Trapping hot quasiparticles in a high power superconducting cooler

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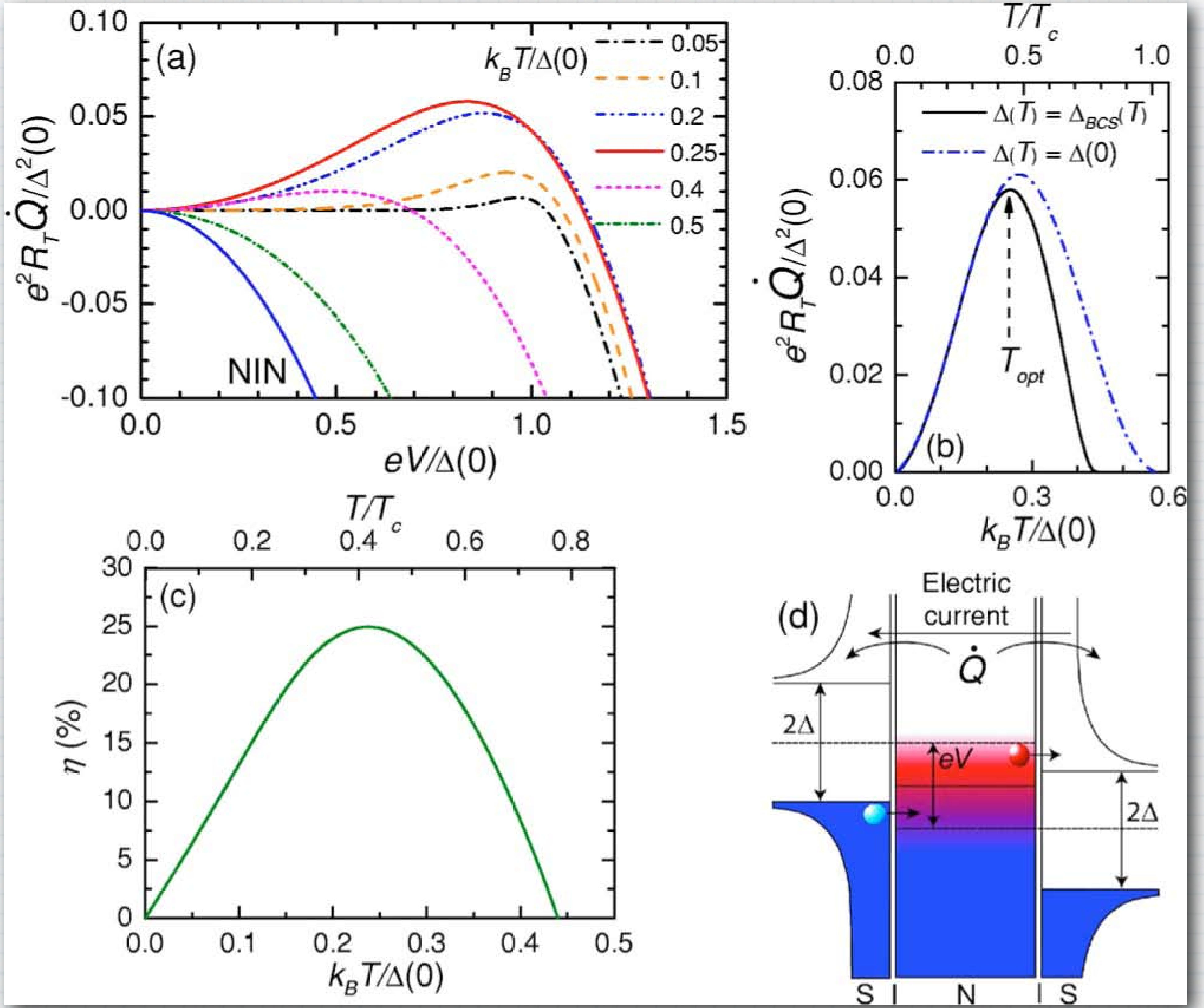
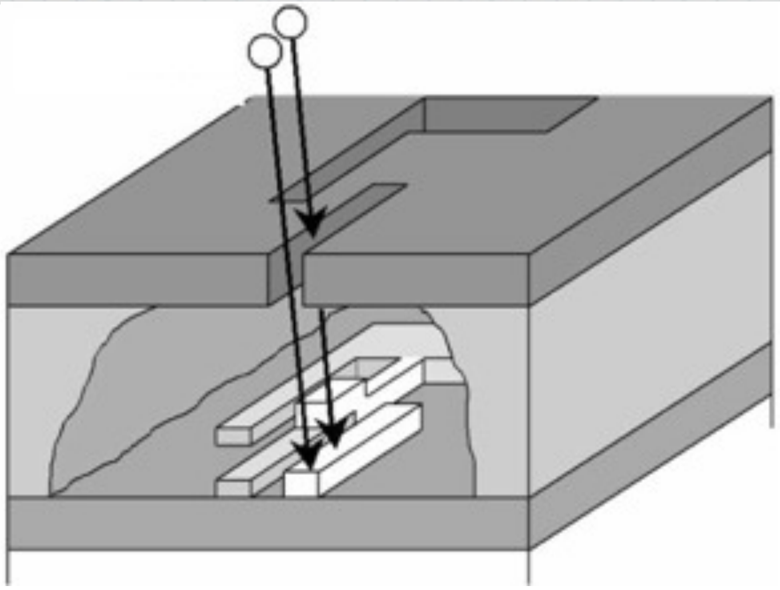
Basic of cooling using superconducting junctions

