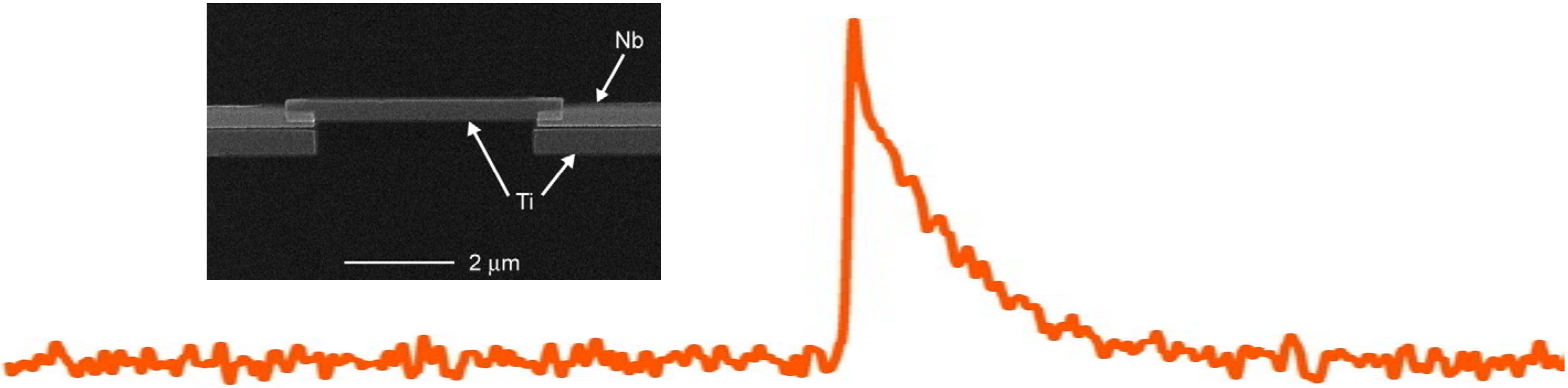
Energy Resolution of THz Single-Photon-Sensitive Bolometric Detectors



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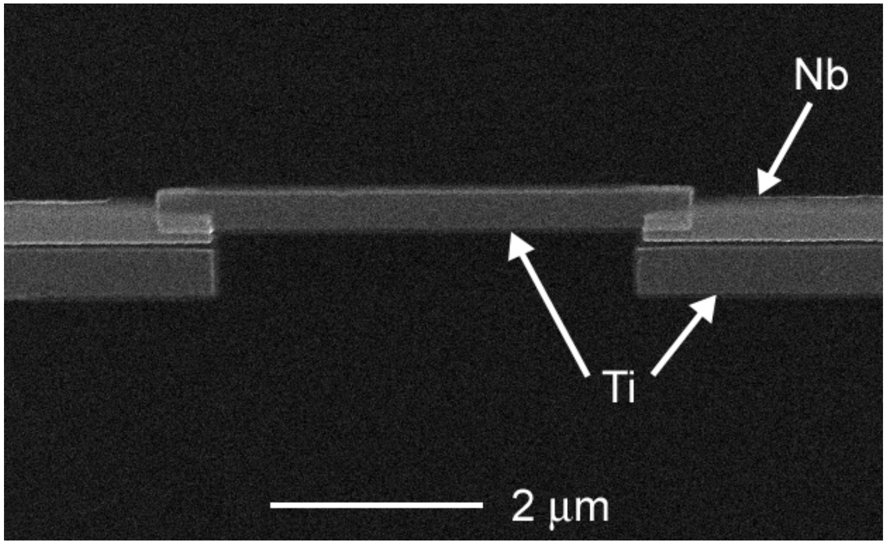
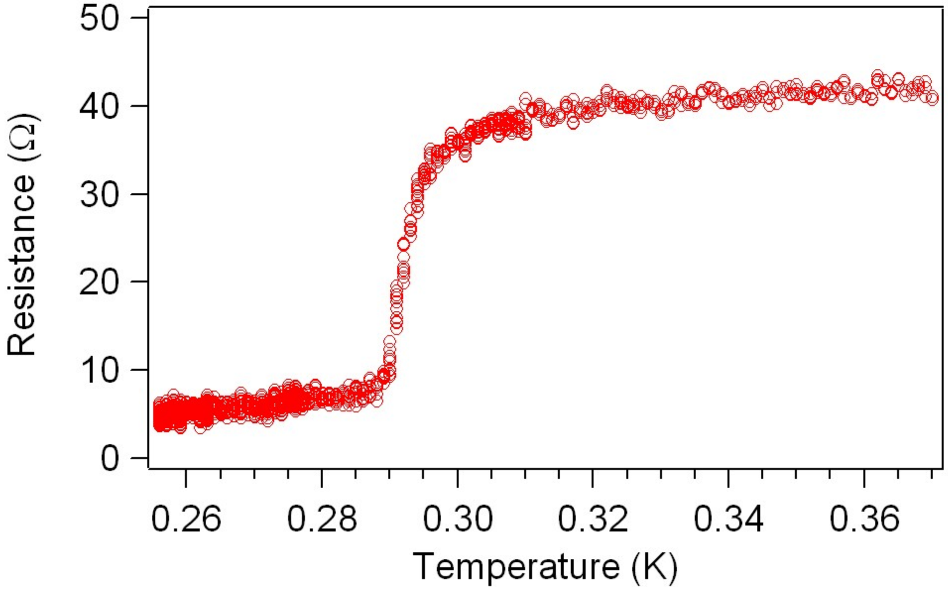
Ti Nanobolometer





