Parallel superconducting strip detectors: operation in the single strip switch regime

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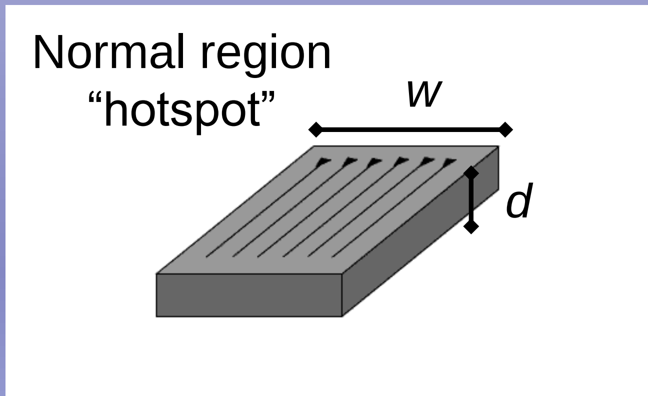
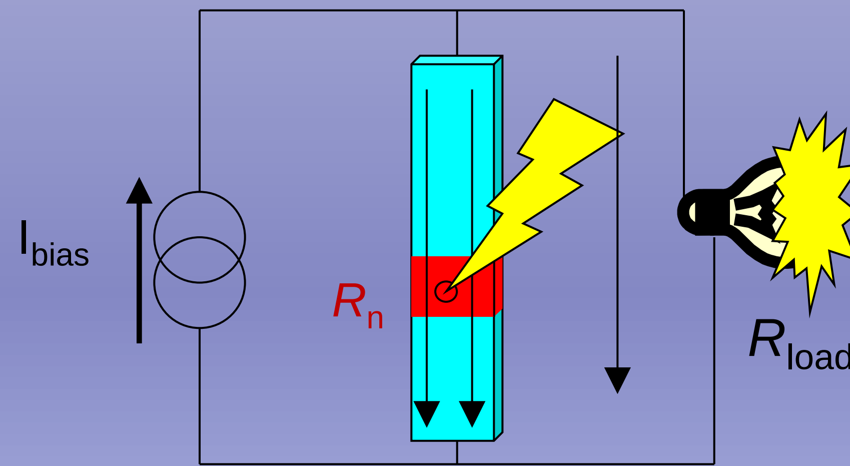
LTD 15, Pasadena, USA, 24/06/2013

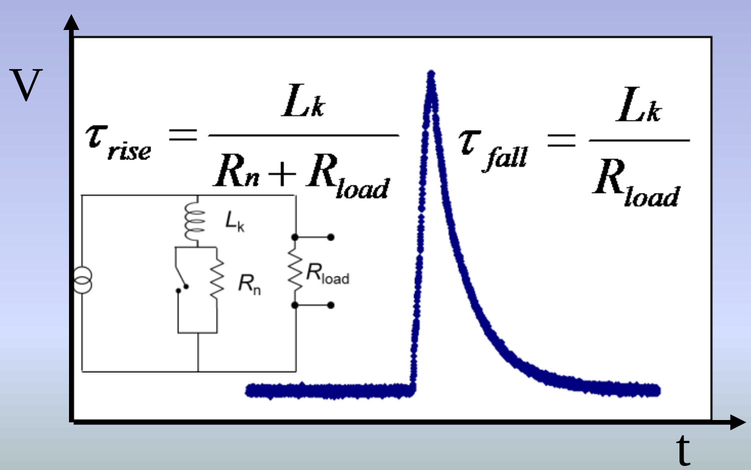
Superconducting strip detector SSD

Supercurrent-assisted formation of normal-region (hot spot)

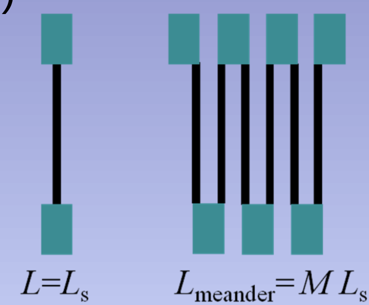


G. Gol'tsman *et* al, Appl. Phys. Lett. **79** (2001)
A. Semenov et al, Phys. C, **35** (2001)





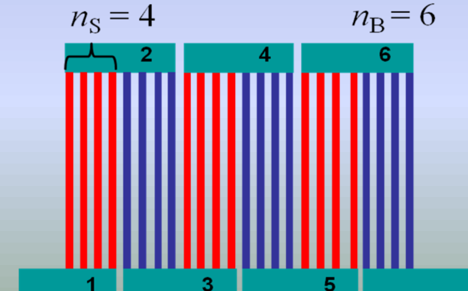
Kerman *et al*, Appl. Phys. Lett. **79** (2006)