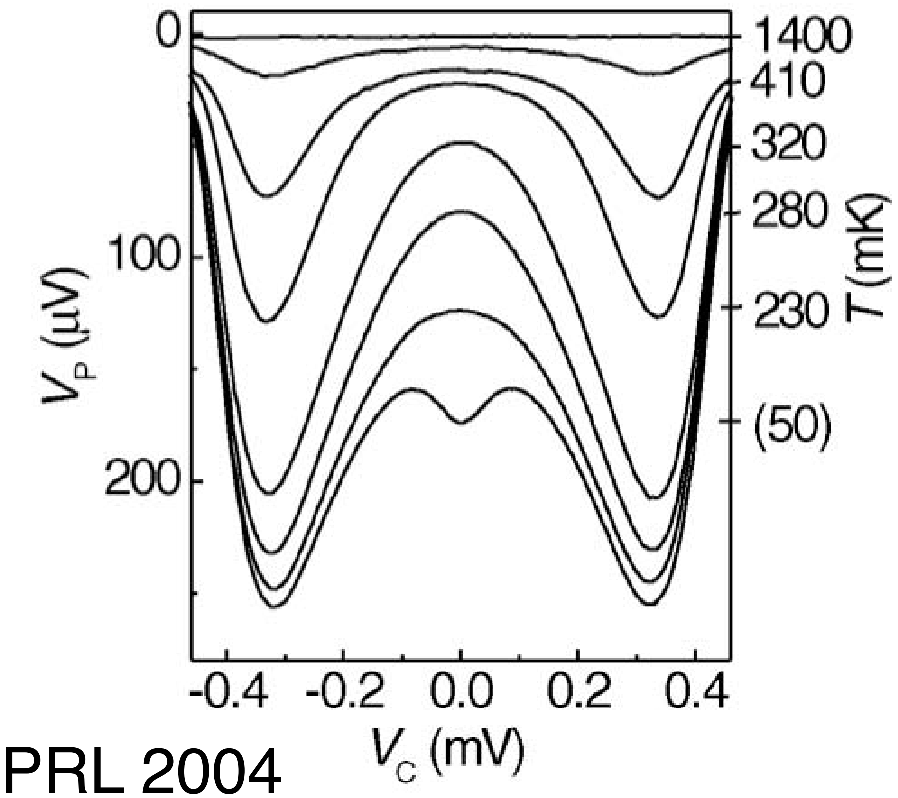


Giazotto et.al. RPM, 2006, figure 26

Two methods to make SINIS coolers

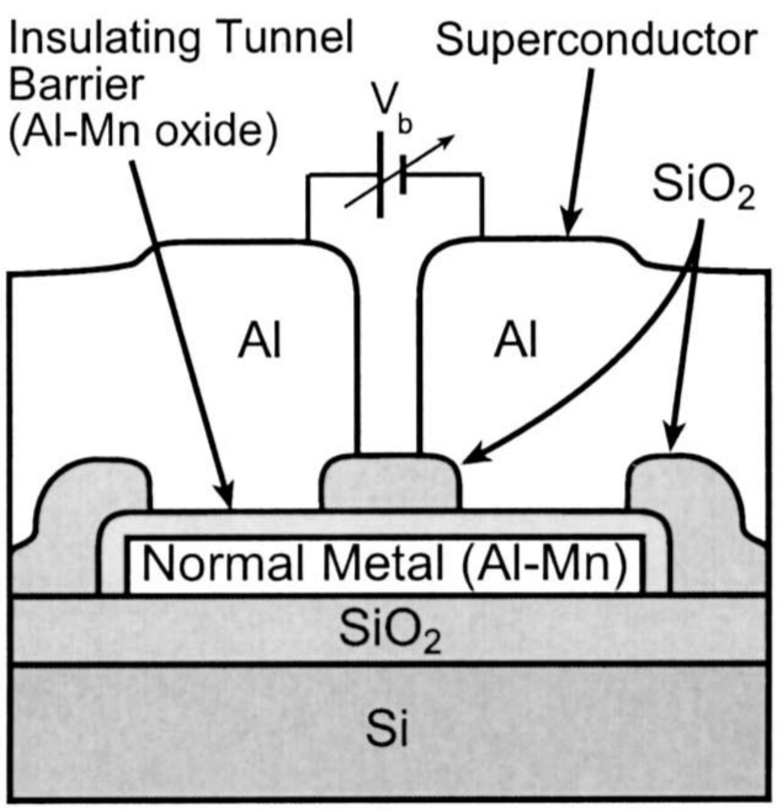


Dolan, APL 1977
(adapted from Rajauria's thesis)

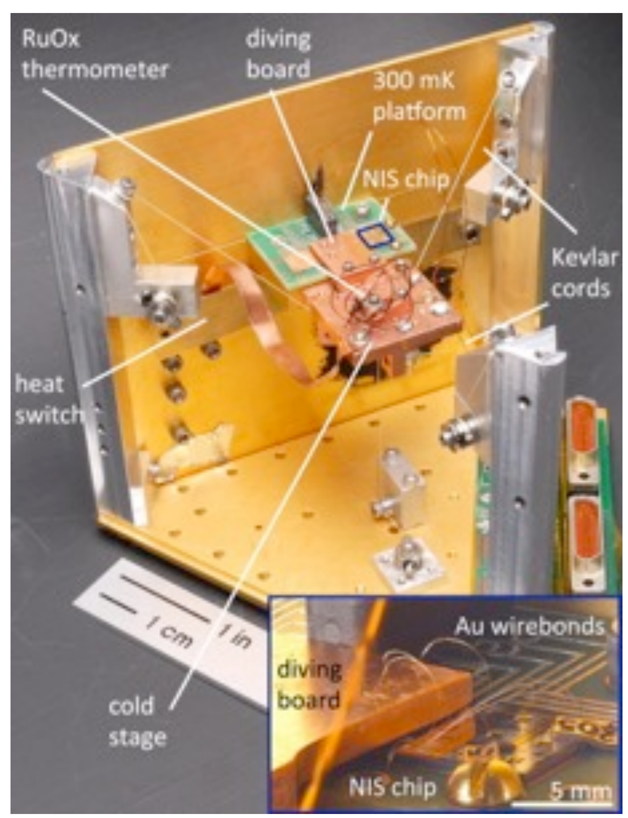


Pekola et.al., PRL 2004

- E-beam lithography
- Mostly Cu/Al
- Great studies about physics.



Clark et.al., APL 2004



Lowell et.al., APL 2013

- Photolithography
- SINIS with AlMn/Al
- Great demonstrations on cooling bulk objects

