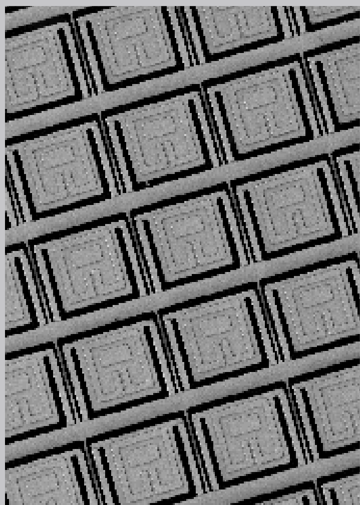
SAND2012-4972C



Metamaterial Enhanced Terahertz Sensing

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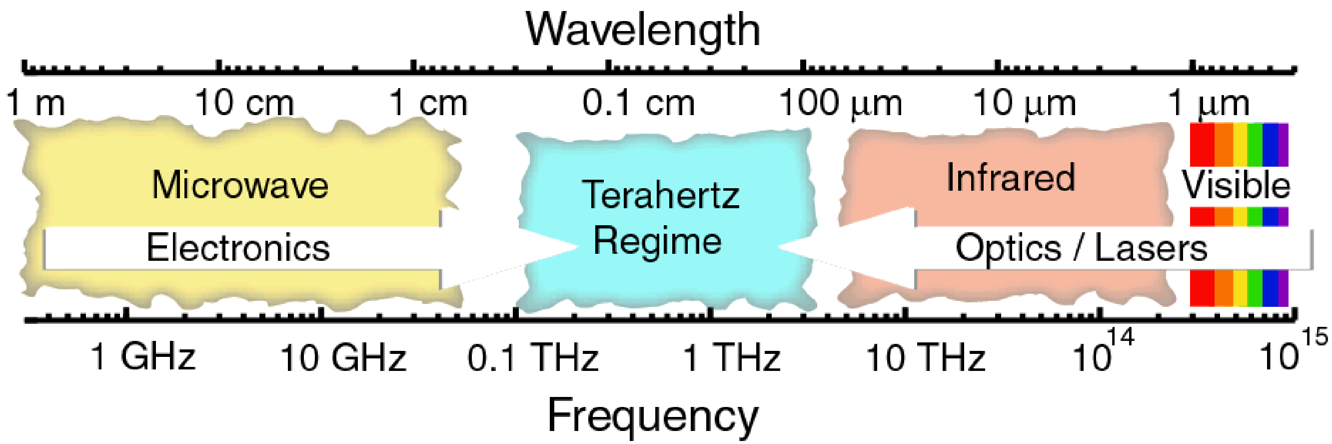
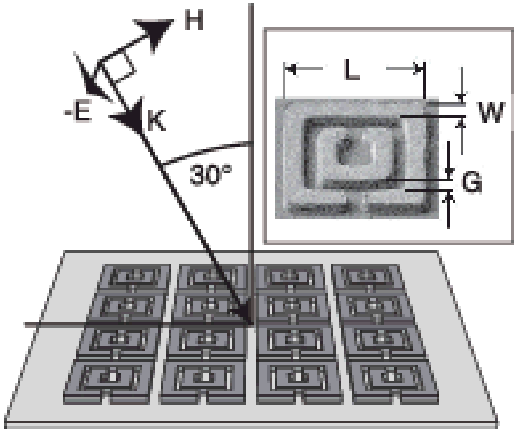
THz Regime Good for Metamaterial Sensing

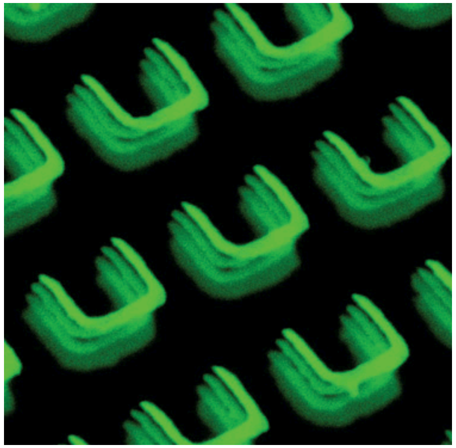
1 THz → 4 meV → 48K → 300 μm → 33 cm⁻¹



D. R. Smith, Phys. Rev. Lett. 14, 234 (2000)

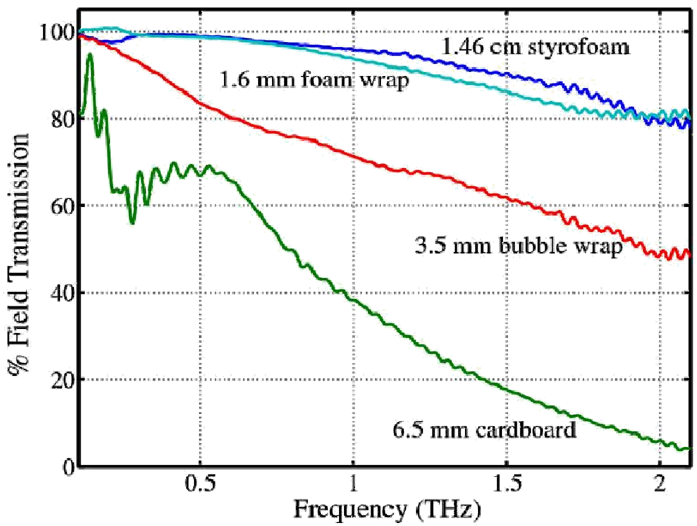


T. J. Yen,Science 393, 1494 (2004)



Na Liu,et al, Nat. Mat. 7, 31 (2008)

THz Imaging – Movement to FPAs



Technology	Sensitivity	Price
Coherent heterodyne	Good	Huge*
Coherent direct (with MMIC preamplification)	Good	Large
Cryogenic Microbolometers	Good	Moderate
Incoherent direct (i.e. diodes, no preamplification)	Moderate	Small
Antenna coupled microbolometers	Poor (active only)	Tiny

Decreasing complexity
Decreasing sensitivity
Increasing detector requirements

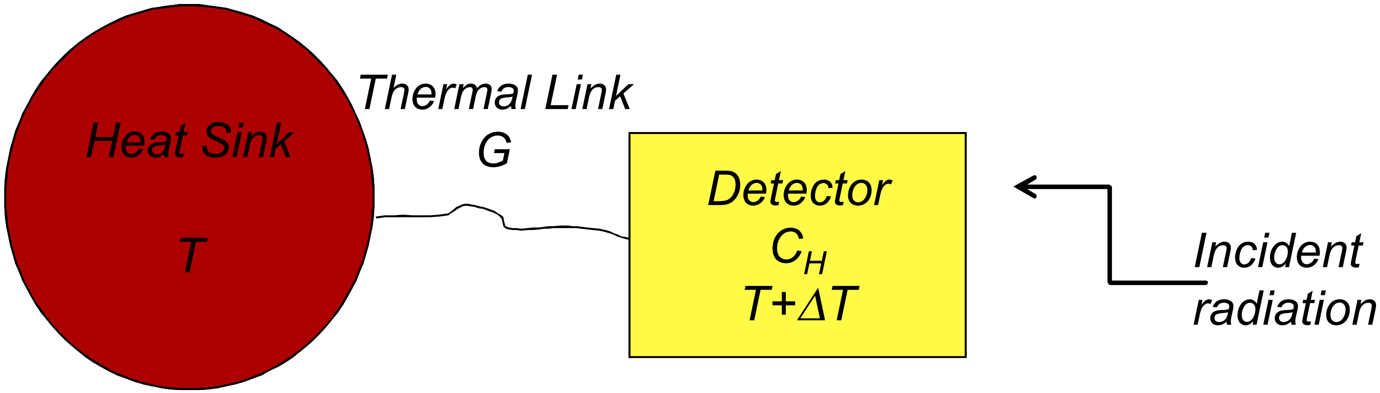
Maximum frequency

~200 GHz	600 GHz	> 1THz

Arttu Luukanen, MilliLab/VTT
Tech. Res. Cent. Finland

Thermal Detector Considerations

Sandia National Laboratories



Three main considerations

- **Thermal Engineering: Conductance and Heat Capacity**
- Physical property with sensitive thermal response
- Signal readout / amplification etc.

$$\eta_{abs} P_{inc} = G\Delta T + C_H \frac{d(\Delta T)}{dt}$$

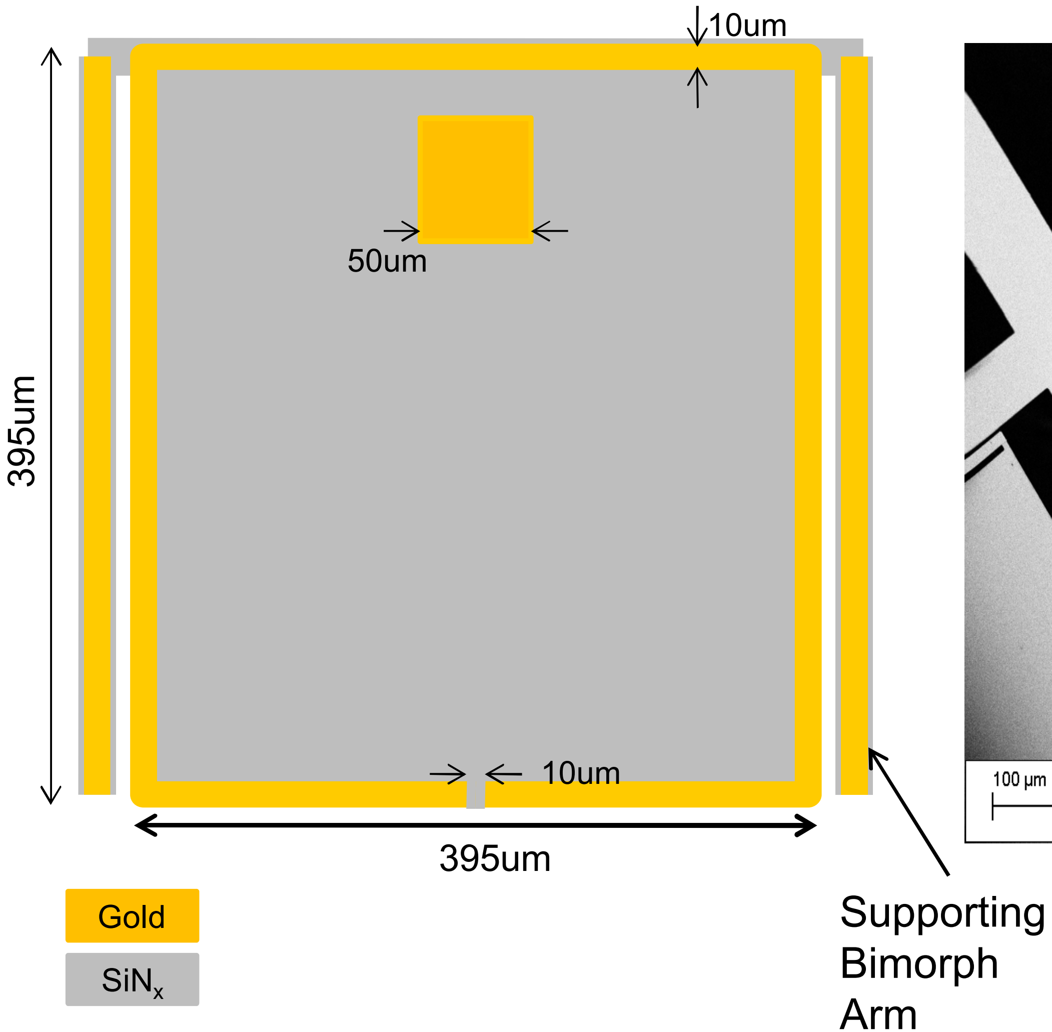
$$\Delta T = \frac{\eta_{abs} P_{\omega}}{(G^2 + \omega^2 C_H^2)^{1/2}}$$

