Terahertz pyroelectric sensor

TeraPyro

A high-performance solution for THz sensing

High sensitivity (up to 2 kV/W) and low NEP

Broad spectral range from 0.1 - 30 THz

High speed detection (up to 2.5 kHz)

Interchangeable pre-aligned optics

High quality THz integrated optics

Sensitivity and bandwidth switch

The TeraPyro sensor is a compact and highly sensitive device, based on the combination of a high-quality absorbing black coating, paired with a LiTaO3 pyroelectric crystal. The broad absorption range of the coating allows the use of this sensor over a large spectral range (from 0.1 to 30 THz). The high sensitivity and low NEP offer no compromise on performances. The integrated, pre-aligned, high quality THz optics based on AR coated Si-lenses ensures maximized optical coupling to the sensor. The optics are highly modular allowing three configurations: bare sensor, collimated input or focused input with 50 mm working distance. A sensitivity switch allows to reduce the response of the detector and gain in response time for faster measurements. A BNC output ensures fast and standard connectivity for data recovery. The sensor operates on a common +/-12 V DC power supply.

Application note

Sensitivity and Bandwidth Selection

Technical Notes

The TeraPyro sensing device is based on an absorbing black coating deposited on top of a 2mmx2mm $LiTaO_3$ pyroelectric sensitive crystal. Absorbed THz radiation induces thermal variations in the black coating which is then converted into electrical signals by the pyroelectric crystal. The absorbing layer's optical typical absorption characteristic is displayed on figure 1.

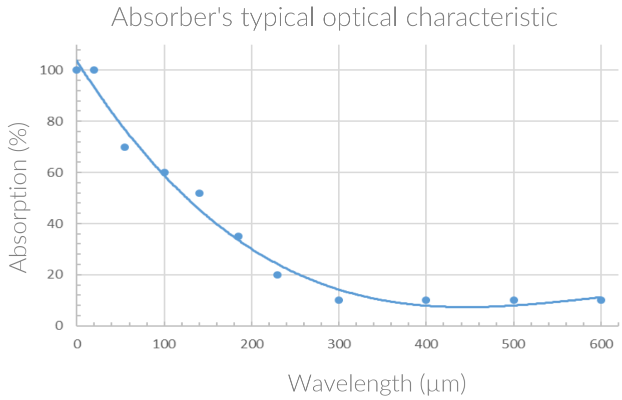

Figure 1 Absorption vs frequency of black coating

The pyroelectric effect generally occurs as minor voltage generation, the high sensitivity of the detector is enabled by the integration of a tunable low-noise op-amp stage located close to the pyroelectric crystal.

The integrated capacitors/resistors for the control of the gain of the amplification stage, selected through the 3-positions switch of the TeraPyro, allows the user to tune the sensitivity and the response time of the detector. The different detection characteristics, depending on the channel, are investigated in this application note.

The following characterizations have been implemented in a non-controlled environment displaying temperature variations higher than 1°C, variations of the hydrometric level up to 5% over the typical measurement times and ambient lightning in order to reproduce typical operating conditions.

A tera pyro sensor, paired with a two collimation and focalization HRFZ-SI lens aligned at the output of the laser have been used to perform those measurements at 2.5 THz for an emitted power of 0.82mW using the TeraCascade 1000 Integrated QCL source. Depending on the measurement, an oscilloscope, a lock-In amplification stage and a spectrum analyzer are used to recover proper signals. A calibrated THZ 20 Pyroelectric detector from Sensor und LaserTechnik (sensitivity of 65.9 V/W) have been used for power calibration.

Emission scheme of TC 1000 in QCW Mode

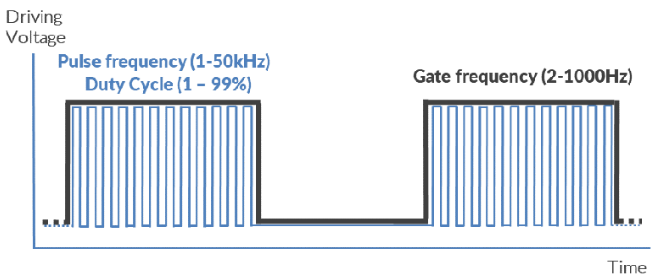

Figure 2 Driving signal scheme for QCL chips in QCW mode

The emission scheme of the source used in those characterizations is an important in order to reach high performances and power levels with the TeraCascade 1000 QCL chips, a Quasi Continuous Wave (QCW) driving signal is generated using a pulsed square signal at high frequency (typically from 10 to 50 KHz) with an adjustable duty cycle (see figure 2). For most THz thermal detectors, this frequency range remains completely un-detectable, therefore, tuning the duty cycle parameter only sets the averaged emitted power.

An exploitable signal for detectors is then obtained by adding a gate signal overmodulation of typically 5-1000 Hz to electrically chop the optical signal into an even square signal (fixed 50% duty cycle).