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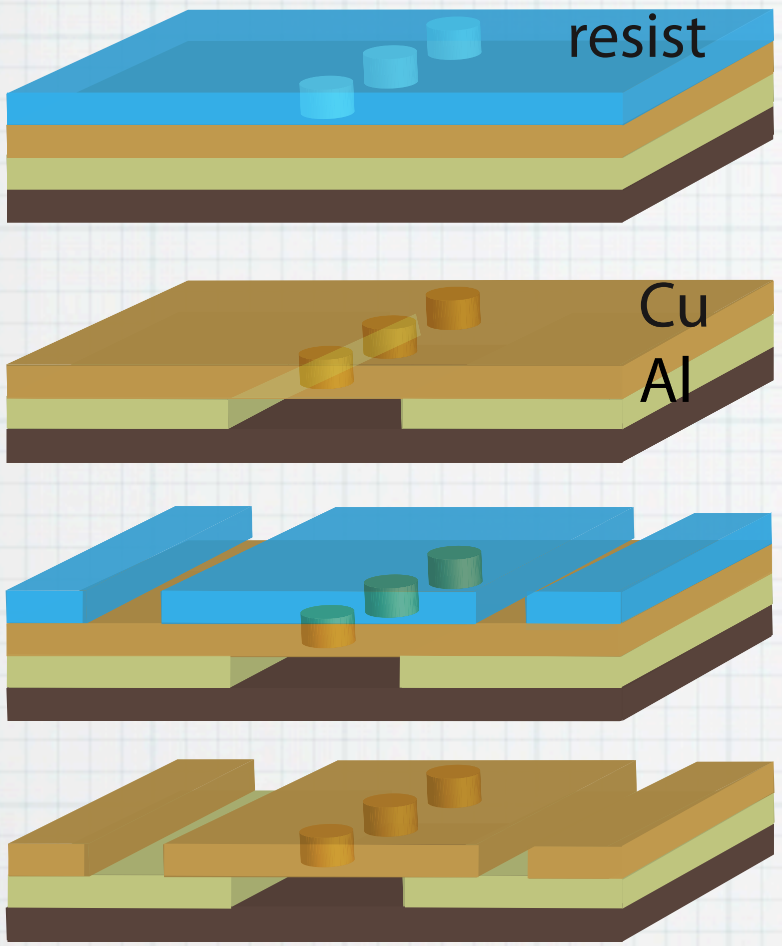
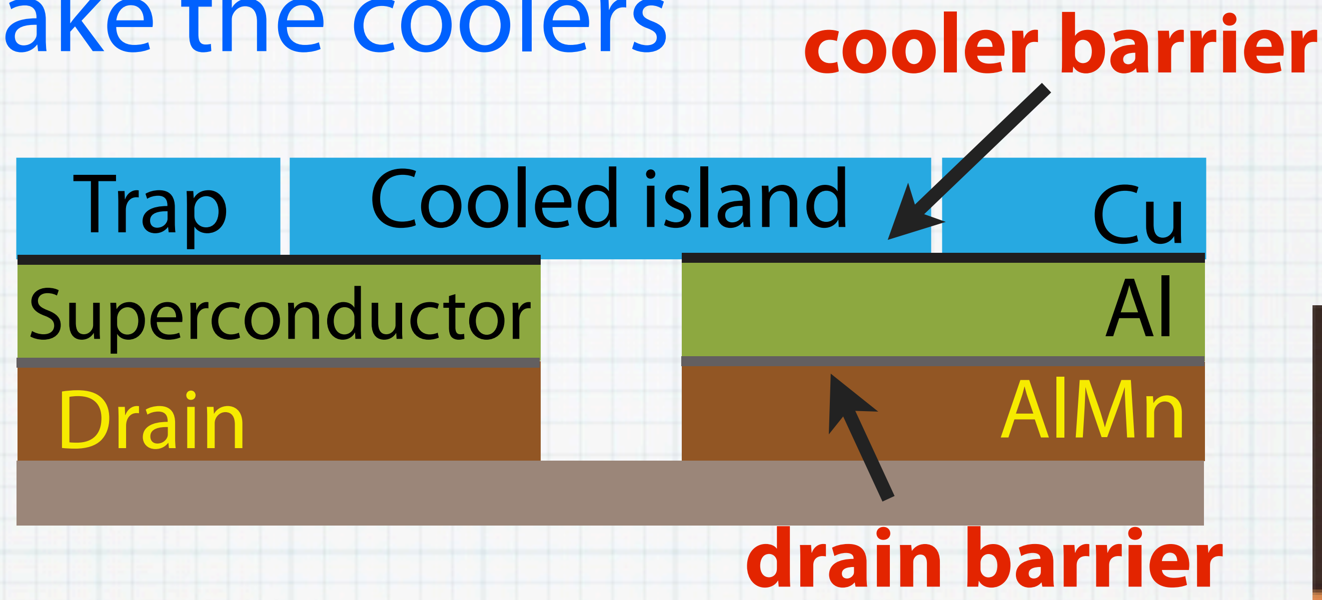
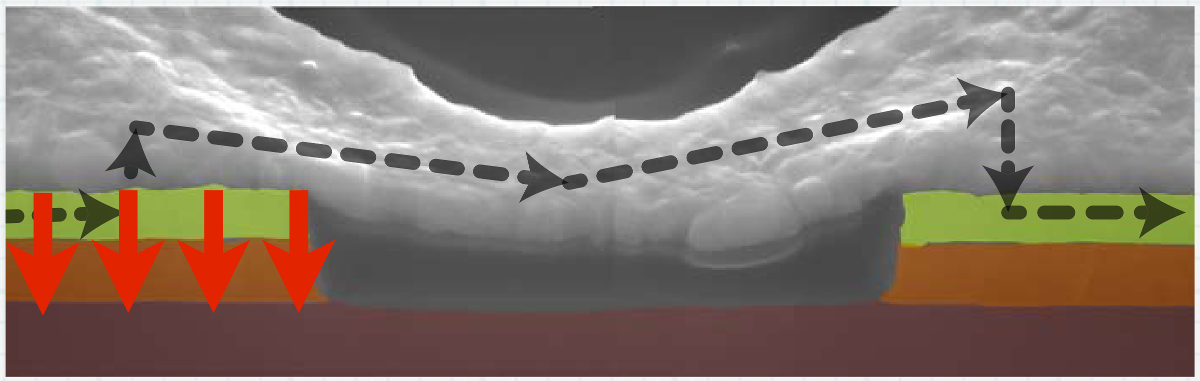
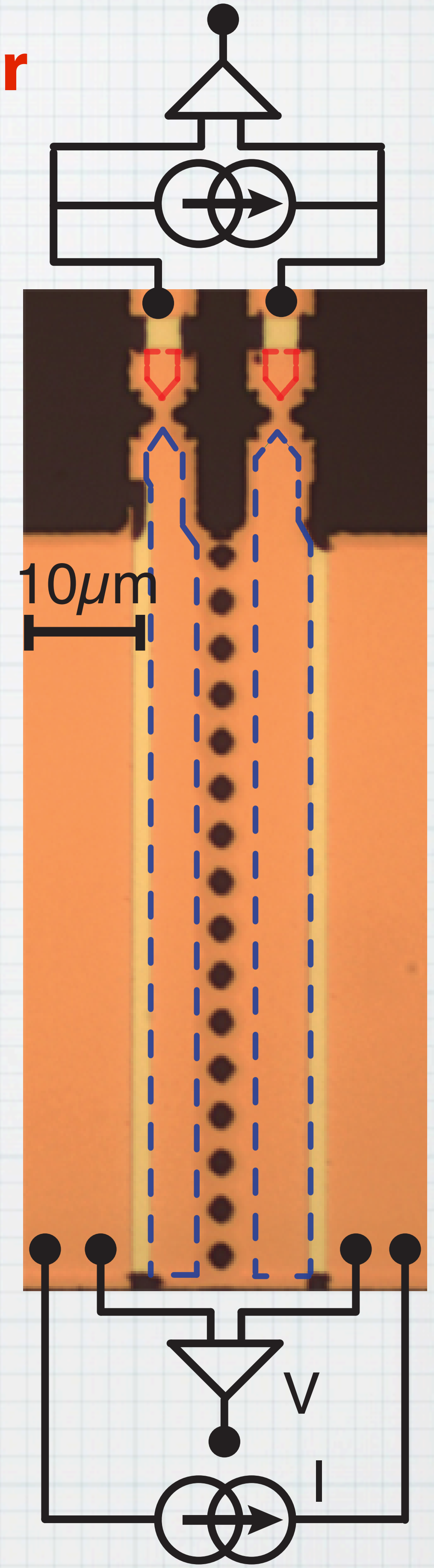
Our method to make the coolers



Nguyen et.al., APL 2012







- Single vacuum deposition
- Trilayer, 2 tunnel barriers
- 2 steps photolithography
- Chemical wet etch Al and Cu
- Suspended cooled Cu island