$$\tau = C_H / G$$

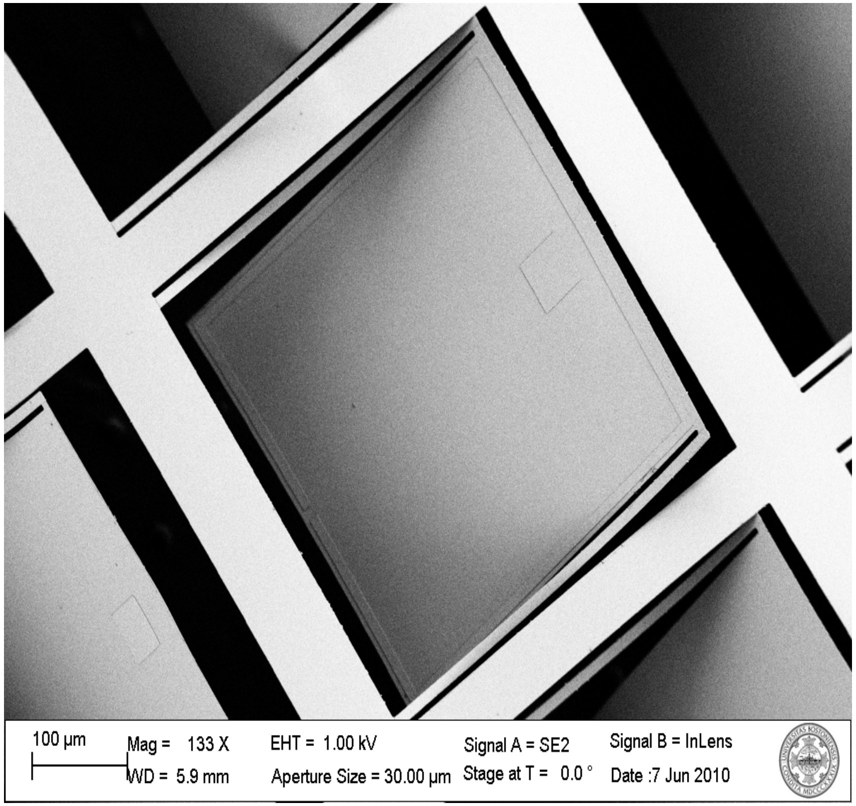
E. H. Putley, "Thermal Detectors"