<u>Ti nanobridge</u>

4 μm x 350 nm x 70 nm

$T_c = 0.3$ K

$R_N \approx 50\ \Omega$

$\delta E_{th} \sim (k_B T^2 C_e)^{1/2}$

smaller, colder =

more sensitive

want $\delta E/h \sim$ THz

Wei *et al.*, *Nature Nanotech*. **3**, 496 (2008)

Challenges of THz Single-Photon Detection

$\delta E/h \sim$ THz ($\delta E \sim$ meV)

Need precise control of incident photon flux over a very wide frequency range

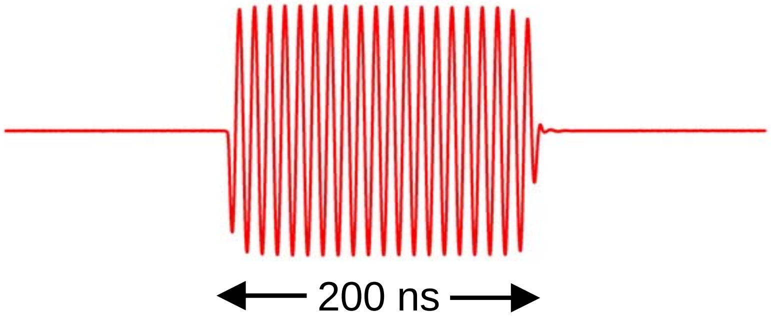
Consider 1-2 THz bandwidth, single-mode detector

