Dissipation in thin narrow superconducting films

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1. Dark counts in photon detectors (dissipation in thin films).
2. Dissipation in superconducting wires, ALMH theory.
3. Dissipation due to vortex motion in thin films.

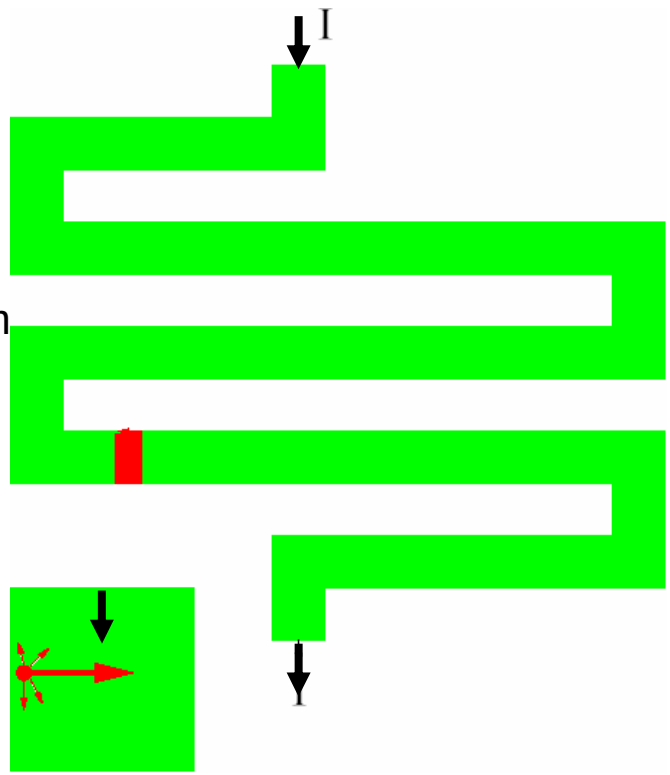
Acknowledgements: I. Martin, M. Graf.

