Gas cell measurement using an HEBM with a phase-locked THz-QCL as a local oscillator at 3 THz band

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Abstract— **We have developed a 3 THz-band HEB mixer with a THz-QCL as a local oscillator. We demonstrated phase-locking of a THz-QCL using an HEBM and a THz-reference, which was generated by a frequency-comb and a UTC-PD. We have measured emission line spectra of methanol [CH_3OH] at 3.7 THz band using the HEBM with a phase-locked THz-QCL as a local oscillator. We also measured H_2O, HDO, and D_2O lines.**

I. Introduction

We are developing a superconducting low noise heterodyne receiver based on a hot electron bolometer mixer (HEBM) with a THz quantum cascade laser (QCL) as a local oscillator for astronomical and atmospheric observations at THz frequencies (2-5 THz). The observing target will be OH (1.83 THz, 3.55 THz) and O-atom (2.06 THz, 4.75 THz) etc. in the Earth's atmosphere. We may plan a balloon experiment in the future. We may consider the first balloon flight at the balloon launch sight of ISAS/JAXA in Japan (Taiki-cho, Hokkaido) mainly for demonstration of a THz receiver.

An NbN HEBM device was fabricated in our laboratory. The device was installed in a quasi-optical mixer mount with a log-spiral antenna and an AR-coated Si lens. A Fabry-Perot type metal-metal THz-QCL lasing at 3.1 THz with output power of 140 μW was also fabricated in our clean room facility. We have achieved uncorrected receiver noise temperature of 1,200 K (DSB) as a best value using a vacuum optics and a 4-μm thick Polyester beam splitter [1]. The THz-QCL was phase-locked [2] to a THz reference, which was generated by an optical-comb and a UTC-PD [3].

We have demonstrated gas cell measurement of emission line spectra of molecules using a HEBM with a phase-locked THz-QCL as a local oscillator at 3.7 THz-band.

II. Measurement Setup and Result

Fig.1 shows a gas cell system for the measurement of emission line spectra of molecules using an HEBM with a phase-locked THz-QCL. Fig. 2 shows the photograph of the measurement setup. Two HEBMs and LNAs were installed into a same cryostat of a pulse tube cooler. A THz-QCL was cooled to 45 K using a Stirling cycle cooler with active vibration cancellation (AVC) system. The temperature fluctuation of the cooler was also stabilized less than 0.01 K. A 3rd order DFB THz-QCL lasing at 3.7 THz was phase locked using an HEBM1 to a THz reference, which was generated by an optical-comb and a UTC-PD. The 3.7 THz-QCL array was fabricated by Longwave Photonics LLC. The output power is ~1 mW at an operation temperature of 45 K in CW-mode. For the spectroscopic measurement, it is important to design and fabricated the THz-QCL with the emission frequency close to the frequency of spectral line. The frequency of a THz-QCL should be close to that of the spectral line around +/-3 GHz, which is an IF bandwidth of a HEBM. At the present, we cannot fabricate a THz-QCL lasing at the required frequency with an accuracy of +/-3 GHz, however, we will try to do. The phase-locked THz signal was fed into another HEBM2 using a beam splitter. The line spectra were obtained using a digital spectrometer with a bandwidth of 1 GHz and 13 K channels. We have also successfully phase-locked the THz-QCL using a superlattice (SL) harmonic mixer. A 181-194 GHz AMC (amplifier/multiplier chain) with a typical output power of 20 mW was used as a local oscillator for the SL mixer. We can also use the SL mixer for this experiment instead of an HEBM. It is noted that the frequency of the local oscillator should be selected considering the required frequency of a THz-QCL, because the conversion efficiency of the superlattice mixer is higher for even harmonic number than odd number.

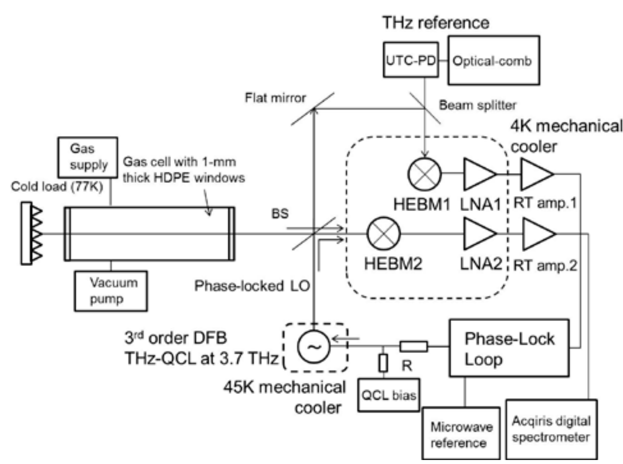
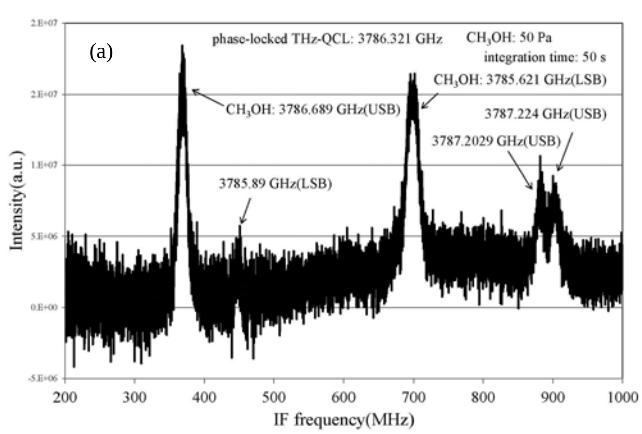


