# DCOOD Optically Pumped by a $^{13}CO_2$ Laser: New Terahertz Laser Lines

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**Abstract**. In this work, we report new optically pumped terahertz laser lines from DCOOD. An isotopic $^{13}CO_2$ laser was used for first time as pump source, and a Fabry–Perot open cavity was used as a terahertz laser resonator. Optoacoustic absorption spectra were used as a guide to search for new terahertz laser lines. We could observe six new laser lines in the range from 303.8µm (0.987 THz) to 725.1µm (0.413 THz). The lines were characterized according to wavelength, relative polarization, relative intensity, and optimum working pressure. The transferred Lamb-dip technique was used to measure the frequency absorption transition both for this laser lines.

## INTRODUCTION

Terahertz is the term used to describe the region of the electromagnetic spectrum between microwave and infrared. This region (between 0.1 THz and 10 THz) is a frontier area for research in physics, chemistry, biology and materials science. Until recently, researchers did not extensively explore the material interactions occurring in the terahertz spectral region in part because they lacked reliable sources of terahertz radiation. The interest in powerful sources of electromagnetic radiation in the terahertz (THz) region (sometimes also identified as far infrared (FIR)) has been renewed due to new applications in imaging and medical sciences [1].

The optical pumping technique on polar molecules is one of the most important for generation of laser lines in this spectral region, with thousands of discrete emissions from 0.2 to 14 THz [2-6] observed until now. The accidental coincidence between $CO_2$ laser lines and a molecular absorption is the rather stringent condition for THz laser emission. To minimize this limitation, several auxiliary techniques were used to increase the possibility of accidental coincidences which can potentially lead to new laser emissions: the use of waveguide $CO_2$ laser of wide tunability [7], of acoustooptic modulators and hybrid metal-dielectric waveguide cavity [8], the use of hot and sequential $CO_2$ laser lines [9] and the use of isotopic $CO_2$ lasers [10-12].

The main purpose of the present work has been a careful search for new laser lines in DCOOD, optically pumped by a $^{13}CO_2$ laser. We have observed six new laser emissions ranging from 303.8µm to 725.1µm, which have been characterized according to relative polarization, intensity, and optimum working pressure.

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## EXPERIMENTAL APPARATUS AND RESULTS

The experimental apparatus used to search for new terahertz (THz) laser lines consists mainly of a Fabry-Perot laser cavity pumped by a $^{13}CO_2$ laser. A commercial sample of DCOOD with 99% purity was used.

A commercial sealed-off $^{13}CO_2$ isotopic laser tube is used in a homemade Fabry-Perot laser resonator, mounted on two aluminum blocks connected by invar rods and separated by 1.35 m long. One block holds a gratting (150 grooves/mm) used in Littrow configuration to select the emission line, while the second block supports a ZnSe output mirror (90% reflectivity and 10 m radius curvature) mounted on a PZT for fine frequency tuning. We use a high voltage power supply (25 kV, 10 mA) to operate the $^{13}CO_2$ laser in CW regime. A cooling system maintains operation of the laser tube at -10 °C. Output powers of 10 W and 110 MHz tuning range are typical for lines with higher optical gains.

For the THz cavity, we use a Fabry-Perot open resonator. It is 100 cm long and 7 cm in diameter, with and has two gold-coated glass spherical mirrors of 70 cm focal length at each end. One mirror has a 2 mm axial hole closed by a ZnSe window for the pump input. The second mirror is mounted on a precision screw to tune the cavity into resonance with the THz transitions and for wavelength measurement. The THz power is coupled out through a silicon window, using an elliptical mirror obtained by cutting at 45° a 6 mm diameter Pyrex rod with a gold coating. This mirror can be moved in the direction perpendicular to the cavity axis to optimize the output coupling at different wavelengths. This design of the cavity allows the observation of both short and long wavelengths. The relative to the polarization of the pump radiation was measured using a metal mesh polarizer and labeled (⊥) by for perpendicular and (//) by for parallel. and the measurement of the relative polarization of THz emission with respect to the $^{13}CO_2$ radiation. The laser cavity is equipped with an internal electric microphone which detects an optoacoustic signal (OA) when the pump line coincides with an absorption transition of the active medium.