$$L_s = \mu_0 \cdot \lambda \frac{l}{d \cdot w}$$

Long, thin and narrow strip results in slow response time

Parallel configuration



$M = n_B \text{ x } n_S$

$$L_{parallel} = \frac{n_B}{n_S} L_s = \frac{L_{meander}}{n_S^2}$$

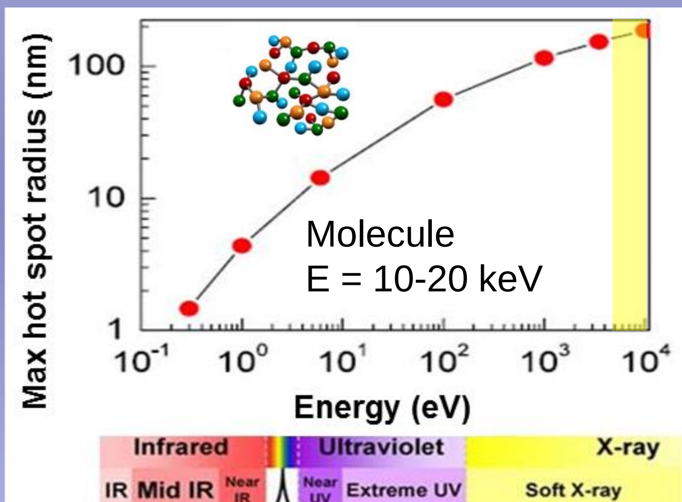
M. Ejrnaes *et al.* Appl. Phys. Lett. **91** 262509 (2007)
M. Tarkhov *et al.* Appl. Phys. Lett. **92** 241112 (2008)

SSD for keV energy molecule detection

Collaboration between CNR – Cybernetics Institute (Italy) and AIST – RIIF (Japan)

Detector requirements for Time Of Flight – Mass Spectrometry

Detector coverage area ~ cm^2 and Response time ~ 1ns



A. Semenov et al, Phys. C, **35** (2001)

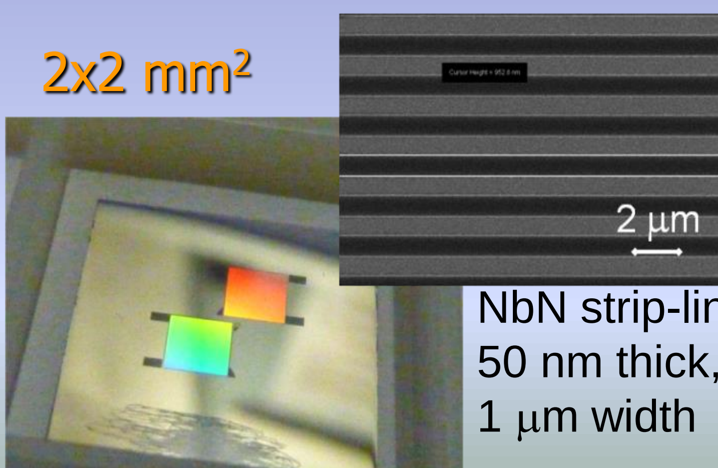
A. Casaburi, N. Zen *et al.*, APL **94** 212502 (2009)

	n_B, n_S	**Area** μm^2	**Filling factor**	**Linewidth** nm	**Thickness** nm	τ_{rise} (ps)	τ_{fall} (ps)
Nb Parallel	39,5	200x200	80%	800	40	**400**	**500**

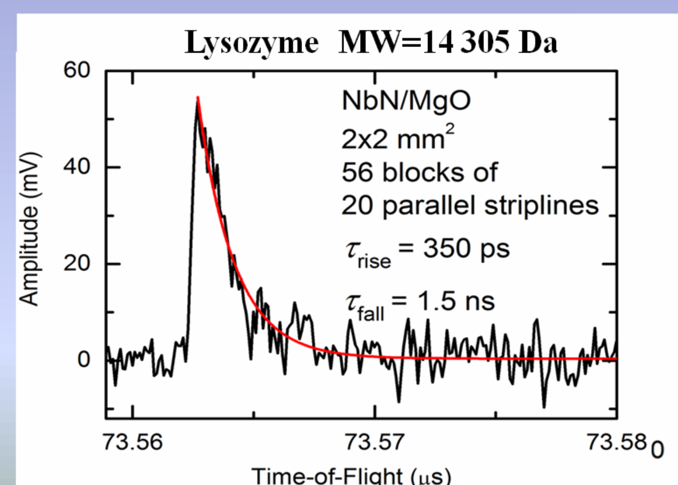
N. Zen, A. Casaburi *et al.*, APL **94**172508 (2009)

	blocks n_B	**parallel** n_S	**filling factor**	**linewidth** nm	τ_{rise} ps	τ_{fall} ps
Nb Parallel	101	5	50%	1000	**600**	**1800**
Nb Parallel	51	10	50%	1000	**520**	**920**

2x2 mm^2



NbN strip-lines
50 nm thick,
1 µm width



A. Casaburi et al, SUST **25**, pg 115004 (2012)

Parallel SSD in single strip switch regime

These devices were operated at a bias current smaller than $I_b / I_C < 0.70$ to avoid latching (no superconducting state recovery after detection event)

From measurements: Pulses amplitude: V_p ~1mV << 3 mA × 50 Ω = 150 mV
Pulse amplitude distribution very large: FHWM ~ 35% of V_p

