Performance evaluation of phase-locking for THz-QCL using a HEB mixer

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Abstract— **We are developing a low noise heterodyne receiver system based on a hot electron bolometer mixer (HEBM) and a THz Quantum Cascade Laser (THz-QCL) as a local oscillator at 3THz for atmospheric or astronomical observations. The DSB receiver noise temperature of 1,930K which corresponds to 13 times quantum limit was achieved. We demonstrated phase-locking of 3THz-QCL and evaluated its performance.**

I. Introduction

We are developing a low noise heterodyne receiver system at 3THz based on a hot electron bolometer mixer (HEBM) and THz quantum cascade laser (THz-QCL) as a local oscillator for atmospheric or astronomical observations. For these applications, it's important to reduce the line width and the phase noise of a THz-QCL. A simple solution for the narrowing is a phase-locking to a stable reference. We have successfully demonstrated a phase-locking of the THz-QCL to a THz reference.

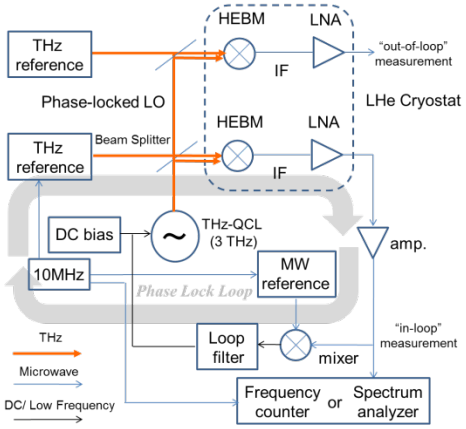

Fig.1 A system block diagram of a phase-locking of a THz-QCL.

II. Development and Measurement

NbN HEBM device on Si substrate with a log-spiral antenna and Metal-Metal waveguide type 3THz-QCL were fabricated in our clean room facility. We have developed a low noise heterodyne receiver system at 3THz and successfully phase-locked the 3THz-QCL to a THz reference (Fig.1) [1]. At first we used a 3THz Amplifier/Multiplier Chain (AMC) source as the THz reference. The beat signal between the 3THz-QCL and the 3THz reference was derived from the HEBM and used for phase-locking the THz-QCL. In addition, we succeeded in phase-locking of the THz-QCL in both cases of using a 3THz-CW source generated by photomixing two modes of an optical comb [2] and a broadband THz-comb generated by Cherenkov radiation as the THz references.

III. Performance Evaluation

Fig. 2 shows a beat signal between 3THz-QCL and 3THz reference in cases of PLL OFF/ON. When the phase-lock loop was closed, the linewidth of the THz-QCL was drastically narrowed. Due to a resolution bandwidth of a spectrum analyzer, the linewidth was limited to 1Hz in Fig.2. For more precise evaluation we did frequency measurements of the beat signal by a high-resolution frequency counter. Longer than 1 hour measurement showed a fractional frequency instability of 2×10^{-16} at an averaging time of 100 seconds (Fig. 3). Note that this is not an actual frequency instability of the phase-locked 3THz QCL but that of phase-lock loop system. The obtained value was much lower than typical frequency stabilities of a hydrogen maser and a Rubidium clock, indicating that our PLL circuit worked properly and the THz-QCL was tightly phase-locked to the THz reference.

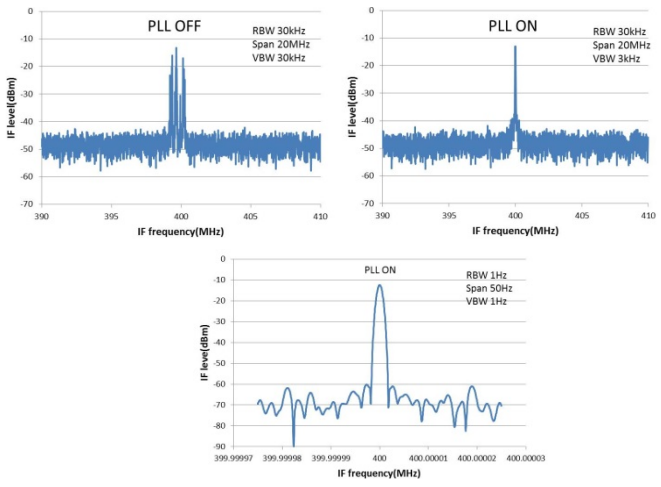

Fig.2 A beat signal between THz-QCL and VDI 3THz source for PLL OFF/ON. The line width of the phase-locked signal is better than 1Hz as shown in the bottom graph.

Also, we confirmed that a frequency tuning of the phase-locked THz-QCL was possible by tuning the THz reference or

the microwave reference. So far, it can be tuned over +/- 90MHz with keeping PLL condition. Further optimizations would expand the tuning range.

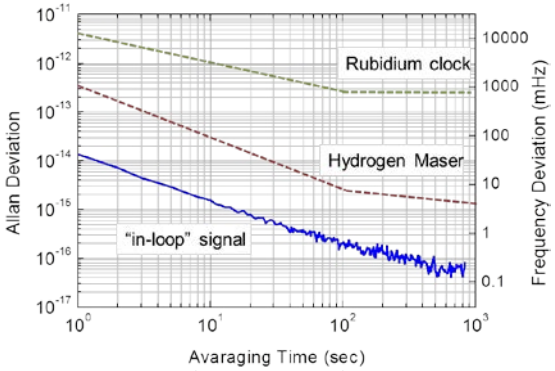

Fig.3 Frequency instability of in-loop signal of phase-locked 3THz-QCL.

IV. Conclusions

We have demonstrated phase-locking of 3THz-QCL using a HEBM and evaluated its performance. By evaluating in-loop signal of phase-locked 3THz-QCL, we confirmed high performance of our PLL system. The phase-locked signal was used as a local signal for another HEBM and beat signal was detected. In order to evaluate actual frequency instability of the phase-locked THz-QCL, we have a plan to measure "out-of-loop" signal using another HEBM and another THz reference.

References

[1] Y. Irimajiri, M. Kumagai, I. Morohashi, A. Kawakami, N. Sekine, S. Nagano, S. Ochiai, S. Tanaka, Y. Hanado, Y. Uzawa, and I. Hosako, "Phase-locking of a 3.1THz quantum cascade laser to terahertz reference generated by a frequency comb", ISSTT 2014 proceedings.

[2] I. Morohashi, Y. Irimajiri, T. Sakamoto, T. Kawanishi, M. Yasui, and I. Hosako, "Generation of Millimeter Waves with Fine Frequency Tunability Using Mach-Zehnder-Modulator-Based Flat Comb Generator", IEICE Trans. Electron., vol. E96-C, no. 2, pp.192-196, 2013.