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6^{th} Patras Workshop on Axions, WIMPs and WISPs

Andreas Engel

Superconducting Single-Photon Detectors from meV to keV

UZH:

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DLR, Berlin:

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Uni-Karlsruhe:

Konstantin Il'in, Michael Siegel

Overview

- Transition-Edge Sensors (TES)
- Kinetic Inductance Detectors (KID)
- Nanowire Photon Detectors (NPD)
- Comparison

NOT:
STJ, magnetic calorimeters, heterodyne bolometers,…

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Brush up on Superconductivity

Gene Hilton @ LTD 13 Workshop 2009:

Application Highlights

. . . introduce LTD technologies to new members of the community and highlight those areas where there is the greatest advantage . . .

Cryogenics is hard!

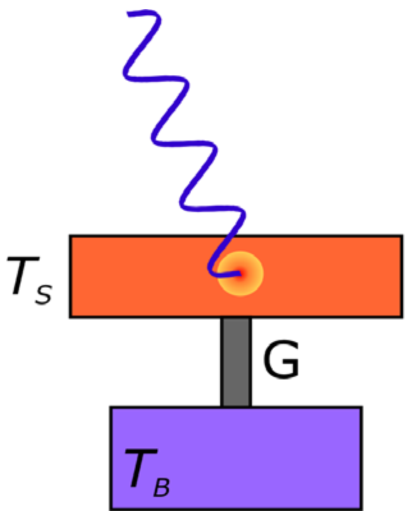
Hard enough that you shouldn't use and LTDs unless there is no other way.

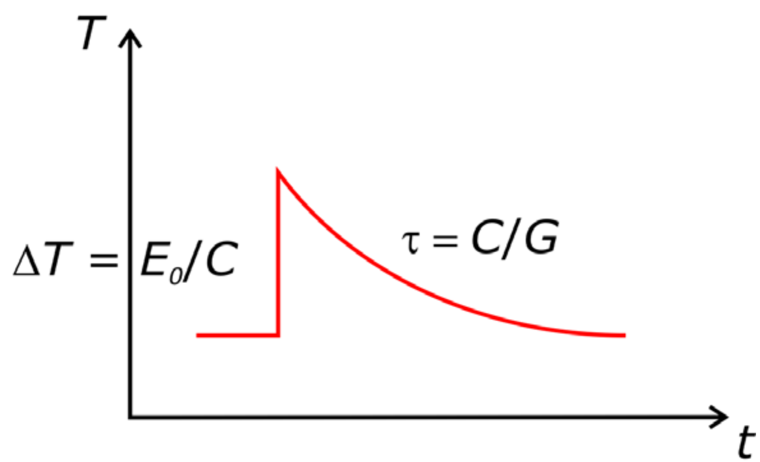
TES – Principle I

- Thermistor

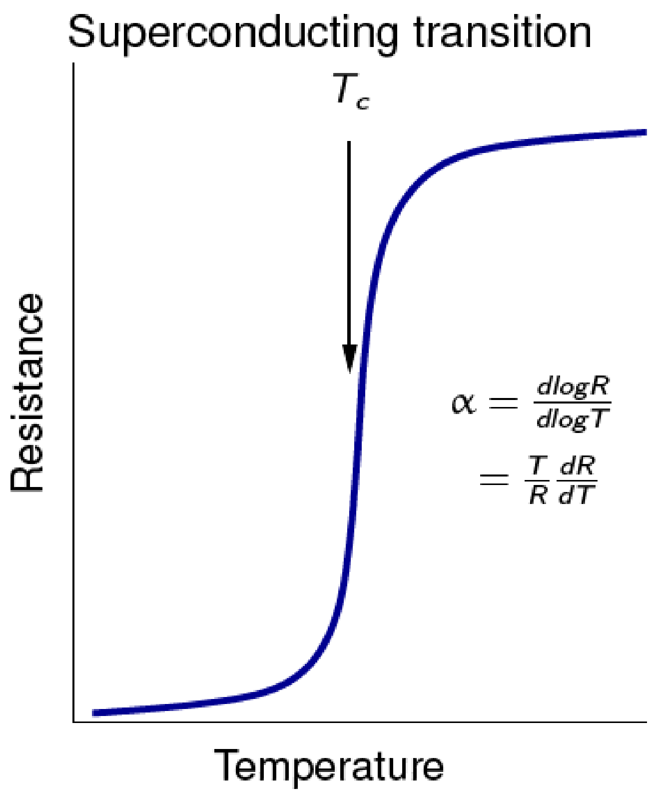
Sensitivity $$\alpha = \frac{d \log R}{d \log T} = \frac{T}{R}\frac{dR}{dT}$$