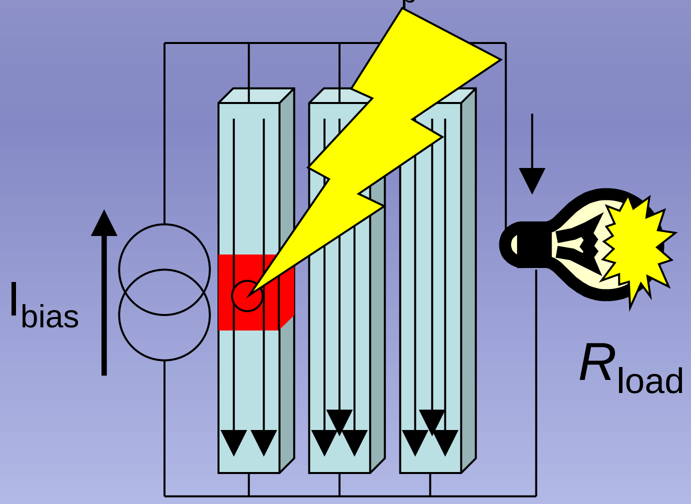
Single strip switch

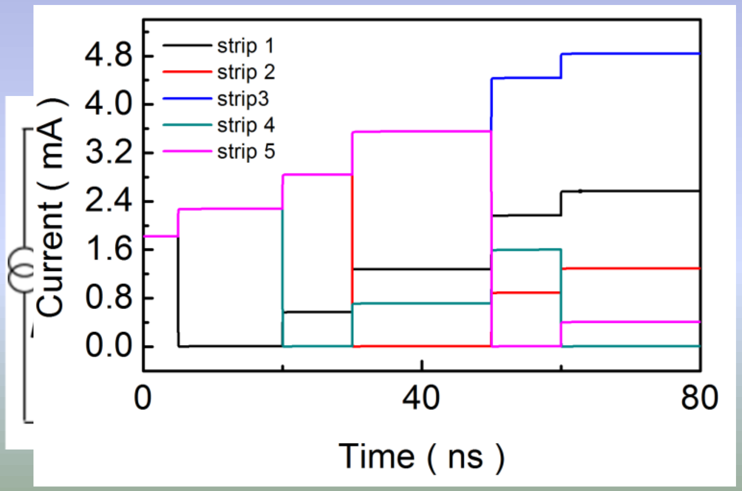
Detector inductance is about $n_S{}^2$ times lower than the meander SSD

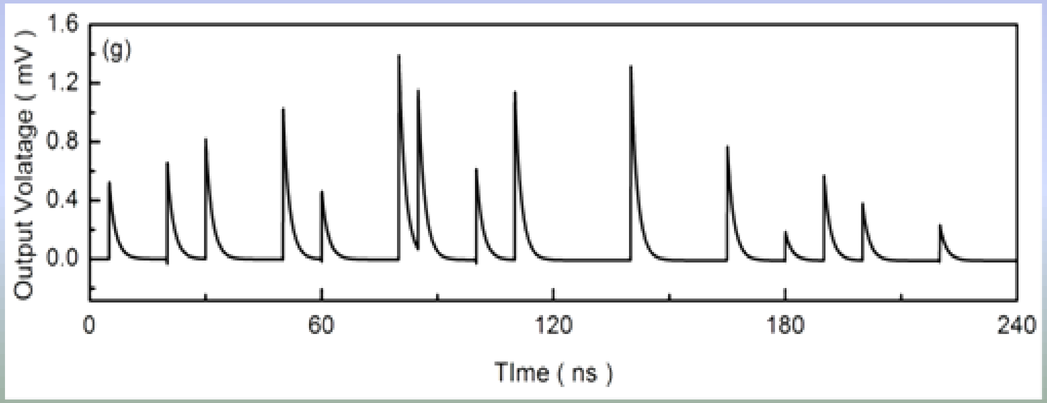
Signal amplitude: < 1 % of I_{bias} and decreases with n_S

