N91-14389

# FABRICATION OF SENSITIVE HIGH $T_c$ BOLOMETERS*

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The rapid change of resistance with temperature of high quality films of high $T_c$ superconductors can be used to make resistance thermometers with very low temperature noise. Measurements on c-axis YBCO films have given a spectral intensity of temperature noise less than $4 \times 10^{-8}$ K/Hz$^{1/2}$ at 10 Hz. Consequently, the opportunity exists to make useful bolometric infrared detectors that operate near 90 K which can be cooled with liquid nitrogen. This talk will summarize the fabrication and measurement of two bolometer architectures. The first is a conventional bolometer which consists of a 3000 Å thick YBCO film deposited *in situ* by laser ablation on top of a 500 Å thick $SrTiO_3$ buffer layer on a {1012} $Al_2O_3$ substrate. The sample was lapped to 20 μm thickness and diced into 1x1 mm$^2$ bolometer chips. Gold black smoke was used as the radiation absorber. The voltage noise was less than the amplifier noise when the film was current biased. Optical measurements gave an NEP of $5 \times 10^{-11}$ W/Hz$^{1/2}$ at 10 Hz. The second architecture is that of an antenna-coupled microbolometer which consists of a small (5x10 μm$^2$) YBCO film deposited directly on a bulk substrate with a low thermal conductance (YSZ) and an impedance matched planar lithographed spiral or log-periodic antenna. This structure is produced by standard photolithographic techniques. Measurements gave an electrical NEP of $4.7 \times 10^{-12}$ W/Hz$^{1/2}$ at 10 kHz. Measurements of the optical efficiency are in progress. The measured performance of both bolometers will be compared to other detectors operating at or above liquid nitrogen temperatures so as to identify potential applications.

* Supported in part by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy under contract No. DE-AC03-76SF00098, and by the Department of Defense.

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# Fabrication of Sensitive High Tc Bolometers

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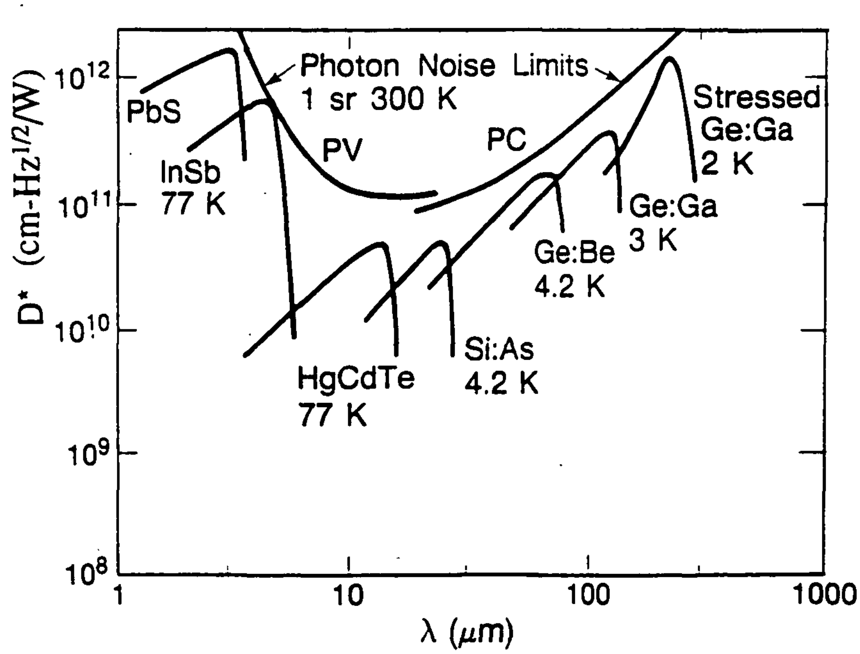
# Outline

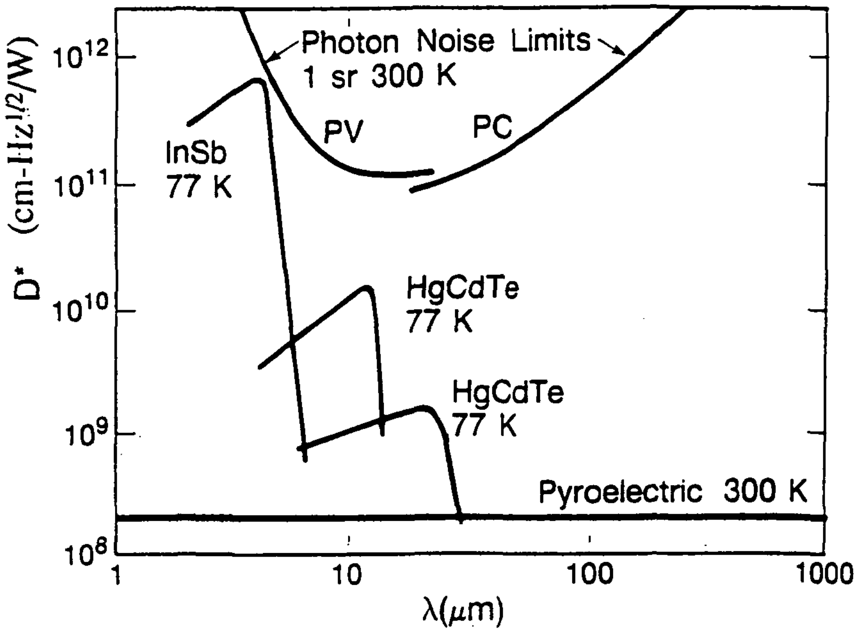
- Motivation and applications
- Conventional composite bolometer
- Microbolometer
- Conclusions

# High background applications

Performance ($D^* = AREA^{1/2}/NEP$) of commercial photon detectors viewing 300K source.