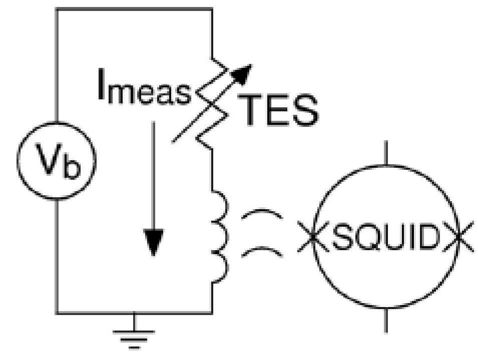
Resolution $$\Delta E_{\mathrm{RMS}} \propto \sqrt{\frac{k_B T_0^2 C_0}{\alpha}}$$





TES – Principle II





- Bias power raises T_{TES} above T_b and into transition ($\sim T_c$)

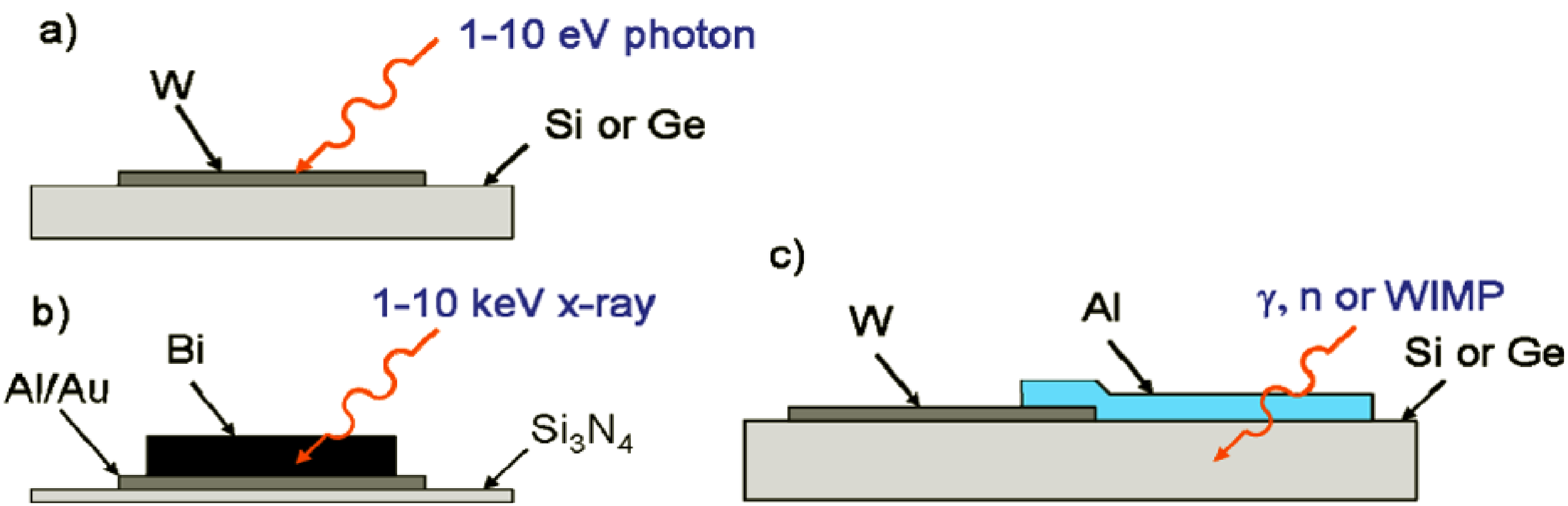
  $$P_{Joule} = V^2/R$$

- Absorbed photon raises T, R, lowers P_{Joule}, speeds up TES

  $$\tau_{TES} \sim CT_c/\alpha P_{Joule}$$

- Self biasing into transition

TES – Examples I



