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Cascaded superconducting junction refrigerators: Optimization and performance limits

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AFFILIATIONS

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Mohammad Samani
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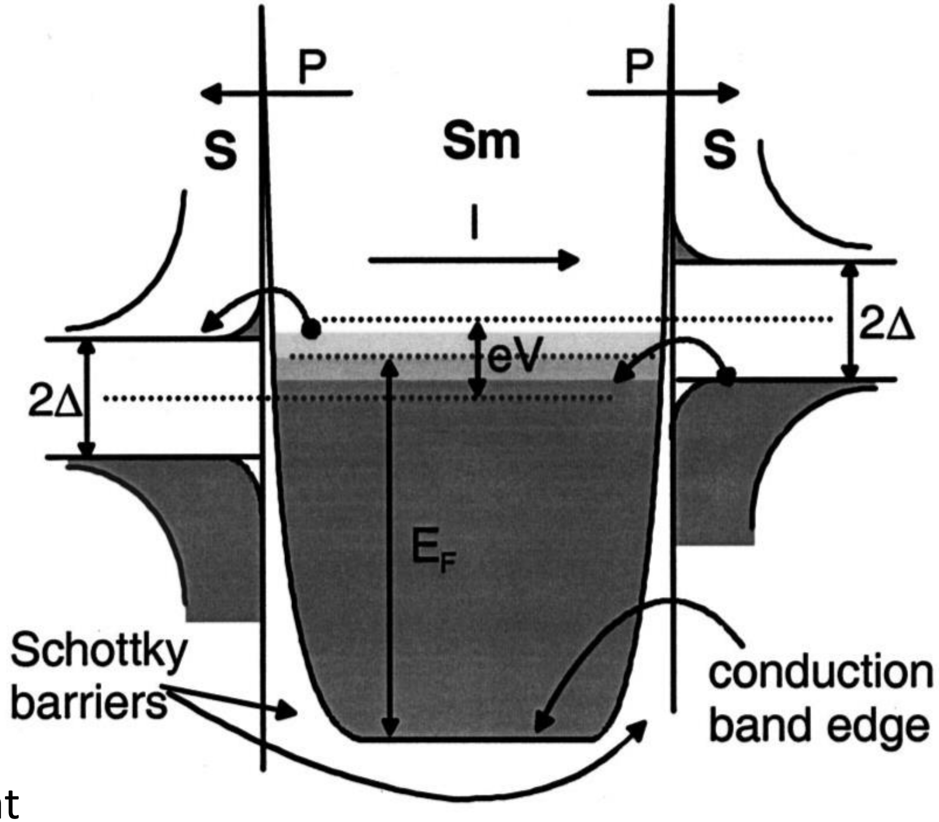
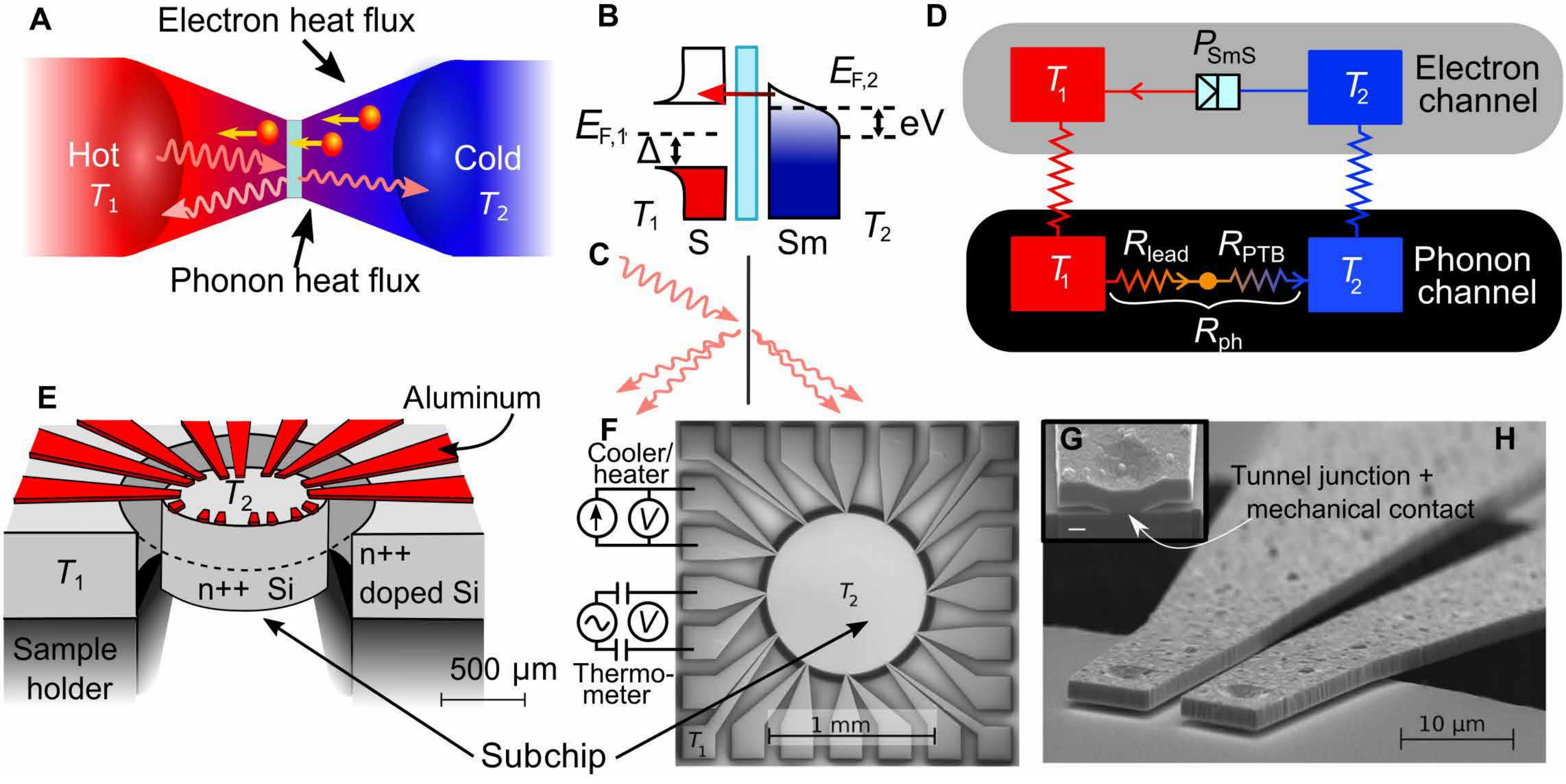
Heavily doped silicon