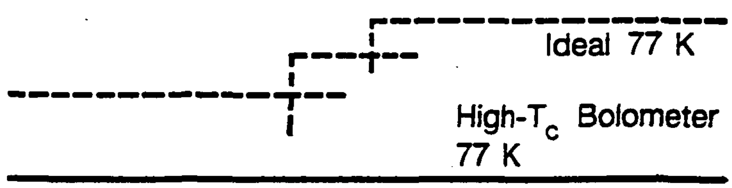


# Performance available at or above 77K




Applications above 77K:

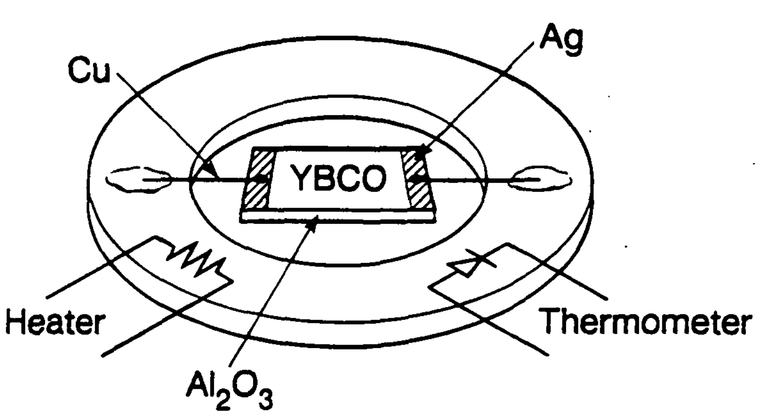
- Laboratory IR spectrometers
- Earth observations from space

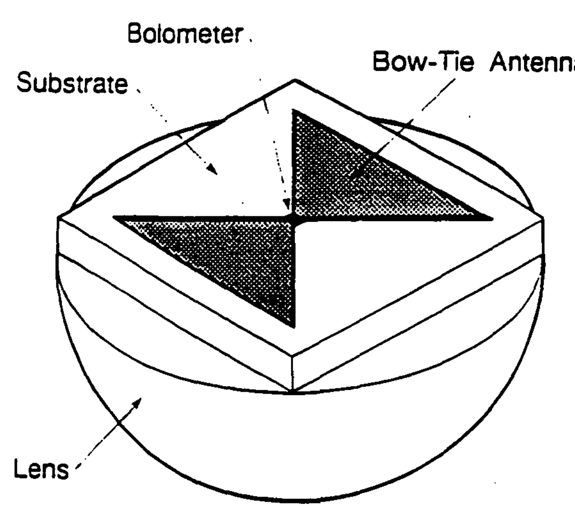



P. L. Richards et al, *Appl. Phys. Lett.* **54**, 283 (1989).

# Elements of high Tc infrared bolometers

| | Conventional Bolometer | Microbolometer |
|---|---|---|
| Substrate | sapphire | yttria stabilized zirconia (YSZ) |
| Radiation absorber | gold black<br>Bi film | antenna-coupled YBCO |
| Thermometer R(T) | YBCO | YBCO |
| Thermal conductance G | Cu leads | thermal spreading resistance |



# The high Tc conventional bolometer

- Easy to make one that "works".
- Hard to get useful sensitivity.
- Good ones can be made now.
- Materials needs very specific.
- Low-noise and high $\frac{1}{R}\frac{dR}{dT}$.
- Proper optimization.

# Fabrication

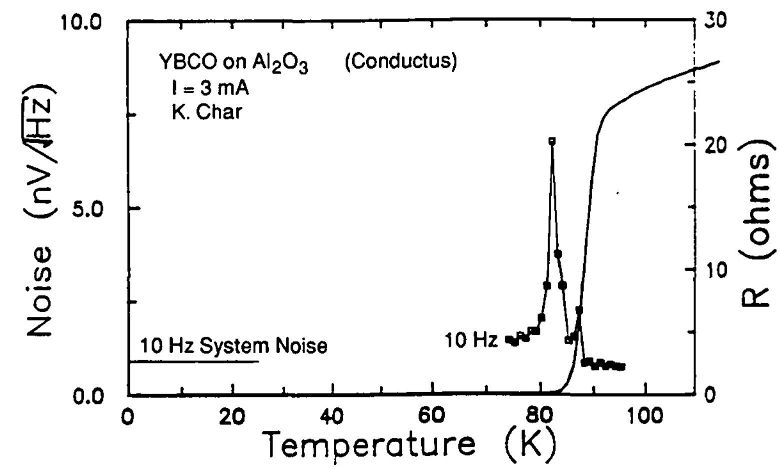
- Substrate 1X1 mm$^2$, 20 µm thick, { $1\bar{1}02$ } sapphire.
  - Low specific heat
  - Strong
  - YBCO compatible
- Laser ablate 3000 Å YBCO on a 500 Å $SrTiO_3$ buffer layer on 6X6X0.5 mm$^3$ sapphire.
- Sputter clean YBCO surface and sputter deposit Ag electrical contacts.
- Polish and dice.