95 GHz Detector

Layout of 95 GHz Detector

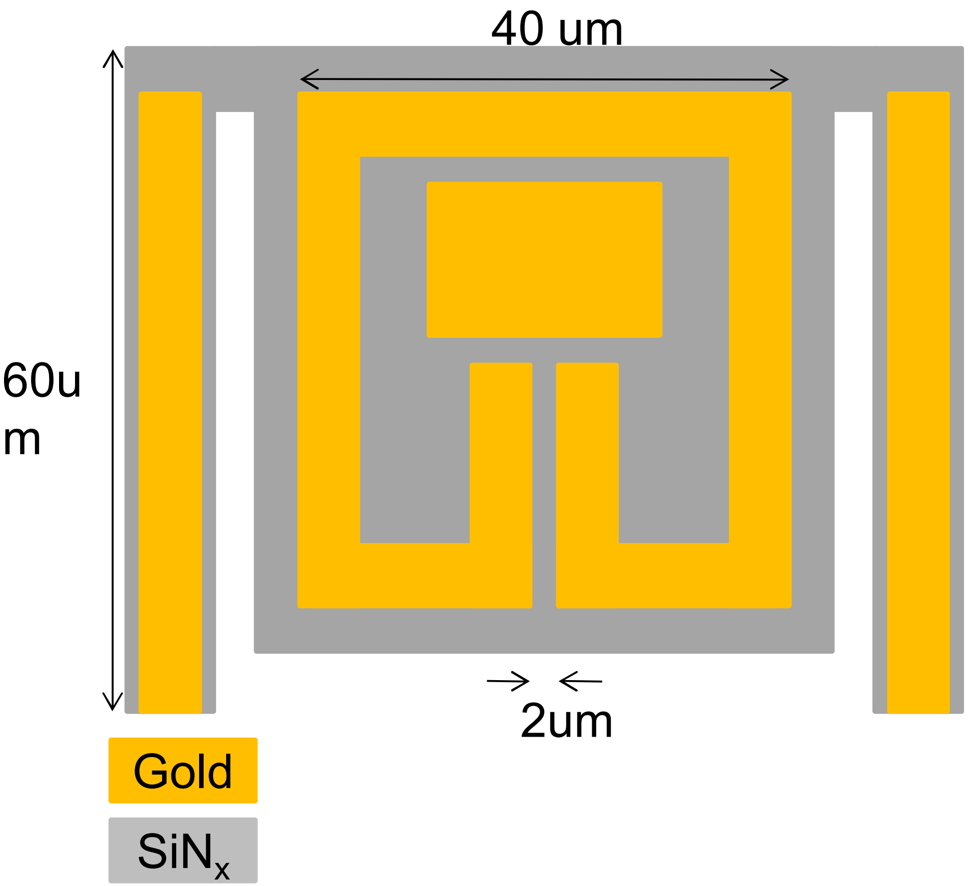


Micrograph of 95 GHz Detector

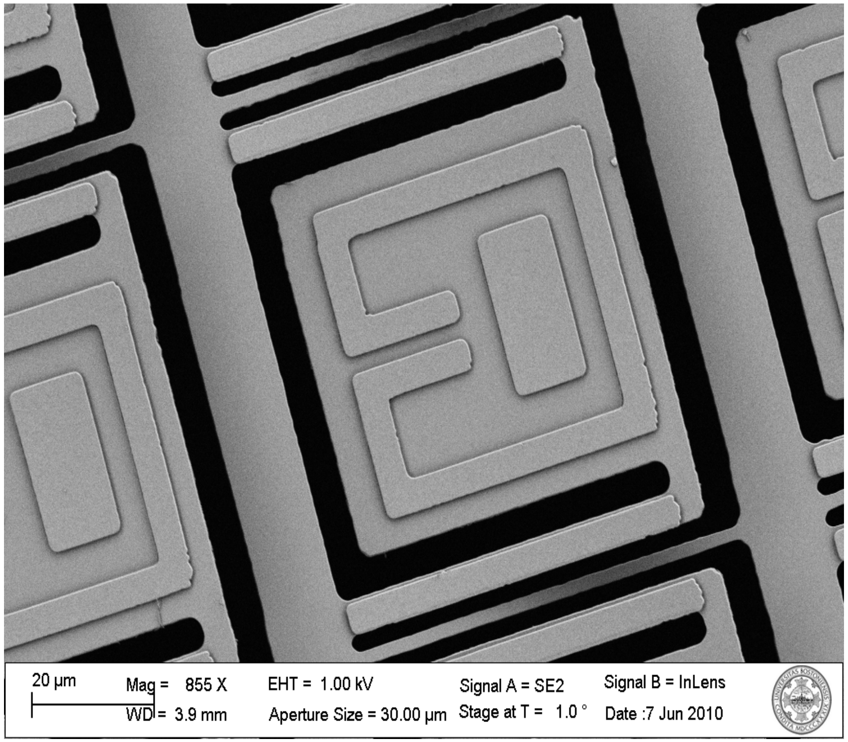


693 GHz Detector

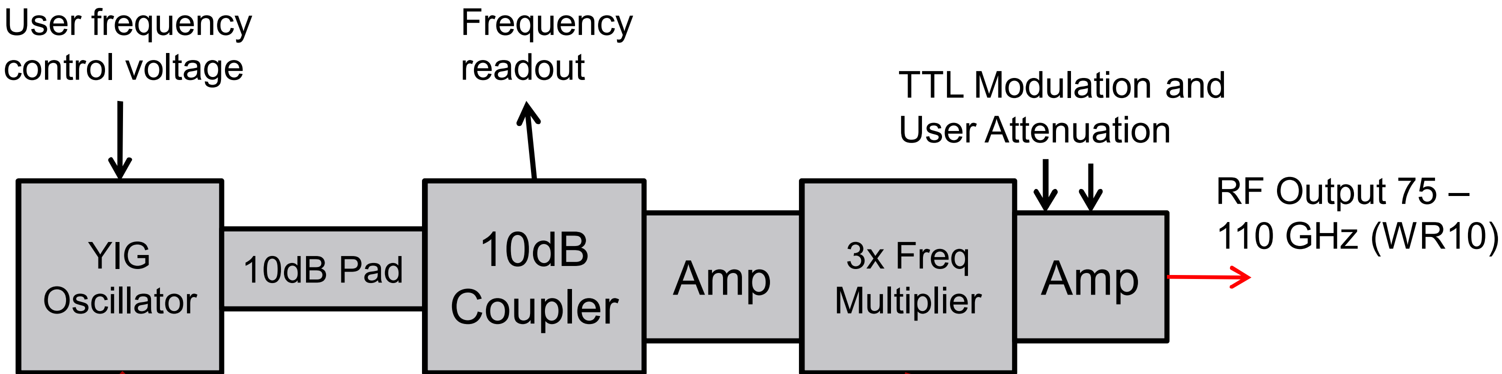
Layout of 693 GHz Detector

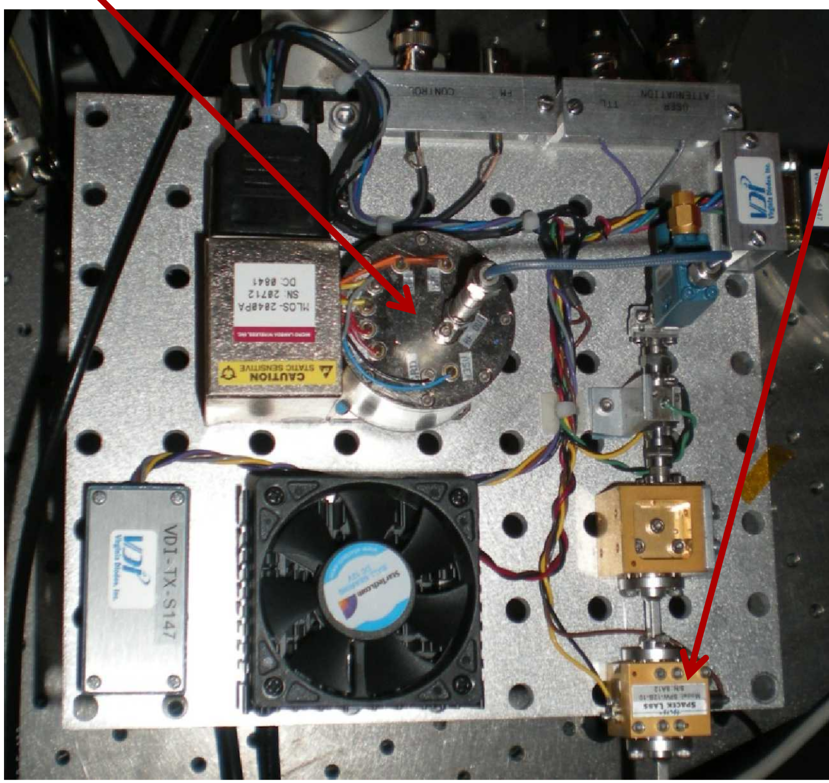


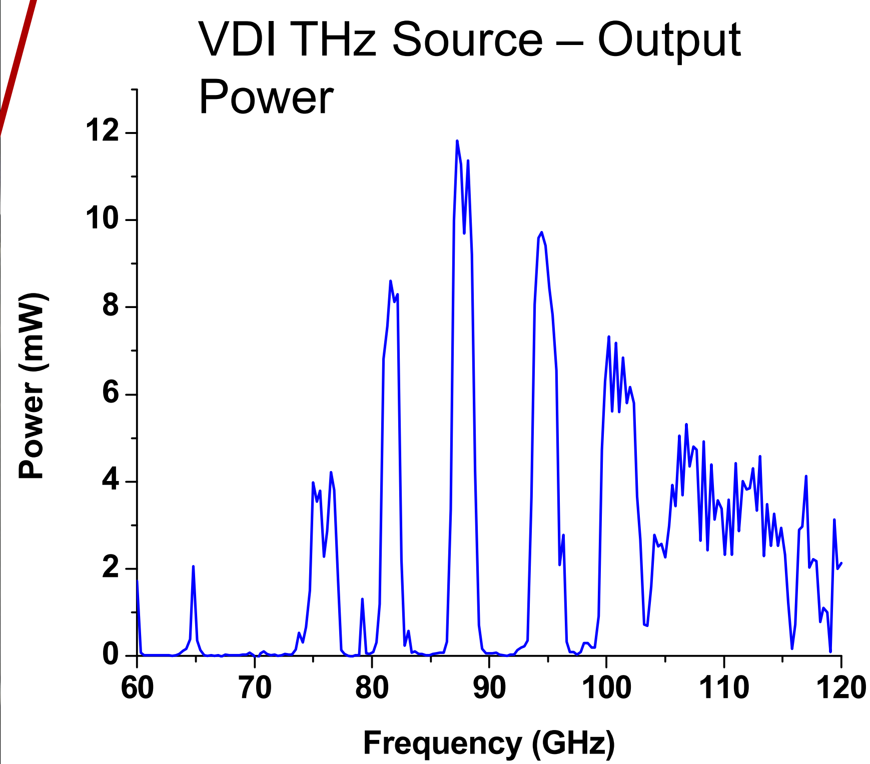
Micrograph 693 GHz Detector



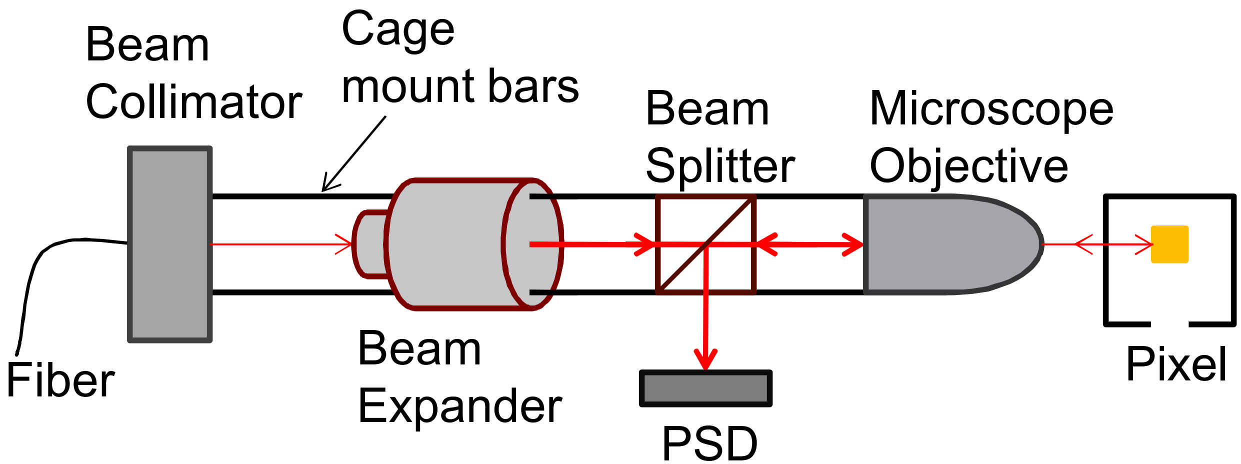
95 GHz Characterization - Virginia Diodes Tunable THz Source