Useful bias range: $\Delta I_B = (I_{thr} - I_{min})$

A. Casaburi, N. Zen *et al.*, APL **94** 212502 (2009)
N. Zen, A. Casaburi *et al.*, APL **94**172508 (2009)

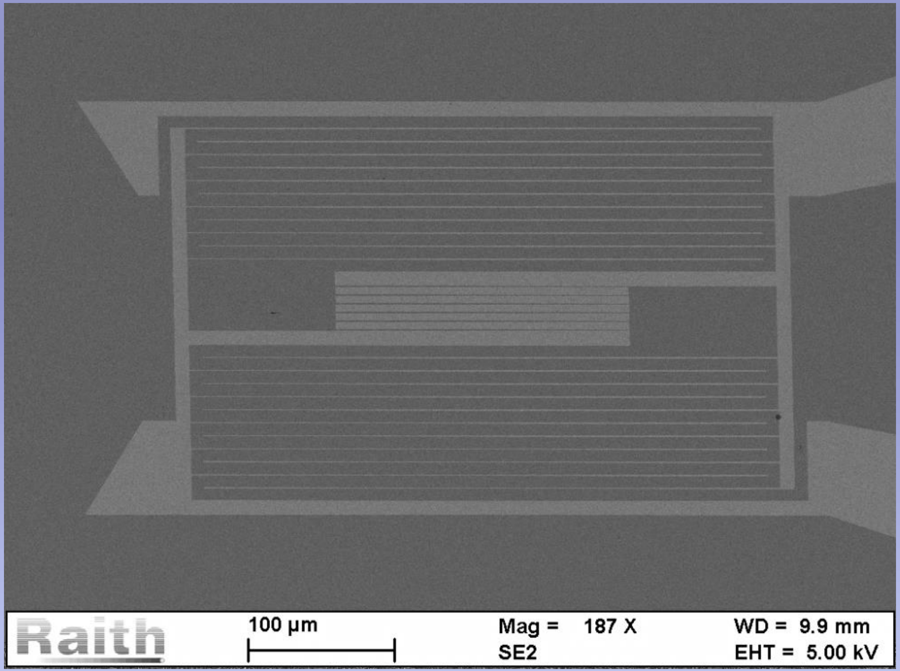


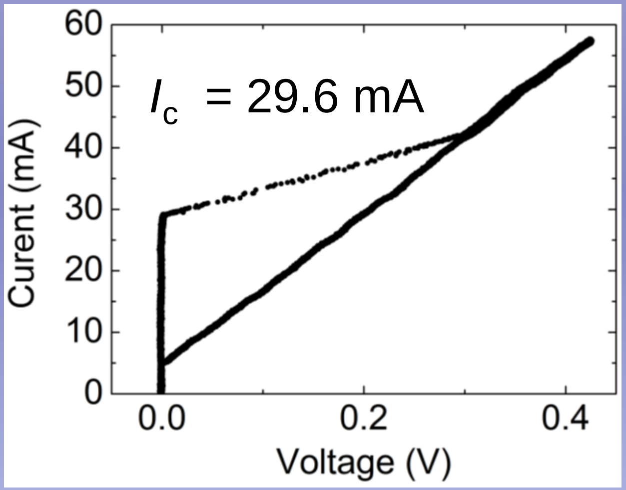


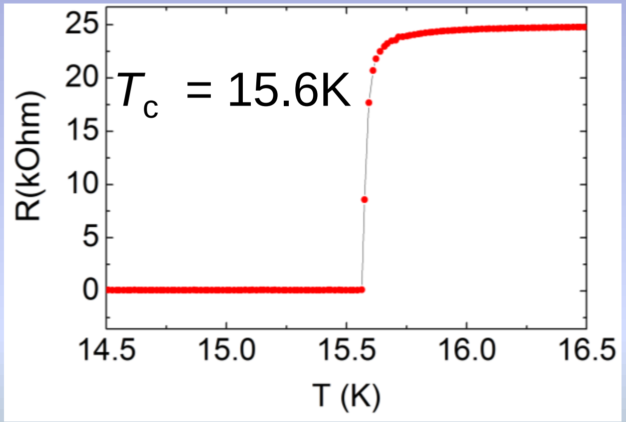


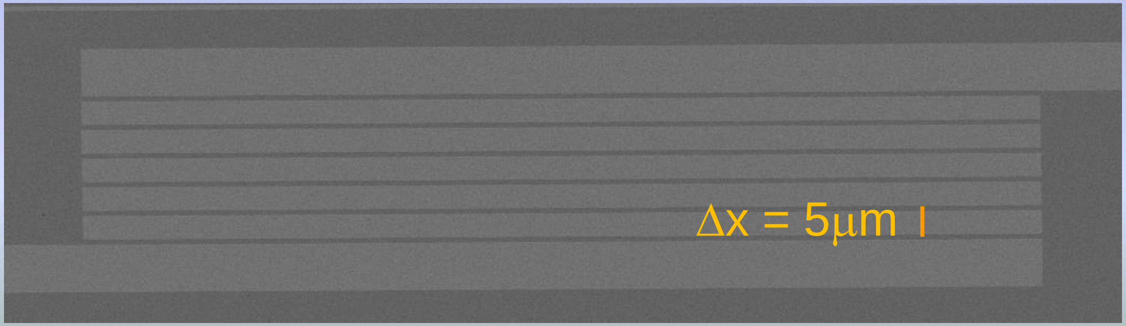
Study of current distribution in a parallel SSD

The device uses 6 NbN parallel strip-lines having a width of 1 μm, thickness of 40 nm and the spacing between strip-lines is 5 μm.