Motivation: dark counts in photon superconducting detectors

d=5 nm

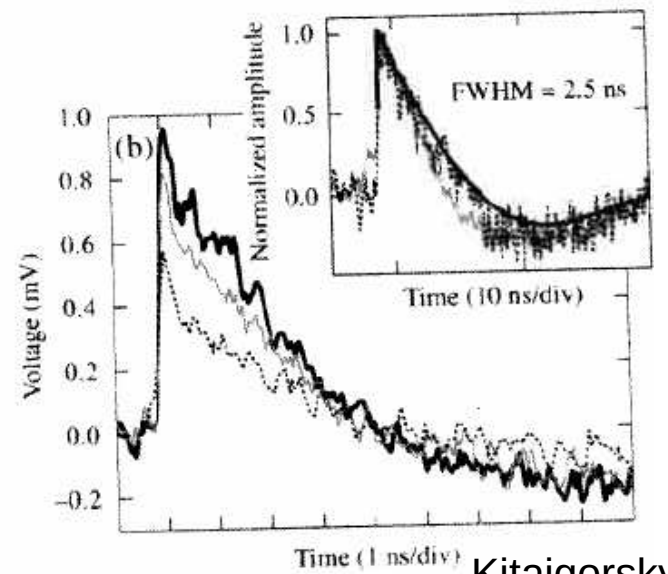
W=120 nm

ξ =4 nm



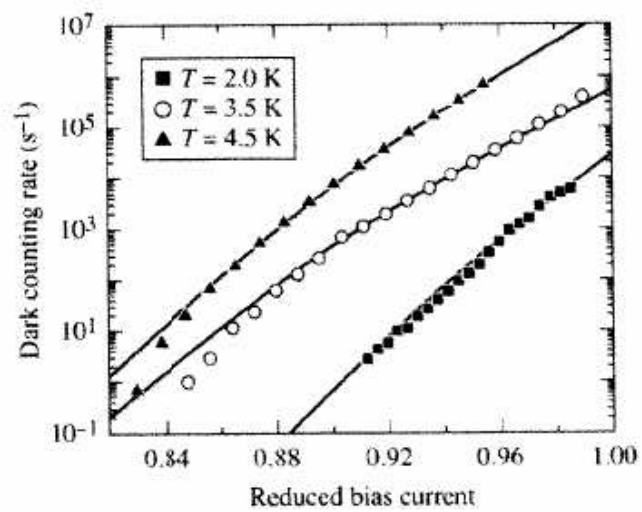
NbN

T_c =15 K



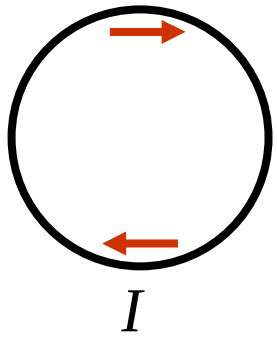
Kitaigorsky

Sobolevsky



- Bias current close to I_c for sensitivity.
- Counts without photons (dark counts), $V_{dc} > 0$.
- Origin: vortex motion across strip

Dissipation in thin wire, length L, ALMH theory.



$$\Psi_n(x) = \Psi_0 e^{i\kappa_n x + \phi}, \qquad \kappa_n = \frac{2\pi n}{L},$$

$$I = I_0 \kappa_n (1 - \kappa_n^2), \qquad \kappa_{\max} = \frac{1}{\sqrt{3}}.$$

- Change of current: $\kappa_n \to \kappa_{n-1}$.
- Phase changes locally inside normal region by 2π.
- Saddle point solution:

$$\Psi_{s,n\to n-1} = [\alpha \tanh(\alpha x / \xi\sqrt{2}) - i\kappa\sqrt{2}]e^{i\kappa x + \phi}, \quad \alpha = (1 - 3\kappa^2)^{1/2}.$$

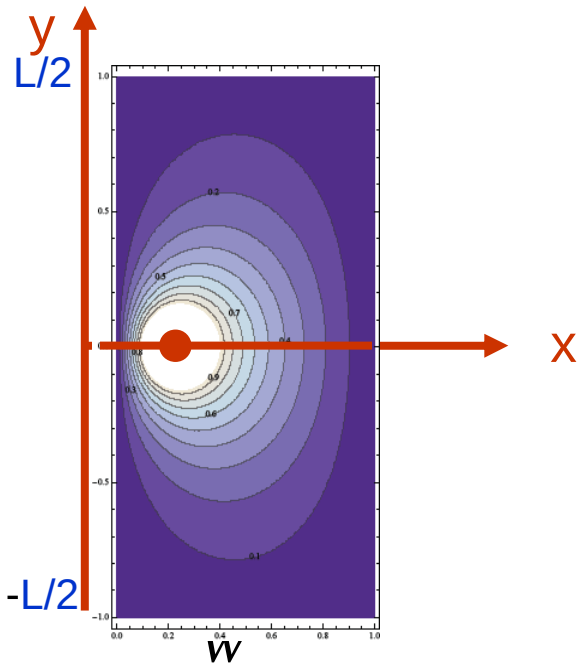
- Barrier $\Delta F_{n\to n-1} = \dfrac{\sigma H_c^2 \xi}{8\pi} f(\kappa) \tan^{-1}(\alpha / \kappa\sqrt{2}), \qquad R = \Omega e^{-\Delta F / T},$

$$\Omega = \frac{L}{\tau_{TDGL}\xi}\left(\frac{\sqrt{2}\sigma H_c^2 \xi \alpha^{3/2}}{24\pi^4 T}\right)^{1/2} \sqrt{|\varepsilon_{1S}|}\left[\varepsilon_{n1}\varepsilon_{n2}\prod_{m=4}\frac{\varepsilon_{nm}}{\varepsilon_{sm}}\right]^{1/2} \approx \frac{1}{\tau_{TDGL}}\left[\frac{\Delta F_{n\to n-1}}{T}\right]^{1/2}.$$