The DCOOD absorption OA spectra obtained around each $^{13}CO_2$ pump line were the starting point of a systematic investigation to observe and characterize new THz laser lines. The THz output power was detected using a Golay cell with a thin quartz window, transparent to radiation with wavelength above 40μm. The lines were characterized by measuring the wavelength, intensity, relative polarization, optimum operating pressure, and the infrared absorption off-set frequency relative to the center of the $^{13}CO_2$ laser line. We determine the laser line wavelengths with an uncertainty of ±0.5μm, by recording the THz laser power as function of cavity length excursion (5 mm typically). In intensity, the lines are characterized as very strong (VS), strong (S), medium (M) or weak (W). A VS line is expected to provide a power larger than 10 mW in a properly designed experimental apparatus, a S line a power in the 1-10 mW range, a M in the 0.1-1 mW and a W a power below to 0.1 mW. The off-set was determined by the Lamb-Dip technique [13]. The absorption transition is saturated by the pump intensity usually employed when generating THz laser emission and, as a consequence, a Lamb-Dip will be generated in the pump absorption if the laser pump frequency is tuned around the absorption center line. This dip is transferred to the THz laser emission and is used to determine the absorption off-set.

As a result, six new THz laser lines were found with wavelength values in the range between 303.8μm and 725.1μm. Table 1 summarizes all measurements and data.

Figure 1 exemplifies the search and characterization of new laser lines. It shows the output power gain curve of $^{13}CO_2$ pump line (A), the optoacoustic signal (B) recorded at 200 mTorr, and the THz laser emission signal (C) showing the transferred Lamb-Dip.

**Table 1.** THz lasers emission from DCOOD optically pumped by a $^{13}CO_2$ laser.

| $^{13}CO_2$ Laser Pump Line | Wavelength (μm) | Frequency (THz) | Off-Set (MHz) | Optimum Pressure (Pa) | Relative Polarization | Relative Intensity |
|---|---|---|---|---|---|---|
| 9P(14) | 303.8 | 0.987 | +15 | 13 | // | M |
| 9P(32) | 571.6 | 0.524 | > +55 | 6 | // | W |
| 10R(04) | 380.2 | 0.789 | –35 | 12 | // | M |
| 10R(12) | 465.9 | 0.643 | < –55 | 11 | // | S |
| 10R(20) | 635.4 | 0.472 | –30 | 12 | // | S |
| 10R(32) | 725.1 | 0.413 | 0 | 12 | // | W |

**9P(14)**

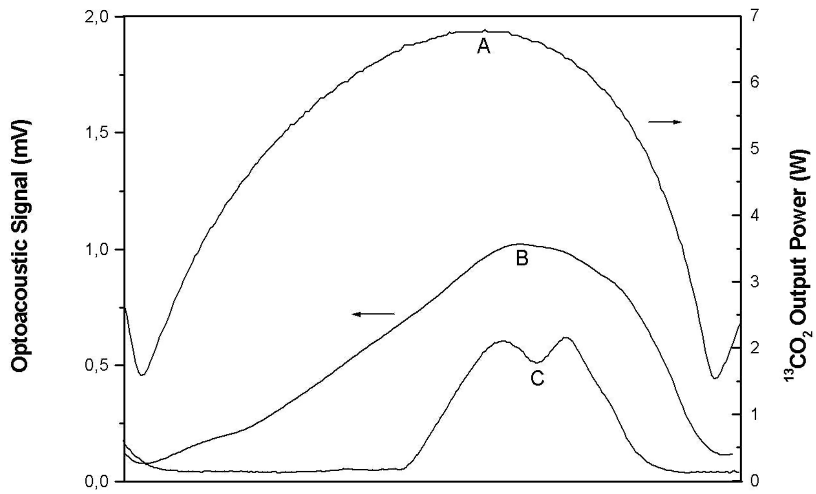


**Figure 1**. A) Output power gain curve of 9P(14) $^{13}CO_2$ pump line, B) Optoacosutic signal recorded at 200 mTorr, C) 303.0μm THz laser emission signal, showing the transferred Lamb-Dip.

## CONCLUSION

In this paper we performed a systematic investigation of the DCOOD absorption using a $^{13}CO_2$ laser as the pump source. We found and characterized six new THz laser lines: 303.8μm, 571.6μm, 380.2μm, 465.9μm, 635.4μm and 725.1μm. For each line, the wavelength, offset, relative polarization, operation pressure and relative intensity were measured.

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