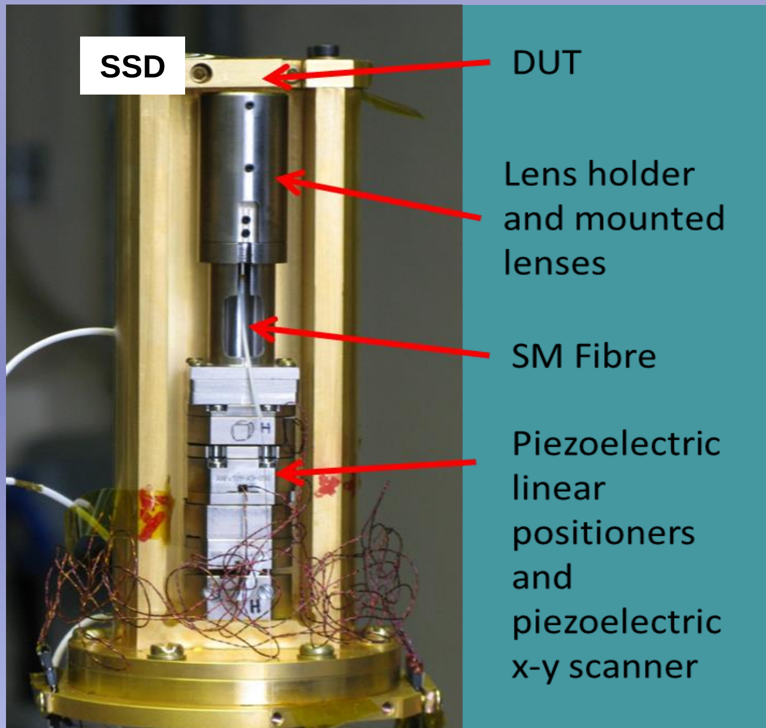


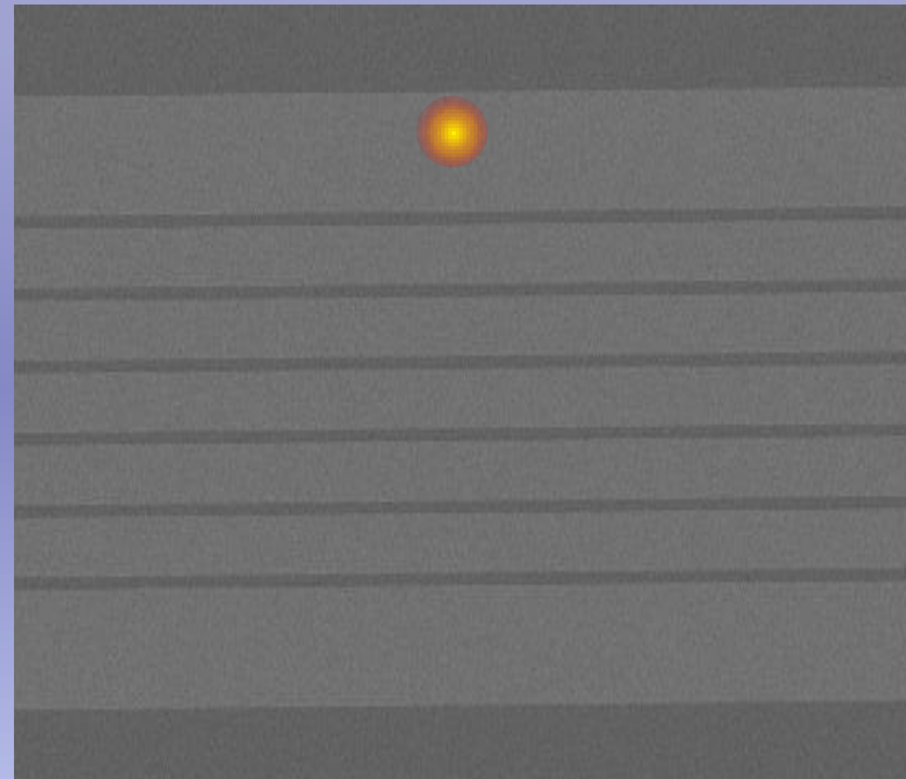


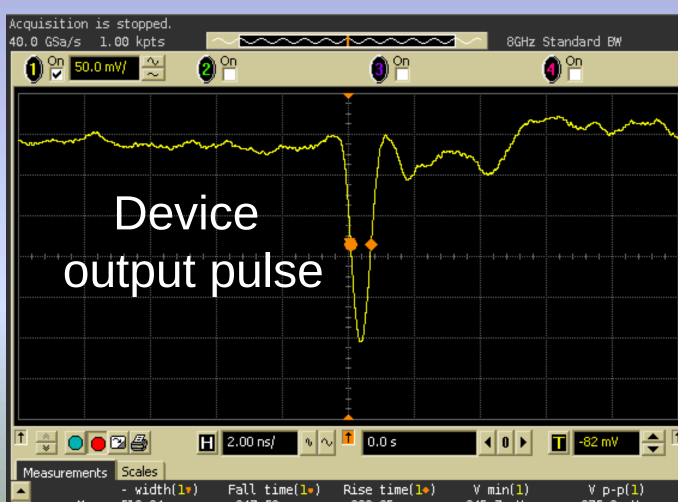


A. Casaburi *et al*, APL 103, 013503 (2013)

Study of current distribution in a parallel SSD



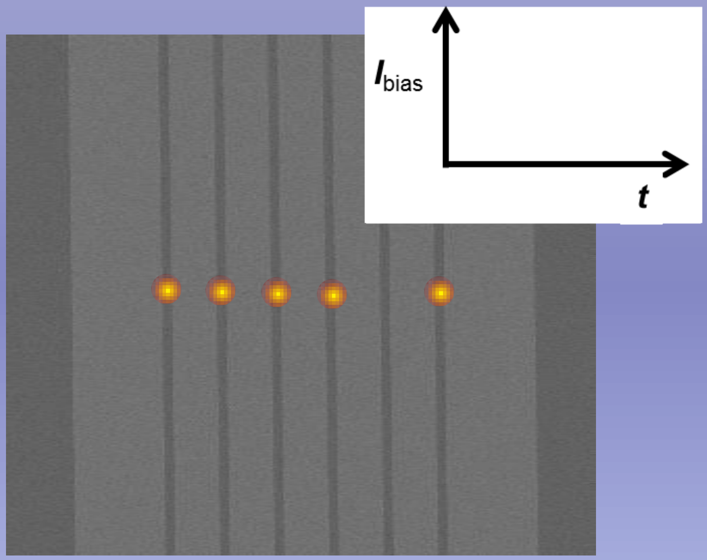


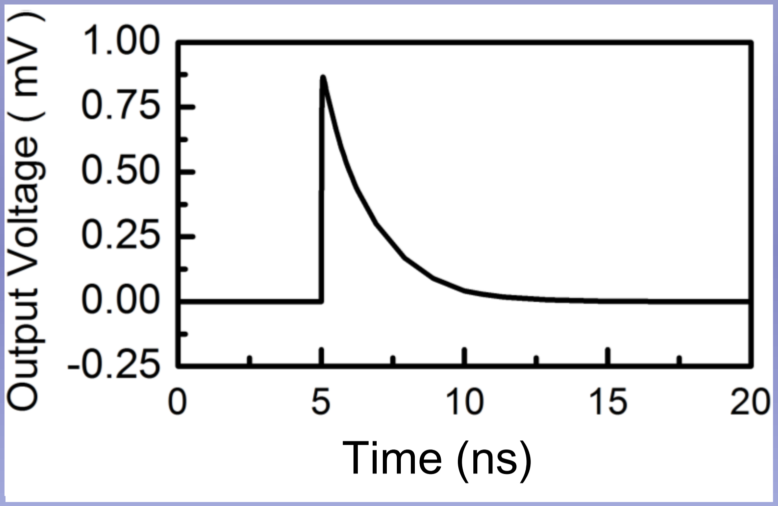


For I_b / I_C > 80 % the device latches (cascade triggering?)

A. Casaburi *et al*, APL 103, 013503 (2013)

Current recovering in the strips





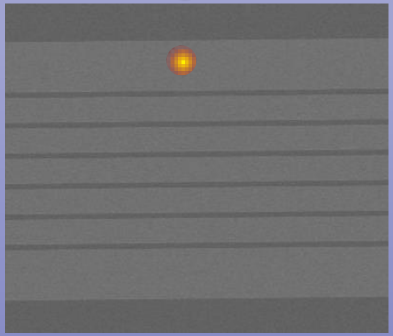
