effects symmetrical and simplify optical correction schemes. The seed laser used is a fiber-coupled 1,064-nm narrowband

(<0.02 nm) diode laser that is discretely driven in a new short-pulsed mode, enabling continuously tunable seed pulse widths in the 0.2-to-0.4-ns range.

The amplifier gain unit consists of a pair of Brewster-cut 6-bounce zigzag Nd:YAG laser slabs, oriented 90° relative to each other in the amplifier head. This arrangement creates a net-symmetrical thermal lens effect (an opposing single-axis effect in each slab), and makes

thermo-optical corrections simple by optimizing the curvature of the nearest cavity mirror. Each slab is pumped by a single 120-W, pulsed 808-nm laser diode array. In this configuration, the average pump beam distribution in the slabs had a 1-D Gaussian shape, which matches the estimated cavity mode size. A half-wave plate between the slabs reduces losses from Fresnel reflections due to the orthogonal slabs' Brewster-cut end faces.

Successful “temporal” seeding of the regenerative amplifier cavity results in a cavity Q-switch pulse envelope segmenting into shorter pulses, each having the width of the input seed, and having a uniform temporal separation corresponding to the cavity round-trip time of  $\approx 10$  ns. The pulse energy is allowed to build on successive passes in the regenerative amplifier cavity until a maximum is reached, (when cavity gains and losses are equal), after which the pulse is electro-optically switched out on the next round trip.

The overall gain of the amplifier is  $\approx 82$  dB (or a factor of 1.26 million). After directing the amplified output through a LBO frequency doubling crys-

tal,  $\approx 2.1$  W of 532-nm output ( $>1$  mJ) was measured. This corresponds to a nonlinear conversion efficiency of  $>60\%$ . Furthermore, by pulse pumping this system, a single pulse per laser shot can be created for the SLR (satellite laser ranging) measurement, and this can be ejected into the instrument. This is operated at the precise frequency needed by the measurement, as opposed to commercial short-pulsed, mode-locked systems that need to operate in a continuous fashion, or CW (continuous wave), and create pulses at many MHz. Therefore, this design does not need to “throw away” or dump 99% of the laser energy to produce what is required; this system can be far smaller, more efficient,

cheaper, and readily deployed in the field when packaged efficiently.

Finally, by producing custom diode seed pulses electronically, two major advantages over commercial systems are realized: First, this pulse shape is customizable and not affected by the cavity length or gain of the amplifier cavity, and second, it can produce adjustable (selectable) pulse widths by simply adding multiple seed diodes and coupling each into commercial, low-cost fiber-optic combiners.

*This work was done by Barry Coyle of Goddard Space Flight Center and Demetrios Poullos of American University. Further information is contained in a TSP (see page 1). GSC-16550-1*

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## X-Ray Diffractive Optics

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X-ray optics were fabricated with the capability of imaging solar x-ray sources with better than 0.1 arcsecond angular resolution, over an order of magnitude finer than is currently possible.

Such images would provide a new window into the little-understood energy release and particle acceleration regions in solar flares. They constitute one of the most promising ways to probe these regions in the solar atmosphere with the sensitivity and angular resolution

needed to better understand the physical processes involved.

A circular slit structure with widths as fine as 0.85 micron etched in a silicon wafer 8 microns thick forms a phase zone plate version of a Fresnel lens capable of focusing  $\approx 6$  keV x-rays. The focal length of the 3-cm diameter lenses is 100 m, and the angular resolution capability is better than 0.1 arcsecond. Such phase zone plates were fabricated in Goddard’s Detector Development Lab. (DDL) and

tested at the Goddard 600-m x-ray test facility. The test data verified that the desired angular resolution and throughput efficiency were achieved.

*This work was done by Brian Dennis and Mary Li of Goddard Space Flight Center and Gerald Skinner of the University of Maryland. For further information, contact the Goddard Innovative Partnerships Office at (301) 286-5810. GSC-16418-1*