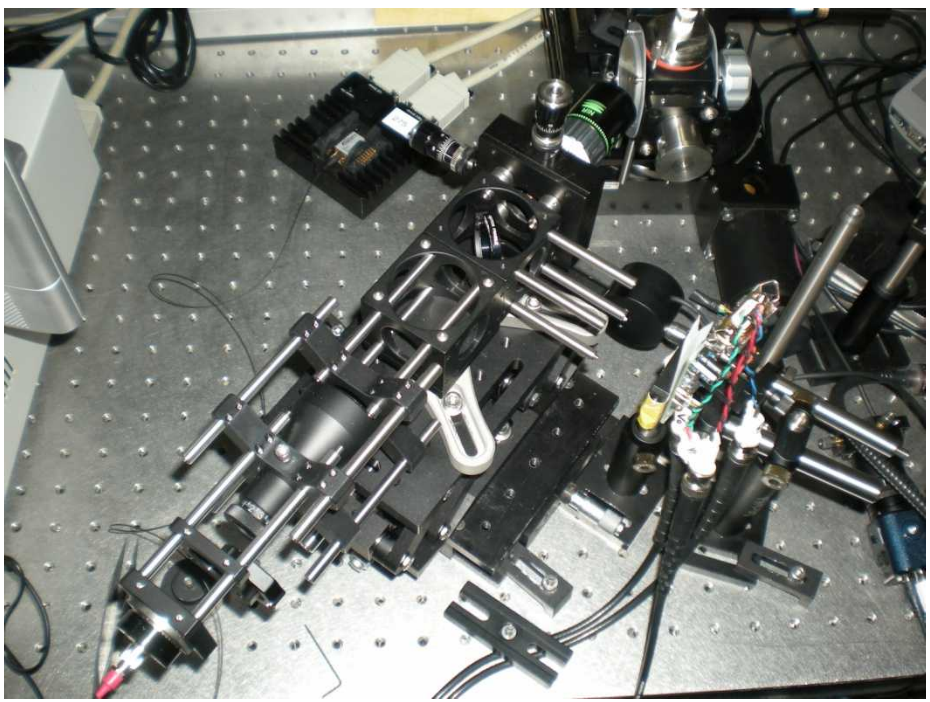


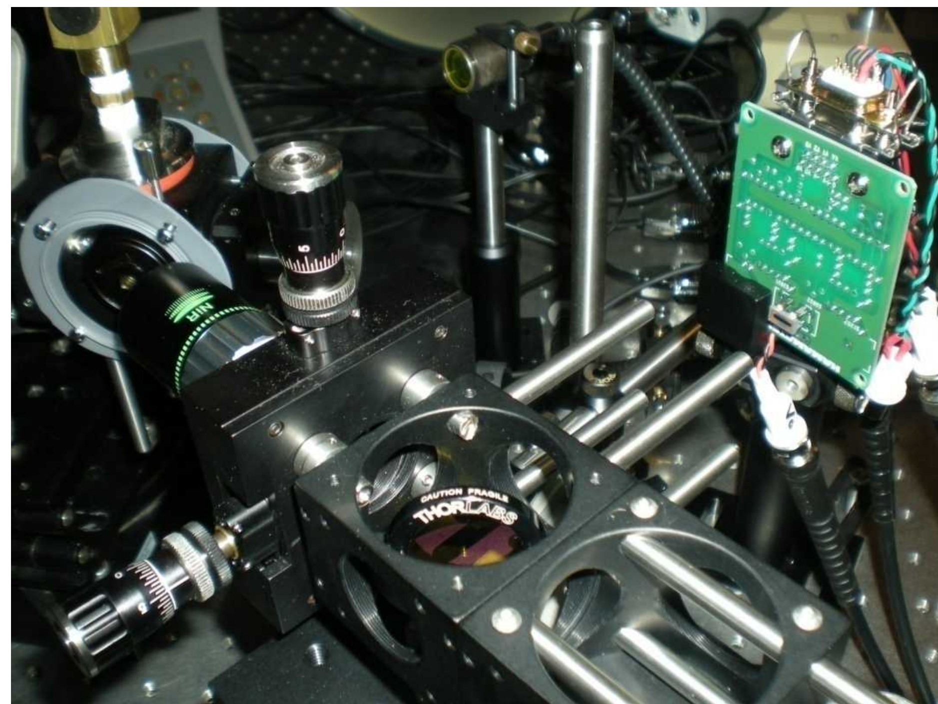




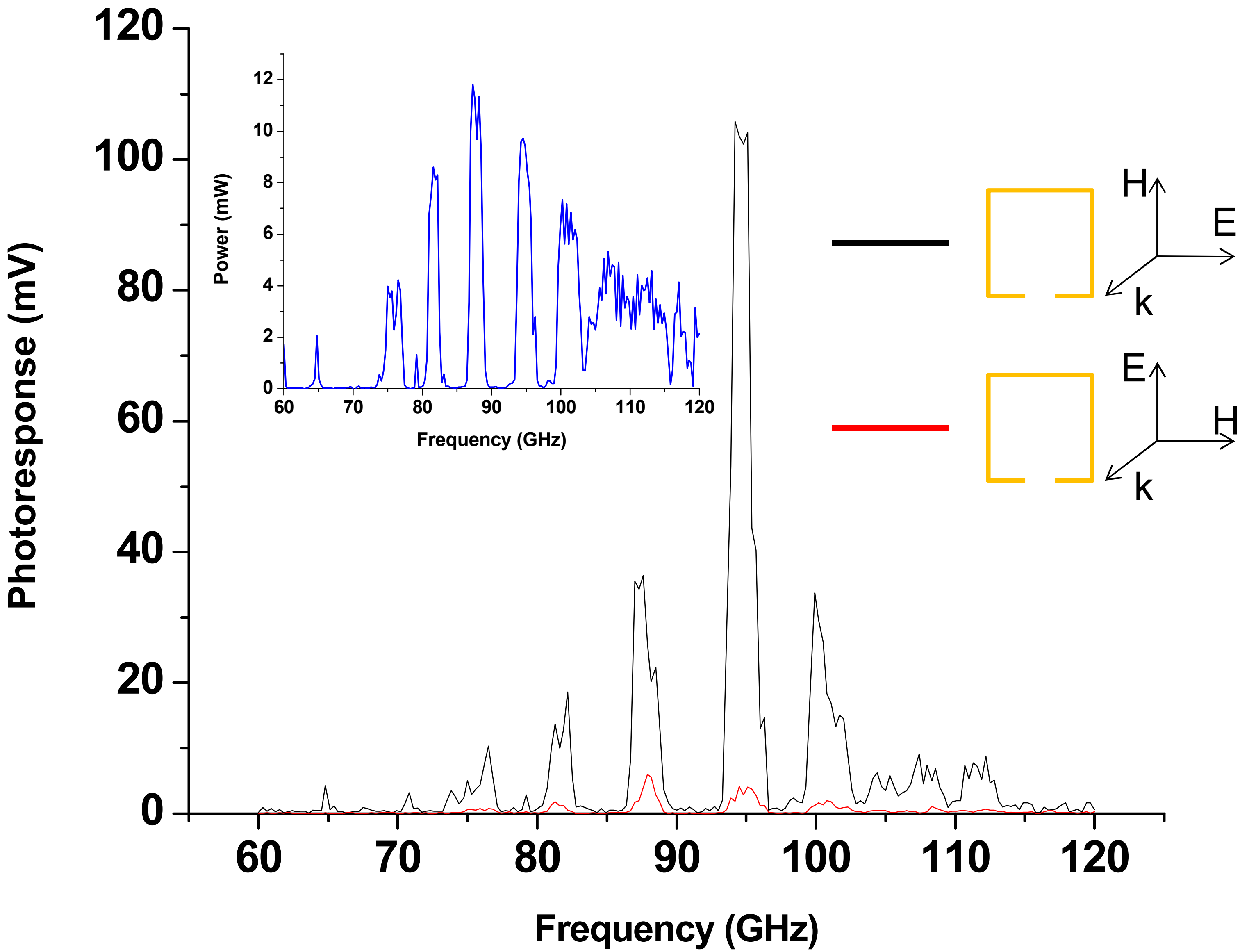
Optical Measurement Apparatus



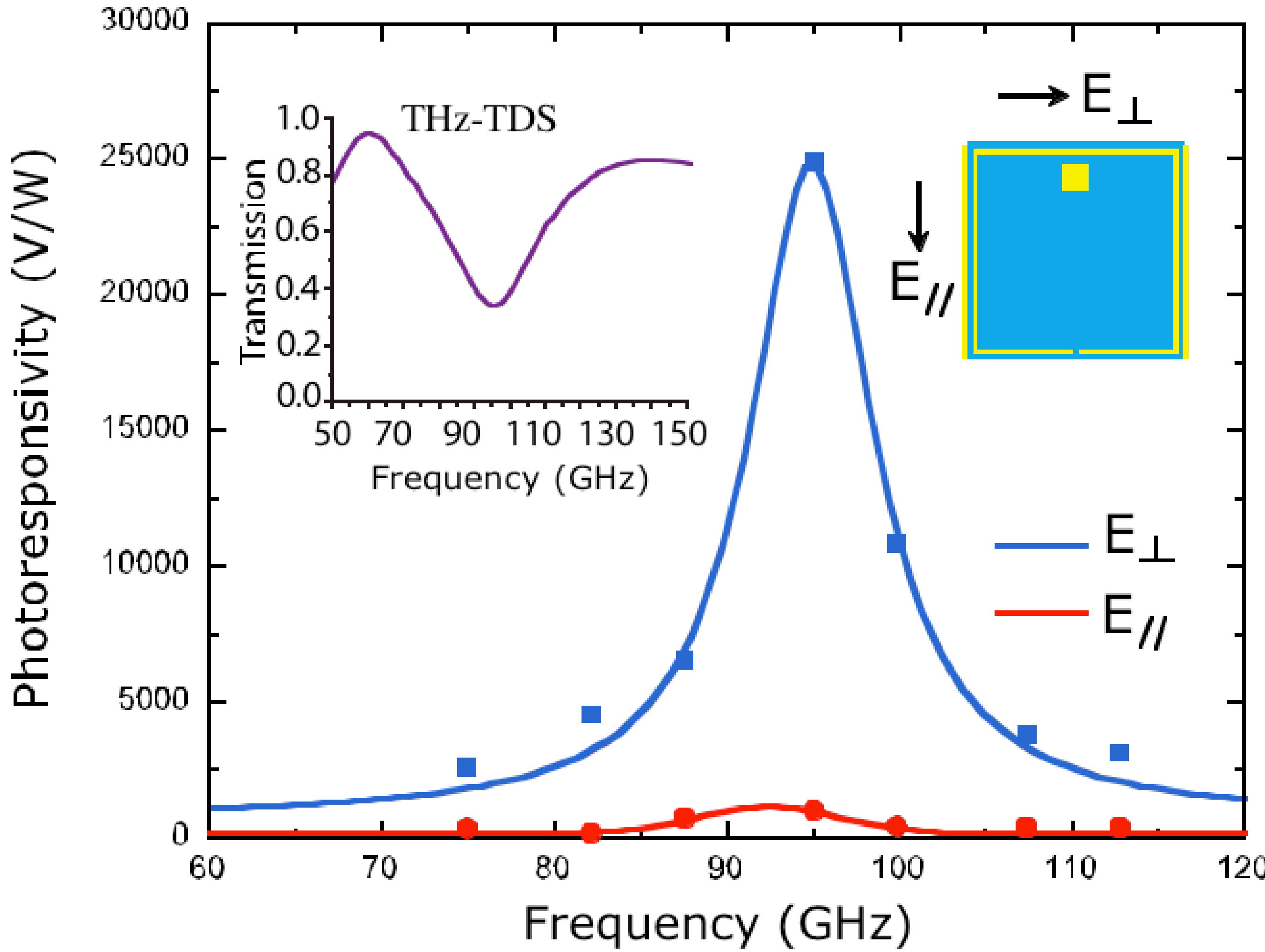




Spectral Response of 95 GHz Detector

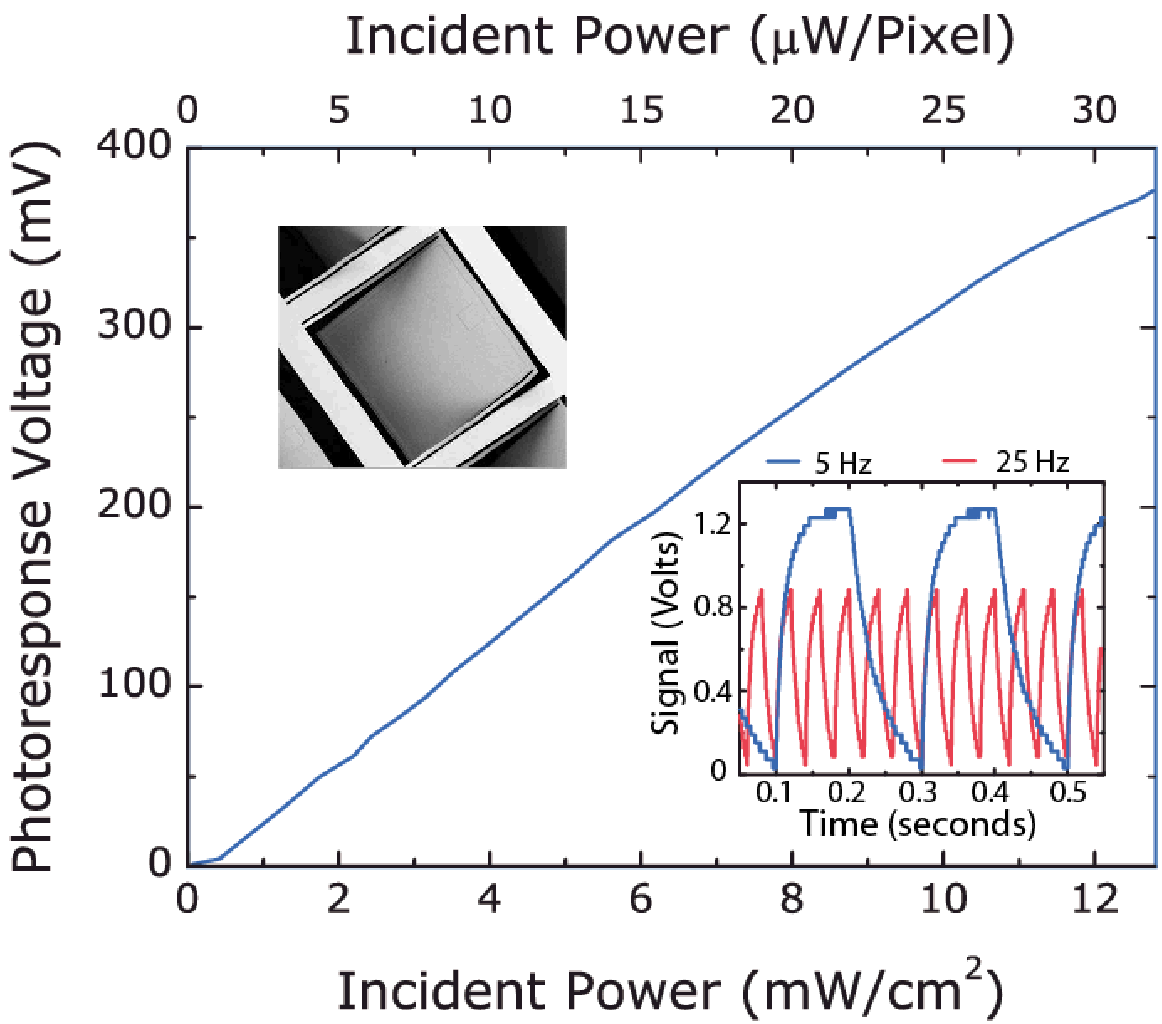


Lorentz Fit of Peak Power Points



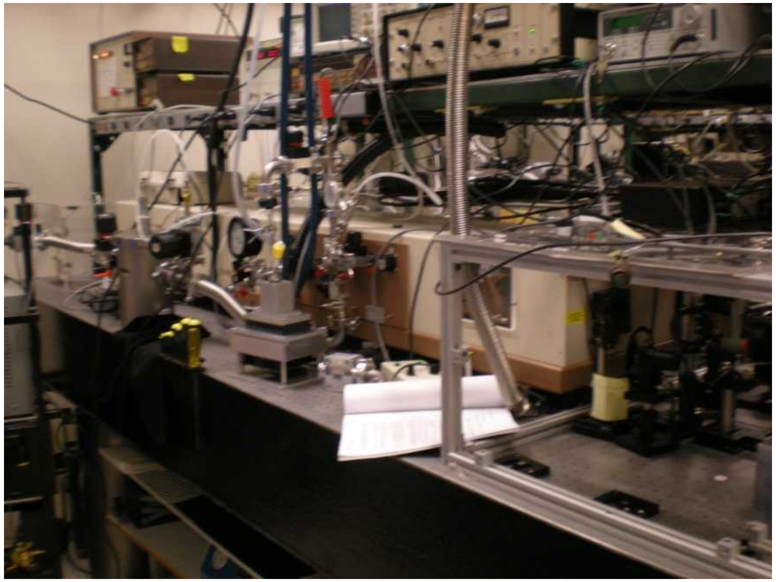
- Room T
- Ambient Pressure
- 15 Hz Chop Rate
- Lorentz fit matches TDS measurement (insert)

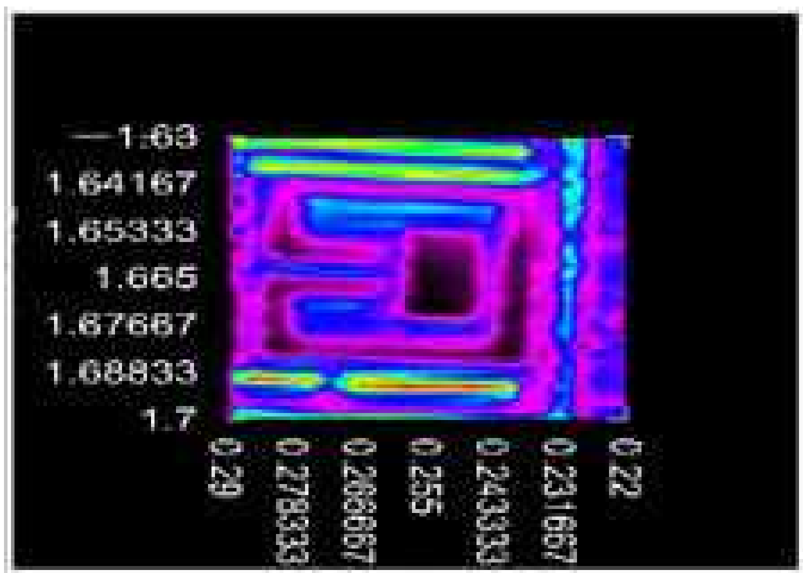