Junction size	70x8 μm
RN	~1 Ω
Optimum current	~10 μA
Cooling power	**~1 nW**

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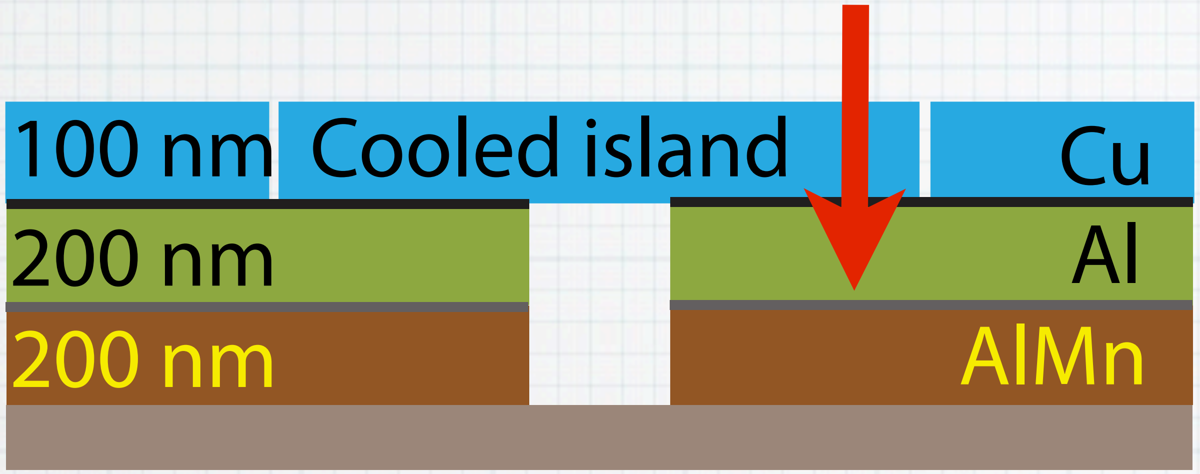
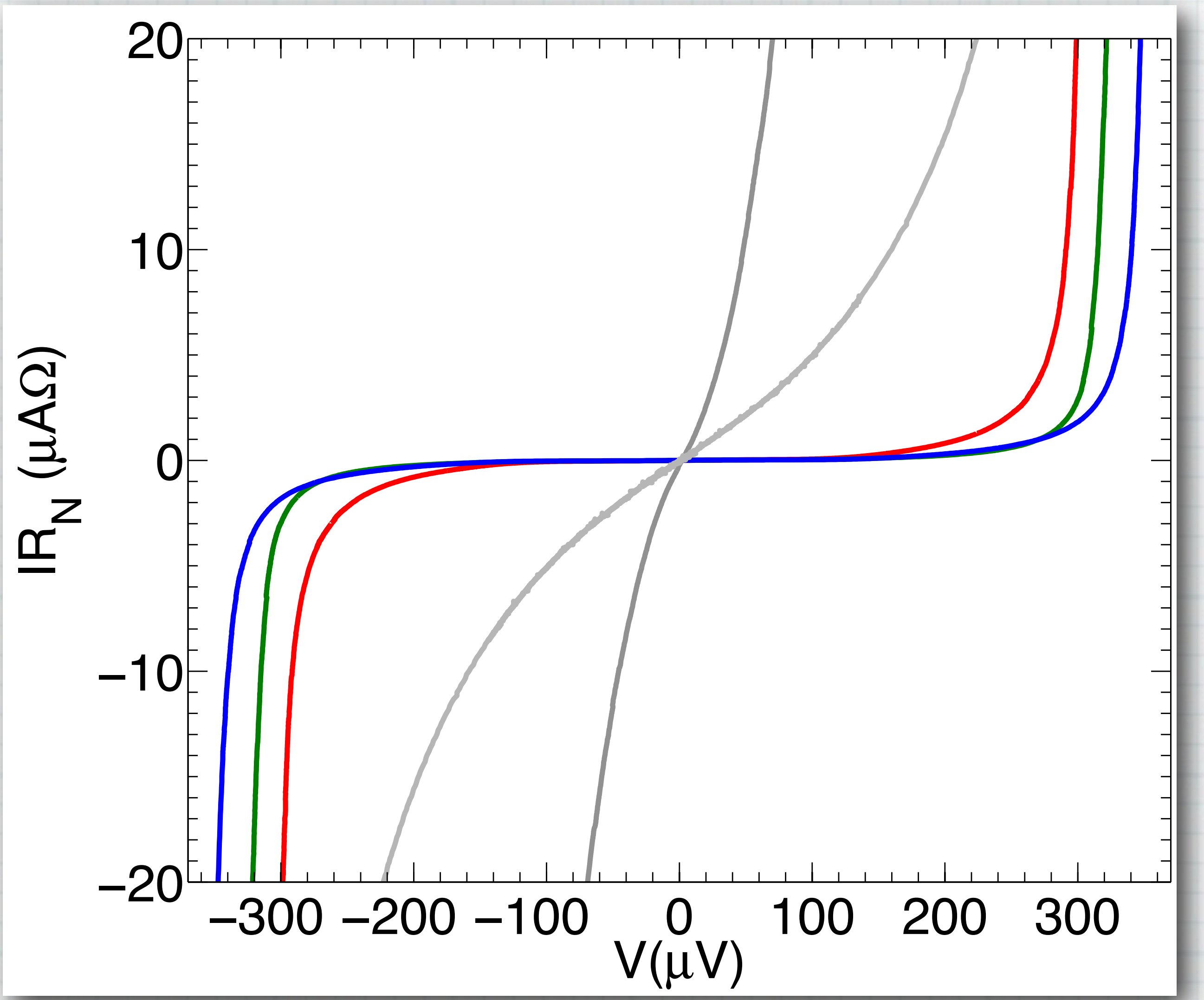
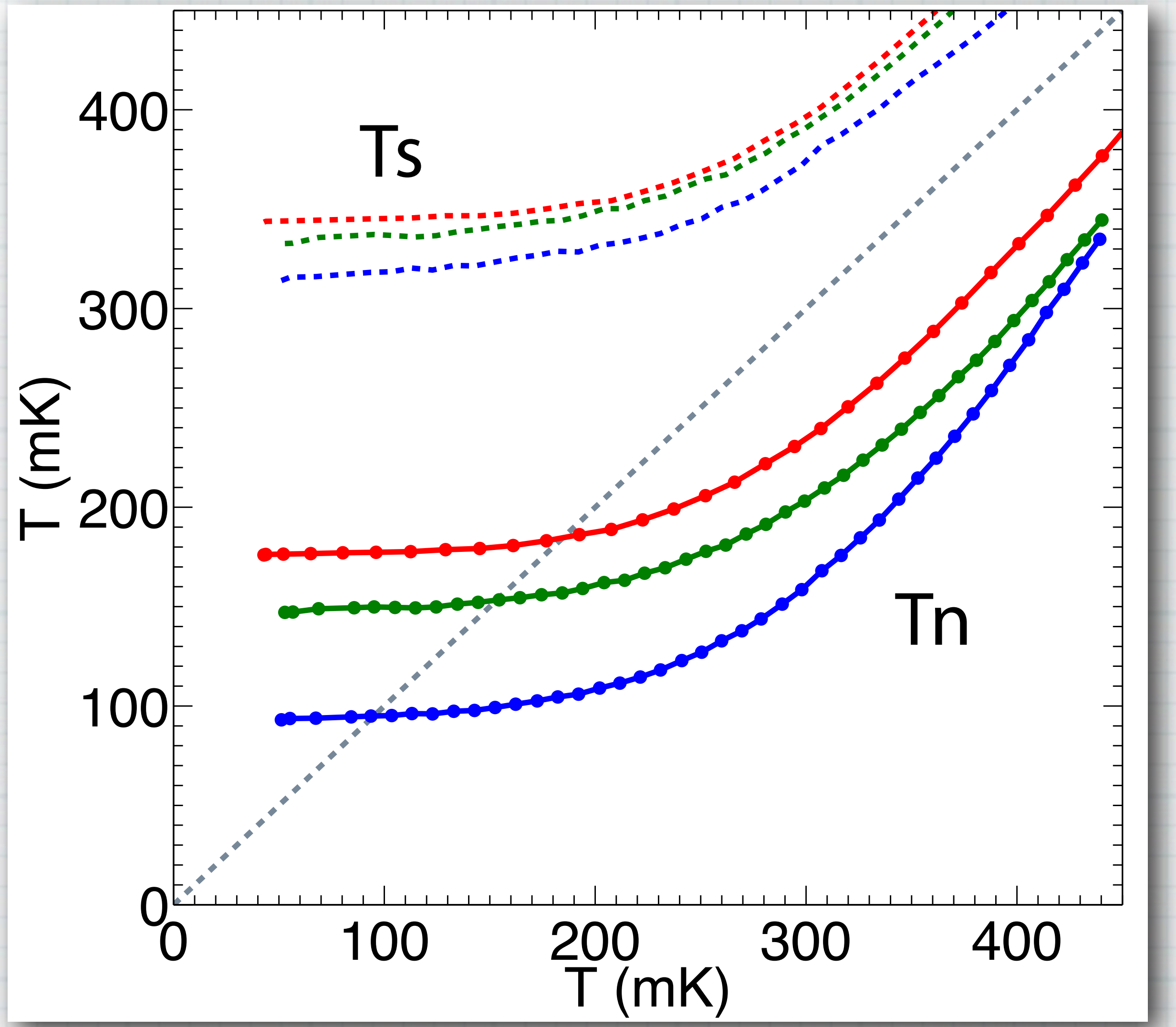
The role of the drain barrier



