500 GHz Sensor System in SiGe for Gas Spectroscopy

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***Abstract*— A 500 GHz sensor system for gas spectroscopy is presented, which includes a SiGe transmitter (TX) array and a SiGe receiver (RX). The integrated local oscillators of the TX-array and RX chips are controlled by two external phase-locked loops (PLL). The reference frequency of the TX-array PLL is modulated for 2f absorption spectroscopy (second harmonic detection). The performance of the sensor system is demonstrated by detecting the 2f absorption spectra of methanol and acetonitrile.**

I. Introduction

Recently, we presented a 245 GHz sensor system in SiGe for gas spectroscopy [1]. Integrated sources and detectors are now available in advanced SiGe technology even for frequencies up to 500 GHz [2, 3]. We have reported a spectroscopic system for 480 – 500 GHz, which includes a SiGe 4x1 TX-array, a Golay cell as detector, and a 1.9 m long gas absorption cell [3]. The estimated radiated output power of the TX-array is -7 dBm at 500 GHz. The absorption spectrum of gaseous methanol was shown for 495 – 497 GHz.

II. Results

We have developed a gas spectroscopy system with frequency modulation (FM) operating from 480 to 500 GHz, which uses a TX-array chip and RX-chip fabricated in IHP's 0.13µm SiGe BiCMOS technology. An integrated local oscillator (LO) is used for the TX-array as well as for the RX, whose frequency is tuned by an external phase-lock loop (PLL). The two PLLs are controlled by two external reference frequencies. The LO of the TX-array and the RX, respectively, contains a 120 GHz push-push voltage controlled oscillator (VCO) with an 1/64 frequency divider for the fundamental frequency. The TX-array includes four TXs for spatial power combining [3], Fig. 1. The TX consists of a two-stage power amplifier, a frequency quadrupler, and an integrated antenna. The RX consists of a LO connected to a frequency doubler to generate a LO-signal at the double frequency, and a transconductance subharmonic mixer (Fig. 2) with a similar design as reported for a RF frequency of 77 GHz in [4]. The LO port of the subharmonic mixer is connected to the 240 GHz LO, and the RF port is connected to the on-chip antenna. The series-stub transmission lines at the RF and LO ports form a diplexer, which isolates the RF port from the LO port. The simulated gain of the single antenna, which is used for the RX, is 6 – 8 dBi in the range of 480 – 500 GHz with a radiation efficiency of 70 - 80%, and the simulated gain of the antenna array is 11 – 14 dBi in this frequency range with an similar efficiency to that of the antenna array. The TX-array and the RX are fabricated in IHP's 0.13µm SiGe BiCMOS technology with f_T/f_{max} of 300 GHz/500 GHz. The die area of the fabricated TX-array is 3.3x2.6 mm^2, Fig. 3b, and the die area of the fabricated RX-chip is 2.3x0.9 mm^2, Fig. 3a. The TX- and RX-chips were bonded on plug-in boards. The plug-in boards with TX and RX, respectively, were mounted on carrier boards with PLL devices. As the TX-array chip consumes 1.1 W, a thermal sink was realized for the bonded chip on board by using through-hole plating to the Cu-back plate. A thermal sink was realized for the bonded RX-chip in the same way.

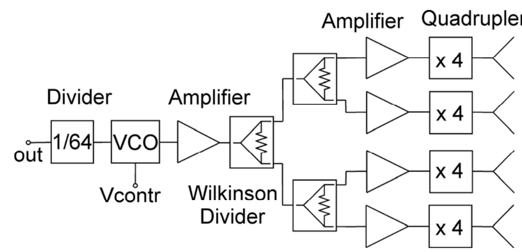

Fig. 1. Schematic of the 0.5 THz TX-array.

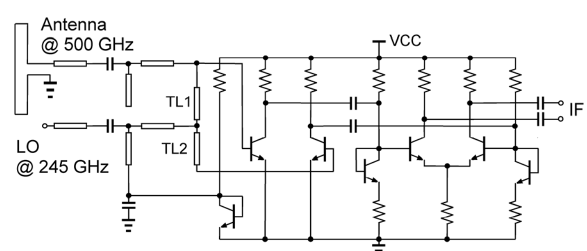

Fig. 2. Schematic of the subharmonic transconductance mixer of RX.

