All Weather Long-Wavelength Infrared Free Space Optical Link for FCS Vehicle-to-Vehicle Communications

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Abstract

Long-wavelength infrared radiation possesses better all-weather atmospheric transmission than the shorter wavelength laser sources in use today. The superior transmission through common atmospheric problems such as fog, clouds, and smoke coupled with improvements in LWIR laser and modulator design makes possible reliable optical replacements for radio and microwave communications links in many battlefield applications. In addition recent development of a wideband, *room-temperature* QWIP receiver enables the fielding of a truly portable LWIR communications package. *Another advantage of LWIR laser radiation is the inherent eye safety of this wavelength region.*

ORNL is developing a high-speed, full-duplex all weather free-space optical communications link for ranges up to 5 kilometers. The link is designed to provide secure vehicle-to-vehicle communications for future military vehicles such as the Future Combat System. The 10-micron wavelength was selected for its ability to penetrate smoke, fog, and rain. We have developed two key components for an all weather free-space optical communications link, an RF-driven waveguide CO_2 laser and a hollow dielectric-waveguide Stark modulator. The laser is a sealed-off, air-cooled waveguide design capable of operating on both the carbon-12 and carbon-13 isotopes of carbon dioxide. The modulator is based on the Stark shift of NH_2D (deuterated ammonia). The hollow dielectric waveguide design of the modulator minimizes the electrode capacitance to allow operation at over 500 MHz.

Laser Characteristics

One of the drawbacks to more widespread applications for long wavelength infrared communications systems is an inexpensive, compact source of 10-micron radiation. We have developed a compact CW RF-driven, air-cooled, sealed-off waveguide CO_2 laser featuring a power level of over 1 watt. The hollow Al_2O_3 ceramic waveguide has an i.d. of 2.4-mm and provides a gain length of 20-cm. Our waveguide laser is based on a design reported by Walsh[i]. A photograph of the laser is shown in Figure 1. This laser produces a power level of approximately 1.6 watts using $^{12}CO_2$ and 0.8 watts using $^{13}CO_2$, both in the EH_{11} dielectric waveguide mode. With a grating installed, our laser produces 0.4 watts on the 10.59-micron line of $^{12}CO_2$. The output mode structure of the laser, measured with a thermally sensitive liquid crystal film, appears to be a TEM_{00} Gaussian mode. Frequency measurements indicate that the laser operates in a single transverse and single longitudinal mode. The gas mixture in the laser is $He{:}CO_2{:}N_2{:}CO$ in the ratio of 65:18:15:2 respectively. This is a commercial mixture purchased for a pulsed CO_2 laser and the composition has not yet been optimized for our CW waveguide laser. Walsh used a mixture of $He{:}CO_2{:}N_2{:}Xe$ in the mixture ratio 77:10:10:3 respectively[i].

One end of the laser cavity consists of a 0.5-inch diameter 3-m radius concave ZnSe 95% reflective output coupler attached to the waveguide through a brass bellows. The ceramic waveguide is attached with epoxy

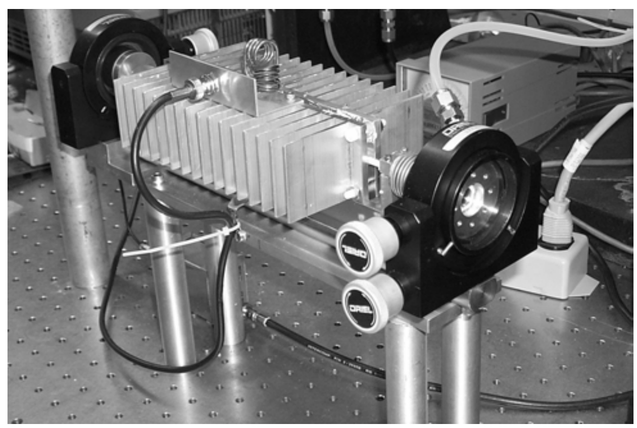

Figure 1 Air-cooled, RF-Driven CO_2 Laser.

