EPJ Web of Conferences **132**, 02001 (2017) DOI: 10.1051/epjconf/201713202001
SPECTROSCOPY.SU 2016

High resolution THz gas spectrometer based on semiconductor and superconductor devices

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Abstract. The high resolution THz gas spectrometer consists of a synthesizer based on Gunn generator with a semiconductor superlattice frequency multiplier as a radiation source, and an NbN hot electron bolometer in a direct detection mode as a THz radiation receiver was presented. The possibility of application of a quantum cascade laser as a local oscillator for a heterodyne receiver which is based on an NbN hot electron bolometer mixer is shown. The ways for further developing of the THz spectroscopy were outlined.

The high resolution THz gas spectroscopy method is of great importance for different analytical applications, because the range contains the strongest rotation gas absorption lines. Practical realization leads to strict requirements for THz radiation sources and receivers. The radiation source must be of high frequency stability (relative instability of 10^{-8}-10^{-9}) and widely tunable [1]. The radiation source consists of a frequency synthesizer based on Gunn generator (112-115 GHz) and a semiconductor superlattice (SSL) frequency multiplier. The SSL diode that is used in the frequency multiplier was grown with the molecular beam epitaxy method on GaAs/AlAs materials and is the sequence of 18 periods of alternating layers of GaAs and AlAs [2, 3]. As a consequence of that the high number (up to 17) harmonics generated by the SSL have quite little power (less than nW), a low noise and high sensitive THz receiver is necessary. We applied the NbN superconductive hot electron bolometer (HEB) operating in the direct-detection mode [4, 5].

The test measurements of the water and deuterium water vapor spectral absorption lines with the spectrometer were performed at 1456–1495 GHz, 1680–1725 GHz and 1904–1955 GHz frequency bands. One of the absorption line spectra is presented at Fig. 1.

A THz quantum cascade laser (QCL) [6] is prospective source of coherent radiation in the THz range. Phase locking (PLL) is needed for practical implementation of QCL in high resolution spectroscopy. We used 2 THz continuous wave (CW) mode QCL with output power around 1 mW. The carried out testing measurements showed the possibility of QCL phase locking and implementing for elaboration of a THz gas spectrometer. The QCL structure was soldered to copper plate holder, which was attached to a cold plate of a closed cycle cryostat. The QCL was operated at CW mode at the holder temperature about 15 K.

The QCL radiation was collimated with external optics and then its radiation power was reflected by abeam splitter (3% reflectance) into a THz transparent optical window of a

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bath helium cryostat to pump a HEB mixer. The QCL worked as a local oscillator for the HEB mixer.

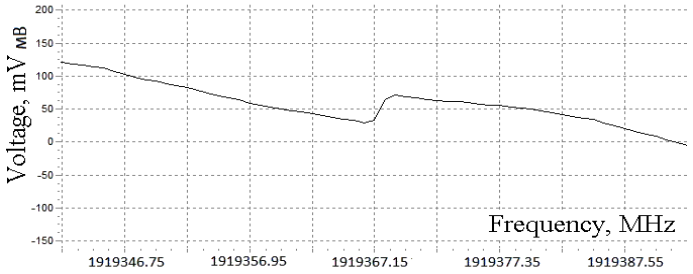

Fig. 1. Water vapor absorption line at 1.919 THz (the 17th harmonic of the synthesizer).

Another radiation was generated with an SSL based multiplier pumped with a backward wave oscillator (BWO) synthesizer, which had frequency stability about 10^{-8} that was much better than the QCL instability. It was transmitted directly through the beam splitter and was used as a probe signal for the HEB mixer.

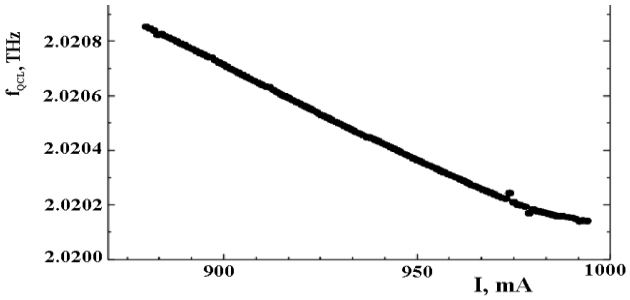

Fig. 2. QCL frequency tuning versus supply current.

The 13th harmonic of the BWO synthesizer had frequency about the same as of QCL. The intermediate frequency signal that resulted from beats of the 13th SSL harmonics and the QCL radiation was studied. We found that the dependence of the QCL frequency upon supply current is monotone and linear (Fig. 2), without instantaneous mode switching in our temperature range and therefore our 2 THz QCL sample was suitable for phase locking [7].

We demonstrated a high resolution THz gas spectrometer for gas studying. We also showed that the QCL is prospective for THz spectrometer developing.

This work was financially supported by RSF (Grant No 15-12-10035).

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