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Difference-frequency generation creates 8.7-micron output

Researchers at Rice University (Houston, TX) and the Naval Research Laboratory (Washington, DC) combined the fiber-coupled output from two diode-pumped lasers operating at 1.3 and 1.5 (m in the nonlinear crystal of silver gallium selenide ($AgGaSe_2$) to produce room-temperature tunable 8.7-(m output via difference frequency generation. This continuous-wave mid-infrared radiation was used to obtain the high-resolution gas-phase spectrum of sulfur dioxide (SO_2). Team member Frank Tittel suggests instruments based on this process could be used to detect and measure many important gaseous species including methane, ammonia, nitrous oxide, ethylene, and benzene.

Experiment design
Because 1.3 and 1.5 (m are key telecommunication wavelengths, commercial diode lasers sources at these wavelengths are now available that have characteristics suitable for the nonlinear mixing process. In collaboration with Lew Goldberg at the Naval Research Laboratory, Konstantin Petrov, Robert Curl, and Tittel at the Rice Quantum Institute used a Russian-made high-power fiber amplifier co-doped with erbium and ytterbium (IRE-Polus). The use of a Er/Yb co-doped fiber amplifier allows the use of high power Nd:Yag pump lasers and larger 1.5 micron output powers than possible with diode laser pumped Er doped fiber amplifiers. Our device is pumped at 1.064 (m and injection- seeded with a distributed feedback diode laser at 1.554 (m to produce a maximum single-frequency output power of 0.5 W.

The amplifier output was passed through an isolator and combined with 35 mW of 1.319-(m output from a model 122 diode-pumped monolithic ring Nd:YAG laser (Lightwave Electronics, Mountain View, CA) through a wavelength-division multiplexer (see Fig. 1). A 4 x 4 x 10 mm $AgGaSe_2$ crystal (Cleveland Crystals, Inc) was used for difference frequency mixing (with no attempt to optimize focusing). The 8.7-(m difference-frequency output was filtered from the pump wavelengths and measured with a mercury cadmium telluride detector.

Using 29 mW pump power (Nd:YAG) and 370 mW signal power (Er/Yb amplifier) incident on the crystal, the researchers measured an idler power (8.7-(m) of about 0.1 (W.1. While this value was less than expected based on calculations of the effective crystal length, they determined that the active area of the detector was too small to collect all the idler output as its spot size was increased by spherical aberrations in the collimating and focusing optics.

This is, however, sufficient power for spectroscopy experiments. A 10-cm long absorption cell filled with 5 torr of SO_2 was placed in path of the idler beam. Temperature tuning of the Nd:YAG pump laser at 1.319 (m provided the frequency sweep. Lock-in detection captured the absorption signal, and band assignments were made with a HITRAN database. The frequency sweep was linear and reproducible, although tuning of the Nd:YAG pump laser allowed only a narrow tuning range.

Many molecules have characteristic "fingerprint" absorption bands in the important 8-12-(m region of the infrared spectrum. Until now, access to this region has been limited to Fourier-transform infrared spectrometers, which the cover the entire infrared range, lead-salt diode lasers, which require cyrogenic cooling and have limited tuning ranges, and carbon dioxide lasers, which have many discrete lines between 9 and 11 (m. The gain curve of the Er/Yb fiber indicates that useful IR powers from 1050 to 1250 cm^{-1} can be obtained using various seeding diodes into Er/Yb amplifier in combination with the 1.319 (m Nd:YAG pump. For many high-resolution spectroscopic measurements, tunability is only required over a relatively narrow range. Using the very limited tunability of the Nd:YAG, the difference frequency mixing technique was able to scan across about 0.5 cm^{-1} around 8.7 (m, which for SO_2, includes five strong peaks near 1144 cm^{-1} (see Fig. 2).

To extend the IR wavelength coverage, Tittel and his associates propose to use a tunable extended cavity diode laser to injection-seed a praesodymium-doped fiber amplifier at 1.319 (m instead of the Nd:YAG laser. The tuning range should then extend from 900 to 1400 cm^{-1}. In addition, this scheme should provide higher pump power of around 300 mW and should allow the difference-frequency output power to reach about 5 (W. The single scan tuning range can be 10 cm^{-1}. The researchers expect such characteristics would benefit many molecular spectroscopy and trace-gas detection experiments.
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Reference
1. K.P. Petrov, R.F. Curl, F.K. Tittel, and L. Goldberg, Opt. Lett., in press.

captions:
Figure 1. Difference frequency mixing in $AgGaSe_2$ crystal of 1.319 (m laser output and 1.554-(m Er:Yb fiber amplifier output produces 8.7 (m radiation for spectroscopic measurement of gaseous SO_2.
Figure 2.
Scanning difference frequency output can resolve five prominent peaks in the absorption spectrum of SO_2 near 1144 cm^{-1}; assignments were maded with a HITRAN database. Scan time:50 sec.