Frequency measurement in THz domain by using femtosecond laser frequency comb

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Abstract— **Recent developments in femtosecond fibre laser combined with the photomixing technique enable THz radiation between 50 GHz up to 3000 GHz to be synthesised. This solid state source THz is dedicated to high resolution spectroscopy in a spectral region no other solution offering the large tunability required.**

Photomixing is now a powerful technique to explore the THz frequency gap and is well established for high resolution spectroscopy applications. The experiment consists of the conversion of an optical beat into the THz domain by using the non linearity of an ultrafast photodetector, or photomixer. Photomixing is now a realistic solution for the pure rotational or rovibrational spectroscopy, and has been used to characterize the absorption profiles of several asymmetric and symmetric tops molecules such as SO_2, H_2S, and OCS [1-3]. The measurement of trace gases in scattering media has been also demeonstrated using this technique [4-5]. When the tedious problem of metrology is solved, the frequency of previously unobserved transitions of H_2O and NH_3 have been determined [6-7].

In this paper, we propose an alternative to the solution proposed by Q. Quraishi *et al*. and we use the latest developments in frequency metrology based on femtosecond fiber lasers for frequency measurement in the THz region by avoiding the use of femtosecond Ti:Sa laser and its expensive pump laser [8]. The frequency spectrum of a pulse train emitted by a femtosecond laser consists of a comb of frequencies, the spacing between each line is determined by the repetition rate of the laser, i.e. governed by the length of the cavity. This frequency comb is then used like a ruler, to measure or/and to stabilized the frequency of others lasers.

The experiment is presented in figure 1. Two external cavity diode lasers which operate near 780 nm, detuned from each other to the desired THz frequency, are overlapped by use of a beam splitter. A first part of the optical beat passes through a tapered amplifier (not represented on the figure) and then is focused onto the ultrafast photomixer to generate the THz radiation. A silicium lens is placed on the back side of the antenna to extract and pre-collimate the THz beam. An off axis parabolic mirror is used to focus the THz beam onto a cryogenic bolometer. The second part of the optical beat is superposed with the frequency comb by using a second beam splitter to measure radio-frequency beats signals between each diode laser and a part of the frequency comb. The detected beat notes are phase locked to a synthesizer, and so stabilize both lasers. The difference of frequency between the diode lasers can be expressed as :

$$f_{THz} = n \cdot f_{rr} \pm 2 f_s$$

where n is an integer, f_{rr} is the repetition rate of the femtosecond laser locked onto a 10 MHz quartz crystal oscillator, and f_s the frequency of the synthesizer used to phase lock the beat signals. A classical wavemeter is used to remove the ambiguty of the integer. In the present demonstration the tunability is obtained by scanning the repetition rate of the femtosecond laser.

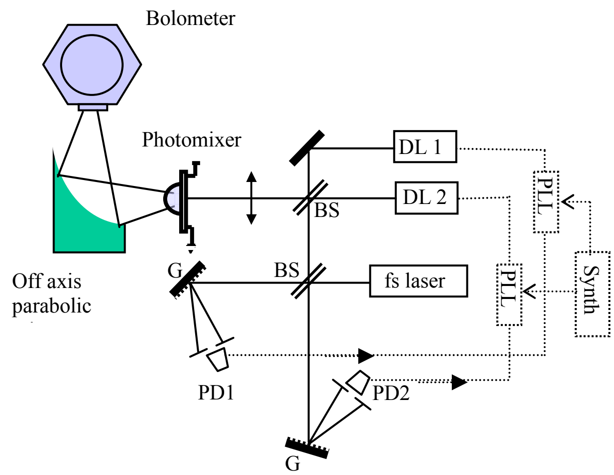

Figure 1: Experimental setup of the synthetised THz source

The figure 2 shows an example of a locked beat note between one of the diode lasers and the femtosecond laser. The curve is the result of an average of 100-recorded signal by using a sweep time of 20 ms. The resolution bandwidth is 25 kHz. The full width at -3db is estimated around 500 kHz. The limited bandwidth of our feedback current source prevents the observation of coherent spike. At present, the performance of the phase lock loop is limited by the response of the error input of the current controller. A bias tee directly connected to the diode laser would increase greatly the bandwidth of the error feedback, and so subsequently improve the present spectral purity. Similar experiment when the phase lock loop is open exhibit a full width at -3db around 6 MHz.

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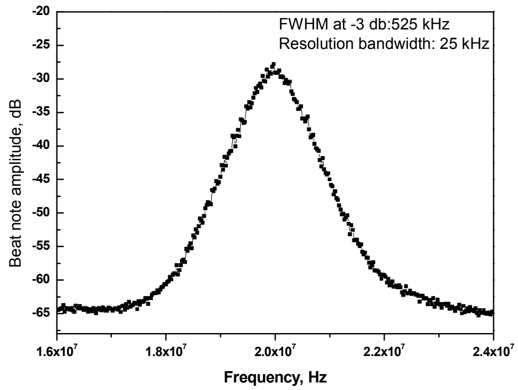

Figure 2: Beat note between a external cavity diode and the frequency comb obtained from a femtosecond laser

By considering the equation 1, the relative accuracy of the THz frequency is determined by the accuracy of the repetition rate of the femtosecond laser and the accuracy of the two beat notes between the frequency comb and diodes lasers. We have measured the frequency of the required signals during 3 minutes. The frequency of the locked repetition rate was 100 MHz with a standard deviation of 5. 10^{-3} Hz while the two beat notes show similar results, recorded around 20 MHz with a standard deviation around 13 Hz. All those measurements are determined by the precision of the quartz crystal oscillator used as reference which has not absolutely calibrated at the present time.

The present good linewidth of the solid state THz source, tunable over more than one decade of frequency, will be dedicated to high-resolution spectroscopy. The future accuracy of the frequency of absorption lines should be rather determined by amplitude noise of the THz radiation and large fluctuation of the base line than the accuracy of the difference frequency synthesised THz source. The baseline is characterised by several Fabry Perot effects produced by different parts of the experiment, and the presence of large absorption lines of water at atmospheric pressure that is often difficult to record several times with a high degree of reproducibility. This latter point is under investigation.

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