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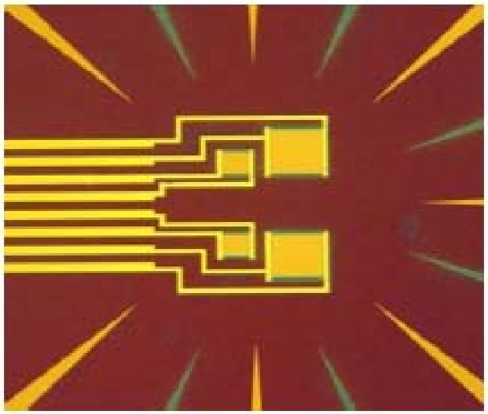
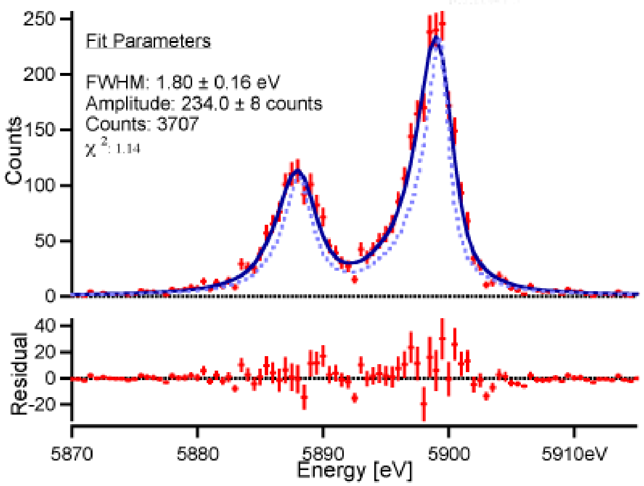
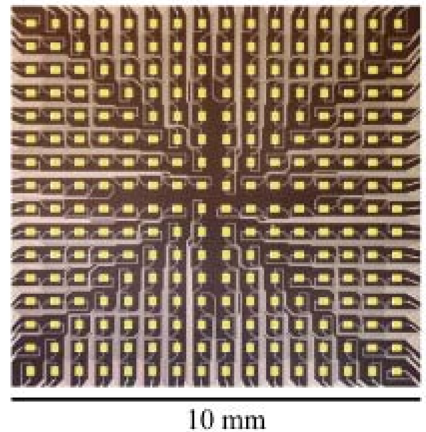
TES – Examples II

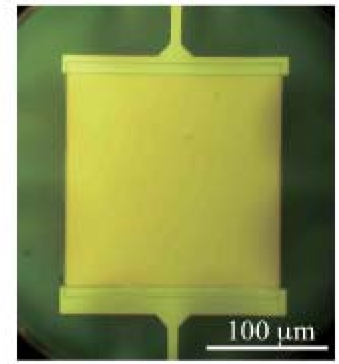


NIST



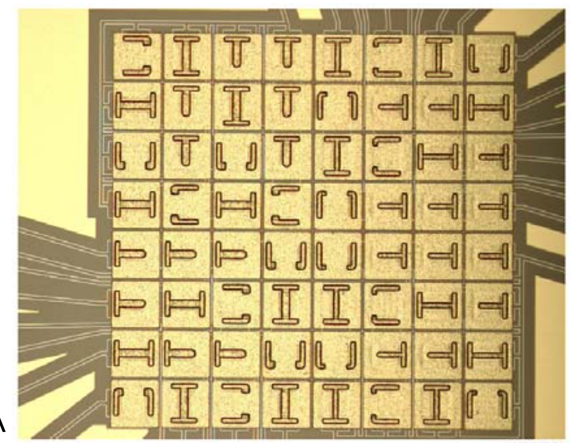
NASA GSFC





Y. Ezoe et al., AIP Conf. Proc., **2009***, 1185*, 60

NASA



KID – Kinetic Inductance

magn. Ind.: $$E_{\mathrm{mag}} = \frac{1}{2\mu_0}\int B^2 \mathrm{d}V = \frac{1}{2} L^{\mathrm{M}} I^2$$

