Energy Resolution of Terahertz Single-Photon-Sensitive Bolometric Detectors

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Nanoscale Hot-Electron Bolometric Detector

$$\delta E \sim (k_B T^2 C_e)^{1/2} \propto T^{3/2}, V^{1/2} \implies \text{Smaller, colder = more sensitive}$$

We have developed a nanoscale superconducting Ti bolometric detector with $T_c = 0.3$ K. Nb contacts, with $T_c = 8$ K, confine hot electrons in the Ti. Thermal relaxation is set by electron-phonon coupling in the Ti, with a time constant ~ μs. [1]
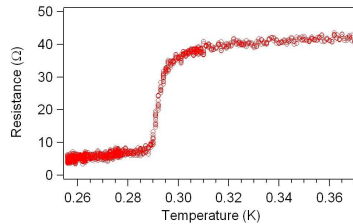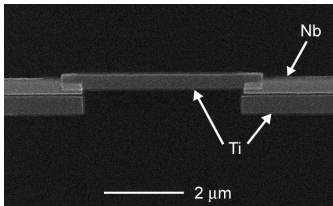
To test a detector with $\delta E/h$ ~ THz, one needs very precise control of the incident photon flux over a very wide frequency range. For example, a 300 K blackbody presents ~10^{12} photons/sec to a single-mode detector in a 1-2 THz bandwidth.

## Experimental Technique: Testing with *Fauxtons*
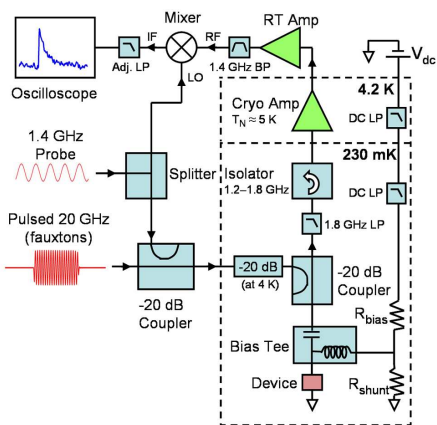
A single THz/IR photon is simulated by a fast microwave pulse, where the absorbed energy of the pulse is equal to the photon energy. We call this pulse a faux photon, or fauxton. This technique has several key advantages:
• The device is operated in a cryogenically dark environment with negligible blackbody photons.
• The input coupling efficiency is precisely calibrated *in situ* using Johnson noise thermometry.
• The fauxton frequency can be tuned simply by adjusting the amplitude of the microwave source.

Readout is achieved by measuring the change in the reflection coefficient with a CW microwave probe. This takes advantage of low-noise amplifiers and isolators available at these frequencies, and is also amenable to frequency-domain multiplexing of a multi-pixel detector array.

Results
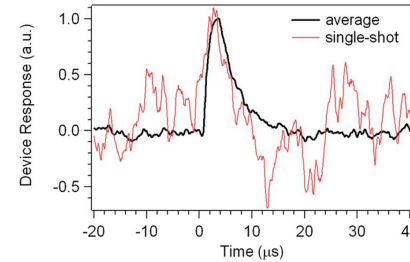
Single-shot and averaged device response to 50 THz fauxtons. The device is measured with a 3 Ω load line (negative electrothermal feedback), with a time constant $\tau = 4$ μs. When measured with a 50 Ω load line (no electrothermal feedback), $\tau = 7$ μs.

Histograms of pulse heights from 10^3 single-shot measurements for different fauxton energies; the FWHM gives the energy resolution. Also shown is the histogram with the device biased well above I_c, which gives the energy uncertainty due to amplifier noise. We find $\delta E_{tot}/h = 49 \pm 1$ THz and $\delta E_{amp}/h = 43$ THz, and hence $\delta E_{intrinsic}/h \approx 23$ THz.
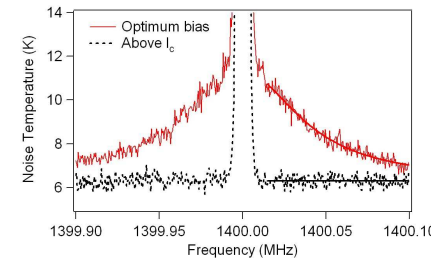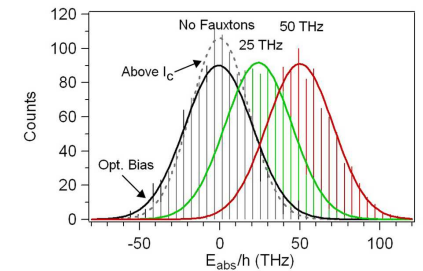
Noise measured at the mixer input, referred to the input of the first stage amplifier. Noise is shown with the device at the optimum bias point for detection and also with the device above I_c, where the dominant noise source is amplifier noise. The measured noise and responsivity correspond to $\delta E_{tot}/h = 50$ THz, consistent with the fauxton measurements.

The predicted intrinsic energy resolution can be calculated from the NEP: $\delta E_{FWHM} = 2\sqrt{2\ln 2}\left[\int_0^\infty \frac{4 df}{NEP^2}\right]^{-1/2}$

$\delta E_{intrinsic}$ is estimated using the thermal fluctuation $NEP_{th} = (4 k_B T^2 G_{th})^{1/2}$ and integrating over the measurement bandwidth of 100 kHz. Using G_{th} from [1], we find $\delta E_{intrinsic}/h = 20$ THz, in good agreement with the fauxton measurements.

Outlook

$\delta E/h$ ~ 1 THz is predicted to be achievable by reducing the Ti nanobridge volume and T_c. The fauxton technique avoids several complications of real optical measurements, such as imperfect optical coupling and the loss of energy from the initial photoexcitation before a thermal electron distribution is achieved. Hence, the fauxton technique is not only useful for preliminary device characterization, it can also be used to understand detector nonidealities in real optical experiments.

References
[1] J. Wei, D. Olaya, B.S. Karasik, S.V. Pereverzev, A.V. Sergeev and M.E. Gershenson, *Nature Nanotechnol.* **3**, 745 (2008).
[2] D.F. Santavicca, B. Reulet, B.S. Karasik, S.V. Pereverzev, D. Olaya, M.E. Gershenson, L. Frunzio and D.E. Prober, *Appl. Phys. Lett.* **96**, 083505 (2010).