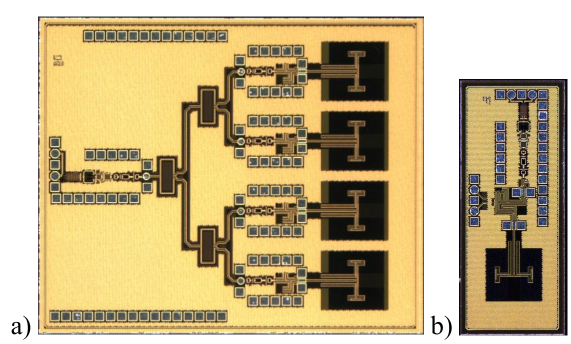

Fig. 3. Photographs of a) SiGe TX-array chip, and b) SiGe RX chip.

The reference signals for the PLLs were delivered from two signal generators. The IF-frequency was set at 780 MHz. A FM with a frequency deviation of 11.5 MHz and a modulation frequency of 50 kHz was applied to the reference frequency of the TX-array PLL. We have used a folded 1.9 m long gas absorption cell between the TX-array and the RX, Fig. 4. Dielectric lenses are used as input and output windows for this gas absorption cell. The IF-signal of the RX was connected to a bandpass filter and then amplified by an external low noise amplifier with a gain of 34 dB. The 2f content of the absorption spectrum was obtained by detecting the IF power using a diode power sensor connected to a lock-in amplifier. Our spectroscopic system allowed the detection of the 2f absorption spectra of methanol (CH_3OH) and acetonitrile (CH_3CN). Fig. 5 shows a part of the measured 2f absorption spectrum of CH_3CN at a gas pressure of 9 Pa after baseline correction, and the integrated absorption coefficient S taken from the JPL database of molecular spectroscopy.

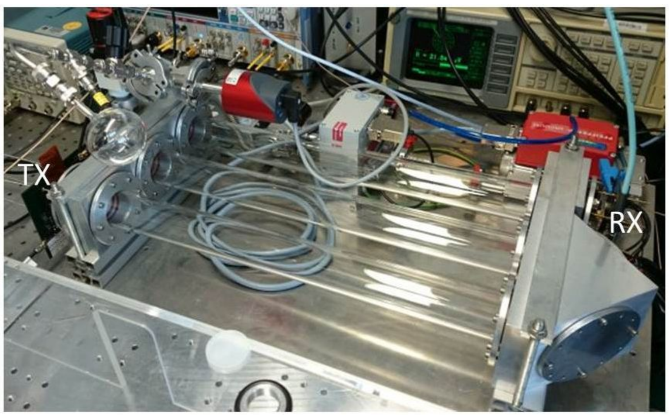

Fig. 4. Photograph of the 500 GHz sensor system with gas absorption cell: left – TX-array module, right –RX-module.

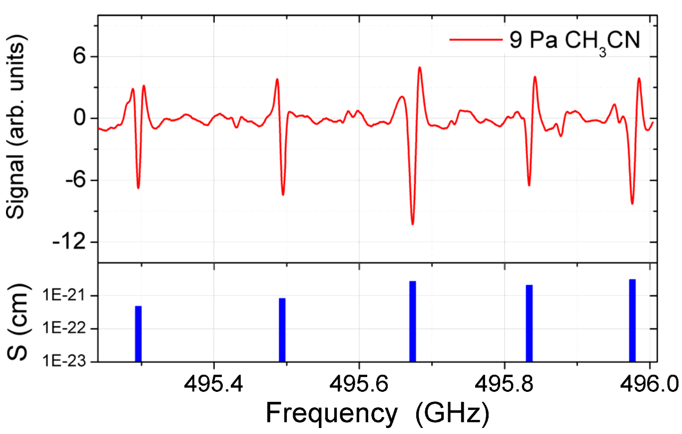

Fig. 5. Measured 2f absorption spectrum of acetonitrile (top), and simulated spectrum (bottom).

It is worth noting that absorption lines with an integrated absorption coefficient as low as 10^{-22} – 10^{-23} cm can be detected with a decent signal-to-noise ratio. Compared to our spectroscopic system with a Golay cell, see [3], this is an improvement of the system sensitivity by a factor of 2 and a 4 times faster frequency sweeping rate. Beside the 4^{th} harmonic of the LO frequency the frequency quadrupler of our TX generates also the 2^{nd} harmonic, which caused corresponding absorption lines in the spectrum of methanol when detected by a Golay cell [3]. However, our subharmonic RX detects only the 4^{th} harmonic of the LO and suppresses the impact of the 2^{nd} harmonic.

References

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