Metallurgical Schottky contact at S-Sm forms a tunnel barrier

A. M. Savin, M. Prunnila, P. P. Kivinen, J. P. Pekola, J. Ahopelto, and A. J. Manninen, Appl. Phys. Lett. **79**, 1471 (2001)

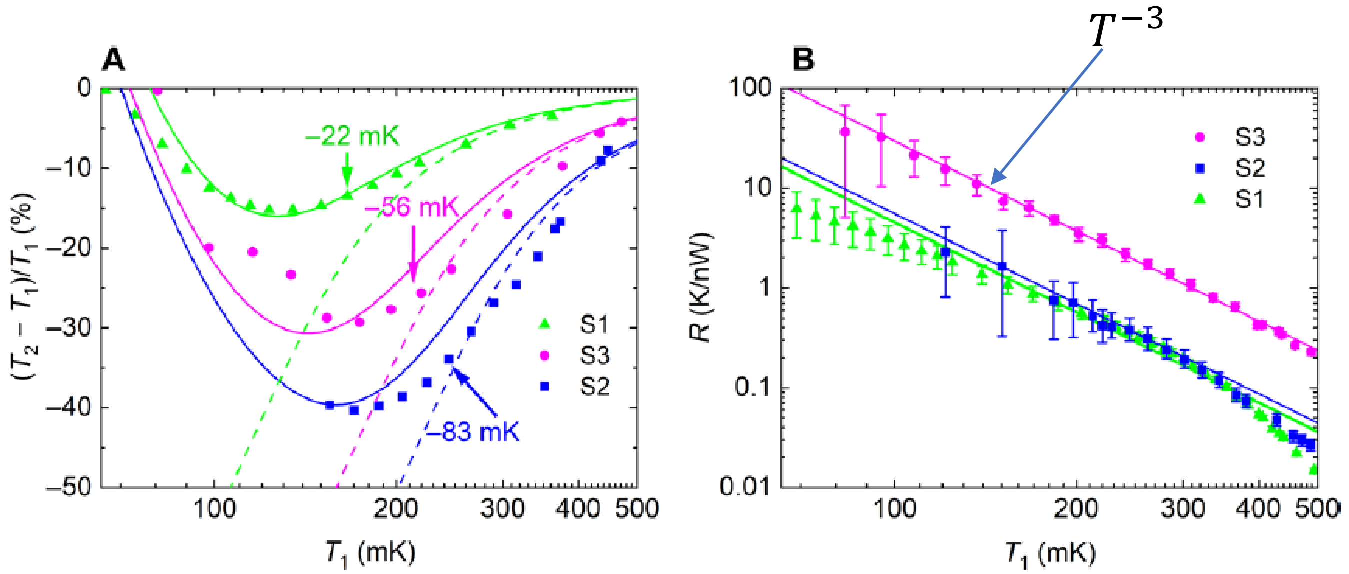


E. Mykkänen, J. S. Lehtinen, L. Grönberg, A. Shchepetov, A. V. Timofeev, D. Gunnarsson, A. Kemppinen, A. J. Manninen, and M. Prunnila, Sci. Adv. **6**, eaax9191 (2020)

Table 1. Sample parameters and literature values for thermal boundary resistance. Here, *A* is the area of a tunnel junction, *d* is the diameter of the subchip, $R_A = R_T A$ is the characteristic junction resistance, and R_T is the junction resistance. Thermal resistance prefactors (α) are the values obtained from the fits of Fig. 2, whereas α_{AMM} and α_{DMM} correspond to theoretical R_{PTB} (*35*).

Sample	A µm^2	d µm	$R_A = R_T A$ Ωµm^2	α K^4/µW	α_{AMM} K^4/µW	α_{DMM} K^4/µW	Max cooling %	Max cooling mK
S1	2.0/137*	300	538	4.5	–	–	15 (@ 140 mK)	22 (@ 166 mK)
S2	7.5	1000	476	5.6	6.5	8.8	40 (@ 170 mK)	83 (@ 244 mK)
S3	3.2	300	1945	29	16	21	29 (@ 173 mK)	56 (@ 220 mK)

*Sample S1 had silicon oxide between leads and subchip, and therefore, the effective area of the phononic heat contact, 137 µm^2, is larger than the junction area 2.0 µm^2.



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Conclusions

1. Since cooling power and phonon leaks are proportional to A, one should decrease $R_A = R_T A$
2. Suppression of phonon thermal conductivity above 500 mK requires "phonon engineering"
3. Above 500 mK, a superconductor with larger Δ is required. Vandilium.

