Stochastic Impact Ionization in Nanostructured Semiconductors

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The Gunn Effect and impact ionization are two well-studied effects in bulk semiconductors. Devices that make use of the Gunn Effect, for example, form an important group of microwave emitters that have numerous applications. Despite their importance, these processes as applied to nanostructured systems are not yet fully understood. The device in this study, a GaAs/AlGaAs heterostructure with a nanoconstriction, has been designed to exhibit strong nonlinearities in its current-voltage characteristics caused by the Gunn Effect and impact ionization. Devices such as these have the potential to become a new class of sensors and emitters, specifically in the THz range. We cannot move forward with these studies, however, until we fully understand these mechanisms. To clarify the role of the impact ionization mechanism in the device, we studied the time dependent current response to an applied bias. At certain applied biases, the current response becomes bi-stable and over time can spontaneously jump in magnitude signifying that the sample has undergone impact ionization, which is followed by Gunn oscillations. This jump in current appears to be stochastic, in other words, it occurs randomly in time. By studying the time dependent current response of this device, we can learn about the mechanisms of these fundamental processes that will enable the rational design of a new class of semiconductor sensors and emitters.

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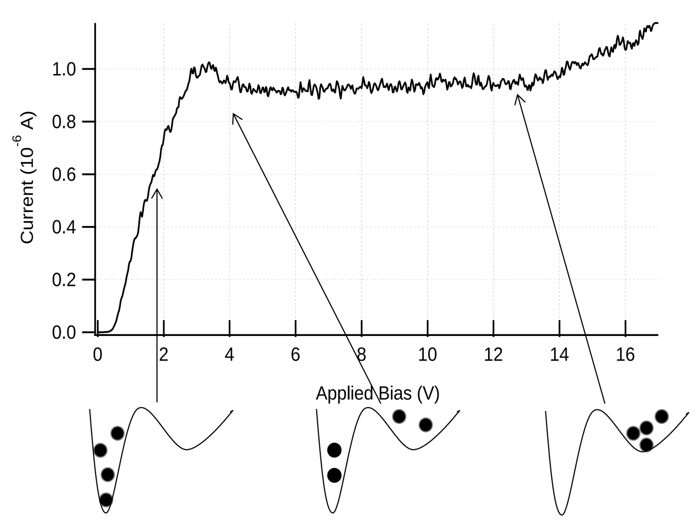
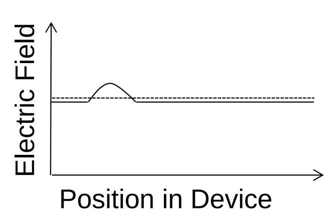
Gunn Effect and Impact Ionization

Gunn Effect → Impact Ionization

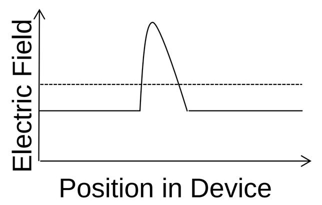
1) DC Bias pushes the system into its negative differential mobility state



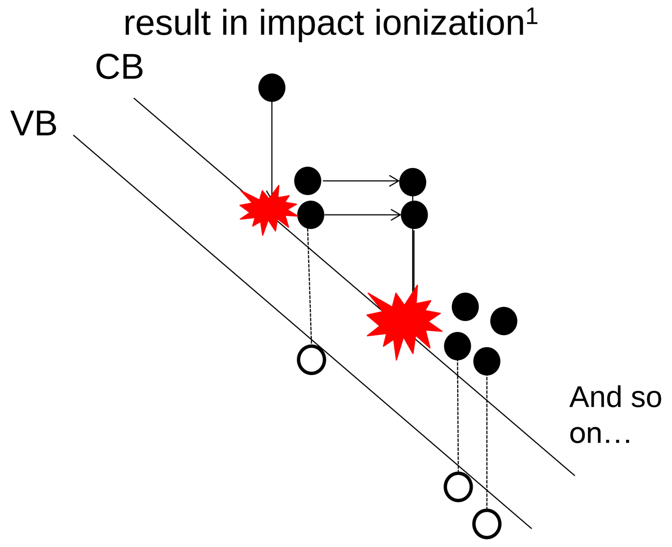
2) Small electric dipole as a result of doping inhomogeneity or random noise



3) Dipoles grow into mature domains and begin travelling, causing current to oscillate



4) Gunn Oscillations and Small fluctuations in current eventually result in impact ionization[1]



Applications

1) Existing Applications

Gunn Diodes are microwave emitters and some existing applications are for **Motion and position sensing**