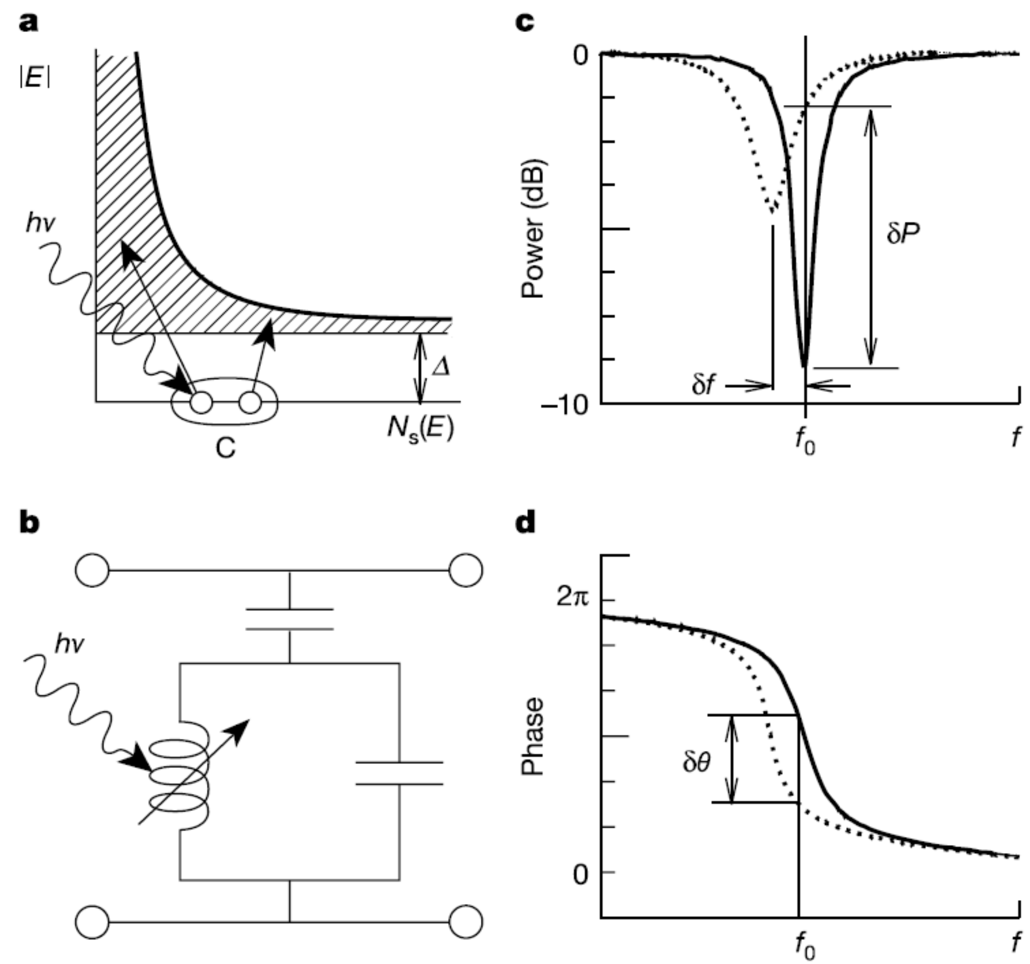
kin. Ind.: $$E_{\mathrm{kin}} = \int n \frac{mv^2}{2} \mathrm{d}V = \frac{1}{2} L^{\mathrm{K}} I^2$$