300 K blackbody = 3.6 nW, ~10^{12} photons/sec

4.2 K blackbody = 0.8 fW, ~10^{6} photons/sec

Testing with Fauxtons

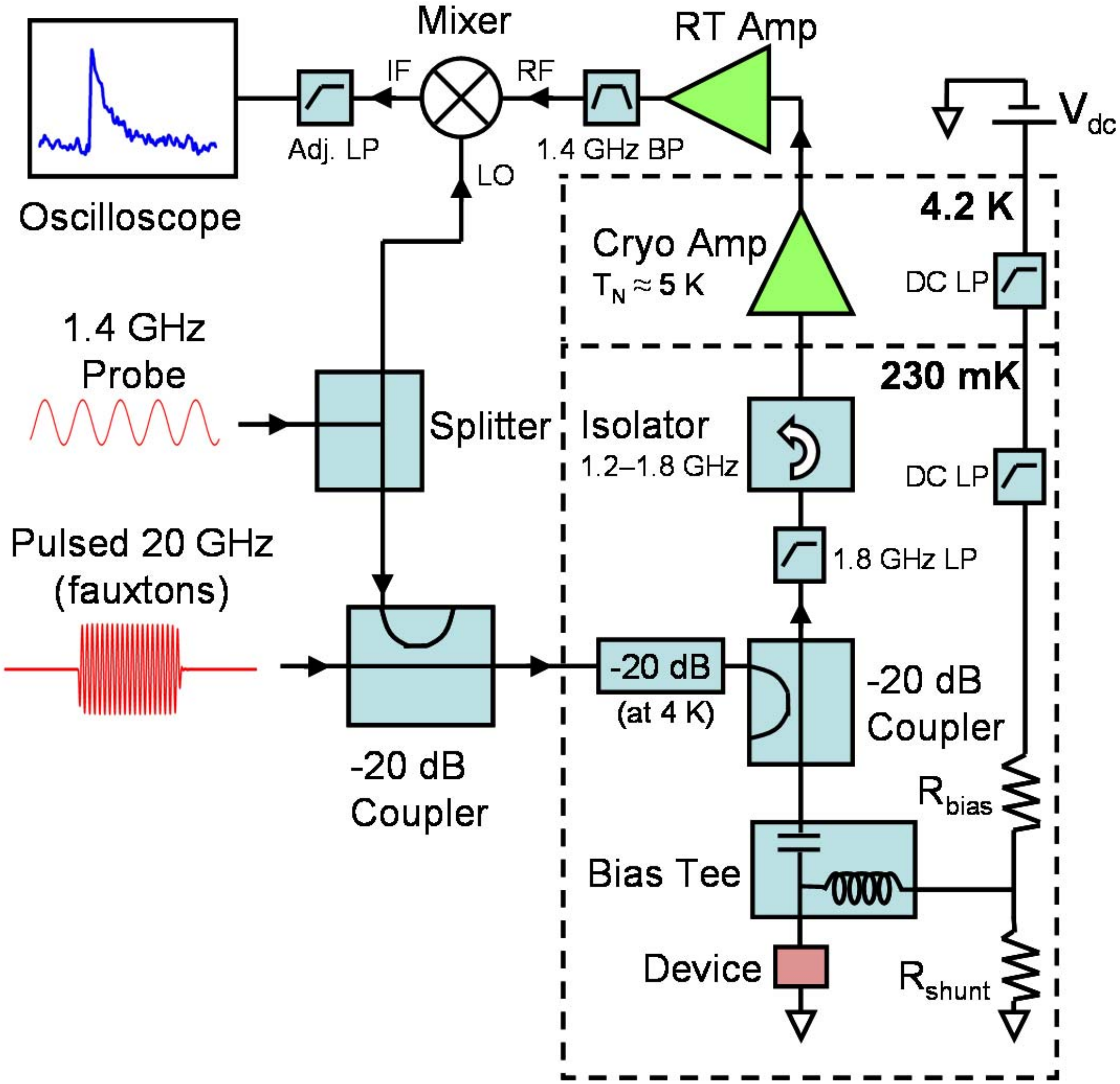
Simulate detection of a single high frequency photon with a fast microwave pulse of equivalent absorbed energy: $f_{fauxton} = E_{abs}/h$



- Device isolated from THz-IR blackbody radiation
- Coupling efficiency can be calibrated precisely with Johnson noise thermometry
- Fauxton frequency can be tuned simply by adjusting the amplitude of the microwave source

= on-demand source of single THz-IR ~~photons~~ fauxtons!