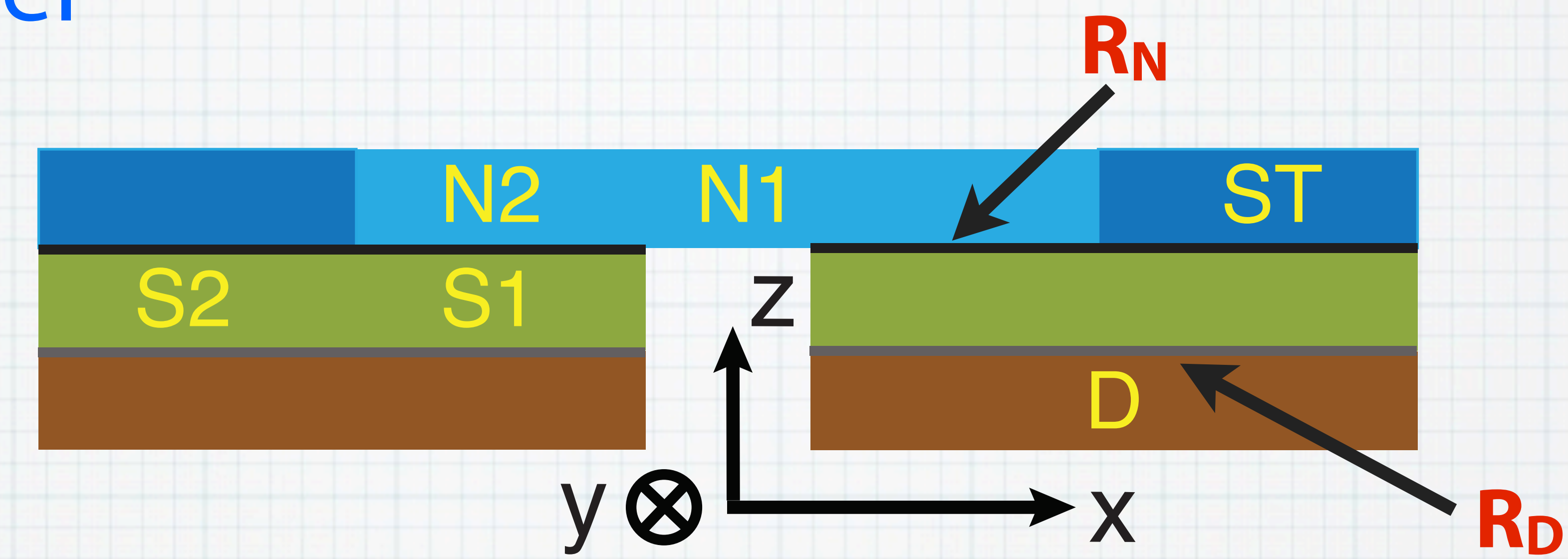
Cooler barrier	Drain barrier
500 Ωμm²	N/A (no AlMn)
500 Ωμm²	1mbar
500 Ωμm²	0.2mbar
500 Ωμm²	0 mbar





Nguyen et.al., NJP 2013

A thermal model



$$N1 : \kappa_N d_N \nabla^2 T_N = -\mathcal{P}_{ep}^{N}(T_N)$$

$$N2 : \kappa_N d_N \nabla^2 T_N = \mathcal{P}_{NIS}(V, T_S, T_N, R_N) - \mathcal{P}_{ep}^{N}(T_N)$$

$$S1 : d_S \nabla.(\kappa_S \nabla T_S) = \mathcal{I}_{NIS}(V, T_S, T_N, R_N)V - \mathcal{P}_{NIS}(V, T_S, T_N, R_N) - \mathcal{P}_{NIS}(0, T_S, T_D, R_D)$$

$$S2 : d_S \nabla.(\kappa_S \nabla T_S) = -\mathcal{P}_{NIS}(0, T_S, T_D, R_D) - \mathcal{P}_{NIS}(0, T_S, T_{ST}, R_N)$$

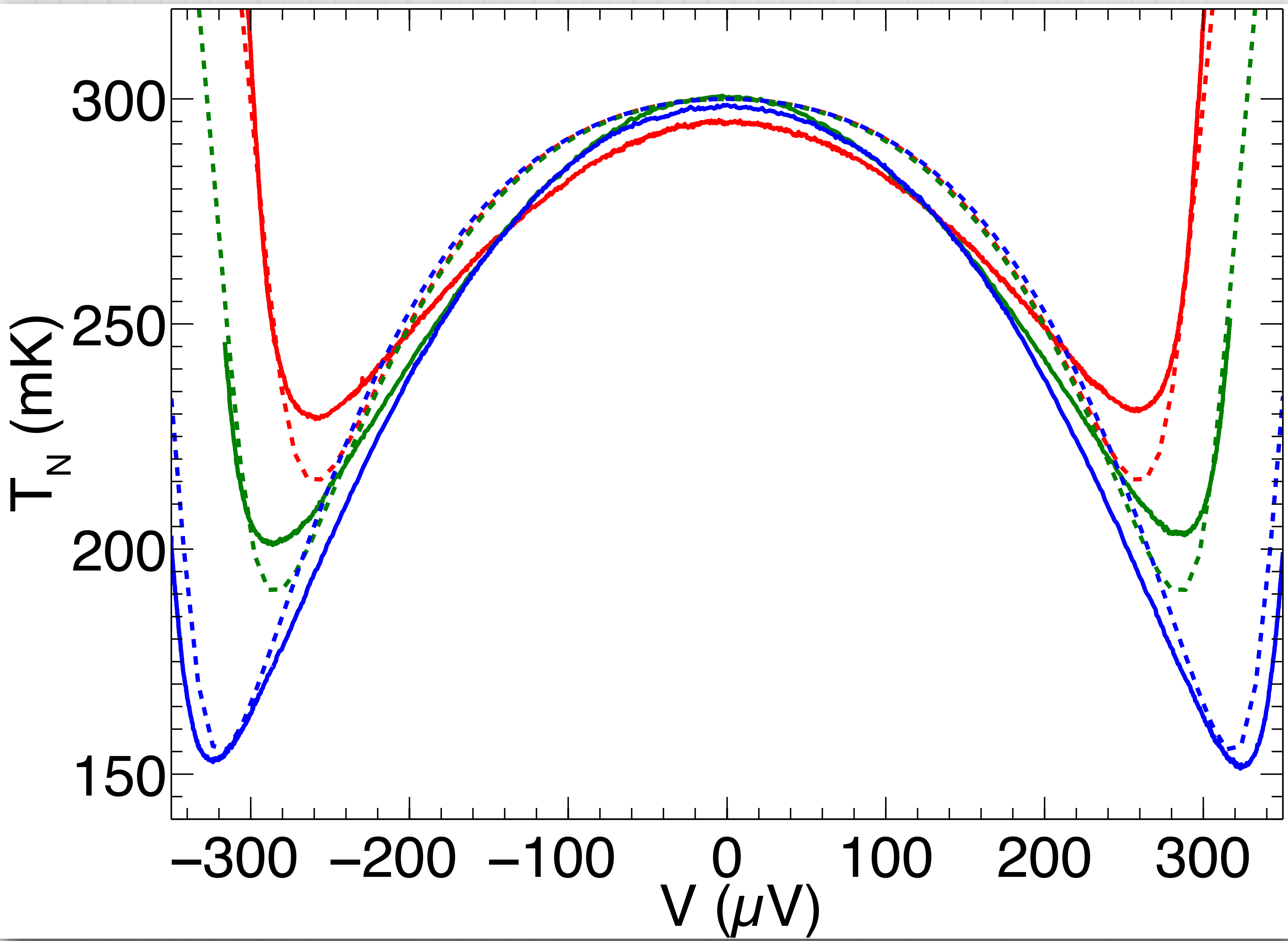
$$D : \kappa_D d_D \nabla^2 T_D = \mathcal{P}_{NIS}(0, T_S, T_D, R_D) - \mathcal{P}_{ep}^{D}(T_D)$$