to a brass fitting soldered to the bellows. Epoxy is also used to attach a ZnSe Brewster window is to the other end of the ceramic tube, which was ground to the Brewster's angle. A 150 l/mm flat master grating mounted on a piezoelectric actuator in an adjustable mirror mount forms the other end of the cavity. A one-inch diameter invar rod machined flat on opposing sides serves as a temperature stable mounting surface for the insulating support for the electrodes and the mirror mounts. The optimum operating pressure of the sealed-off laser is 60-65 torr. The laser is driven by a 58.5 MHz RF amplifier at a power level of approximately 50 watts. Machined aluminum heatsinks mechanically clamped to each side of the waveguide serve as RF electrodes and provide cooling for the tube. The two electrodes are shaped to conform to the round dielectric waveguide. A thin coating of heatsink compound applied to the electrodes during assembly improves thermal contact with the dielectric waveguide and enhances cooling. One side of the electrode is grounded and an air wound autotransformer couples RF power to the other electrode. The inductance of the 4-turn autotransformer resonates with the capacitance formed by the heatsinks attached to the waveguide at a frequency of 58.5 MHz. Another air-core inductor is used to connect the 50-ohm coaxial cable from the RF power supply to a tap (approximately 1-turn from the grounded end) on the autotransformer to efficiently couple power to the laser. The inductance of the coupling coil is adjusted by compressing or expanding the coil to optimize the impedance match to the 50-ohm cable. Both coils are constructed from #12 AWG copper wire.

Stark-Effect Modulator

Stark-effect modulation occurs when an electric field is applied to a gas molecule that has a substantial polarization. The applied electric field effectively changes the energy spacing of the molecular levels changing the wavelength that is absorbed by the gas. Also, the energy spacing is very small compared to the energy of the optical photon interacting with the gas. The modulator is filled with approximately 2 or more torr of partially deuterated ammonia (NH_2D), which has a molecular absorption resonance near the 10.59-micron line of a CO_2 laser. The frequency difference between the absorption resonance and the laser line is reported to be approximately 2189-MHz[ii] from the laser line. The dotted curve in Figure 2 depicts the transmission of a 30-cm cell containing 2-torr of NH_2D in the absence of an applied electric field. The laser light (located at zero difference frequency on the scale) is not strongly absorbed by the cell. The solid curve in the right graph in Figure 2 shows the transmission of the same cell in the presence of an applied electric field of 300 V/mm. The electric field causes this absorption line to split into nine Stark components classified by the designation M = 0, ±1, ±2, ±3, and ±4. The M = 0 component is roughly in the center of the plot at a difference frequency of 2189 MHz and the M = ±4 components are at the extreme left and right ends of the structure. As the electric field is increased the M = ±4 absorption component moves closer to zero difference frequency until the peak of the absorption is in coincidence with the laser line corresponding to an electric field of approximately 380 V/mm. This situation is depicted in left graph shown in Figure 2. As the applied electric field is varied from 350 to 380 V/mm, the transmission of the cell varies from 90% to 75%. If we impressed a steady state or d-c electric field on the electrodes half-way between 350 and 380 V/mm and apply a sinusoidal voltage, a sinusoidal modulation of the laser beam would occur.

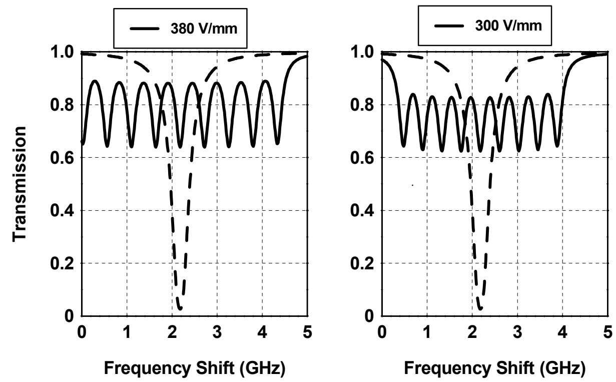

Figure 2 The application of an electric field to deuterated ammonia causes the absorption peak to split into nine components.

Normally Stark modulators are constructed from two parallel electrodes separated by a distance much smaller than the width to minimize the variation of the electric field across the laser beam. The electrodes are placed inside of a dielectric tube, typically glass or ceramic, held at a pressure appropriate for the gas used for modulation, typically a few torr. A typical spacing would be on the order of 2-mm with a width of 20 or more millimeters and a length of more than 200 millimeters. One of the problems with this design is that normal expansion of the laser beam through such a structure causes a loss of laser light due to vignetting of the beam by the electrodes. To reduce this vignetting loss, we have designed a Stark modulator using a hollow glass dielectric tube to confine the optical beam with minimum loss. The laser beam is focused into the proper size by a lens to form a match to the EH_{11} waveguide mode of the dielectric tube. A lens following the waveguide collimates the beam for propagation to a detector or to other optical components. The electrodes are external to the dielectric tube that serves to confine the optical beam and provide a means to operate the modulator at the reduced pressures required for operation.

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[i] Walsh, C. J., "An rf excited circular waveguide CO_2 laser," Rev. Sci. Instrum. 61(9), Sept. 1990

[ii] Johnston, A. R. and Melville, R. D. S., "Stark-Effect Modulation of a CO_2 Laser by NH_2D," Applied Physics Letters, vol. 19, no. 12, 1971.