95 GHz Response to Power Attenuation



- Linear response with power
- τ ≈ 10 ms, sufficient for video rate applications

Characterization of 693 GHz Detector

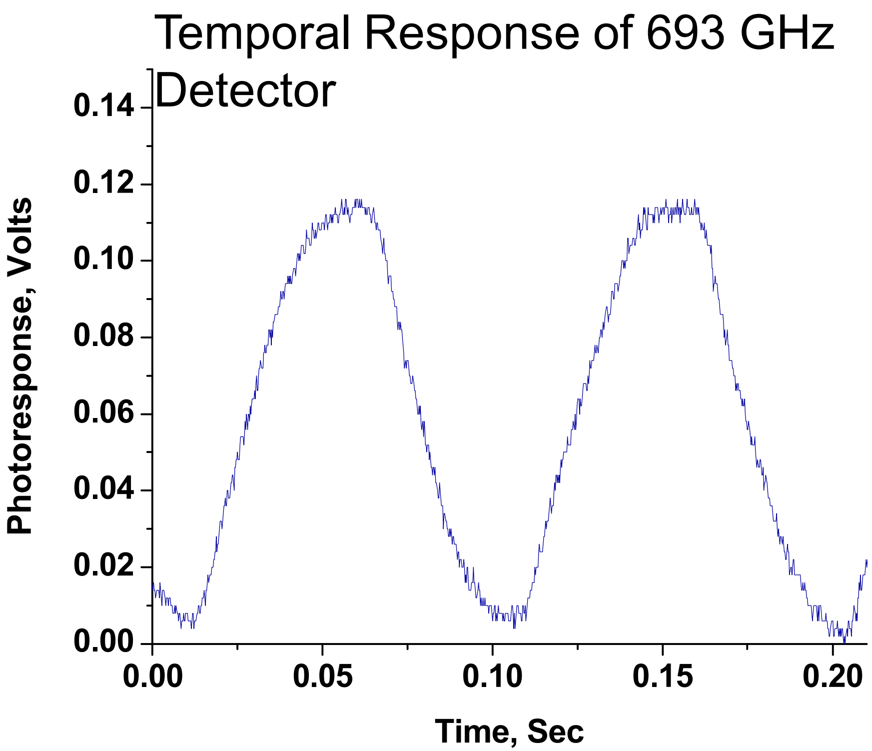


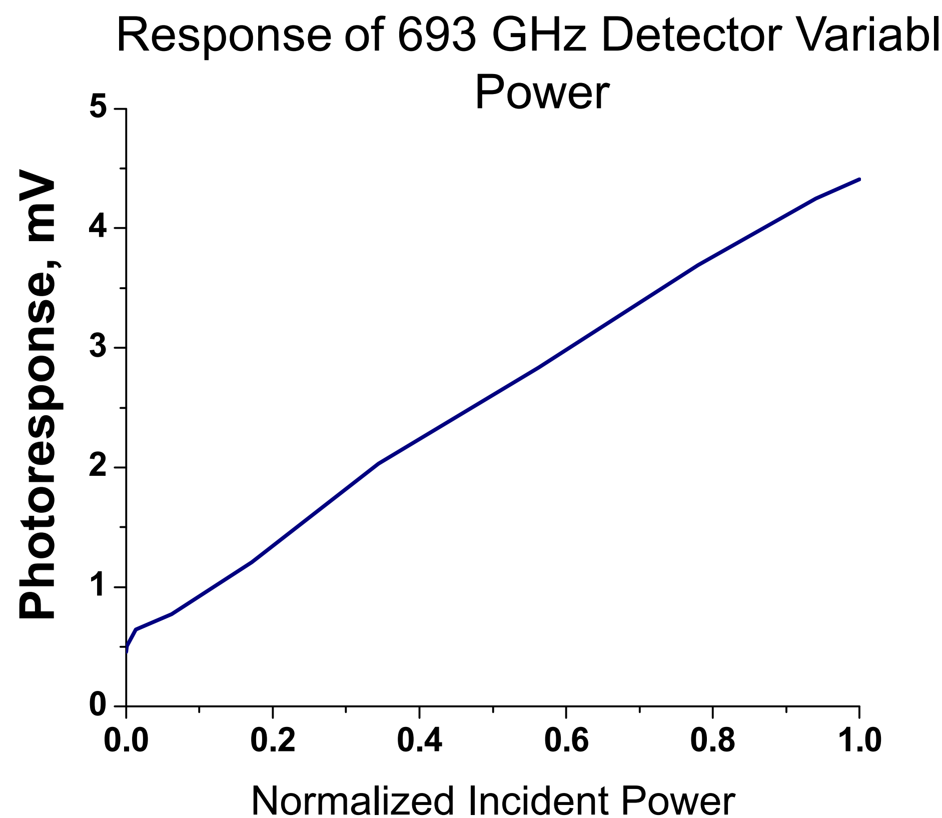


- Characterization done using a far infrared laser
- Formic acid line pumped with CO2
- High power but not tunable

- Beam alignment done using labview
- Raster scan of detector measuring transmission of measurement beam