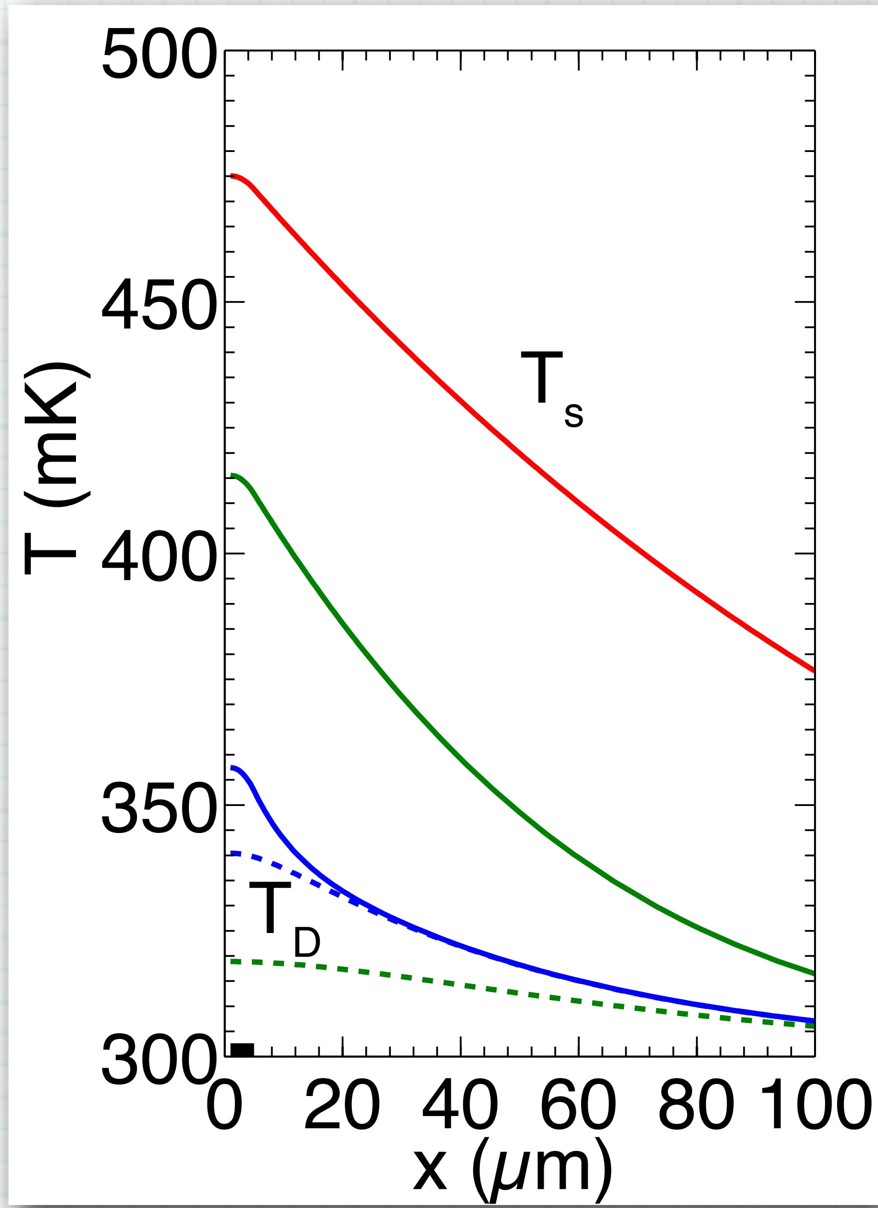
$$ST : \kappa_N d_N \nabla^2 T_{ST} = \mathcal{P}_{NIS}(0, T_S, T_{ST}, R_N) - \mathcal{P}_{ep}^{ST}(T_{ST}).$$

Nguyen et.al., NJP 2013

A thermal model

Cooler barrier	Drain barrier
500 $\Omega\mu m^2$	no AlMn, no T_D term
500 $\Omega\mu m^2$	500 $\Omega\mu m^2$
500 $\Omega\mu m^2$	10 $\Omega\mu m^2$