kin. Ind. square film: $$L^{\mathrm{K}}_{\square} = \frac{\mu_0 \lambda^2}{d}$$

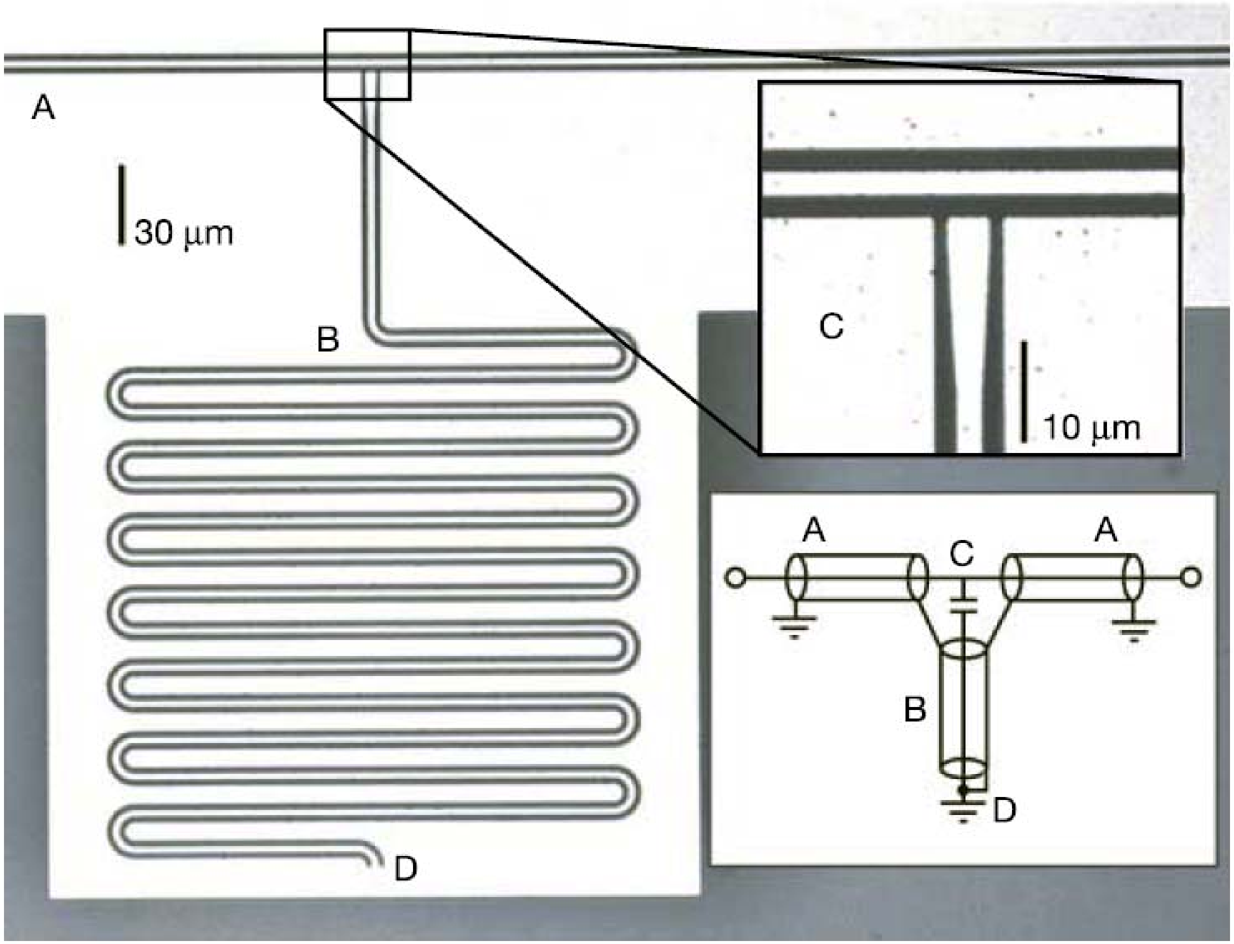
KID - Principle

$$\lambda \propto n_s^{-1/2}$$

$$L^{K}_{\square} \propto \lambda^2 \propto 1/n_s$$



KID – Examples I



*P. K. Day et al., Nature, **2003** , 425 , 817*