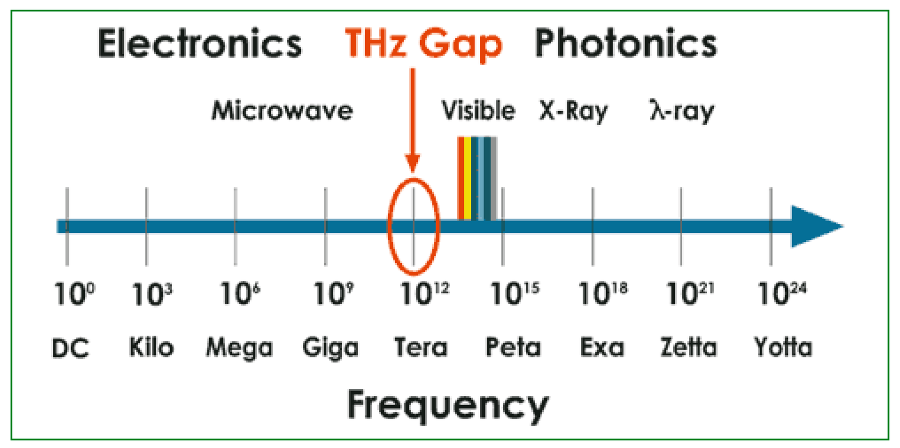
2) Potential Future Applications

Terahertz (THz) sensors and emitters

Sensors: The device in this study has already exhibited a THz Photo-response at cryogenic temperatures, and shown potential for detection at room temperature.[2]

Emitters: Frequency (f) of Gunn Oscillations depends on the length of device (L) and average velocity (*v*)

$$f = \frac{v}{L} = \sim \frac{2.2X10^5 (m/s)}{1.8X10^{-7}(m)} \sim 1X10^{12} = 1\text{THz}$$



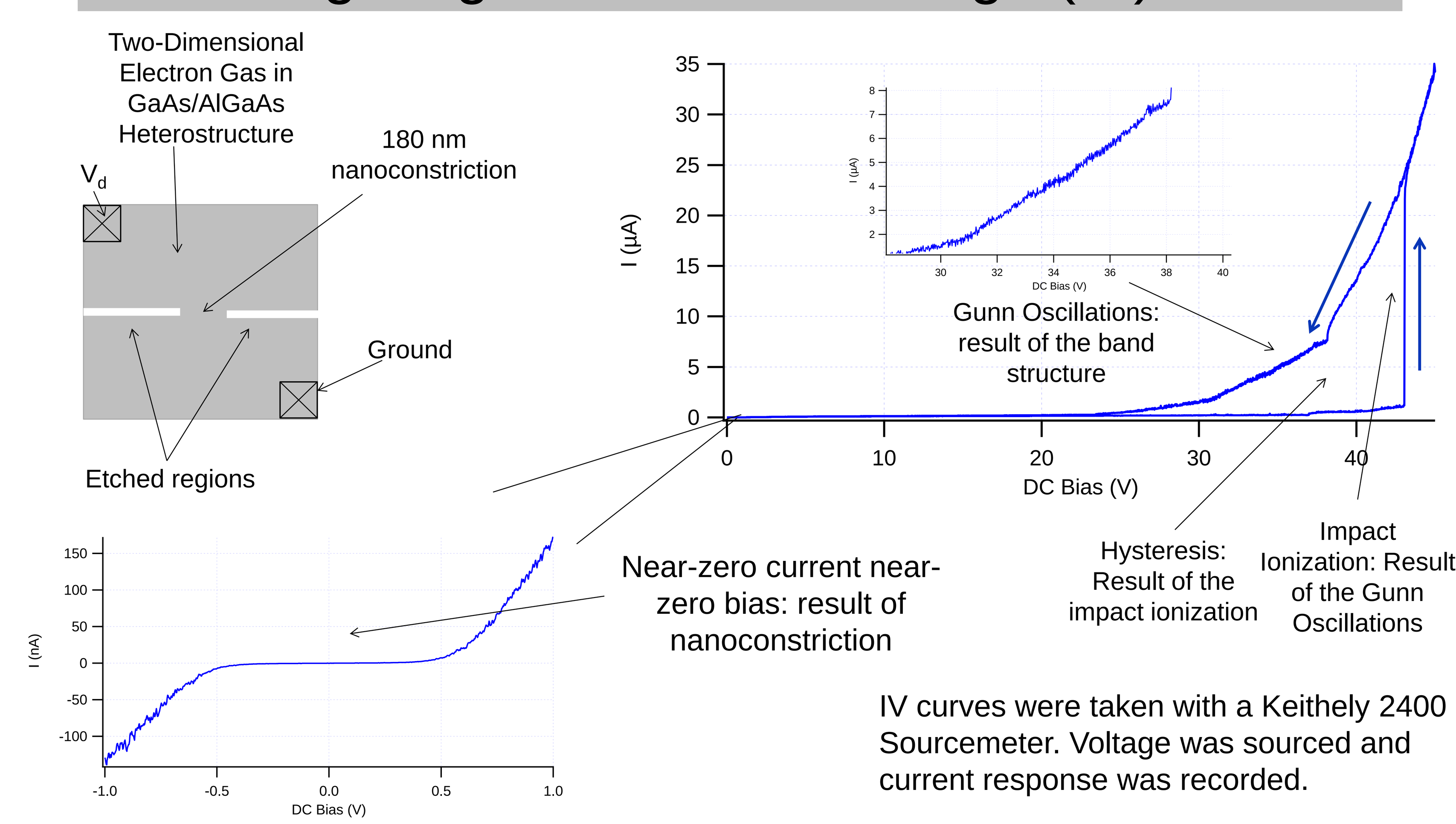
The reason the THz gap is called such is because there is a lack of practical detectors and sources. Think about how easily you detect radiowaves and generate microwaves, operation in the THz range is no where near this ease. This is why we are so interested in this device.

