Optical Sidebands Multiplier

NASA's Jet Propulsion Laboratory, Pasadena, California

Optical sidebands have been generated with relative frequency tens to hundreds of GHz by using optical sidebands that are generated in a cascade process in high-quality optical resonators with Kerr nonlinearity, such as whispering gallery mode (WGM) resonators. For this purpose, the WGM resonator needs to be optically pumped at two frequencies matching its resonances. These two optical components can be one or several free spectral ranges (FSRs), equal to approximately 12 GHz, in this example, apart from each other, and can be easily derived from a monochromatic pump with an ordinary EOM (electro-optic modulation) operating at half the FSR frequency. With sufficient nonlinearity, an optical cascade process will convert the two pump frequencies into a comb-like structure extending many FSRs around the carrier frequency. This has a demonstratively efficient frequency conversion of this type with only a few milliwatt optical pump power.

The concept of using Kerr nonlinearity in a resonator for non-degenerate wave mixing has been discussed before, but it was a common belief that this was a weak process requiring very high peak powers to be observable. It was not thought possible for this approach to compete with electro-optical modulators in CW applications, especially those at lower optical powers. By using the high-Q WGM resonators, the effective Kerr nonlinearity can be made so high that, using even weak seeding bands available from a conventional EOM, one can effectively multiply the optical sidebands, extending them into an otherwise inaccessible frequency range.

This work was done by Dmitry V. Strekalov and Nan Yu of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47322

Single Spatial-Mode Room-Temperature-Operated 3.0 to 3.4 µm Diode Lasers

These devices can be used in gas sensing for environmental monitoring.

NASA's Jet Propulsion Laboratory, Pasadena, California

Compact, highly efficient, 3.0 to 3.4 µm light emitters are in demand for spectroscopic analysis and identification of chemical substances (including methane and formaldehyde), infrared countermeasures technologies, and development of advanced infrared scene projectors. The need for these light emitters can be currently addressed either by bulky solid-state light emitters with limited power conversion efficiency, or cooled Interband Cascade (IC) semiconductor lasers.

Researchers here have developed a breakthrough approach to fabrication of diode mid-IR lasers that have several advantages over IC lasers used for the Mars 2009 mission. This breakthrough is due to a novel design utilizing the strain-engineered quantum-well (QW) active region and quinternary barriers, and due to optimization of device material composition and growth conditions (growth temperatures and rates). However, in their present form, these GaSb-based laser diodes cannot be directly used as a part of sensor systems. The device spectrum is too broad to perform spectroscopic analysis of gas species, and operating currents and voltages are too high.

In the current work, the emitters were fabricated as narrow-ridge waveguide index-guided lasers rather than broad stripe-gain guided multimode Fabry-Perot (FP) lasers as was done previously. These narrow-ridge waveguide mid-IR lasers exhibit much lower power consumptions, and can operate in a single spatial mode that is necessary for demonstration of single-mode distributed feedback (DBF) devices for spectroscopic applications.

These lasers will enable a new generation of compact, tunable diode laser spectrometers with lower power consumption, reduced complexity, and significantly reduced development costs. These lasers can be used for the detection of HCN, C_2H_2, methane, and ethane.

This work was done by Siamak Forouhar, Clifford F. Frez, and Alexander Soibel of Caltech and Gregory Belenky, Leon Shterengas, and Gela Kipshidze of The State University of New York at Stony Brook for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47377

Self-Nulling Beam Combiner Using No External Phase Inverter

NASA's Jet Propulsion Laboratory, Pasadena, California

A self-nulling beam combiner is proposed that completely eliminates the phase inversion subsystem from the nulling interferometer, and instead uses the intrinsic phase shifts in the beam splitters. Simplifying the flight instrument in this way will be a valuable enhancement of mission reliability. The tighter tolerances on $R = T$ (R being reflection and T being transmission coefficients) required by the self-nulling configuration actually impose no new constraints on the architecture, as two adaptive nullers must be situated between beam splitters to correct small errors in the coatings.

The new feature is exploiting the natural phase shifts in beam combiners to achieve the 180° phase inversion necessary for nulling. The advantage over prior art is that an entire subsystem, the field-flipping optics, can be eliminated.

For ultimate simplicity in the flight instrument, one might fabricate coatings to very high tolerances and dispense with the adaptive nullers altogether, with all their moving parts, along with the field flipper subsystem. A single adaptive nuller upstream of the beam combiner may be required to correct beam train errors (systematic noise), but in some circumstances phase chopping reduces these errors substantially, and there may be ways to further reduce the chop residuals. Though such coatings are beyond the current state of the art, the mechanical simplicity and robustness of a flight system without field flipper or adaptive nullers would perhaps justify considerable effort on coating fabrication.

This work was done by Eric E. Bloemhof of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47027

Portable Dew Point Mass Spectrometry System for Real-Time Gas and Moisture Analysis

This system has applications in semiconductor fabrication, industrial gas production, and natural gas refineries.

John F. Kennedy Space Center, Florida

A portable instrument incorporates both mass spectrometry and dew point measurement to provide real-time, quantitative gas measurements of helium, nitrogen, oxygen, argon, and carbon dioxide, along with real-time, quantitative moisture analysis.

The Portable Dew Point Mass Spectrometry (PDP-MS) system comprises a single quadrupole mass spectrometer and a high vacuum system consisting of a turbopump and a diaphragm-backing pump. A capacitive membrane dew point sensor was placed upstream of the MS, but still within the pressure-flow control pneumatic region. Pressure-flow control was achieved with an upstream precision metering valve, a capacitance diaphragm gauge, and a downstream mass flow controller. User configurable LabVIEW software was developed to provide real-time concentration data for the MS, dew point monitor, and sample delivery system pressure control, pressure and flow monitoring, and recording. The system has been designed to include *in situ*, NIST-traceable calibration.

Certain sample tubing retains sufficient water that even if the sample is dry, the sample tube will desorb water to an amount resulting in moisture concentration errors up to 500 ppm for as long as 10 minutes. It was determined that Bev-A-Line IV was the best sample line to use. As a result of this issue, it is prudent to add a high-level humidity sensor to PDP-MS so such events can be prevented in the future.

This work was done by C. Arkin, Stacey Gillespie, and Christopher Ratzel of ASRC Aerospace Corporation and Mary Whitten of the University of Central Florida for Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13316

Maximum Likelihood Time-of-Arrival Estimation of Optical Pulses via Photon-Counting Photodetectors

NASA's Jet Propulsion Laboratory, Pasadena, California

Many optical imaging, ranging, and communications systems rely on the estimation of the arrival time of an optical pulse. Recently, such systems have been increasingly employing photon-counting photodetector technology, which changes the statistics of the observed photocurrent. This requires time-of-arrival estimators to be developed and their performances characterized.

The statistics of the output of an ideal photodetector, which are well modeled as a Poisson point process, were considered. An analytical model was developed for the mean-square error of the maximum likelihood (ML) estimator, demonstrating two phenomena that cause deviations from the minimum achievable error at low signal power. An approximation was derived to the threshold at which the ML estimator essentially fails to provide better than a random guess of the pulse arrival time. Comparing the analytic model performance predictions to those obtained via simulations, it was verified that the model accurately predicts the ML performance over all regimes considered.

There is little prior art that attempts to understand the fundamental limitations to time-of-arrival estimation from Poisson statistics. This work establishes both a simple mathematical description of the error behavior, and the associated physical processes that