Sensitivity selection

The choice of the sensitivity channel among the 3 positions of the TeraPyro sensor, allows for the user, to select a tradeoff between the sensitivity and the bandwidth of the detector. Indeed, due to the amplification stage, the higher the sensitivity, the lower the detection speed and vice versa.

This effect is due to the fact that the rise time of the signal is directly linked to the RC constant that have been set on the amplification stage. Bellow the recommended maximum chopper frequency for a given switch position, no sensitivity variation will be observed.

Typical scope signals from square modulated waveforms at 2Hz and 23 Hz (with a pulse frequency at 10 kHz and 40% Duty cycle) are respectively displayed in figure 3 and 4 with adequate sensitivity selection (high sensitivity channel à 2Hz and medium sensitivity channel at 23Hz).

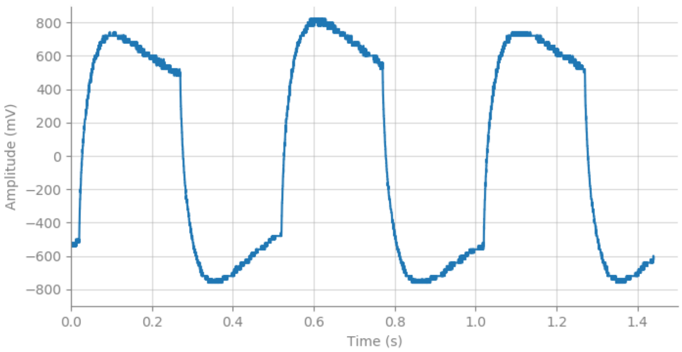

Figure 3 Typical measurement for a 2 Hz square modulation signal in high sensitivity mode

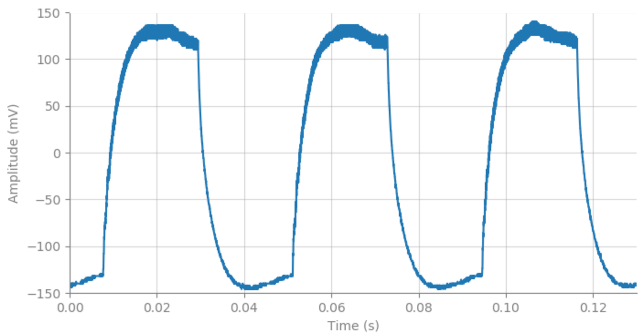

Figure 4 Typical measurement for a 23 Hz square modulation signal in medium sensitivity mode

At higher modulation frequencies, the detection will then be limited by this RC rise time and will give rise an incomplete charge-discharge detection scheme (as showed in Figure 5). The main effect on the detection is the lowering of the sensitivity when increasing the chopping frequency (this effect is highlighted in the High-speed use section of this application note in the case of the low sensitivity channel).

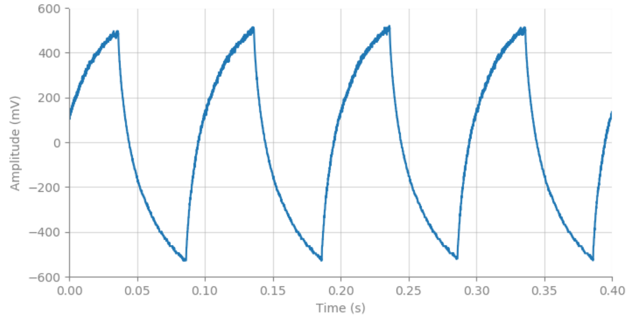

Figure 5 Typical measurement for a 10 Hz square modulation signal in high sensitivity mode

The thermal relaxation of the sensor is noticeable when using the TeraPyro sensor at too low modulation frequencies for a given sensitivity channel. A typical example is displayed on Figure 6 in the case of the use of the medium sensitivity channel for the detection of a signal modulated at 5Hz.

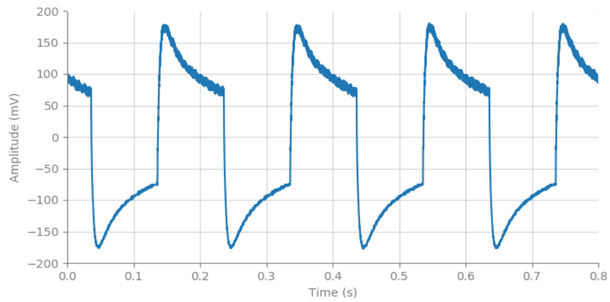

Figure 6 Typical measurement for a 5 Hz square modulation signal in medium sensitivity mode

High Sensitivity use

On the amplification stage, an open circuit configuration ($R \rightarrow \infty$) could be set and would give access to an extremely sensitive detection at really low chopping frequencies (up to 10kV/W @ 2.5THz for measurements using a few Hz chopping frequency). Nevertheless, the major drawback in this configuration comes from the extreme responsiveness to any external environmental disturbance, from air flow, to temperature changes, minor sound disturbances, vibrations or disturbances from the operator. This setting is not included in the TeraPyro sensor.