Problem and Motivation

THz Gunn Effect in a nanometer scale structure is not fully understood or observed yet

Aim to clarify the nature of the Gunn Effect and impact ionization in nanostructured semiconductors

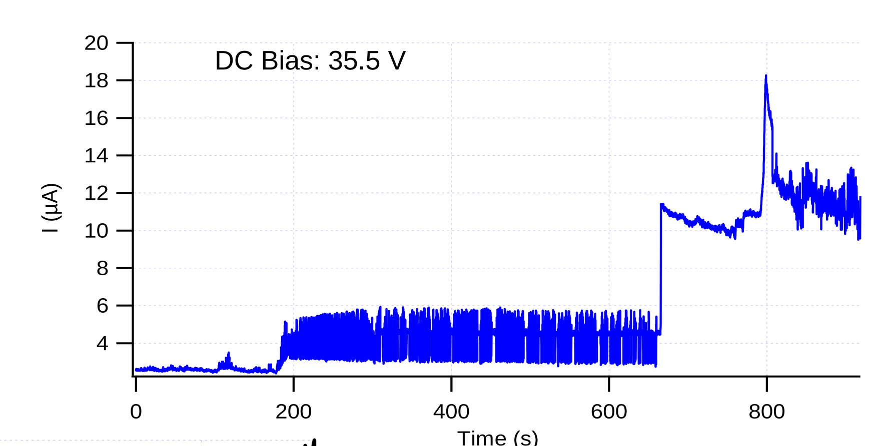
Investigating the Current-Voltage (IV) Curve

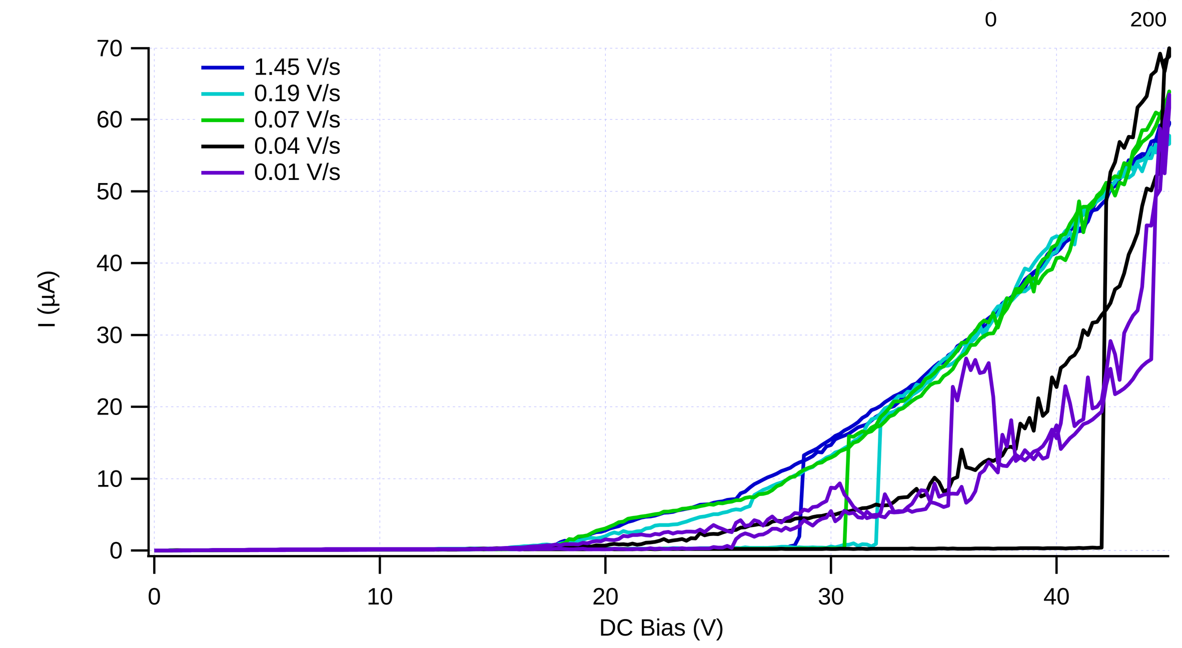


IV curves were taken with a Keithely 2400 Sourcemeter. Voltage was sourced and current response was recorded.