$$P_{\Sigma 2} = P_{H3} - P_{C2} + P_{L2} - P_{L3}$$

Progressively smaller area is good

$$P_{H3} = P_{C3} \propto A_3$$

Less efficient at high T

$$P_L \propto T^4$$

$$P_C \propto T^2$$

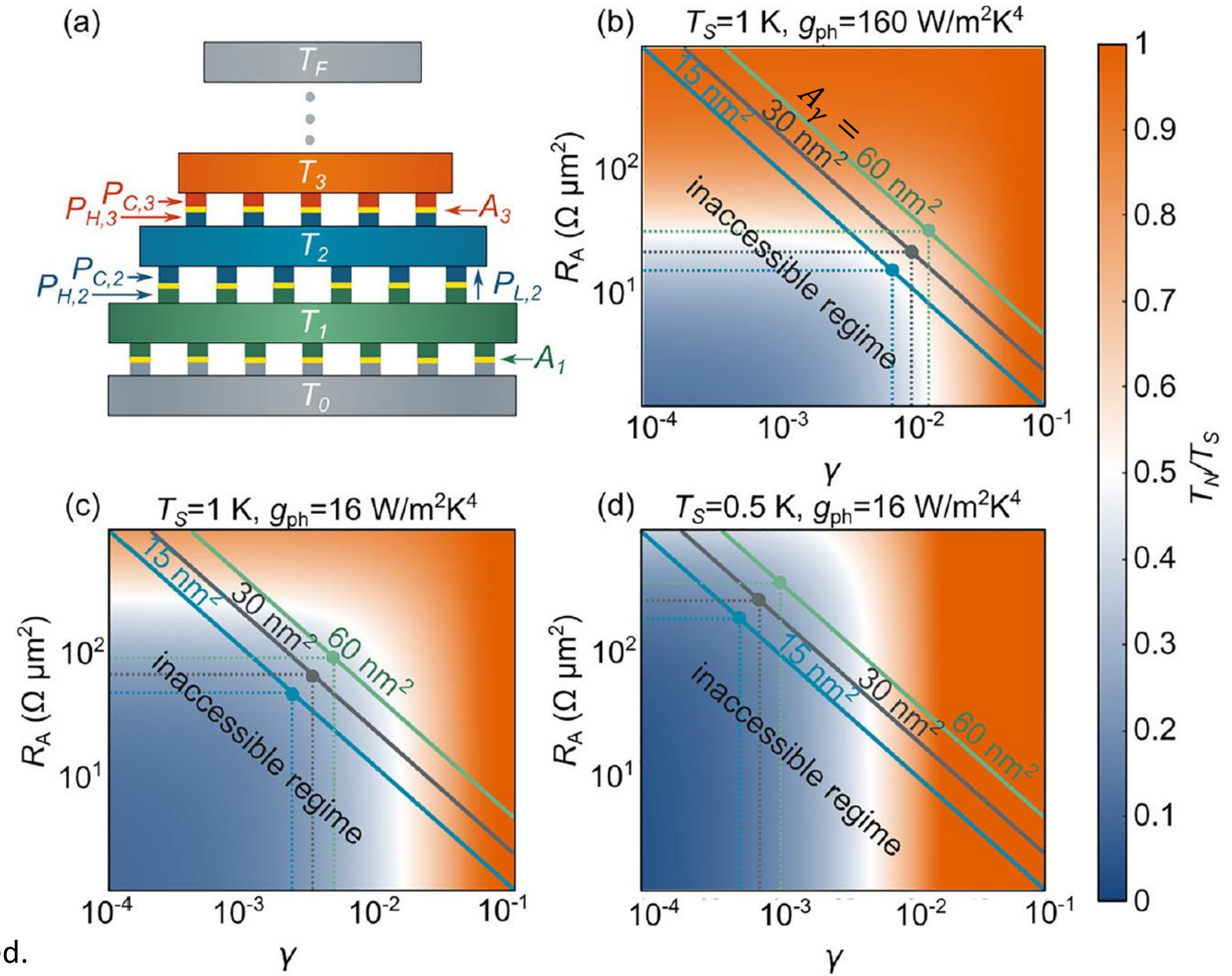
R_0 is sub-gap leakage resistance

A_{ch} is effective tunneling area/G_0

$$\gamma = \frac{R_0}{R_T} = \frac{A_{ch} R_K}{4 R_A}$$

$$P_L = g_{ph} A (T_S - T_N)^4$$

$A_\gamma = \frac{4\gamma R_A}{R_K}$ phenomen. leakage area



Lower R_A at the cost of high γ is preferred.

A good refrigerator is energy efficient too.