The strip-line generates only one pulse and then becomes insensitive to further laser pulses unless bias current is reset or several strips are switched.

From this observation we deduce:

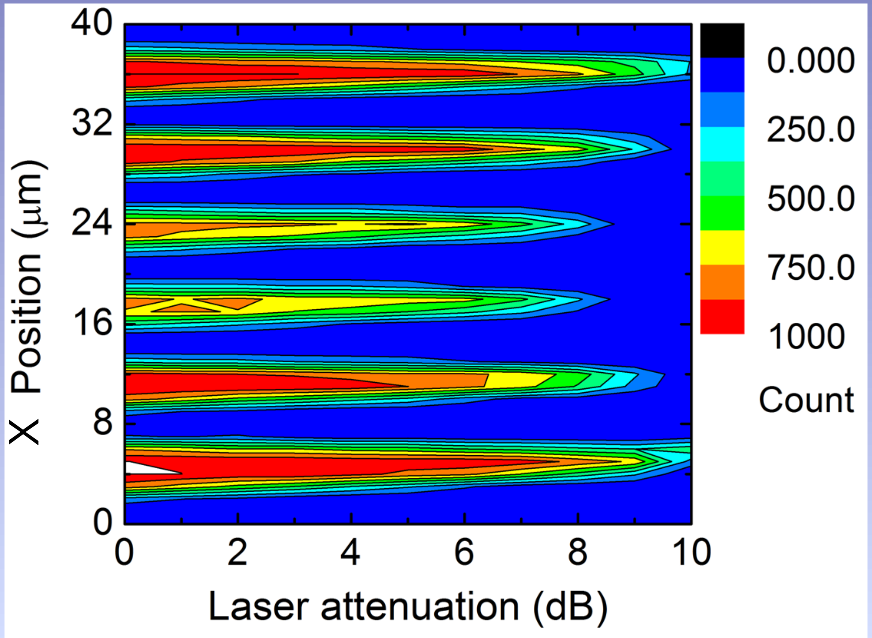
- The strips recover the superconducting state but not the initial bias current

Count rate in the different strips

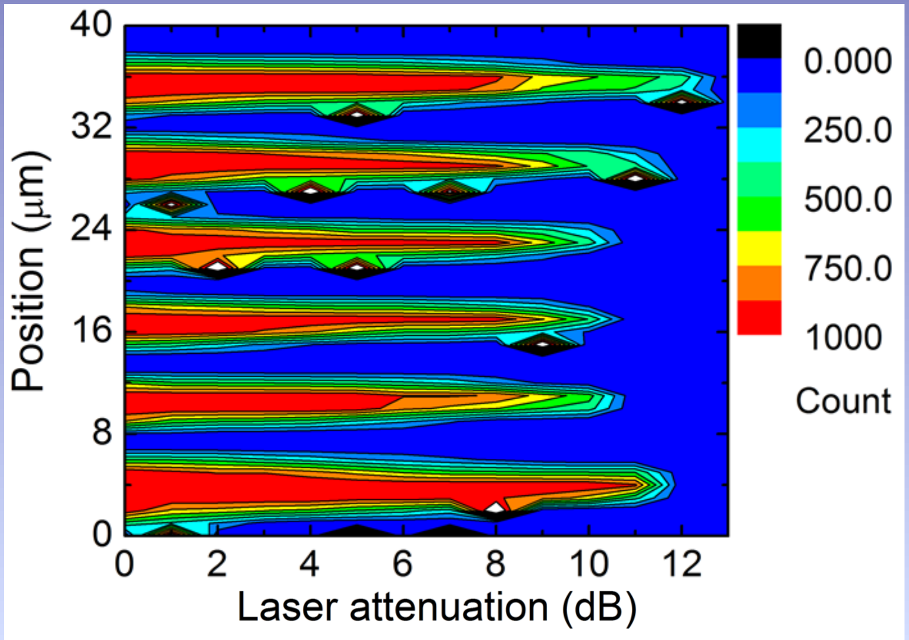
The laser pulses were scanned transversally across the strips with 1 μm step size. On each point 1000 laser pulses were delivered and between successive pulses the bias current is reset.