693 GHz Detector - Characterizatio

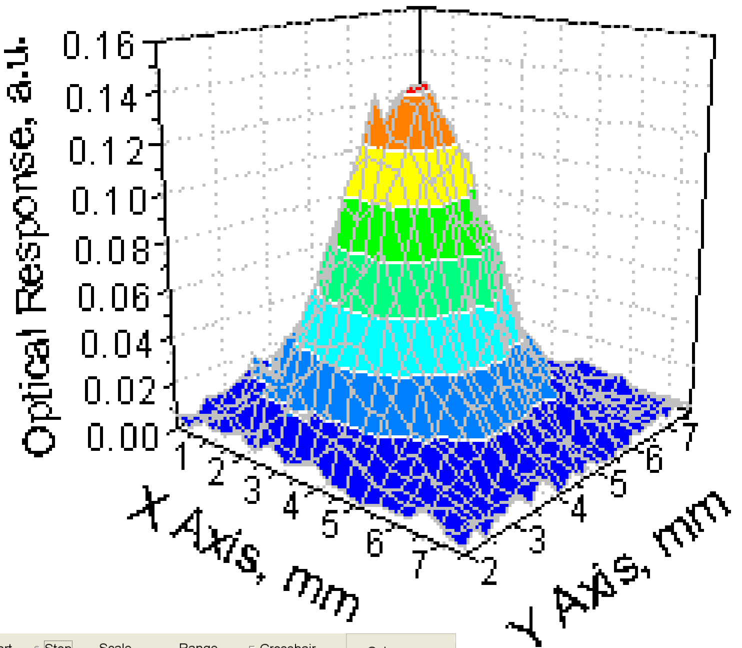


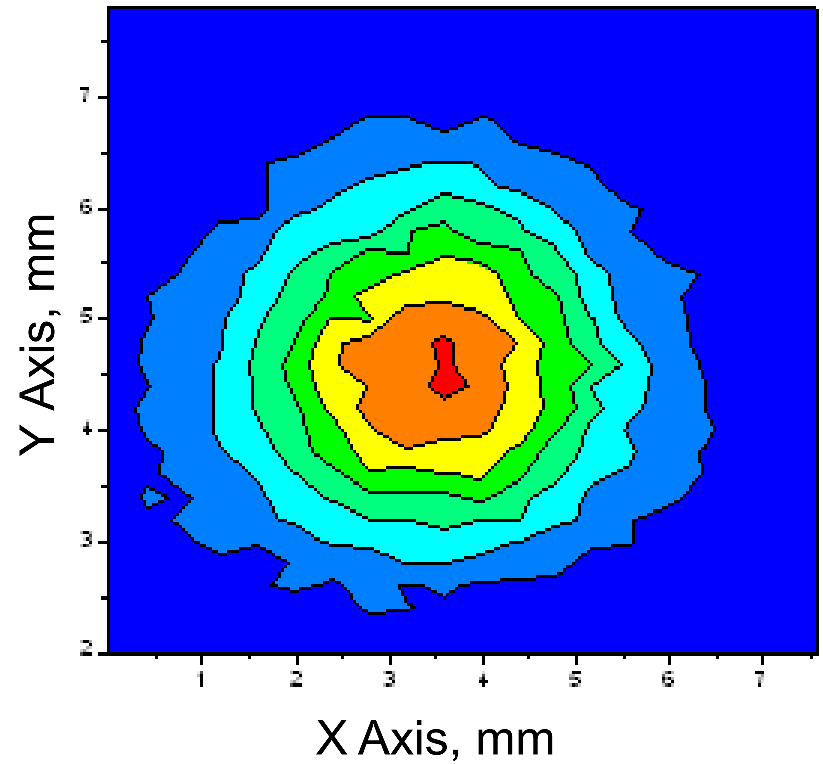


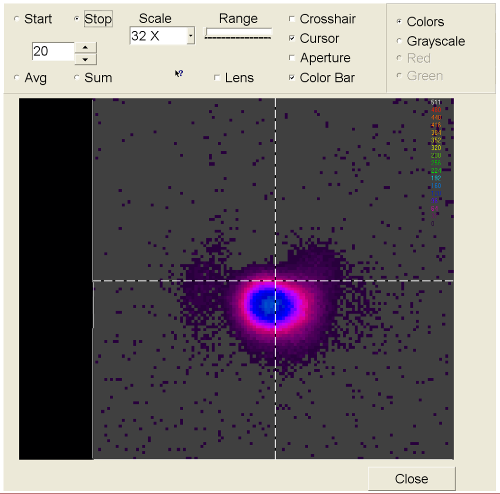
NEP = 2.96×10^{-8} W/√Hz
τ = 20 ms
Sufficient for video rate applications

Detector response linear with respect to incident power

693 GHz Detector - Beam Image of FIRL





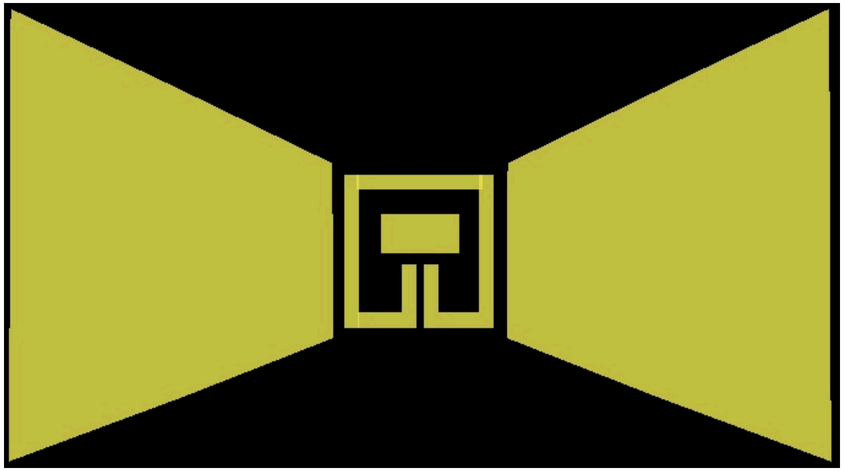


Beam profile matches Pyrocam image

Beam profile taken by performing a raster scan of the FIRL beam

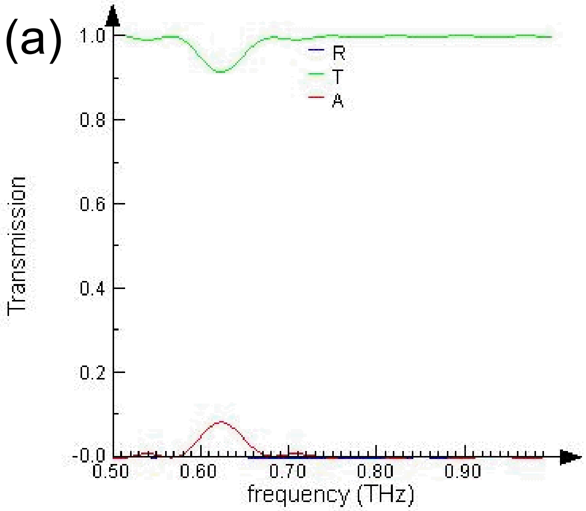
- The 95 GHz and 693 GHz detectors can be used in beam diagnostics

Future Work – Dipole coupled SRR

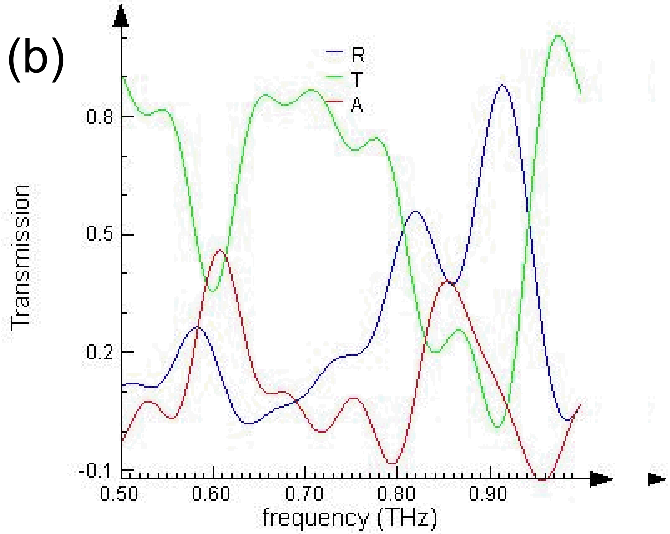


- SRR size ~λ/10
- Far below diffraction limit
- Dipole Antenna ~λ/2 maintain fast thermal time constant

(a)

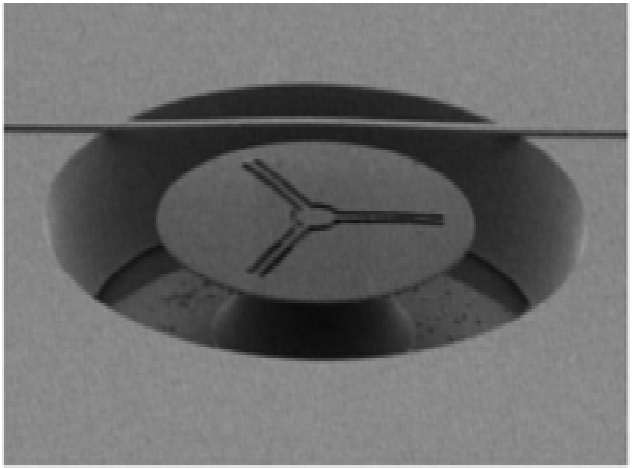


(b)



(a) Absorption and transmission plot of single SRR with no dipole antenna
(b) Plot of Absorption in SRR with dipole antenna

Future Work – Combining Silicon Photonics with Metamaterials

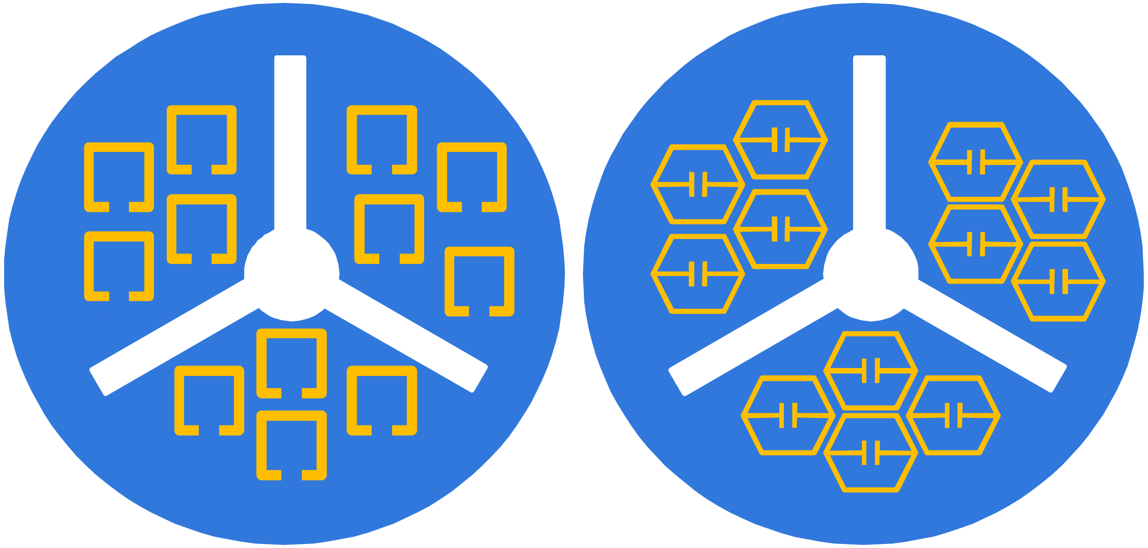


Thermal Micro Photonic Focal Plane Array (TMFPA)