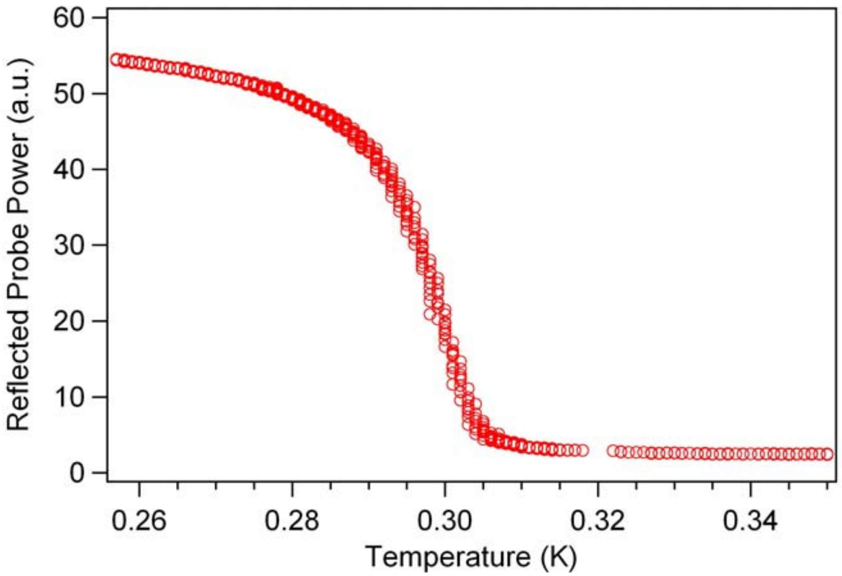
Testing with Fauxtons



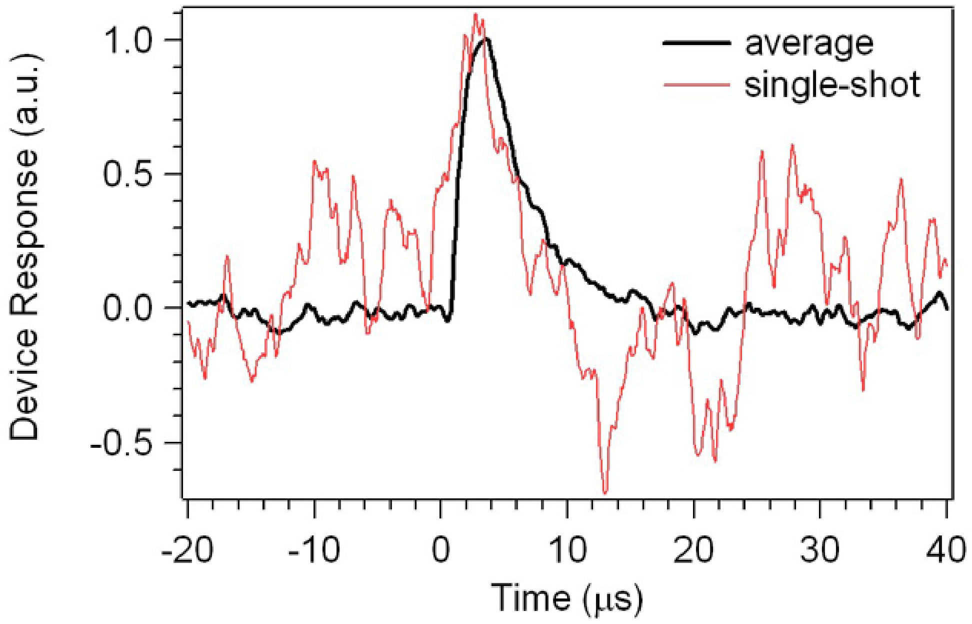
Experimental Schematic

<u>Microwave reflection readout of the device impedance</u>

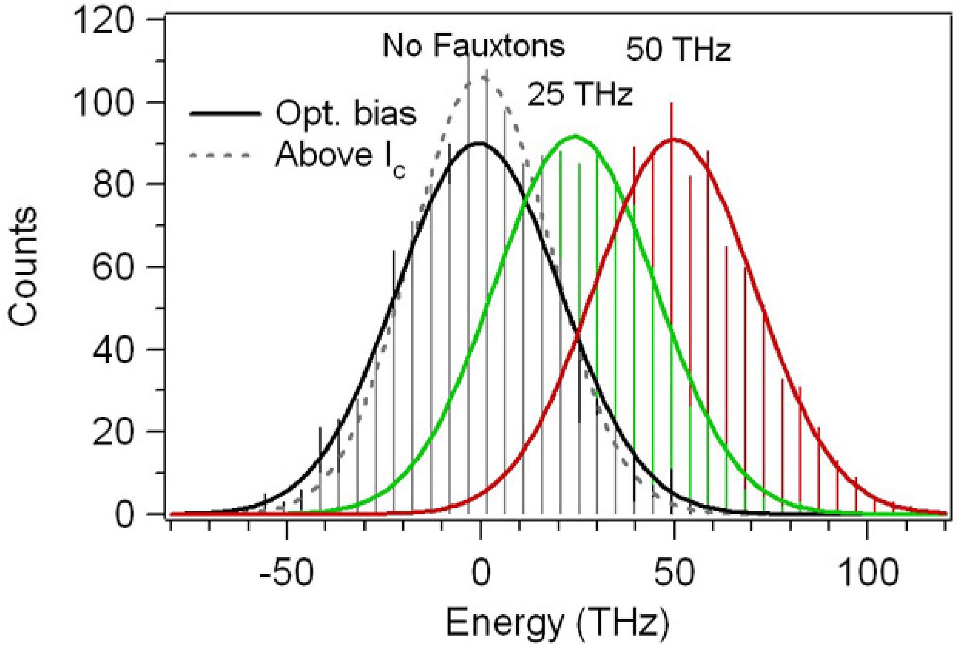
ultra-low-noise amplifier with negligible backaction