Fig. 1. A gas cell system for the measurement of emission line spectra of molecules using an HEBM with a phase-locked THz-QCL-HEBM. A 3rd order DFB THz-QCL at 3.7 THz was phase locked using an HEBM1 to a THz reference, which was generated by an optical comb and a UTC-PD. The phase-locked THz signal was fed into another HEBM2 using a beam splitter. The line spectra were obtained using a digital spectrometer with a bandwidth of 1 GHz and 13 K channels.

Fig.3 (a) and (b) show the measured emission line spectra of methanol [CH_3OH] at 3.7-THz band. The integration time was around 50 s. Because the receiver was operated in DSB mode, both upper and lower sideband lines were measured. The frequency of the THz-QCL was phase-locked to 3786.321 GHz. We confirmed the frequency of all the lines of methanol using JPL catalogue. We measured the lines at the different gas pressure at 50 Pa and 100 Pa. We see the pressure broadening of the spectral lines. Fig. 3 (c) and (d) show the measured lines of [H_2O, HDO] and [D_2O] with an integration time of 5 s and 25 s, respectively. The THz-QCL was operated in free-running for the measurement of H_2O and its isotopes. We will improve the S/N ratio of the data, and measure the center frequency of the spectral lines accurately using a hydrogen maser as a reference for the phase-locking.

For the real application of the phase-locked THz-QCL to an air-borne, balloon-borne, or satellite-borne system, it is important to stabilize the phase-locking in long term, hopefully more than a week. Currently, we have measured longest stabilization time of ~15 hours. The larger S/N ratio of a beat signal more than 30-40 dB is one of the important issues. The bias point of a THz-QCL should be at the point where the emission frequency of a THz-QCL changes linear with the bias. It may be necessary slow control of an operation temperature of a THz-QCL monitoring a correction signal for a phase-locking in addition to fast control using PLL. An automatic or remote-control recovery system might be considered when a THz-QCL becomes unlocked.

Fig. 2. A photograph of a gas cell system for the measurement of emission line spectra of molecules. A 1-m long gas cell with 1-mm thick HDPE windows at both sides was used.



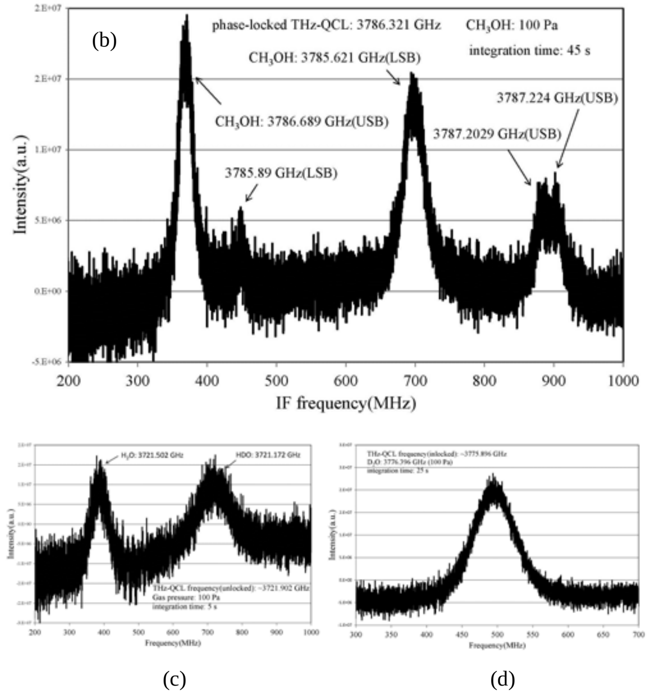


Fig. 3. Measured emission line spectra of methanol [CH_3OH] (a), [H_2O, HDO] (b), and [D_2O] (c) at 3.7-THz band. The methanol lines were measured using a HEBM and a phase-locked THz-QCL. The integration time was around 50 s for the measurement of methanol. We see pressure broadening at the different gas pressure. The spectral lines of H_2O and its isotopes were measured using a free-running THz-QCL with the integration time of 5 s and 25 s, respectively. The vertical line was not calibrated in this experiment.

III. Conclusions

We have developed a 3-THz HEB mixer with a phase-locked THz-QCL as a local oscillator. We have measured emission line spectra of methanol [CH_3OH] at 3.7 THz band using a gas cell system. We also measured H_2O, HDO, and D_2O lines. Long-term stabilization of the phase-locked THz-QCL will be an important task for the real application.

Acknowledgments

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References

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