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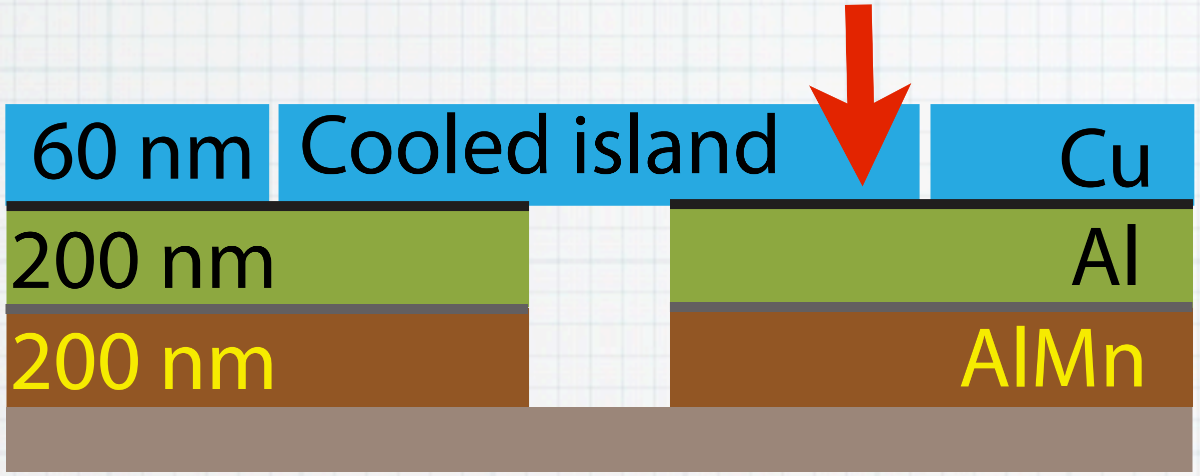
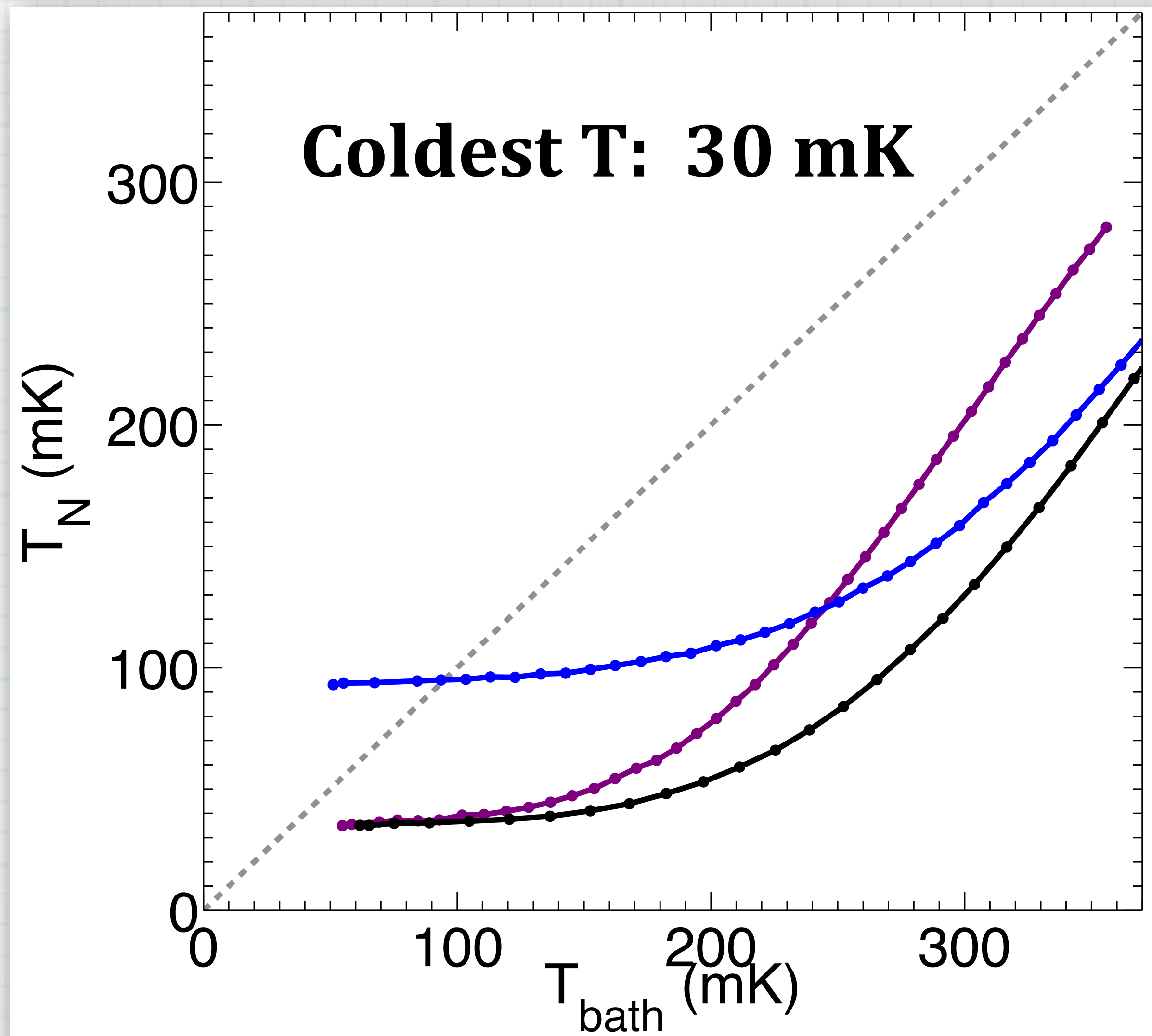
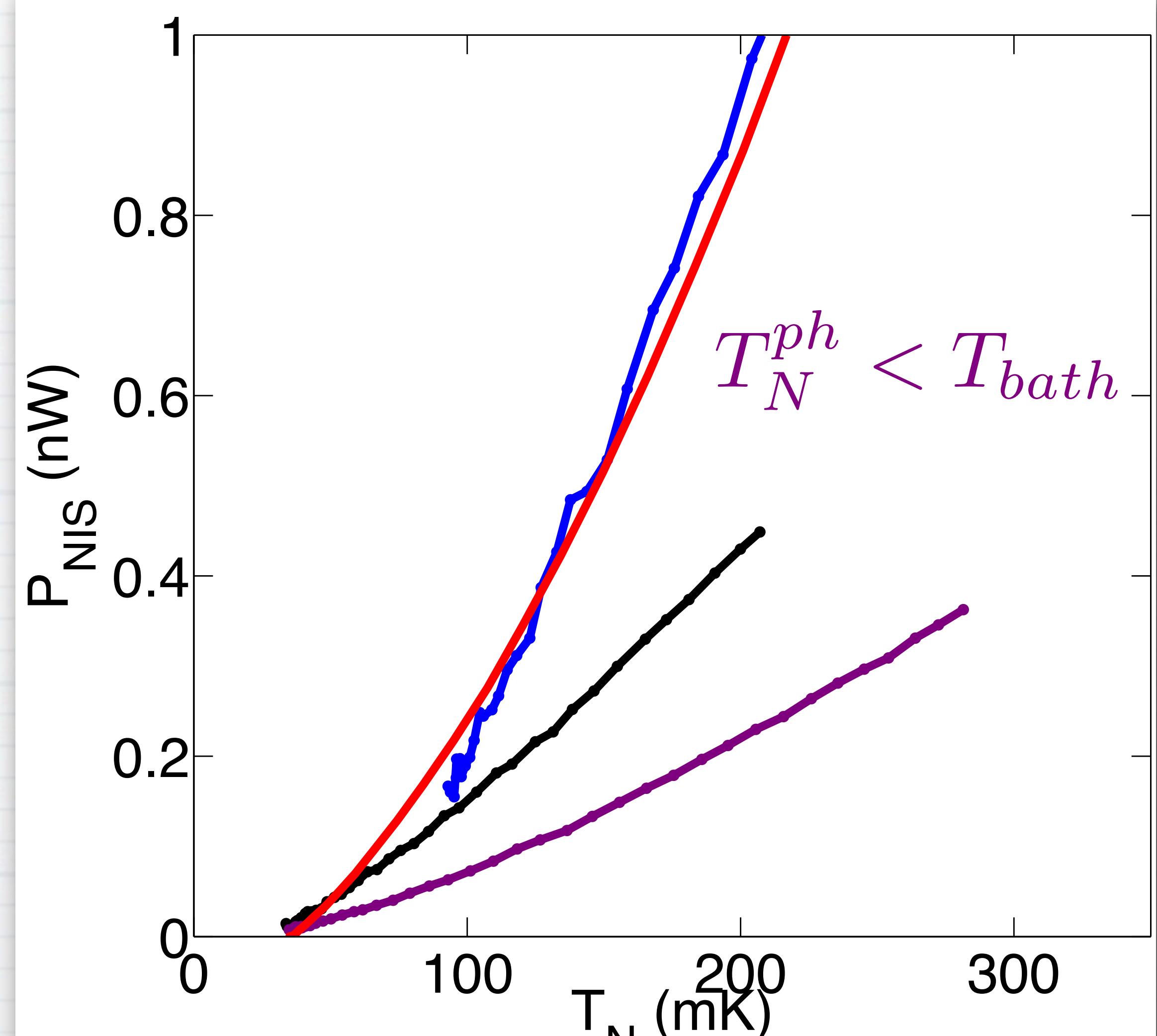
The role of the cooler barrier



Cooler barrier	Drain barrier
500 Ωμm²	0.2mbar
2500 Ωμm²	0.2mbar
5000 Ωμm²	0.2mbar



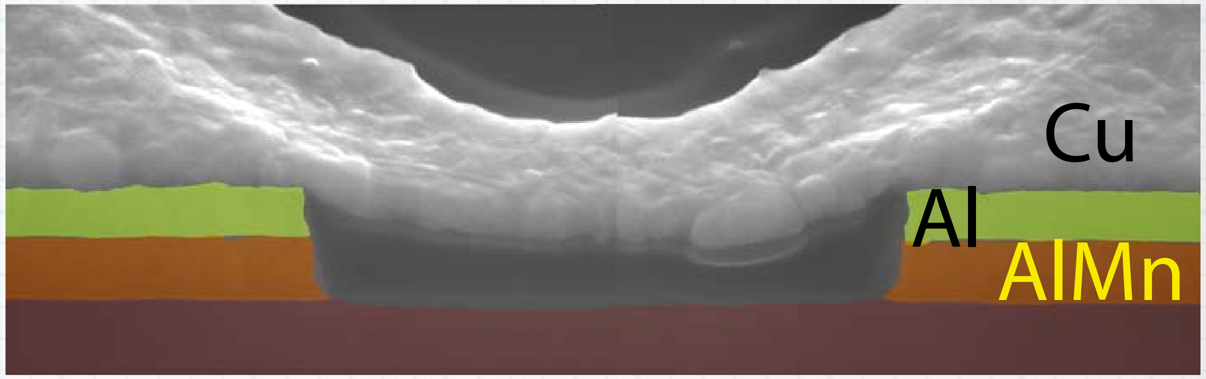
$$\dot{Q}_{ep} = \Sigma\Omega(T_N^5 - T_{ph}^5)$$