# Sensitivity ⇒ YBCO film quality

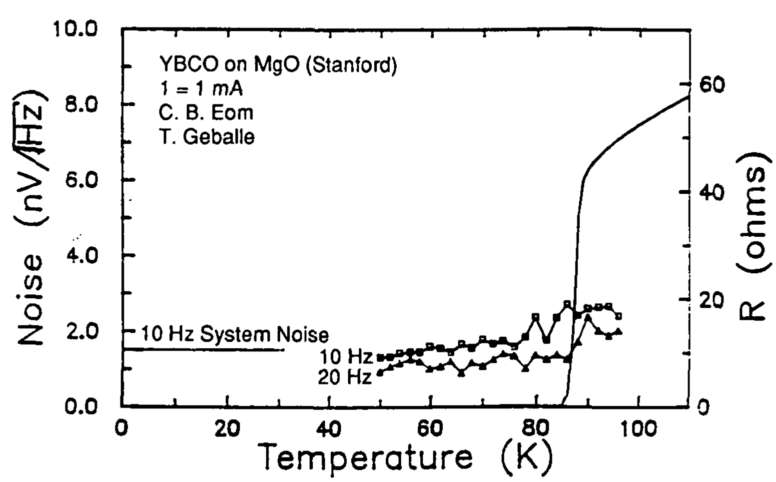
high $\frac{1}{R}\frac{dR}{dT}$, low noise

- Laser ablating YBCO on sapphire gives sharp resistive transitions (K. Char et al, *Appl. Phys. Lett.*, 56. 785 (1990)).

- But there is excess voltage noise near $T_C$ under current bias in these films.




- Using the 500Å $SrTiO_3$ buffer layer ⇒ reduced voltage noise.



# Bolometer optimization

Given: $\frac{1}{R}\frac{dR}{dT}$, C -- heat capacity

Pick:
- I -- current bias
- R -- operating resistance
- G -- thermal conductance
- $\omega$ -- chopping frequency

$$\mathrm{NEP} = \left(4kT^2G + \frac{4kTR + V_{amp}^2 + V_{1/f}^2}{|S|^2}\right)^{1/2}$$

$S = I\,\frac{dR(T)}{dT}\,|G + i\omega C|^{-1}$ ,  $I^2R < 0.3G\delta T$ for stability .

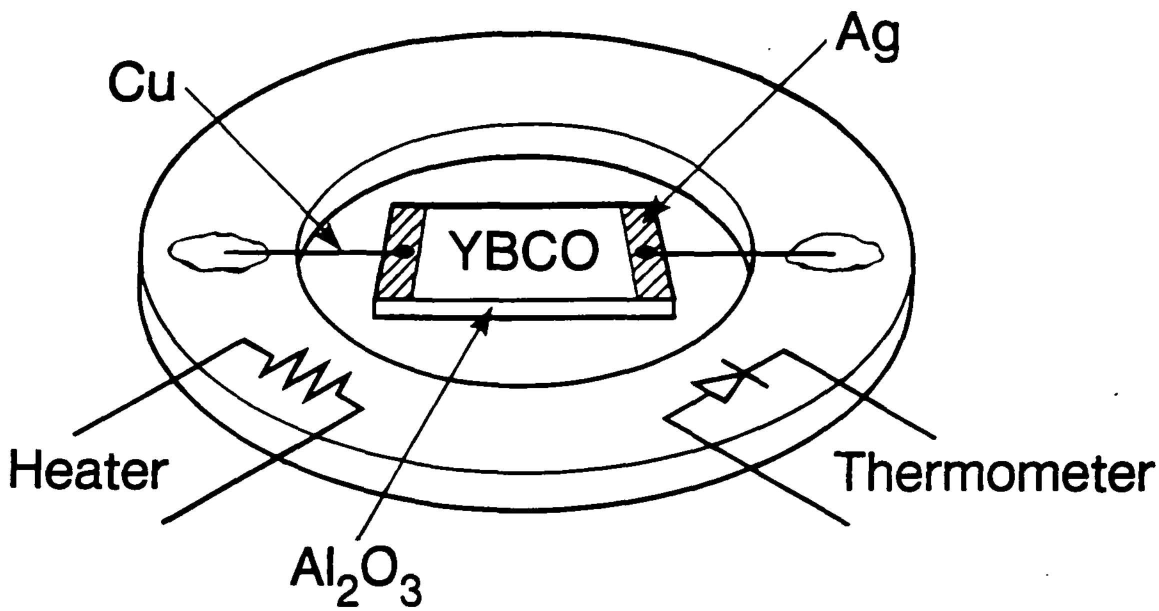
$\delta T$ -- transition width

For a sapphire bolometer:

$\omega/2\pi = 10$ Hz  1X1X0.02 $mm^3$ sapphire

$\delta T = 0.5$ K  NEP $\leq 10^{-11}$ W/Hz$^{1/2}$

# Measurements

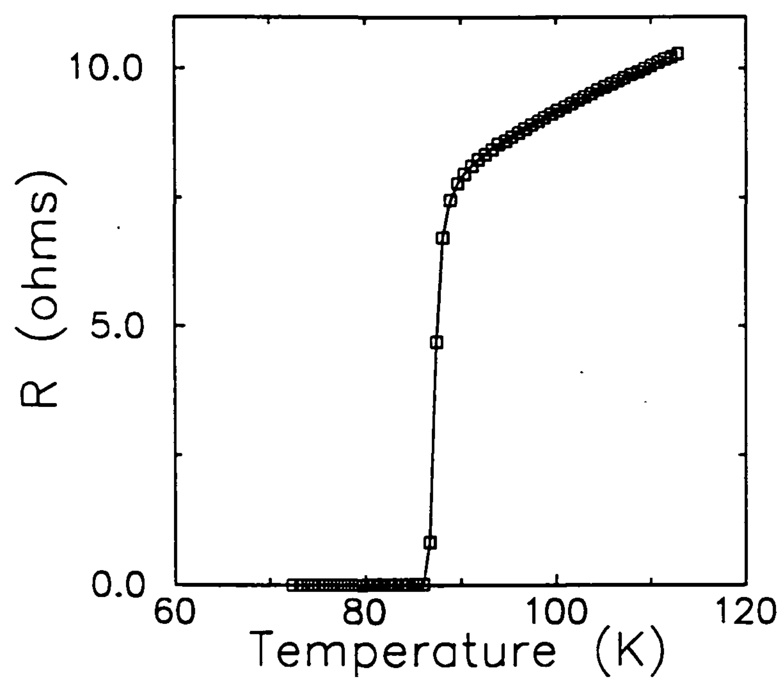



Typical Size 1×1 mm

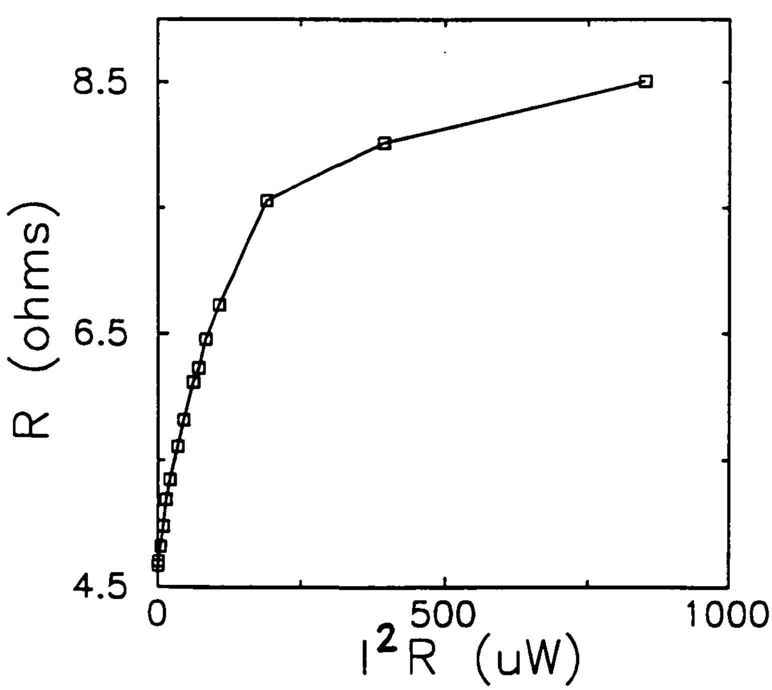
- R(T) and load curve ⇒ $S_{electrical}$ = 26 V/W , 10 Hz
- Chopped He-Ne laser ⇒ $S_{optical}$ = 22 V/W , 10 Hz
- At present, noise is amplifier limited ⇒ NEP = $5 \times 10^{-11}$ W/Hz$^{1/2}$, 10 Hz

# Electrical measurements

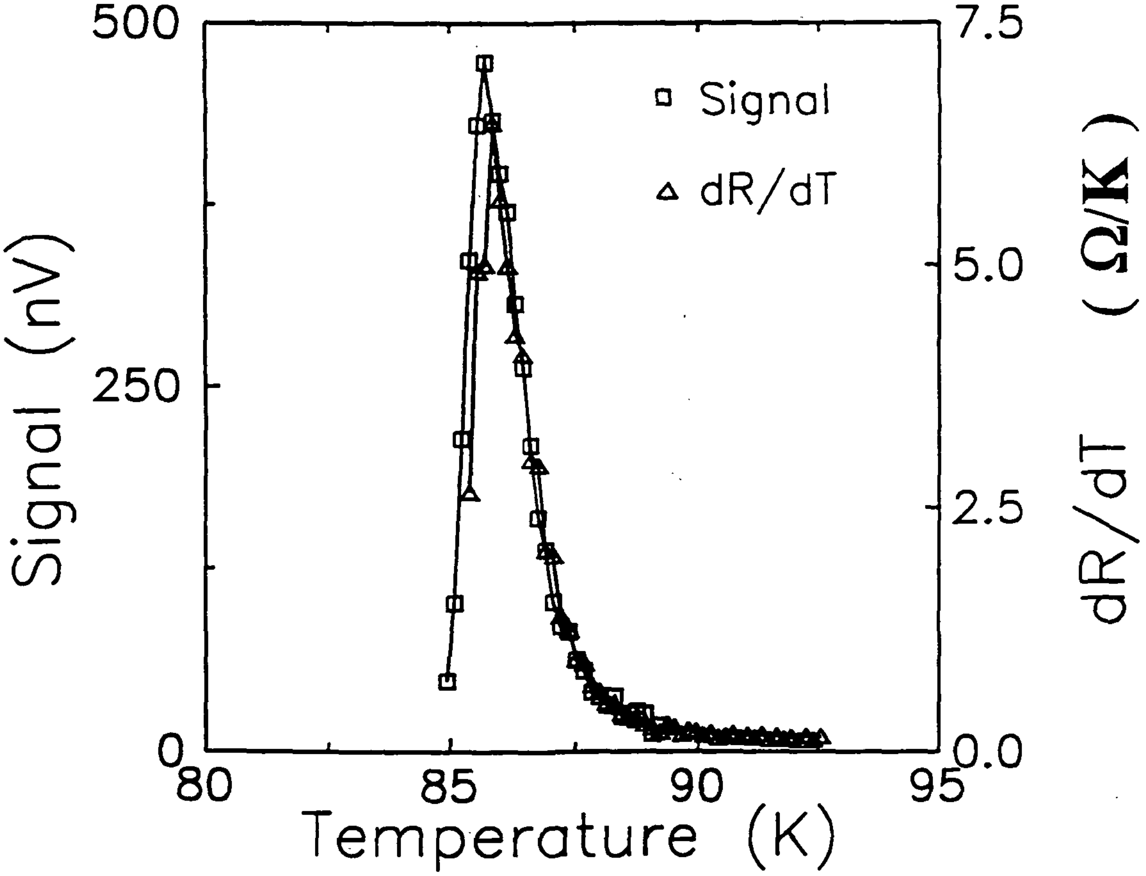
## Bolometer R(T)