High speed use

On the other hand, when using the low sensitivity channel of the TeraPyro sensor, very fast detection can be achieved. Indeed, due to the lower RC time constant of the amplification stage, despite the lower sensitivity (~70V/W), detection up to a few kHz chopping frequencies is achievable with an oscilloscope.

Different waveforms have been acquired on the low sensitivity channel at different modulation frequencies from 100Hz to 10 kHz on an oscilloscope, (using a 50kHz sub modulation and 50% duty cycle for an average output power of 0.82 mW). Some of them are displayed in Figure 8. No filtering or additional processing have been applied to those raw oscilloscope signals.

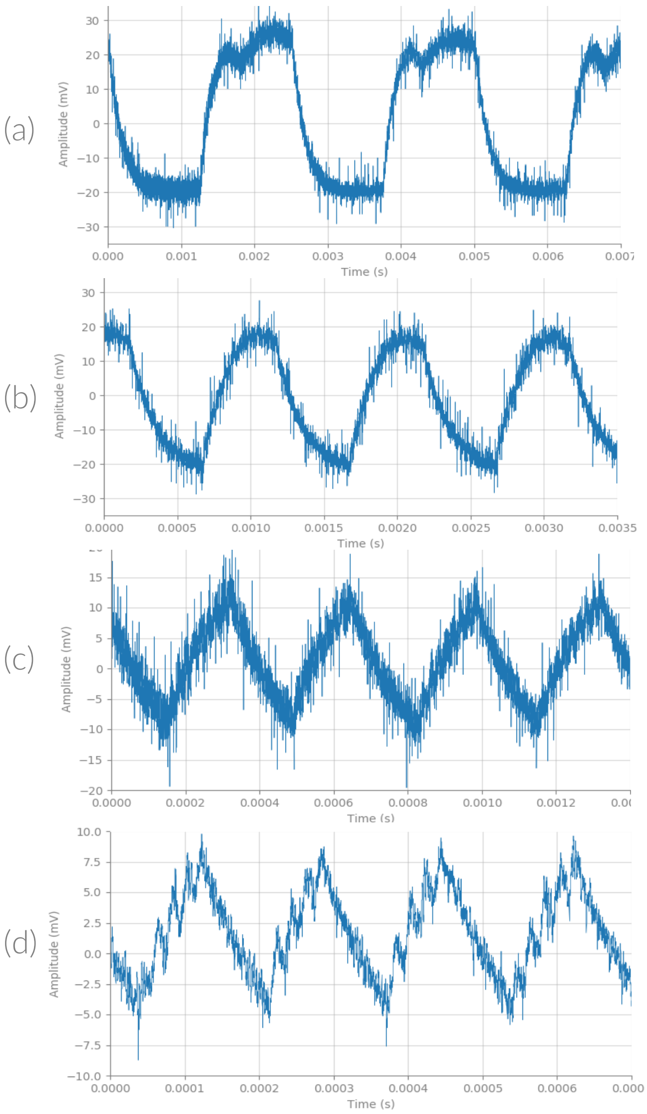

Figure 8 Typical waveform at (a) 400,(b) 1000, (c) 3000, (d) 6000 Hz respectively in low sensitivity mode

The measured peak to peak sensitivity is reported in figure 7 where we can see a constant sensitivity bellow the recommended maximum chopper frequency (400Hz), and a decrease in responsivity beyond, due to the incomplete charge-discharge detection profile, giving a 3dB bandwidth higher than 2.5 kHz and detectible signal up to more than 10 kHz.

In the previous waveform for a 6kHz Gate frequency, the sub modulation at 50kHz is even noticeable on the rising edge of the signal, when the source emits. This point is issued bellow in this section.