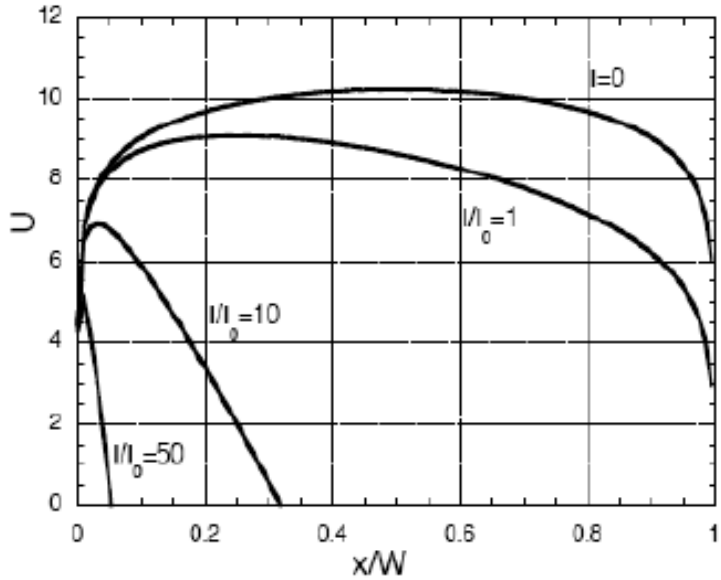
[Fluctuation factor]

Thin film, length L, width w, ξ w $\Lambda = 2\lambda_L^2 / d$

- Pearl vortex energy inside strip (kinetic energy of currents), $A \propto 1/\Lambda \to 0.$



V. Kogan



$$I_0 = \frac{c\Phi_0}{8\pi\Lambda}$$

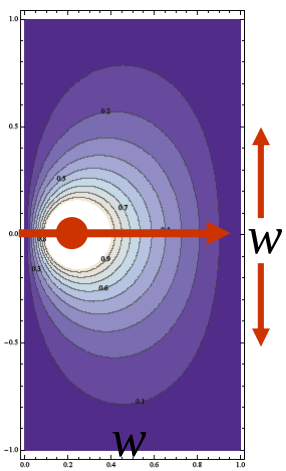
U in units

$$\varepsilon_0 = \frac{\Phi_0^2}{8\pi^2\Lambda}$$

- Phase difference between y-edges for L>>w $\varphi(L/2) - \varphi(-L/2) = 2\pi x.$
- Vortex moving x=0 and x=w changes phase difference by $2\pi.$
- Saddle point solution: vortex at maximum of the potential at given current.
- Barrier: $\Delta F_{n\to n+1} = \varepsilon_0 \ln \frac{2wI_0}{e\pi\xi I},$ I $I_0,$ $I_c = I_0 \frac{2w}{e\pi\xi}.$

Attempt frequency and fluctuation factor

- Rate of vortex crossings: $R_{n\to n-1} = \Omega e^{-\Delta F/T}$,
- DC voltage given by Josephson relation: $V = (\hbar / 2e_{el}) R_{n\to n-1}$.
- Attempt frequency: $\Omega \approx \dfrac{L}{\tau_{TDGL}\xi}\left[\varepsilon_{n2}\varepsilon_{n3}\prod_{m=4}\dfrac{\varepsilon_{nm}}{\varepsilon_{sm}}\right]^{1/2}$. $\varepsilon_{sm} > \varepsilon_{nm} > 0$.
- Exponential factor: $e^{-\Delta F/T} = (2\nu/\pi)^{1/2}(I/I_c)^{\nu}$, $\nu = \varepsilon_0 / T$,
- Near critical current exponential dependence: $(I/I_c)^{\nu} \approx \exp[\nu(I/I_c - 1)]$.
- Estimate for fluctuation factor (numerical calculations are in progress):



$$\left[\varepsilon_{n2}\varepsilon_{n3}\prod_{m=4}\frac{\varepsilon_{nm}}{\varepsilon_{sm}}\right]^{1/2} \propto \exp\left(-\frac{r w^2}{\xi^2}\right), \quad r(I) = \ ?$$

- 1D: fluctuation factor is of order unity $w \approx \xi$.
- Strip: fluctuation factor diminishes strongly dissipation rate.