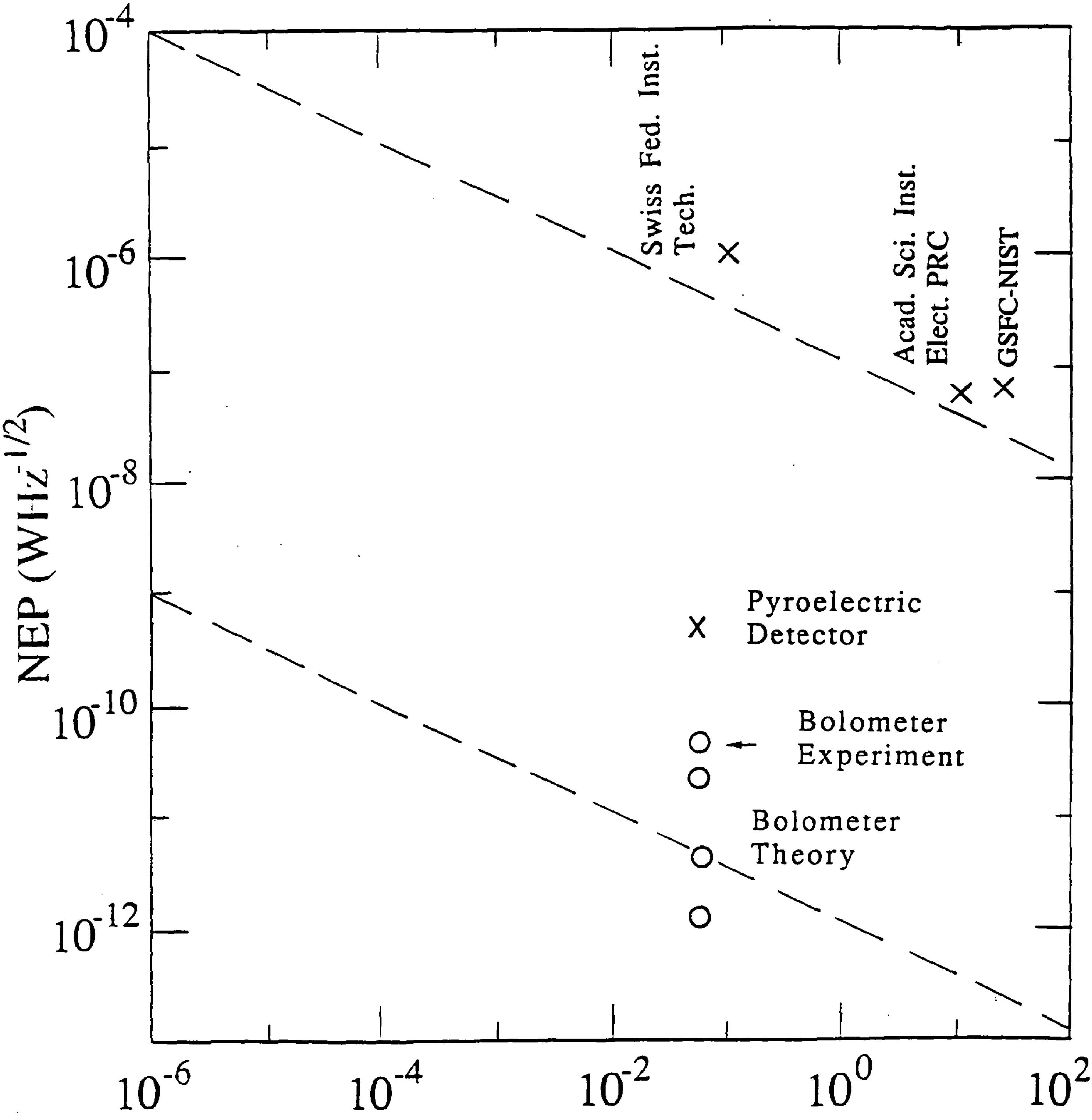



## Load Curve



# Optical response





10-4
10-6
10-8
10-10
10-12
NEP (WHz-1/2)
Swiss Fed. Inst. Tech.
Acad. Sci. Inst. Elect. PRC
GSFC-NIST
Pyroelectric Detector
Bolometer Experiment
Bolometer Theory
10-6
10-4
10-2
100
102
τ (sec)


XBL 903-5434

# High Tc Microbolometer

## Sensitive and fast

- Small area ($A \approx 5\ \mu m^2$)
- Deposited directly on thick substrate
- Only small volume of substrate contributes thermally ($V \approx 10\ \mu m^3$)
- NEP $\alpha$ $A^{1/4}$
- Response time $\alpha$ A
- Couple directly $\lambda < 2\ \mu m$
- Couple with antenna $\lambda > 100\ \mu m$
- Array compatible fabrication

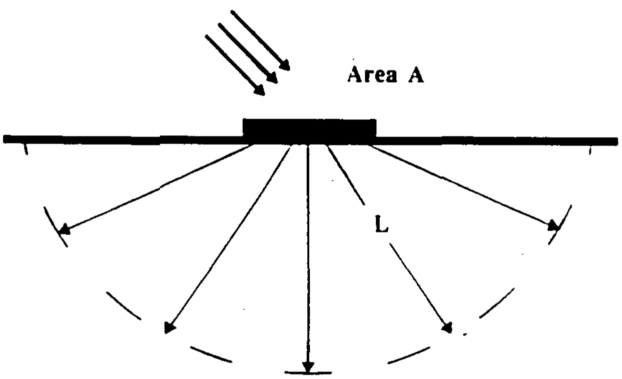
Qing Hu and P. L. Richards, *Appl. Phys. Lett.* **55**, 2444 (1989).