Bias current 13 mA



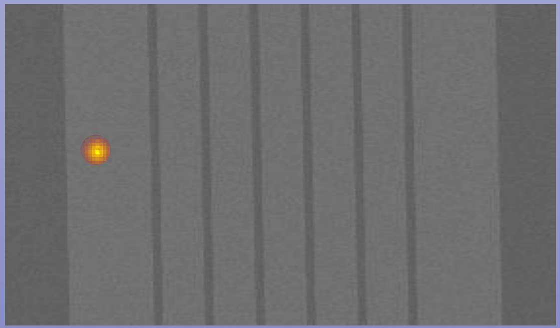
Bias current 21 mA

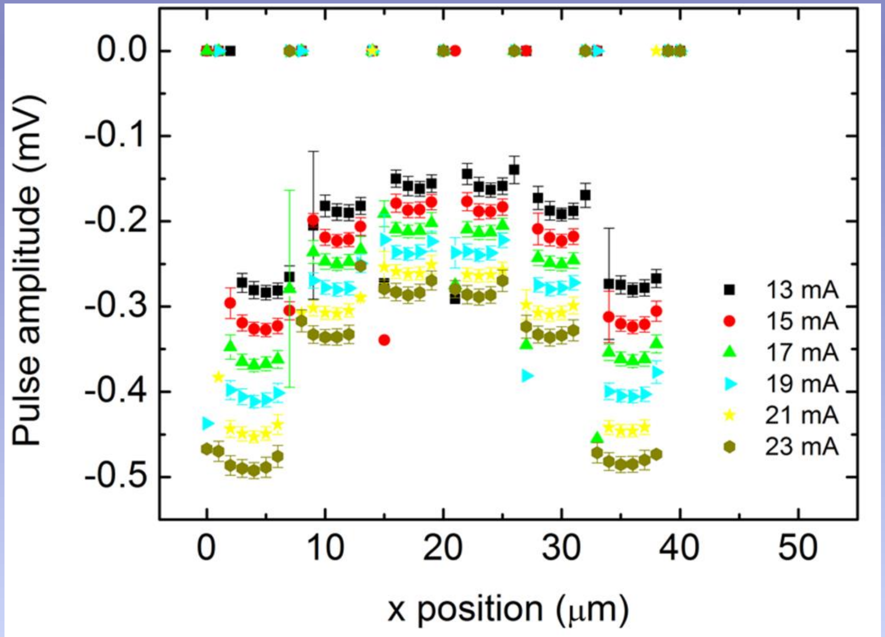


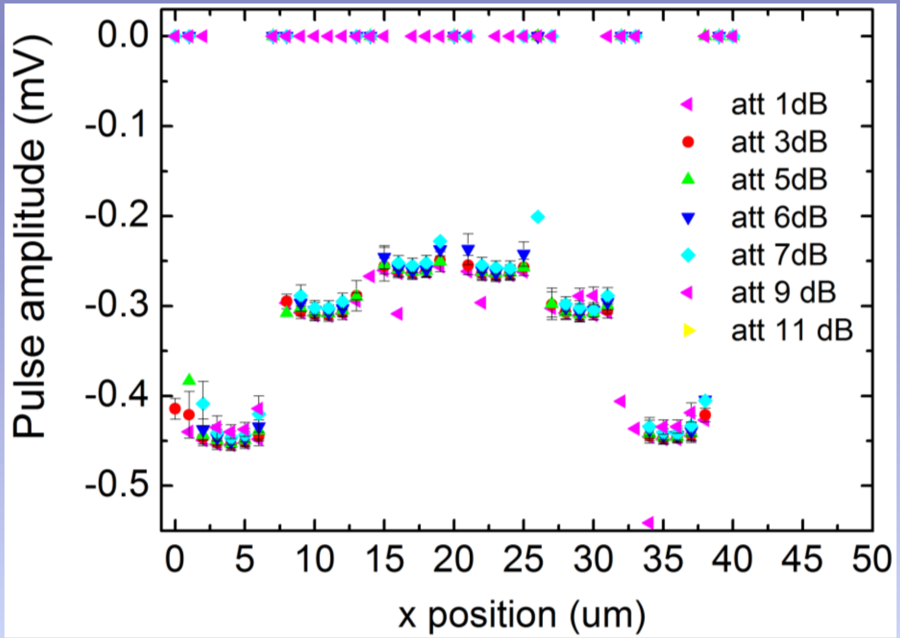
The count rate decreases from the outer strip-lines to the inner ones in a symmetric way

Pulse amplitude for different strip-lines

The laser pulses were scanned transversally across the strips with 1 μm step size. On each point 1000 laser pulses were delivered and between successive pulses the bias current is reset.