Sufficient cooling power:

$$\frac{T_N^2}{T_S^2} \cong \frac{P_C}{P_H}$$

Maximum heat load: $P_{in} = P_C - P_L$

$$a = \frac{A_{n-1}}{A_n} = \frac{P_H T_N^2}{P_{in} T_S^2}$$

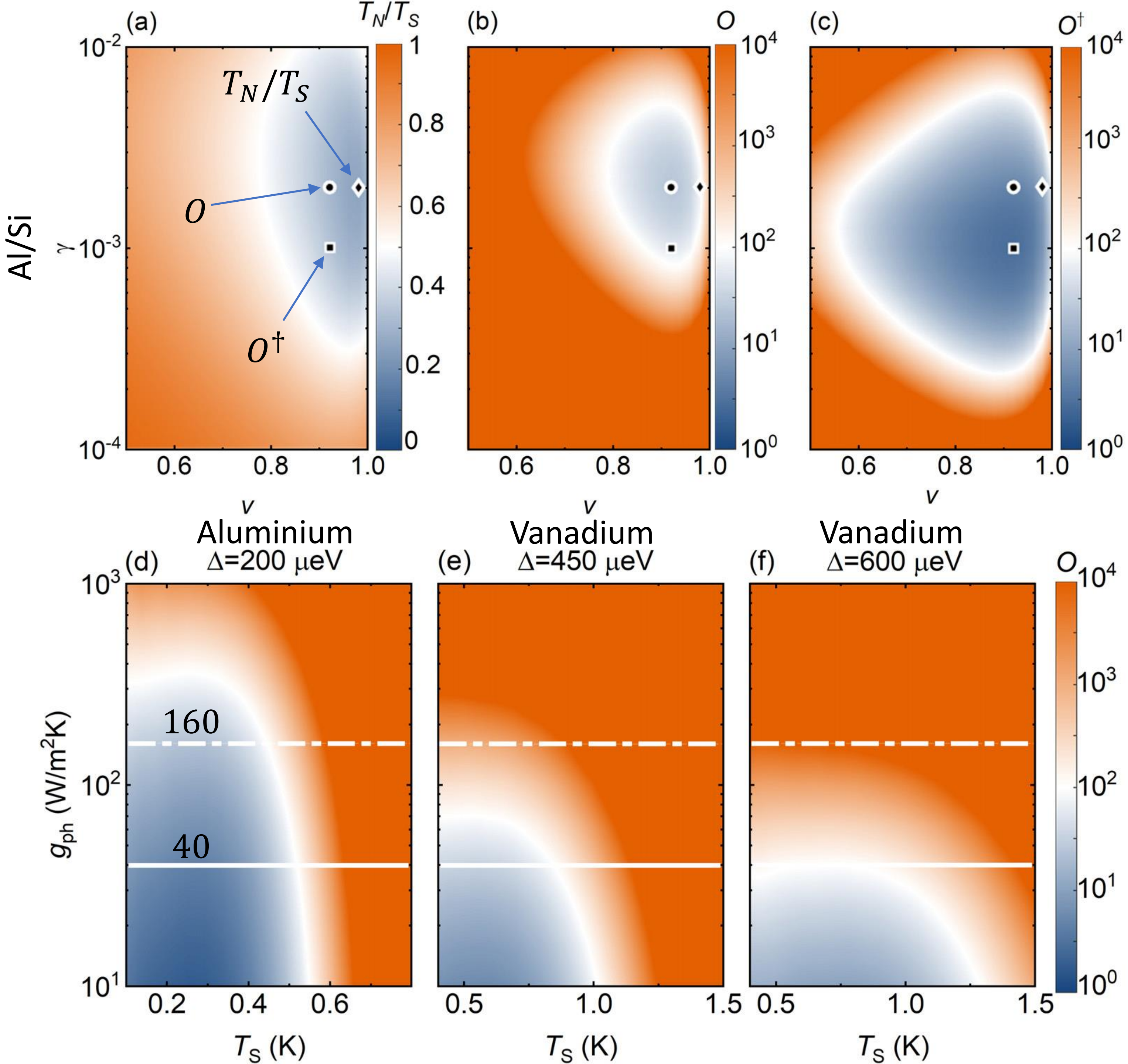
$$O = a^{1/\log\left(\frac{T_S}{T_N}\right)}$$