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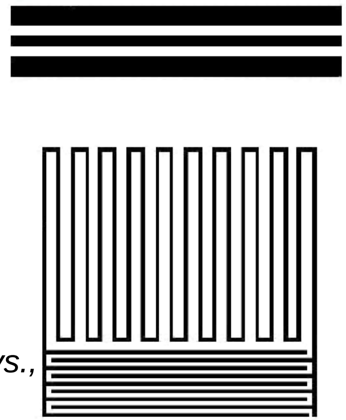
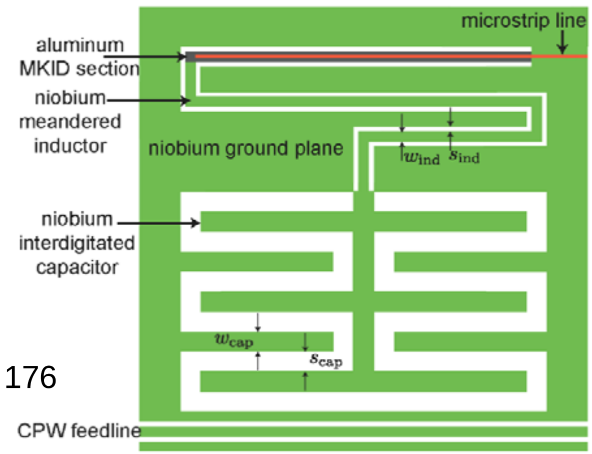
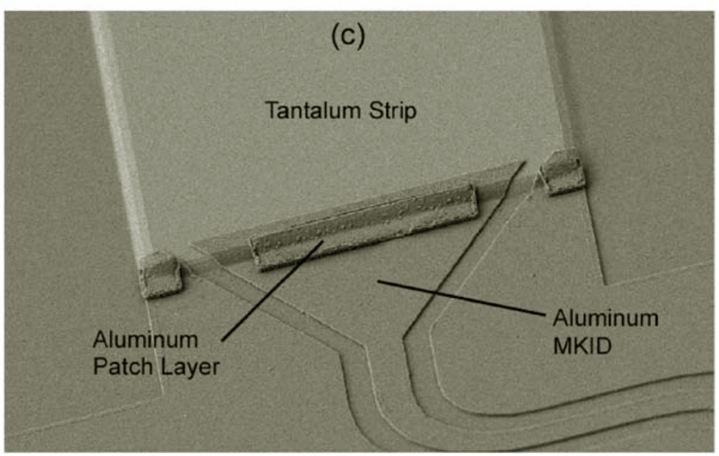
KID – Examples II



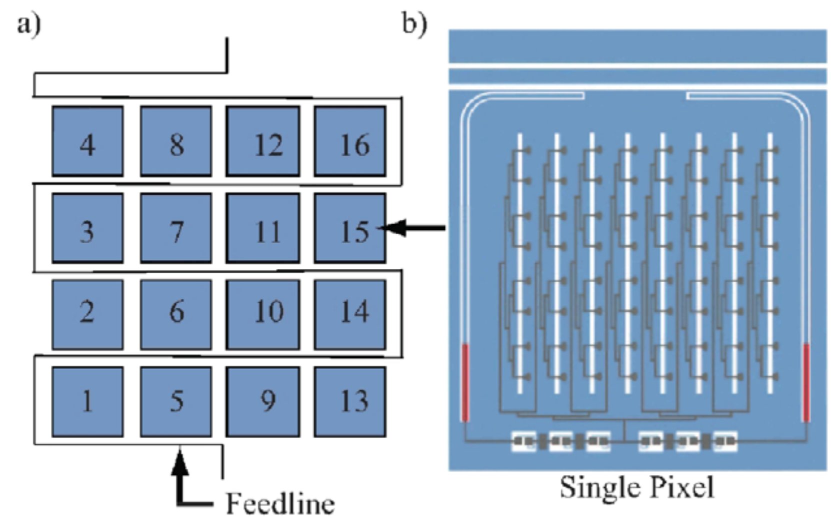
S. Doyle et al., J. Low Temp. Phys., ***2008*** *, 151 , 530*