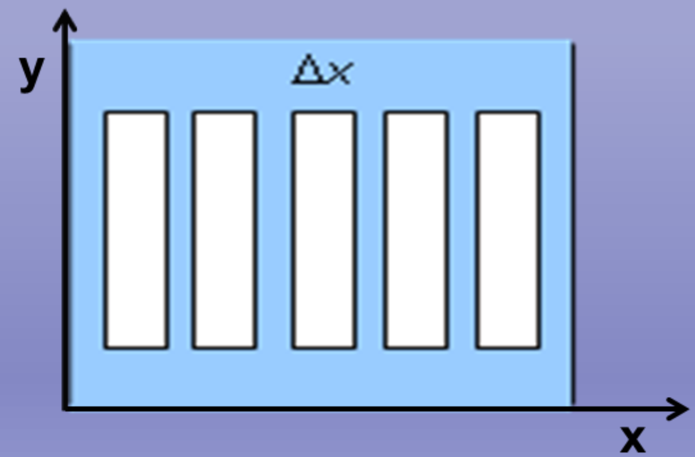




The maximum pulse amplitude A_i decreases from the outer strip-lines toward the inner ones in a symmetric way (a much smaller variation is observed within each strip-line). A similar trend is observed for the count rate

Current distribution in the London model

$$\nabla^2 \mathbf{j} = \frac{1}{\lambda^2}\mathbf{j} \qquad j_x = j_z = 0 \text{ e } j_y = j_y(x) = j(x)$$



$$\frac{j_{i+1} - 2j_i + j_{i-1}}{(\Delta x)^2} = \frac{1}{\lambda^2} j_i \qquad i = 2,3,4,5$$

$$\frac{j_2}{j^*} = \frac{j_5}{j^*} = \frac{1+a}{1+3a+a^2} \qquad a = (\Delta x^2/\lambda^2)$$

$$\frac{j_3}{j^*} = \frac{j_4}{j^*} = \frac{1}{1+3a+a^2} \qquad j_1 = j_N = j^*$$

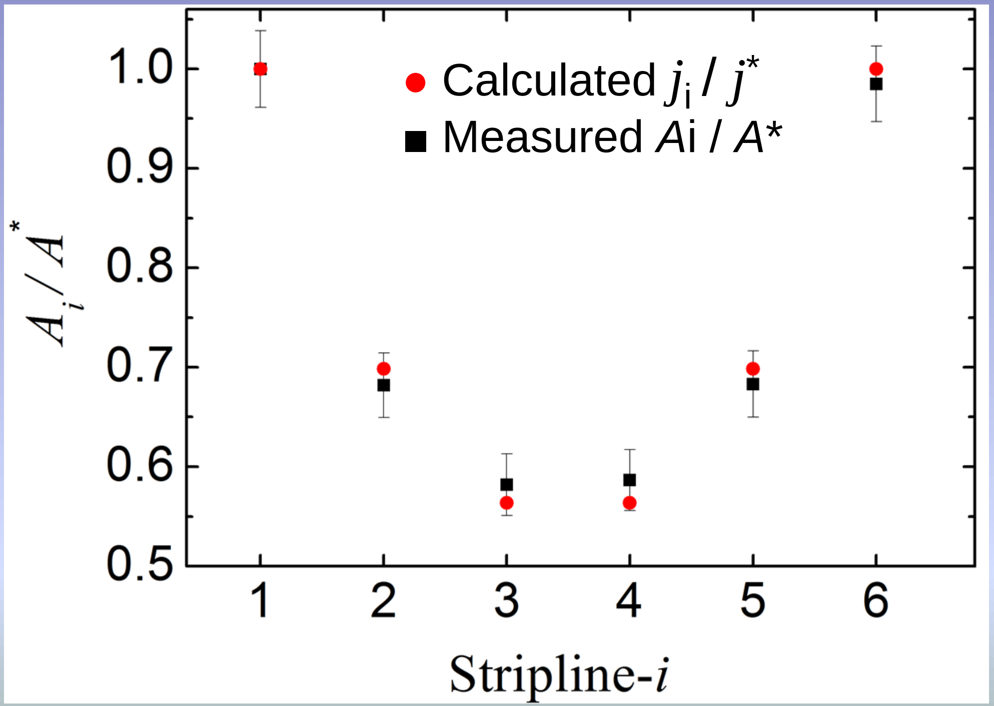
$$A_i / A^* = I_i / I^* = j_i / j^*$$

***From the fit : a* = 0.239 ± 0.002**

λ = 10.2 ± 0.2 μm

$\tau_{fall} = L_k / R_L \,,\ L_k = \mu_0 \lambda^2_L\, 2\, l / (wd)$

$\lambda_{eff} = 2\lambda^2_L / d = 12.2 \pm 3.6\ \mu m$



A. Casaburi *et al*, APL 103, 013503 (2013)

Parallel SSD in single strip switch regime

Conclusions

Using nano-optical techniques we have investigated the physics of a parallel superconducting strip detector (SSD) operating in the single strip-switch regime by observing the current distribution

The strips recover the superconducting state but not the initial bias current becoming insensitive to further events unless bias current is reset or several strips are switched

Current distribution after biasing is symmetric and not uniform to exclude the self induced magnetic field. After each detection event the current distribution should change to sustain the zero current in the fired strip **and** exclude magnetic field

This study represents an important step forward in the development of next generation parallel configuration designs with large active areas. This is relevant to both SSDs for TOF-MS and to the SNSPDs for infrared single-photon detection.