Time and Sweep Rate Dependence

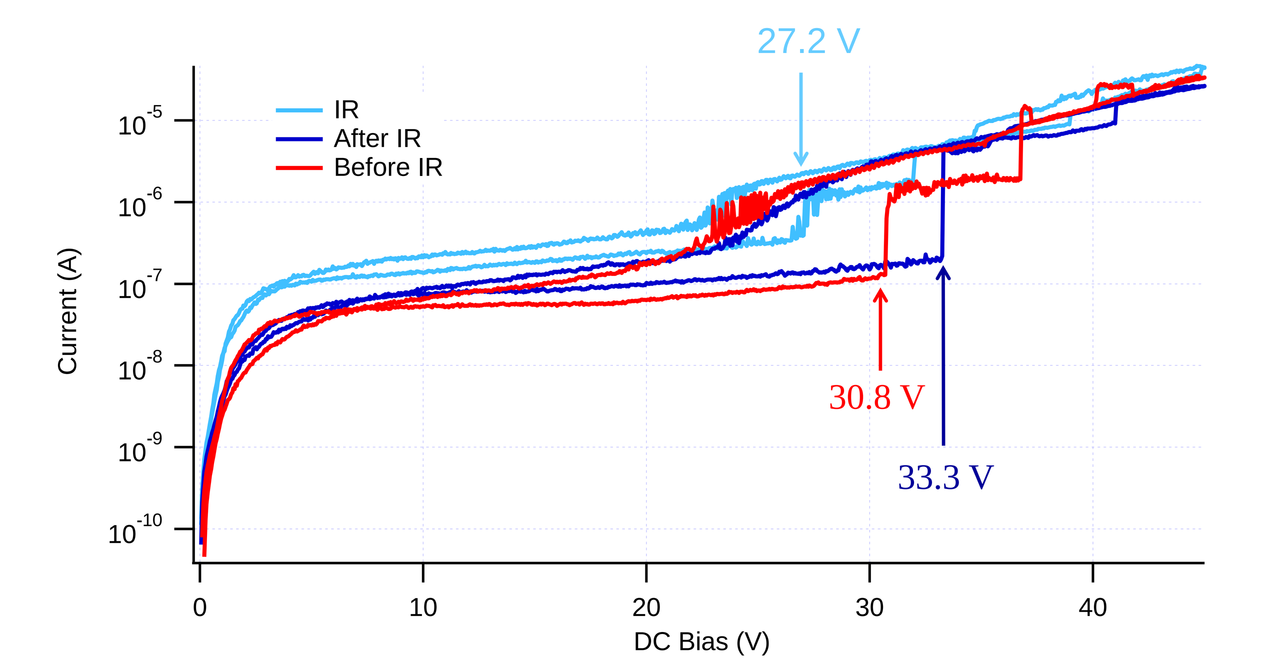
In the region of hysteresis, the current becomes bi-stable and can experience Gunn oscillations and impact ionization at any time





Five different IV curves taken at five sweep rates. As the sweep rate decreases, the onset of impact ionization is pushed back in voltage. Fluctuations in current and random noise are reduced by decreasing the sweep rate.

Near Infrared (IR) Influence



The Near IR radiation excites electron hole pairs in the nanoconstriction so the sample responds to the same biases with a higher current. This effect is washed out with the onset of impact ionization. The log of the current versus DC Bias shows that the IR does affect the voltage at which impact ionization occurs, beyond the error of the stochastic behavior.

Conclusions and Future Work

- The "jump" in current occurs randomly in time, it is stochastic
- Slower sweep rates allow for more stable behavior
- The Near IR generates a photo-current in the sample and affects the onset of impact ionization
- Future work should focus on learning how to exploit this behavior for THz emission/detection

References

1) Sze, S. M., & Lee, M. K. (2012). *Semiconductor devices, physics and technology* (3rd ed.). Hoboken, N.J.: Wiley
2) R. Chen *et al.*, "Terahertz detection with nanoscale semiconductor rectifiers", IEEE Sensors Journal **13**, 24 (2013).

Acknowledgements & Contact

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