Energy Resolution



Single-shot and averaged response to 50 THz fauxton



Histograms of pulse heights for different fauxton energies; δE above I_c set by amp. noise

$\delta E_{tot}/h = 49 \pm 1$ THz

$\delta E_{amp}/h = 43$ THz

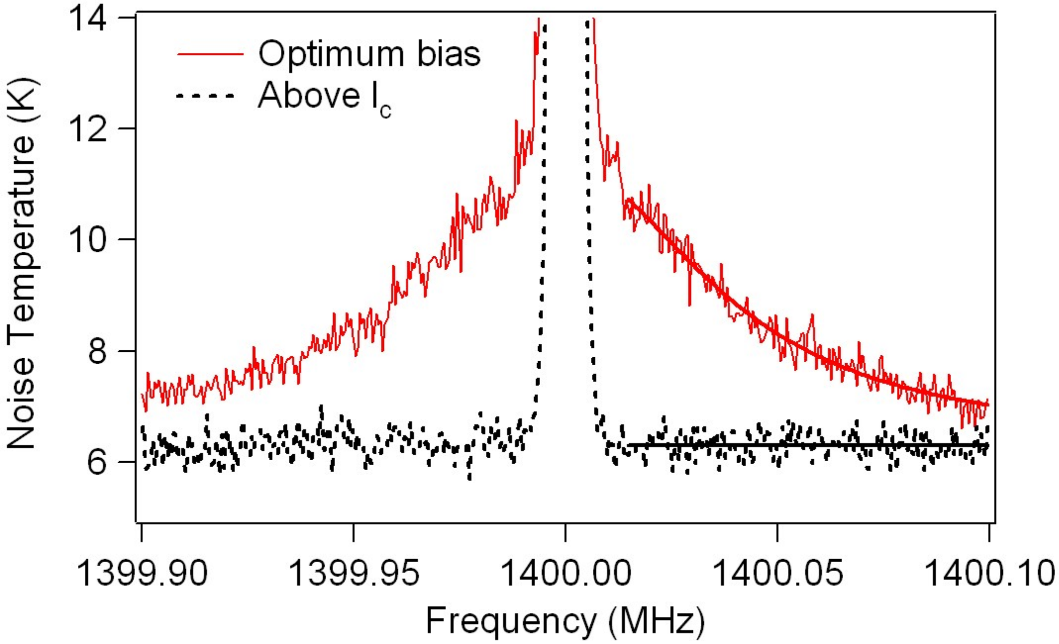
$\delta E_{intrinsic}/h \approx 23$ THz

Energy Resolution

$$\delta E = 2\sqrt{2\ln 2}\left(\int_0^\infty \frac{4df}{NEP^2}\right)^{-1/2}$$

$NEP_{th} = (4k_B T^2 G_{th})^{1/2}$

$\delta E_{intrinsic}/h$ (0-100 kHz) = 20 THz



Noise measured at mixer input; T_N referred to amplifier input

Measured responsivity

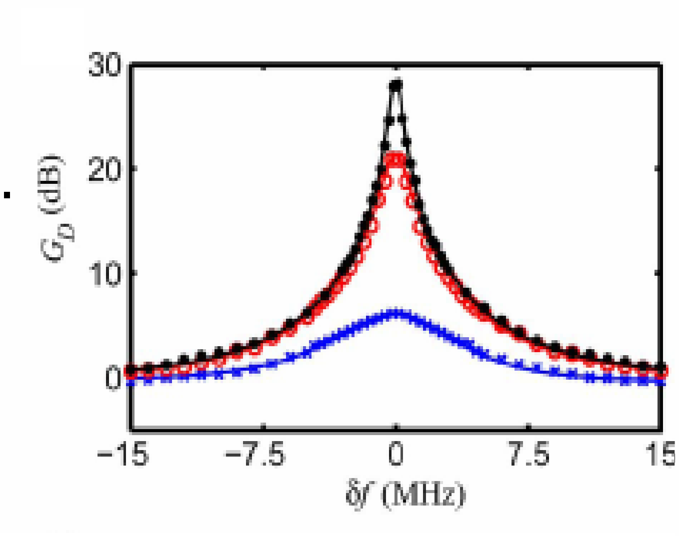
$S = 1.7 \times 10^7$ V/W

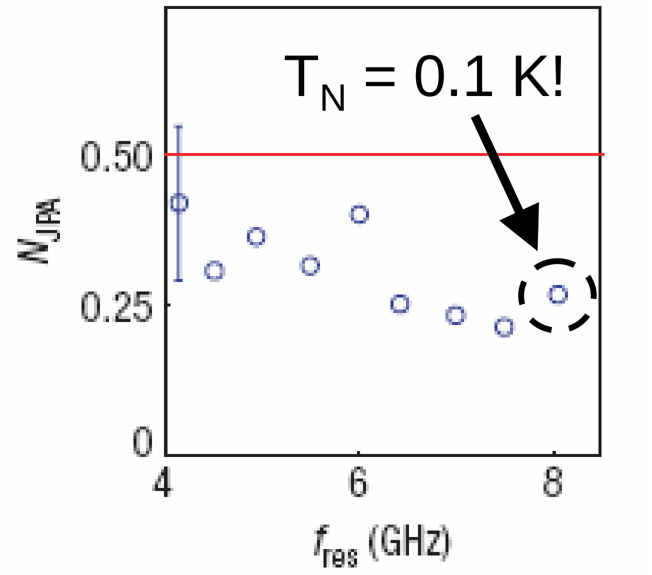
$\delta E_{tot}/h$ (0-100 kHz) = 50 THz

Improving δE

Need a lower noise amplifier…

Josephson Parametric Amp.
Castellanos-Beltran *et al.* (Colorado/JILA/NIST), *Nature Physics* **4**, 928 (2008)





Also

Josephson Parametric Converter, Bergeal *et al.* (Yale), arXiv 0912.3407 (2009)

Josephson Parametric Amp., Yamamoto *et al.* (NEC), APL **93**, 042150 (2008)

DC-SQUID Microwave Amplifier, Spietz *et al.* (NIST), APL **93**, 082506 (2008)