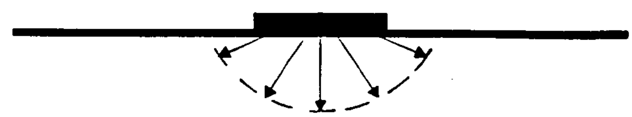
Idea from: Hwang, Schwarz, Rutledge
Neikirk, Lam, Rutledge
Rutledge, Neikirk, Kasilingam

# Microbolometer thermal response

$\text{NEP} = \left(4kT^2G(f)\right)^{1/2}$, $\quad G(f) = ?$

Diffusion length $\quad L = \left(\dfrac{\kappa_s}{c_s \pi f}\right)^{1/2}$



$L > \sqrt{A}$

$G = \sqrt{2\pi A}\,\kappa_s$

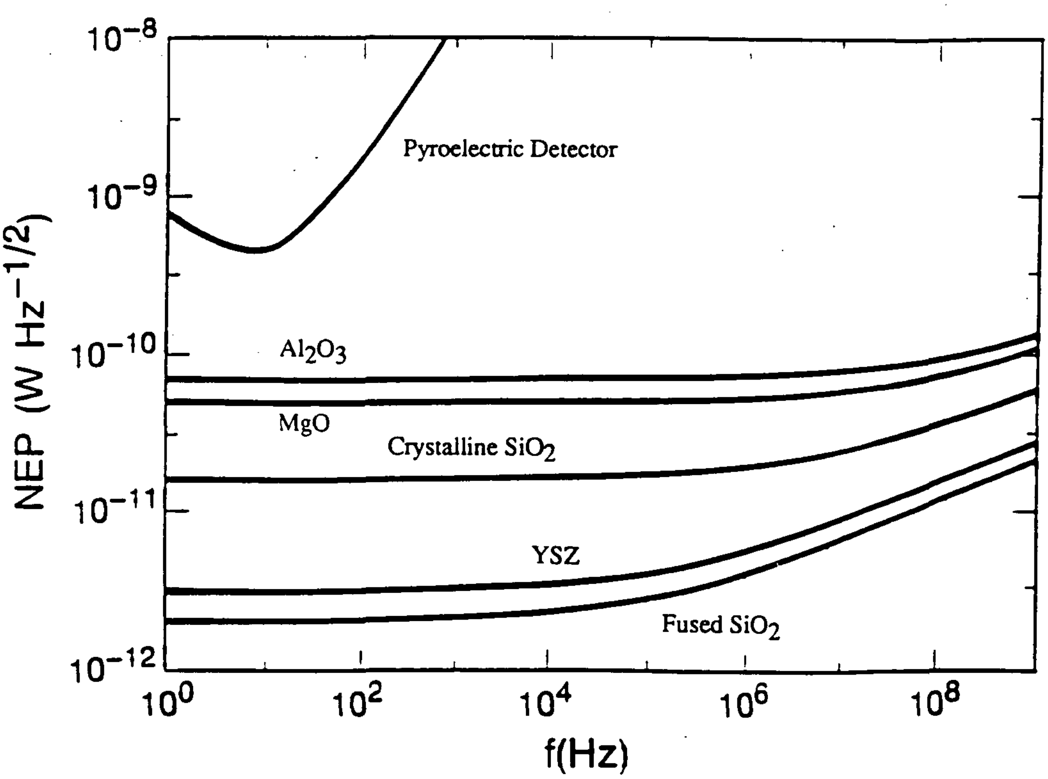
$\text{NEP} \propto A^{1/4}$

$L < \sqrt{A}$

$G = \sqrt{2\pi}\,A\left(\kappa_s c_s f\right)^{1/2}$

$\text{NEP} \propto A^{1/2} f^{1/4}$

**Calculated NEP** (Area = 1X5 μm²)



# How to couple long wavelengths into a small bolometer?

- Antenna-coupled microbolometer
- Self complementary planar antenna
  - Real antenna impedance
  - Broadband response $\lambda > 100\ \mu m$
- Single mode throughput $A\Omega = \lambda^2$

