High-Sensitivity Room Temperature THz Sensor Based On Impact Ionization

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Over the past few decades, electronics and photonics have been gradually approaching the terahertz (THz) regime (optoelectronics) as electronics become faster and photonics utilize lower frequencies for telecommunications and thermal imaging. Because the energy of THz radiation is too low for normal photonic detection but has a frequency too high for normal electronic detection, there is a lack of practical THz detectors. The sample in this study has been designed to make use of the Gunn Effect to produce high sensitivity to THz radiation. Previous experiments [1] show that the detector can produce a photocurrent when exposed to a high-power coherent wave THz laser at room temperature and in ambient lighting. In this study, we performed a series of experiments to verify that the impact ionization due to the Gunn Effect is indeed responsible for the THz-induced photocurrent, as the theoretical model predicts, and that it remains photosensitive at low powers of THz irradiation. We measured this by performing current-voltage sweeps across a range of voltages and for varying THz beam intensities. In our experiments, the sensor remained sensitive to low-power THz radiation. We found that as the power of the THz beam is decreased, the voltage width of the photocurrent decreased. By designing a novel high-sensitivity THz detector, new research methods and applications of THz radiation become possible. Using classical techniques, we show that a THz sensor based on the Gunn Effect and impact ionization can be highly sensitive to low-power THz sources at room temperature.

1.
R. Chen *et al*., "Terahertz detection with nanoscale semiconductor rectifiers", IEEE Sensors Journal **13**, 24 (2013).

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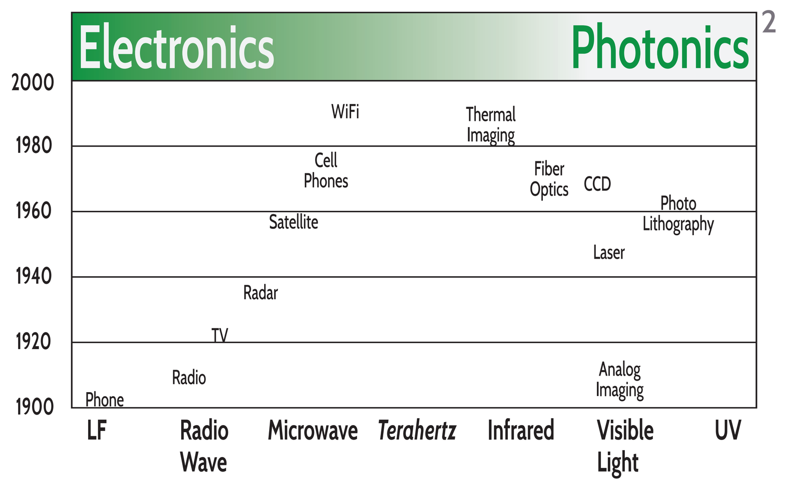
Introduction

Devices of the future will use terahertz, but development is hindered by a lack of practical sensors.

Terahertz is difficult to detect because its wavelength is too short for classical electronic detection and its photon energy is too low for optical sensing. Experiments[1] have shown that the sensor in this study can detect terahertz radiation with a high-power terahertz laser.

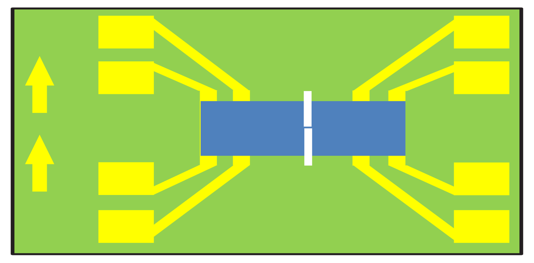


	Schottky Diode	Cryogenic Bolometer	CMOS Sensor	*This Sensor*
Room Temperature	✓	✗	✓	✓ [1]
Ambient Lighting	✓	✗	✓	✓
Broadband - Far THz	✗	✓	✓	?
High Sensitivity	✓	✓	✗	?

Terahertz triggers avalanche of electrons.

Many electrons per photon of terahertz radiation can be excited in the sensor from this study due to the Gunn Effect, which introduces Impact Ionization.

The sensor in this study is a Gallium Arsenide (GaAs) heterostructure with a quantum point contact (QPC). The sample has been designed to produce Gunn Oscillations at a certain voltage. These oscillations create domains of high electric field, where impact ionization occurs. The theoretical model for this sensor says that terahertz (THz) waves are superimposed on these oscillations, allowing for changes in breakdown voltage.



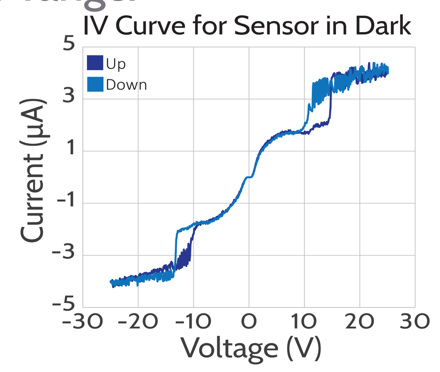
Gunn Oscillations continue below Impact Ionization voltage, creating hysteresis.

Impact Ionization occurs at when a specific voltage is applied to the sensor. After Impact Ionization occurs, Gunn Oscillations begin to propogate throughout the sample. Once the Gunn Oscillations begin, the applied voltage on the sensor can be lowered below the Impact Ionization trigger voltage without losing the Gunn Oscillations.

Methods

Investigating the current-voltage curve.

By measuring the current-voltage (IV) curve of the sensor with and without exposure to terahertz radiation we tested the sensitivity of the sensor to low-power terahertz sources as well as verified that the Gunn Effect is indeed responsible for the sensor's ability to detect these low-power terahertz waves. We focused on the 5-17V range.