O. Noroozian et al., AIP Conf. Proc., **2009**, *1185*, 176



B. A. Mazin et al., Appl. Phys. Lett., ***2006*** *, 89 , 222507*



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P. R. Maloney et al., AIP Conf. Proc., **2009**, *1185*, 176

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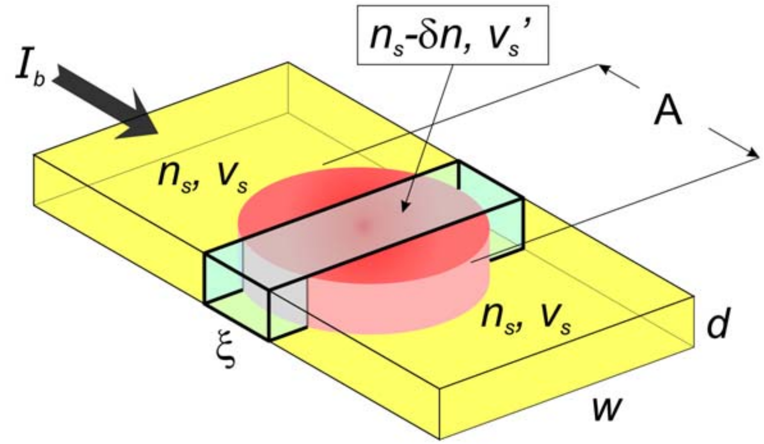
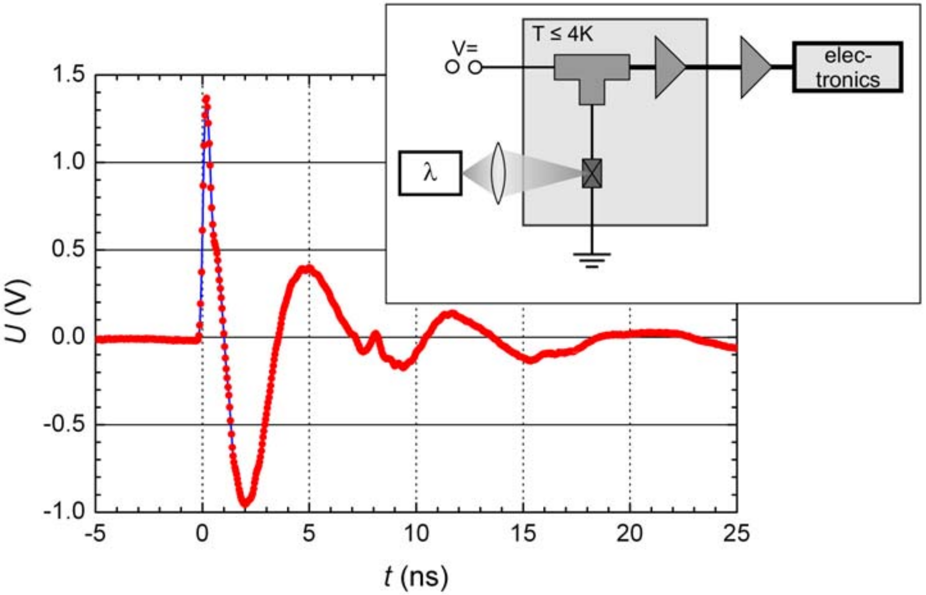
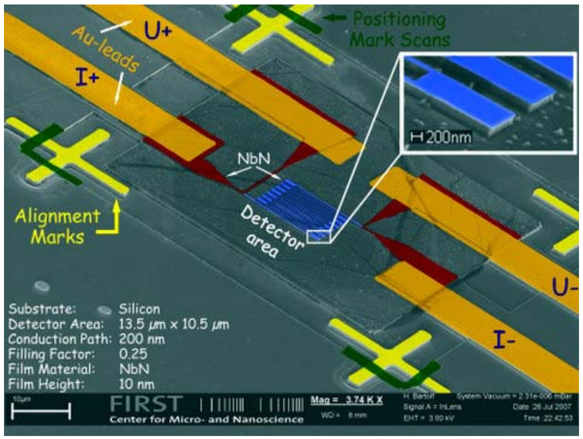
NPD - Principle