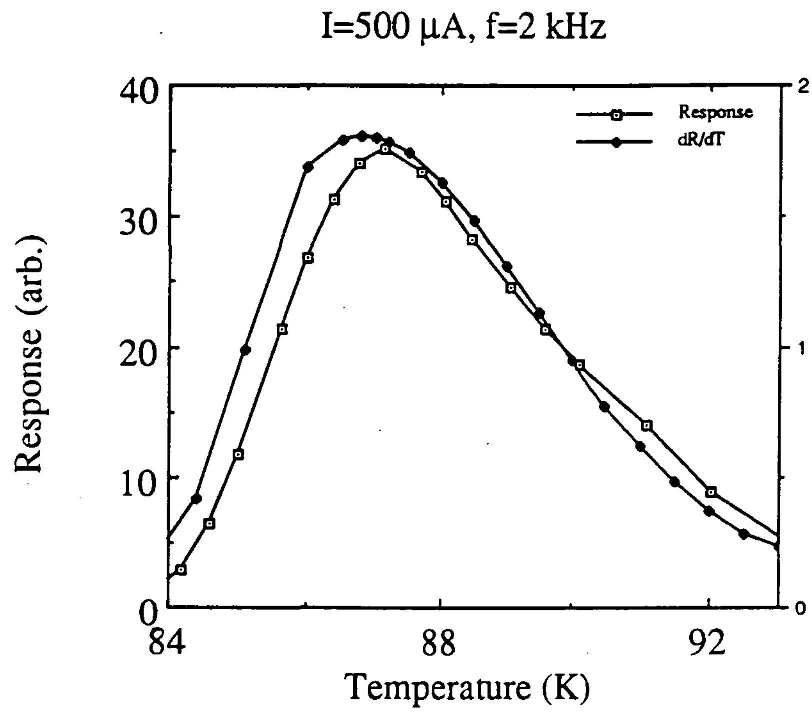
Log-Periodic Antenna

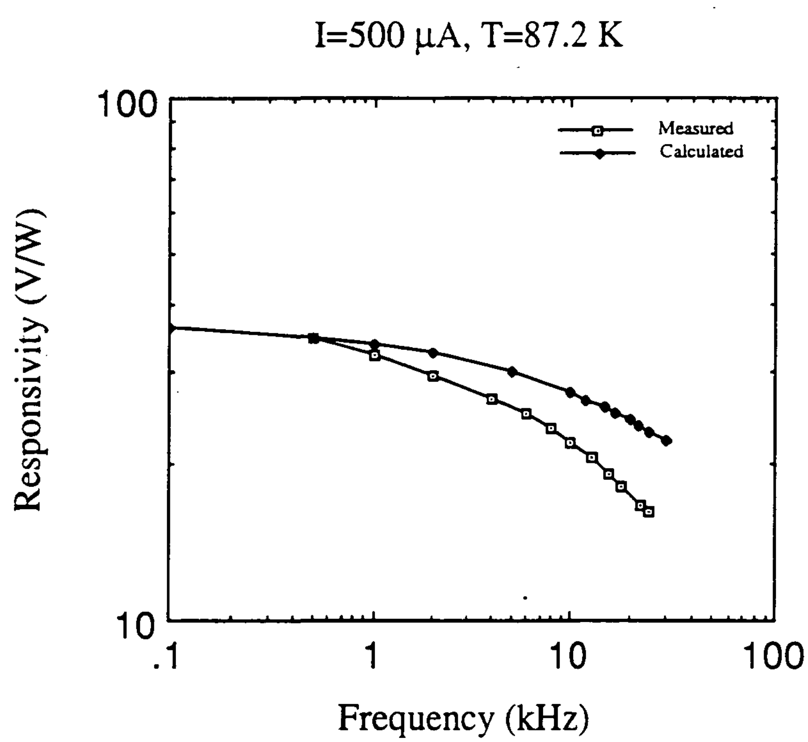
Spiral Antenna

# Fabrication of microbolometer

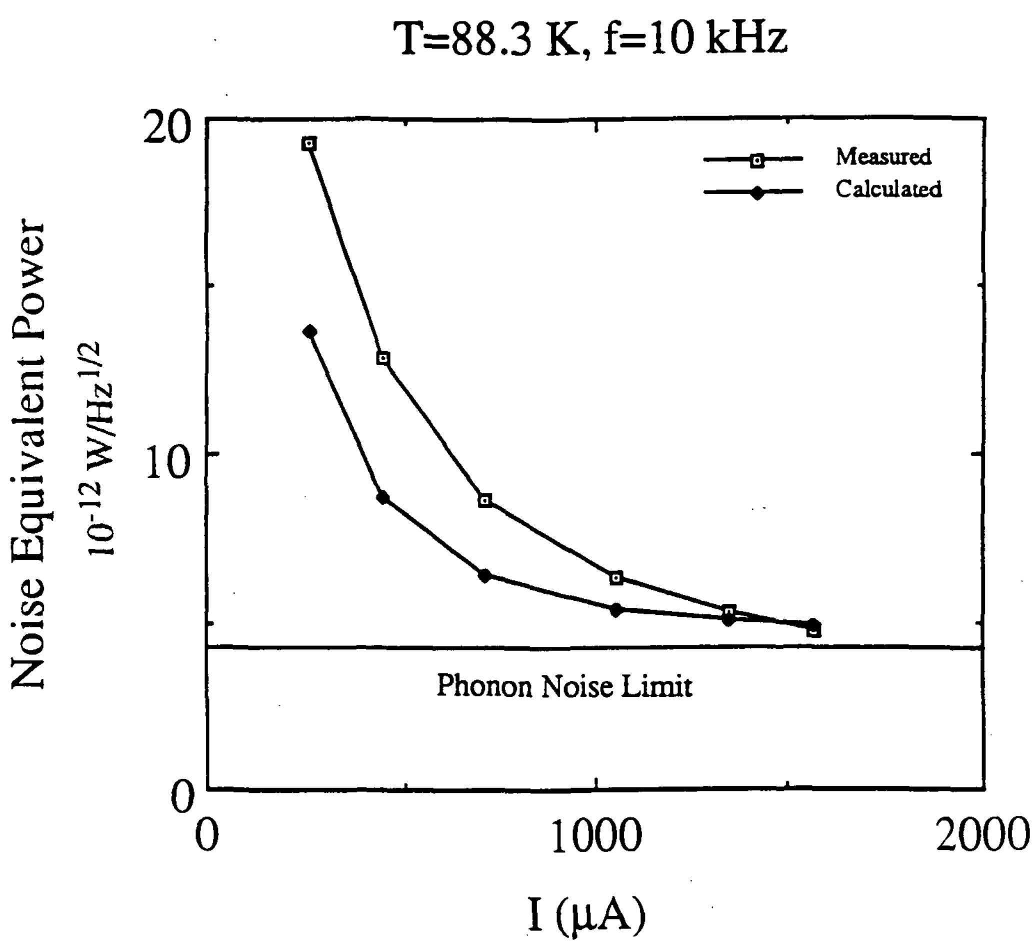
- Single target sputtered 3000 Å YBCO on YSZ.
- Pattern YBCO into 5 μm wide strips in acid etch.
- Sputter clean YBCO surface and sputter deposit Ag.
- Wet etch Ag antenna pattern.
- Oxygen anneal 500° C for 1 hr.