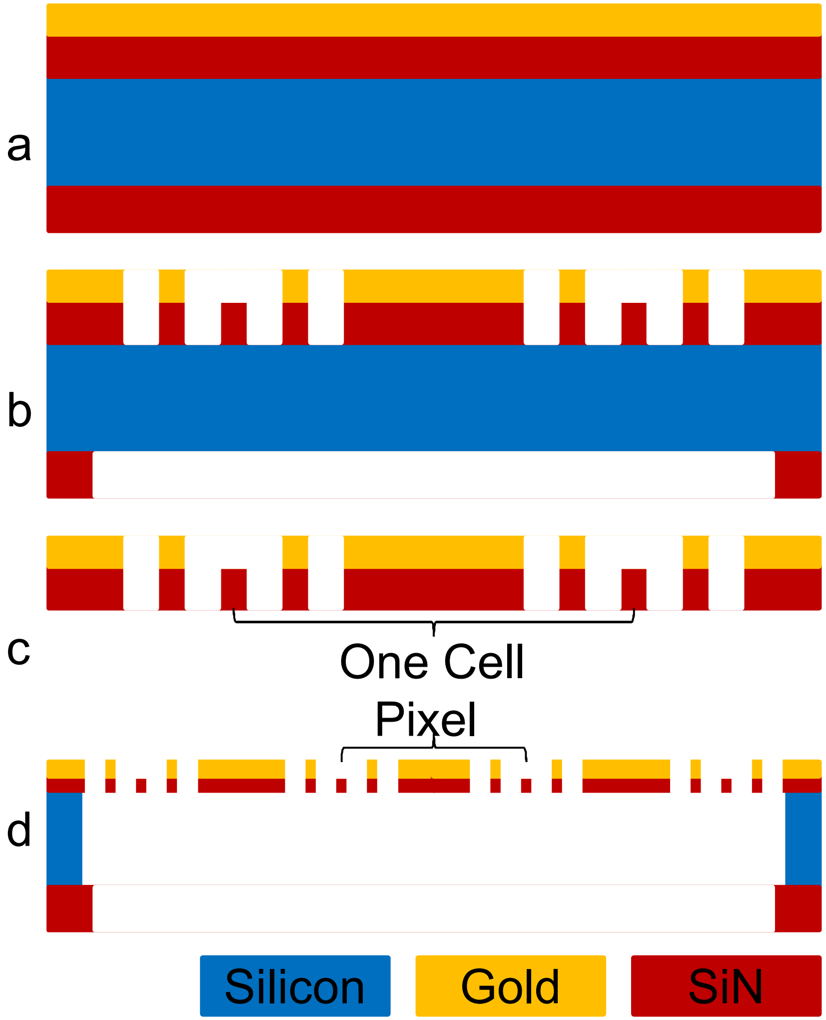
- NEP = 7.15×10^{-12} W/Hz$^{1/2}$
- τ = 2 ms
- D = 2.47×10^{8} cmHz$^{1/2}$/W

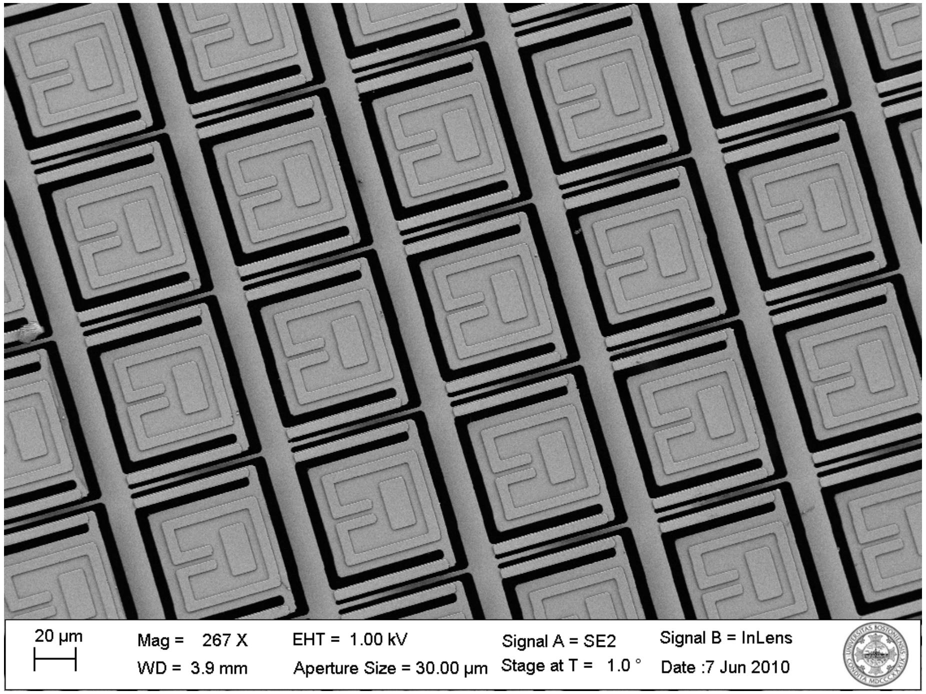
Design layout combining silicon photonics and metamaterials

- Place SRRs onto microdisk resonator
- Enhance absorption in LWIR
- Extend detection into other regions (THz)