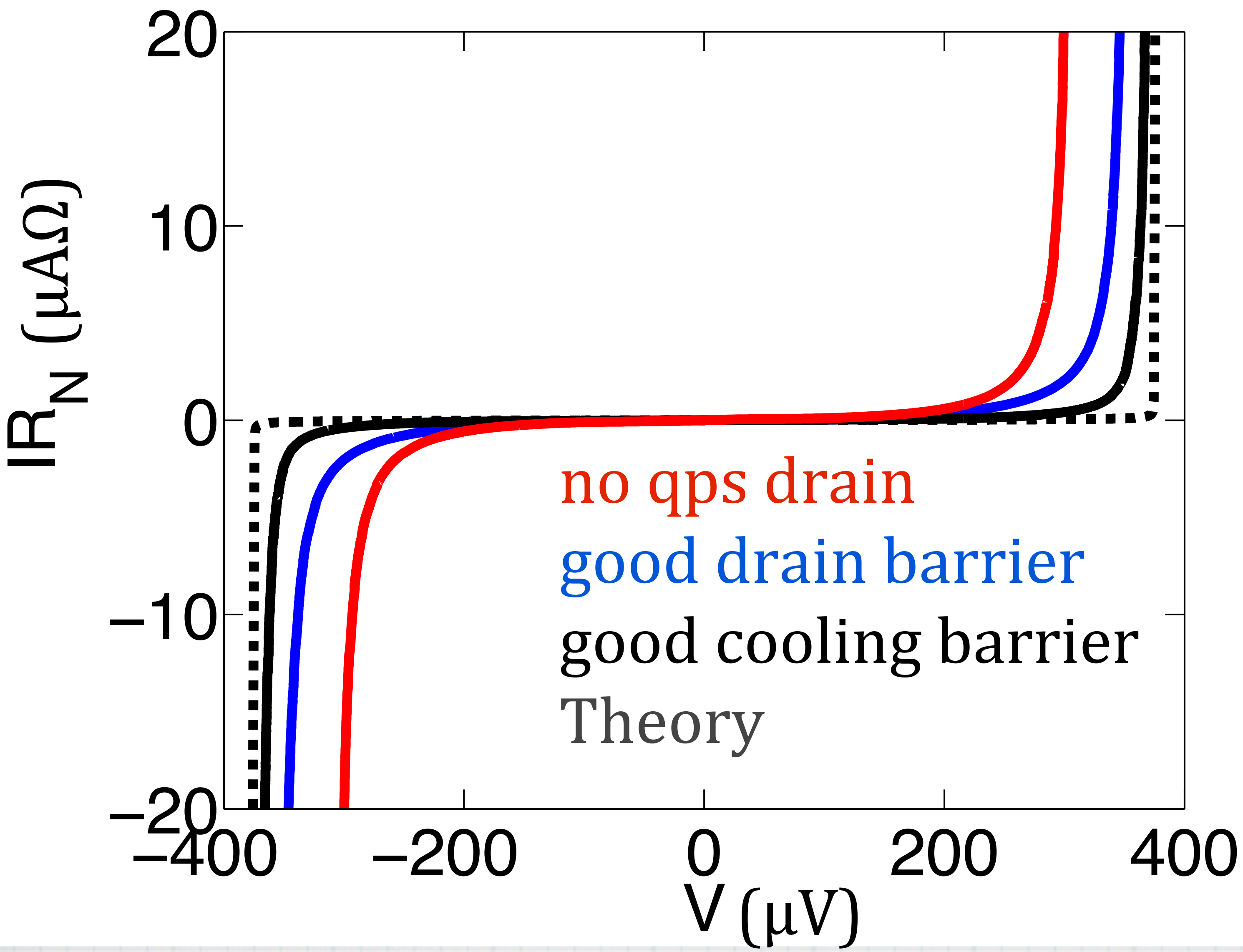
$$\dot{Q}_{NIS} = \frac{1}{e^2 R_N}\int dE(E - eV)n_S(E)[f_N(E - eV) - f_S(E)]$$

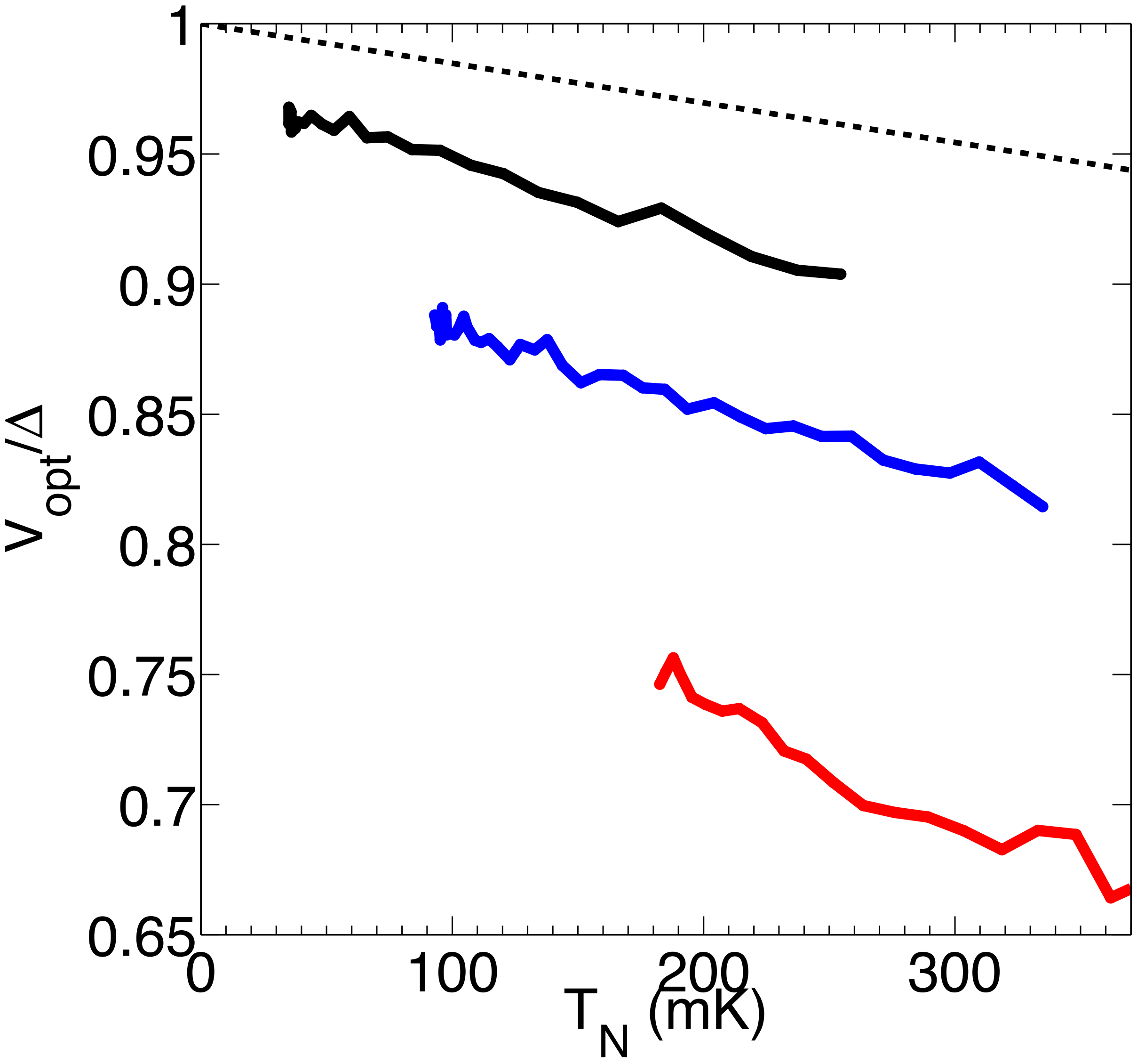
Conclusion

With good quasiparticle trapping, the SINIS coolers cool from 200 mK to 50 mK at 400 pW per device!



But there are still quasiparticles to trap.





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