# Optical response of microbolometer

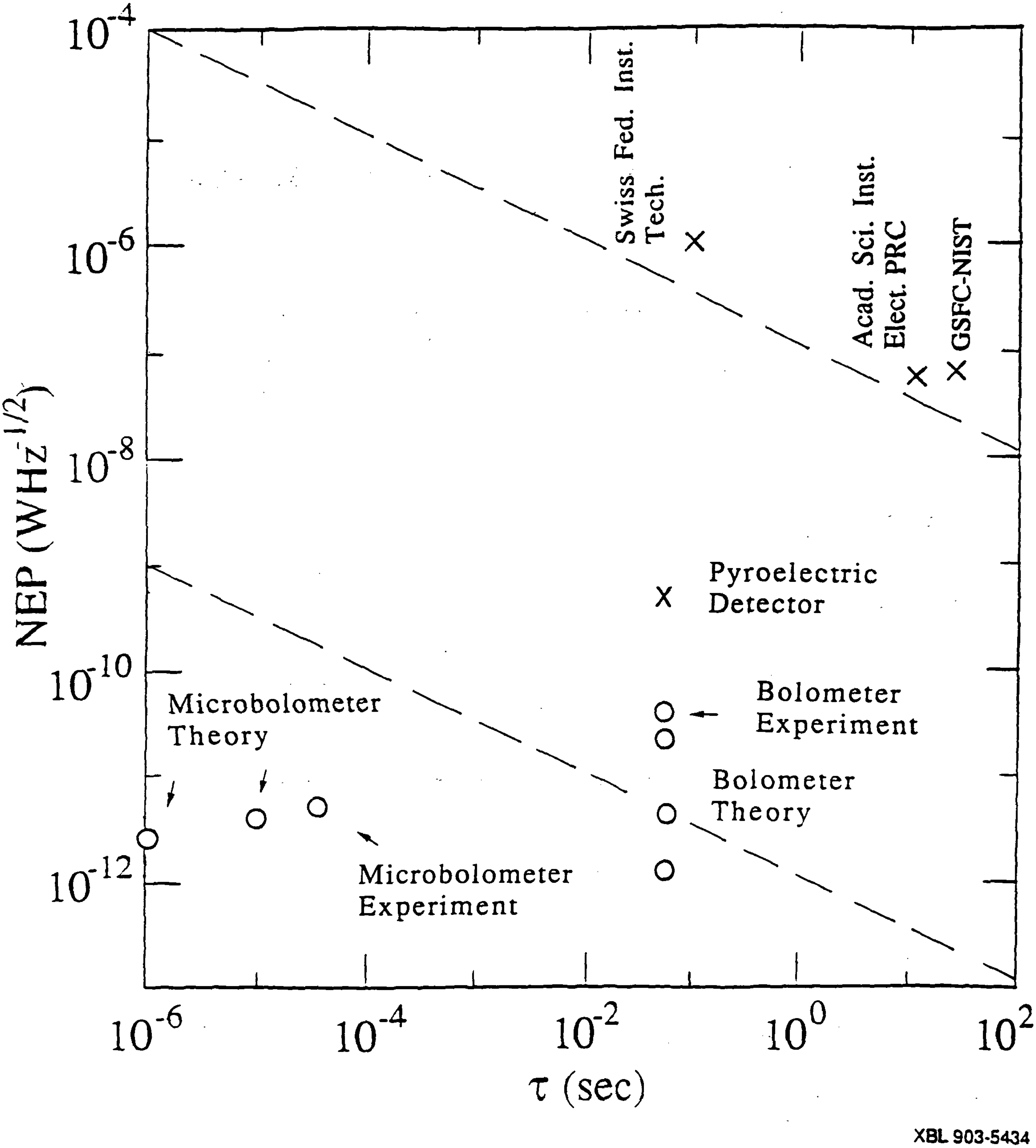


# Electrical NEP of microbolometer




- Electrical NEP is G-noise limited.
- $R = 6\Omega \Rightarrow$ transformer - coupled.
- Optical efficiency measurements in progress.



NEP (WHz$^{-1/2}$)
$10^{-4}$
$10^{-6}$
$10^{-8}$
$10^{-10}$
$10^{-12}$
Swiss Fed. Inst. Tech.
Acad. Sci. Inst. Elect. PRC
GSFC-NIST
Pyroelectric Detector
Bolometer Experiment
Bolometer Theory
Microbolometer Theory
Microbolometer Experiment
$10^{-6}$
$10^{-4}$
$10^{-2}$
$10^{0}$
$10^{2}$
τ (sec)
XBL 903-5434

# Conclusions

- High $T_c$ bolometers have a future for applications where cooling is limited.

- Best opportunities are for $\lambda \geq 15$ μm.

- Require highest materials quality on the "right" substrates.

- We have made conventional bolometers and microbolometers with performance approaching theoretical predictions.