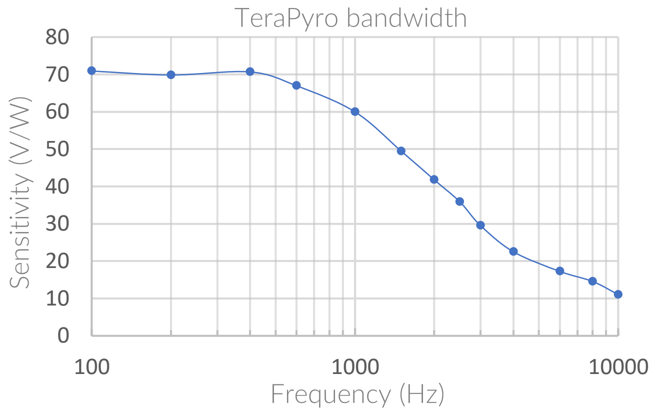

Figure 7 Sensitivity as a function of the gate frequency

Using then more sensitive measurements tools such as spectrum analyzer or lock in amplifiers it is clearly possible to detect signals up to tens of kHz. While Figure 9a and 9b display respectively the gate voltage and the detected time evolution signals, figure 9c represents related spectrum measurement, performed with a spectrum analyzer, for a 5kHz gate modulation with 40kHz pulse frequency. We can clearly identify the gate fundamental frequency and harmonics (odd orders due to the triangular profile of the waveform) as well as the higher frequency pulse fundamental frequency at 40 kHz. Two sideband beating peaks with quite high amplitudes are noticeable at 35 and 45 kHz and originate from the combination of the 7th and 9th order gate harmonics and a frequency beating between the two fundamentals (gate and pulse frequencies).

(a)

(b)

(c)

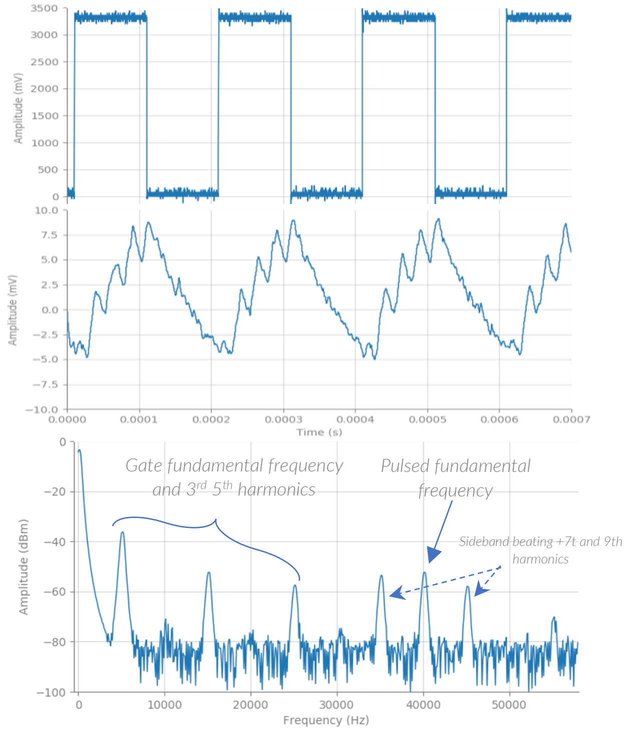

Figure 9 Typical signals for a 5kHz modulation and 40kHz sub modulation: (a) Laser Trigger signal, (b) tera pyro Waveform, (c) related spectrum

An extra filtering step (low pass up to 125kHz) have been performed on the waveform (figure 8b) in order to remove most of the oscilloscope measurement noise and allows a clear visualization of those two components: the combination of the 5kHz main modulation and the high frequency oscillations of the 40kHz sub modulation when the laser is active (rising edge of the triangular signal).

Focusing then on the gate fundamental component, the following powers have been measured at different modulations frequencies and are represented on figure 10 and giving a -3dB bandwidth at 1.1 kHz. The slight difference with the sensitivity bandwidth might be due to the evolution of the signal waveform from a quasi-square signal at low frequencies to quasi-triangular signal due to the incomplete charge-discharge detection signal at high frequencies.

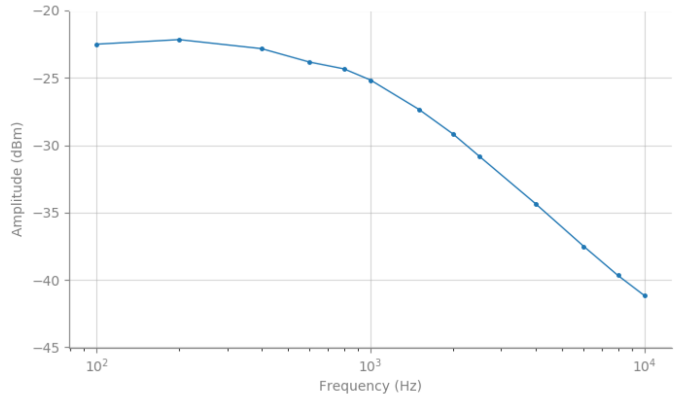

Figure 10 Detected gate fundamental amplitude as a function of the gate frequency

The following table summarizes the different characteristics of the tera pyro sensor for the 3 ranges and especially the recommended modulation frequencies in light of all the elements that have been presented on this application note.

Specifications	TeraPyro		
Sensitivity switch	High	Medium	Low
Sensitivity at 2.5 THz	1.8 kV/W	390 V/W	66 V/W
Rise time	80 ms	10 ms	1.5 ms
Recommended maximum usage frequency	5 Hz	50 Hz	400 Hz -3dB at 2.5 kHz