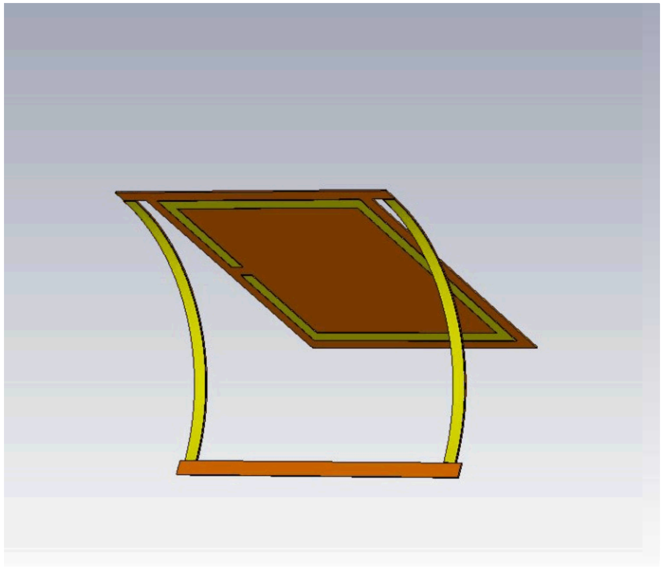


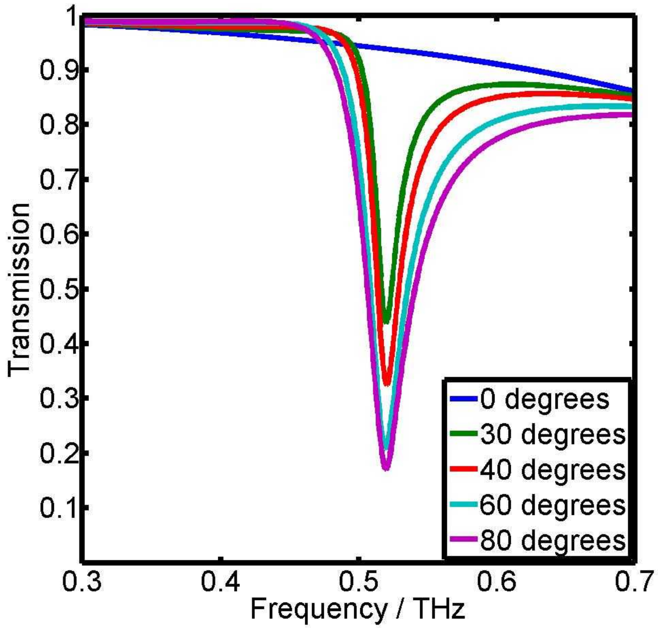
Cantilever Fabrication Process

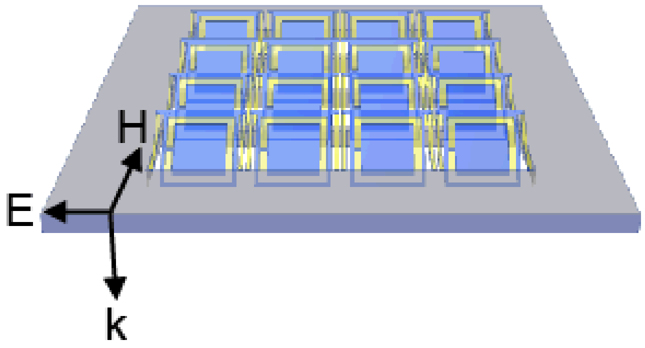


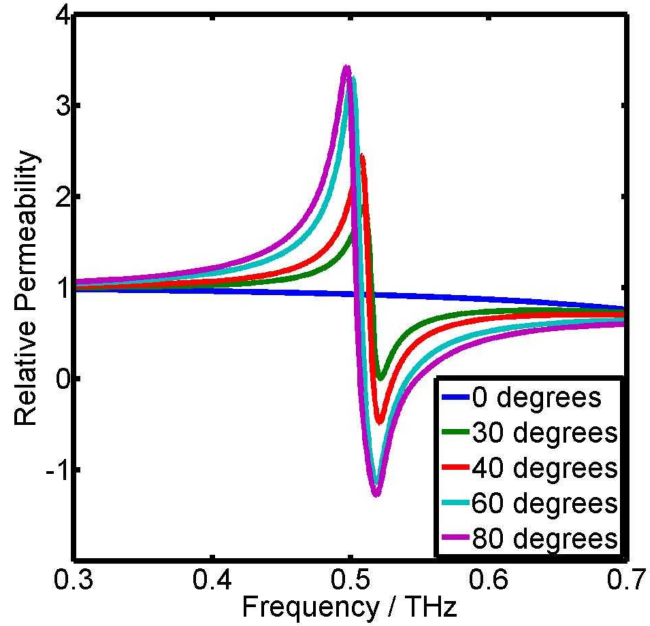


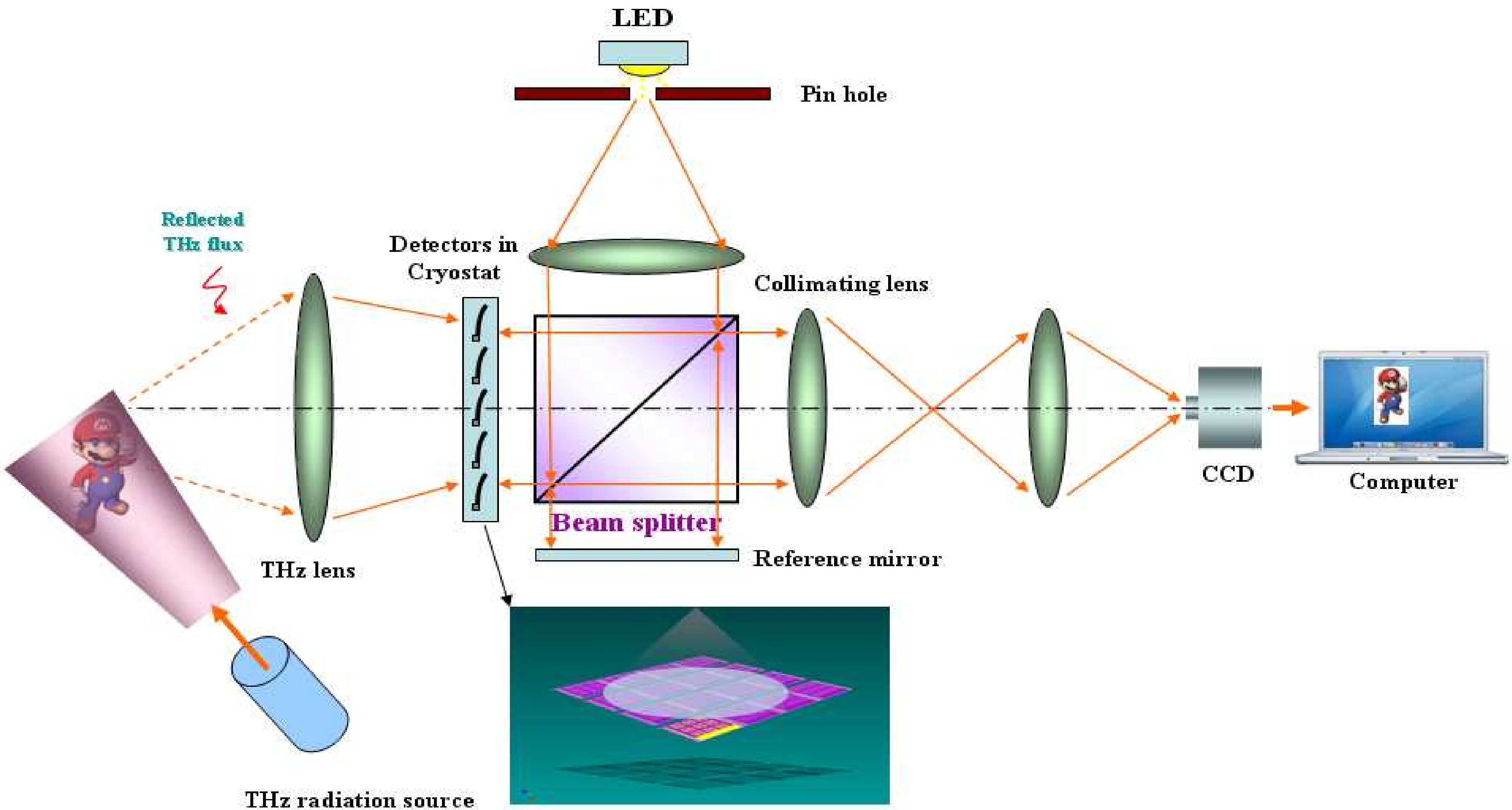
Simulation of the Magnetic Response










LED
Pin hole
Reflected
THz flux
Detectors in
Cryostat
Collimating lens
Beam splitter
Reference mirror
THz lens
CCD
Computer
THz radiation source

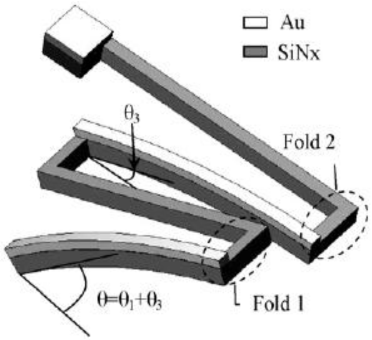
Bimaterial Cantilever Analysis

Table 1: Thermophysical properties of materials

	Young's modulus (GPa)	Poisson ratio	Expansion coefficient ($\times 10^{-6}$ K^{-1})	Thermal conductivity (W/(m·K))	Heat Capacity (J/Kg·K)	Emissivity	Density (g/cm^3)
Au	73	0.42	14.2	296	132	0.01	19.30
SiN_x	180	0.26	3.2	5.5	333	0.8	2.44

Table 2: Dimension of microcantilever unit

Unit Size (μm)	Reflector (μm)	Leg length (μm)	Leg width (μm)	Au thickness (μm)	SiNx thickness (μm)	Frame width (μm)	Fold number
200×200	180×25	180	2	0.4	0.55	10	2

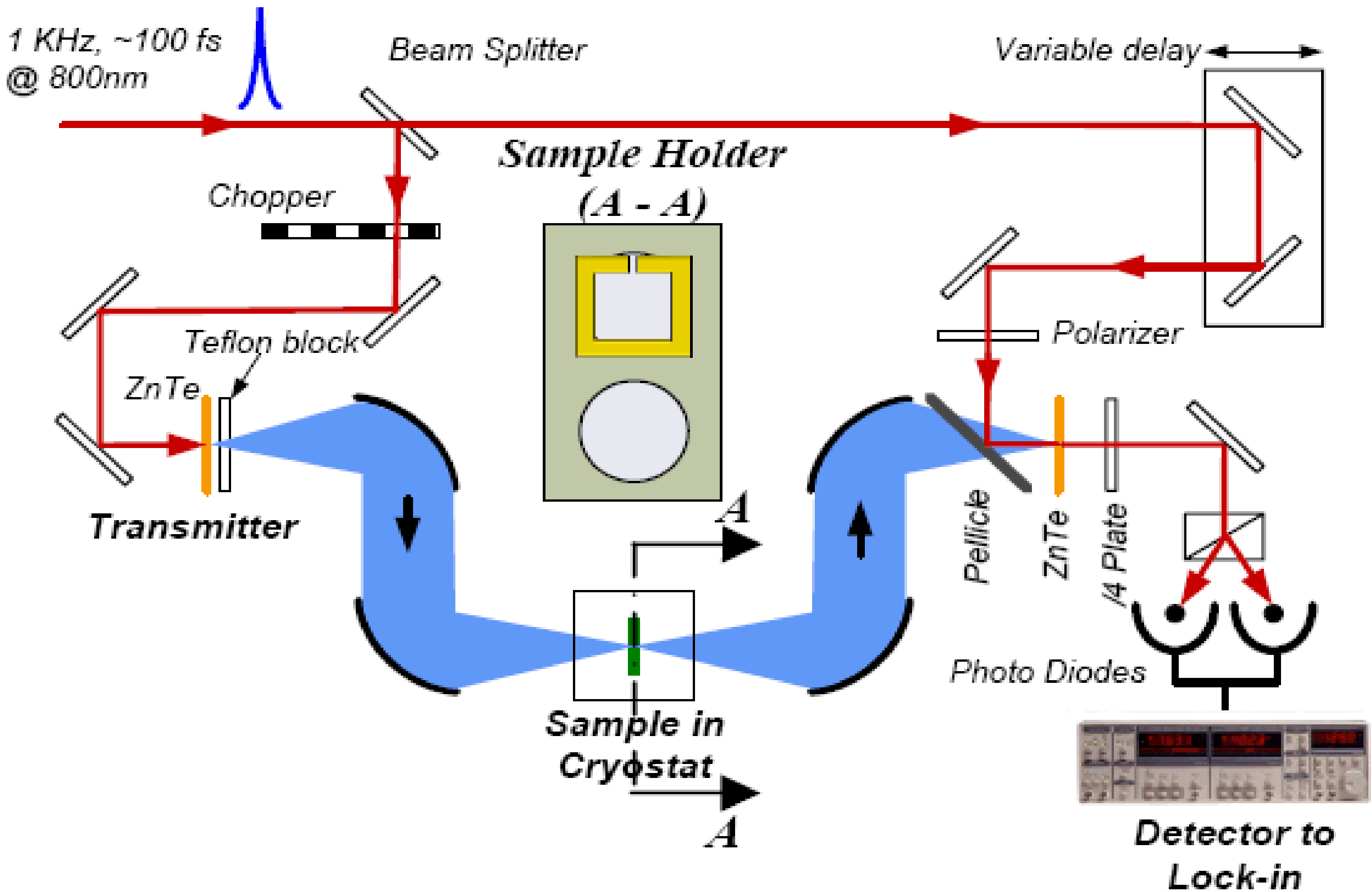


Thermal Analysis Yields

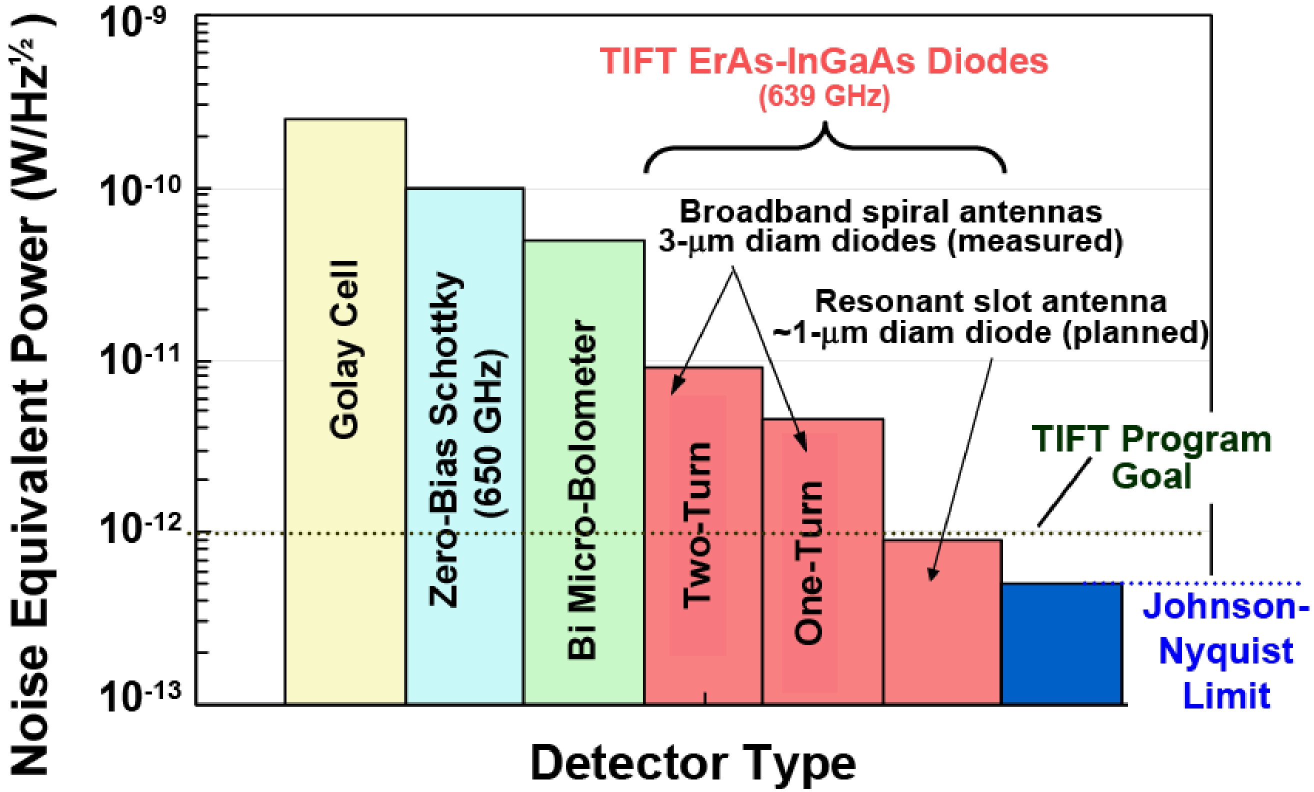
NETD: 10 mK

Limited by temperature stability

Experimental Setup: THz-TDS



From DARPA TIFT Program



We have an NEP of ***~ 10^{-10} W/Hz$^{1/2}$***

Similar Responsivity at 640 GHz

We think we can easily obtain a factor of ten improvement by increasing the absorptivity and decreasing the thermal conductance