… $\delta E_{total}/h < 1$ THz appears feasible

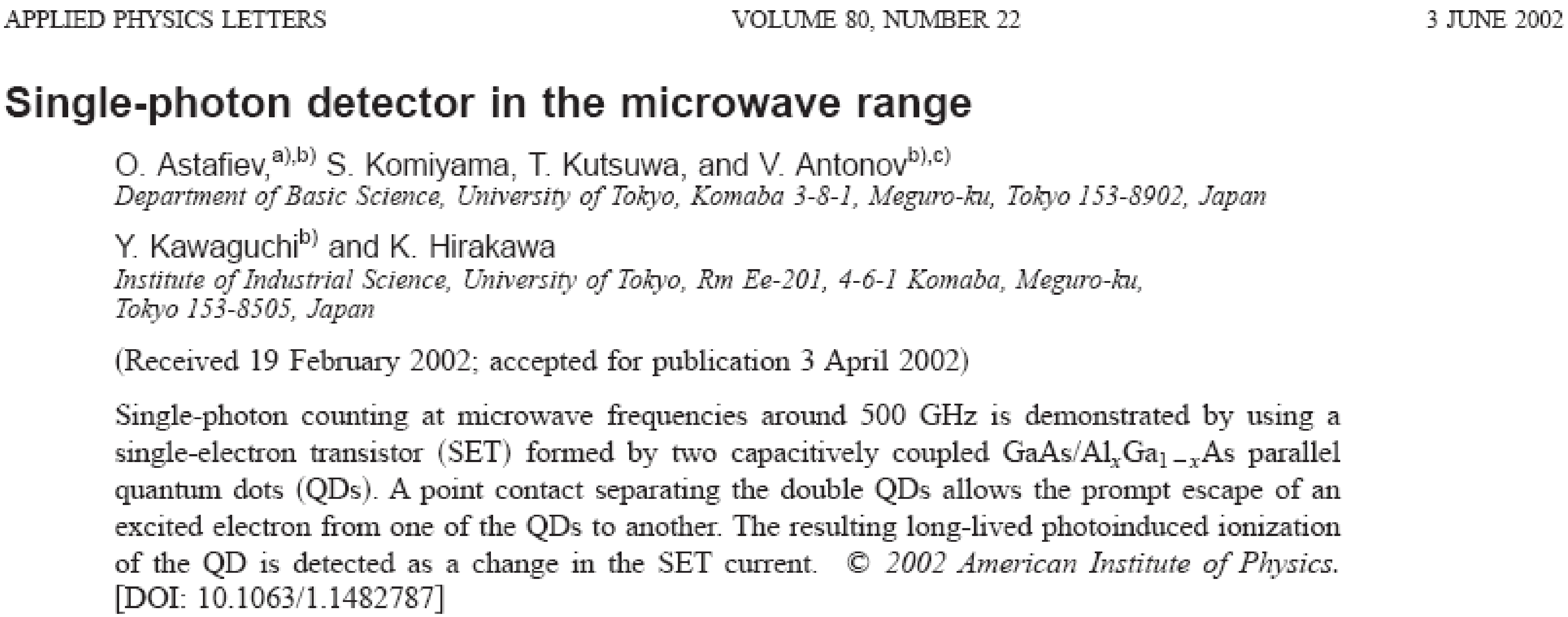
A Few Words about the Competition

Semiconductor quantum dot with SET readout

Excellent sensitivity – demonstrated detection of single 0.5 THz photons

But…

- not energy resolving
- low quantum efficiency
- complex device geometry and readout; no clear approach to multiplexing



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Single-photon detector in the microwave range

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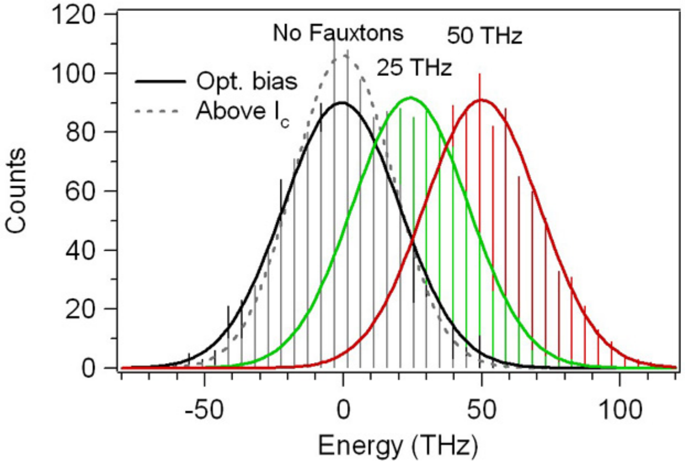
(Received 19 February 2002; accepted for publication 3 April 2002)

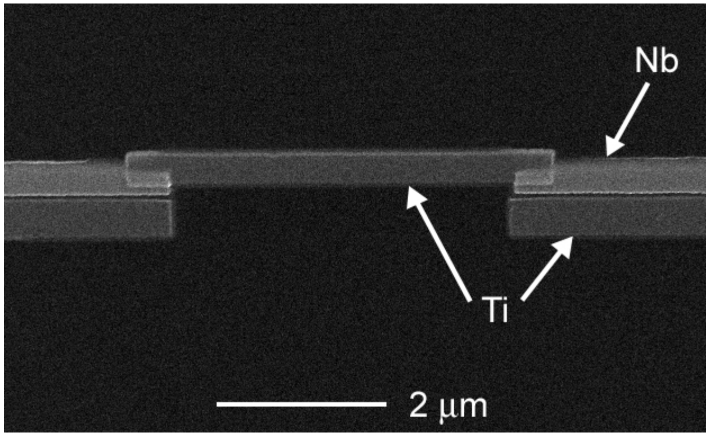
Single-photon counting at microwave frequencies around 500 GHz is demonstrated by using a single-electron transistor (SET) formed by two capacitively coupled GaAs/$Al_xGa_{1-x}As$ parallel quantum dots (QDs). A point contact separating the double QDs allows the prompt escape of an excited electron from one of the QDs to another. The resulting long-lived photoinduced ionization of the QD is detected as a change in the SET current.
[DOI: 10.1063/1.1482787]

Conclusion

Fauxton characterization technique for ultra-sensitive bolometric calorimeters – can serve as a benchmark for more challenging optical experiments

preprint: arXiv:0906.1205





$\delta E < 1$ THz appears feasible through reducing the Ti nanobridge volume/T_c + lower noise readout

Funding provided by NSF and NASA-JPL