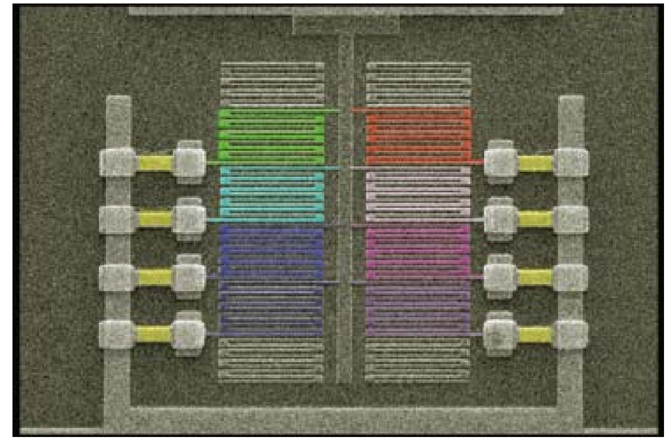
- Diffusion leads to quasi-particle cloud
- Reduction of critical current density
- Normal domain formation for $j'_c < j_b \approx 0.95\, j_c$





NPD - Examples





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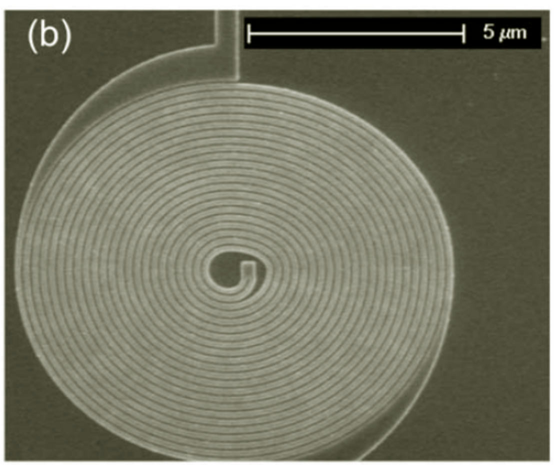

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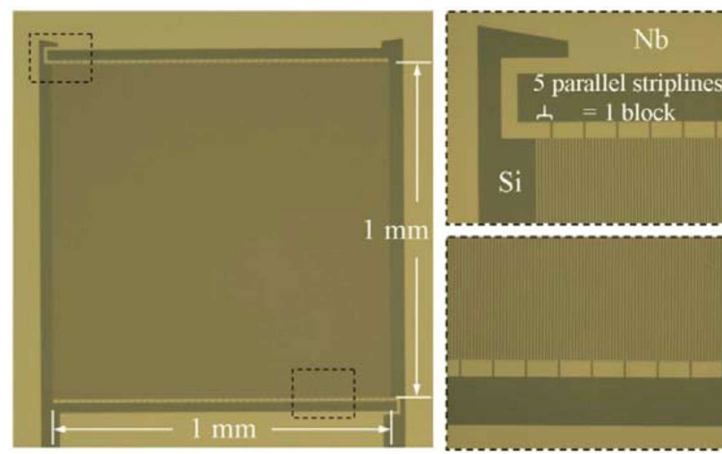

N. Zen et al., Appl. Phys. Lett., AIP, **2009** , *95* , 172508

Detector Comparison

Detector	*T* (K)	η (%)	Jitter Δt (ns)	max. counts (Hz)	NEP (W/Hz$^{1/2}$)	ΔE	comment
TES	□0.1	~95	100	10^5	10^{-19}	yes	highest energy resolution
KID	~0.3	~35	—	10^5	10^{-17}	yes	easily multiplexed
NPD	2-4	~10	0.03	10^9	10^{-18}	no	fastest detector

A. Verevkin et al., J. Mod. Opt., ***2004*** *, 51 , 1447*
R. H. Hadfield, Nature Photonics, ***2009*** *, 3 , 696*

Thank you!