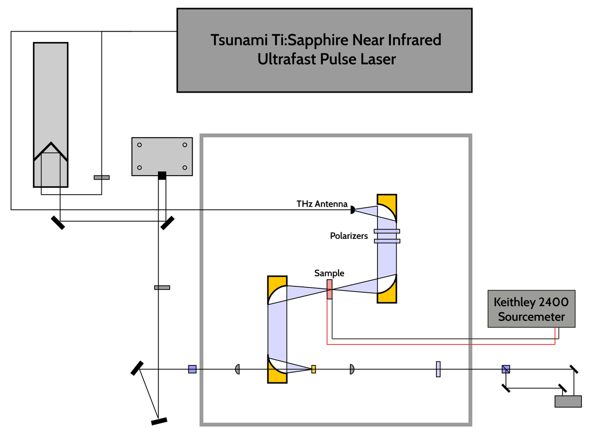


Keithley 2400 Sourcemeter Configuration

Source Mode (Dependant Variable)	Voltage
Sense Mode	2-Wire
Compliance Level	105 μA
Data Averaging	Moving Point 10 samples
Remote Trigger	Yes, LabView via GPIB
Source Delay	1 second
PLC Speed	Normal (20ms)

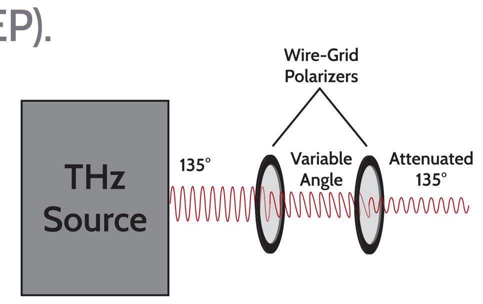
Ultrafast coherent terahertz pulse beam.

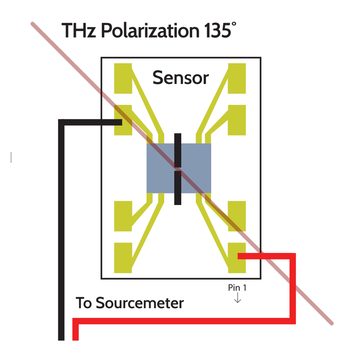
The sensor was placed in the focal point of an ultrafast terahertz beam. The beam consists of picosecond-long pulses of terahertz that repeats every thirteen nanoseconds.



Dual polarizers for terahertz attenuation.

We used two wire-grid polarizers to attenuate the terahertz beam in order to perform our power-dependence experiments. The purpose of these experiments was to estimate the order of magnitude of the sensor's noise-equivalent power (NEP).





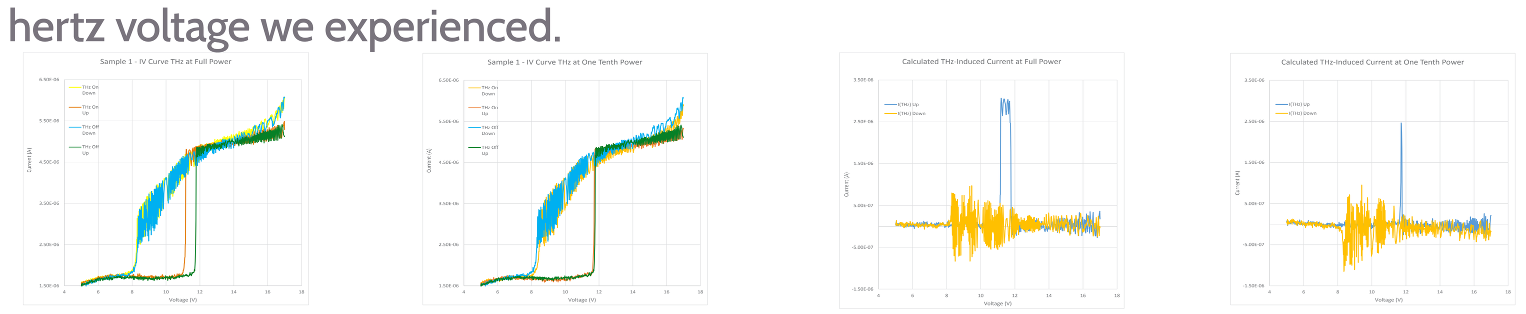
Results

The sensor exhibited a high photocurrent at low powers of terahertz radiation.

We found that even with the low power of terahertz radiation provided by the pulse laser, the sensor still exhibited a relatively strong photocurrent. The small amount of terahertz radiation significantly decreased the voltage threshold for impact ionization to occur.

Signal-to-noise ratio of approximately one was achieved at a power of 5×10^{-14} W.

We used the dual-polarizer attenuation method to decrease the power of the terahertz radiation on the sensor to the point where the change in avalanche breakdown voltage was comparable to the day-to-day changes in the baseline no-terahertz voltage we experienced.



Analysis & Conclusion

Sensor exhibit levels of sensitivity on par with cryogenic bolometers but at room-temperature.

Noise Equivalent Power (NEP) estimated to be between 5.29 x 10^{-14} $W/Hz^{-1/2}$ and 5.29 x 10^{-11} $W/Hz^{-1/2}$

Depending on the material used, the NEPs of cryogenic bolometer may be between 10^{-11} $W/Hz^{-1/2}$ and 10^{-14} $W/Hz^{-1/2}$.

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References:
1. R. Chen et al., "Terahertz detection with nanoscale semiconductor rectifiers", IEEE Sensors Journal 13, 24 (2013).