For small phonon leak (low T or good ph-filtering:

$$a^\dagger = \frac{P_H T_N^2}{P_C T_S^2}$$

$$O^\dagger = a^{\dagger\, 1/\log\left(\frac{T_S}{T_N}\right)}$$

Minimization parameters: $v, \gamma, g_{ph}, T_S, T_N$

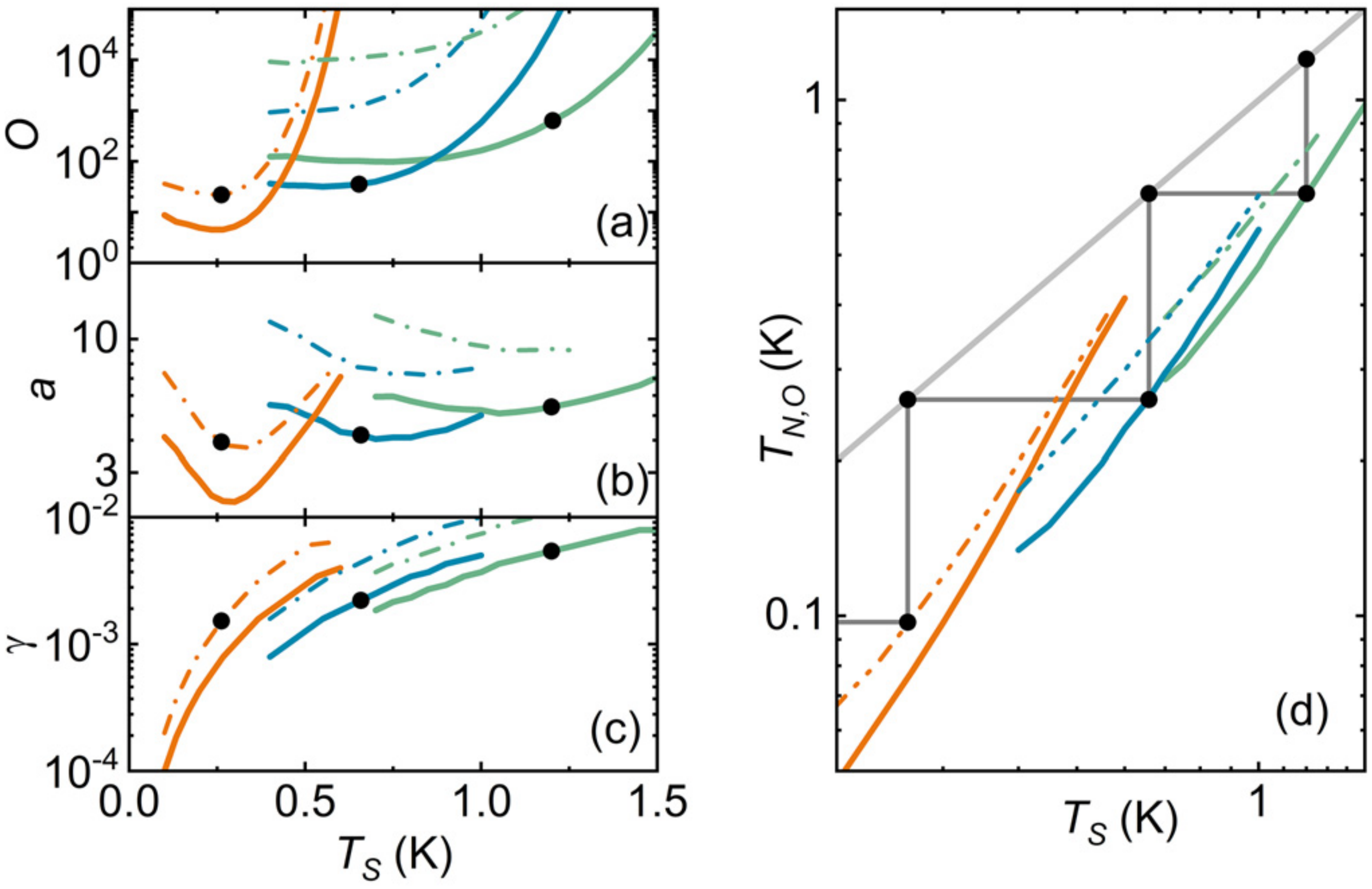


The Plan

$\Delta = 200\ \mu eV$

$\Delta = 450\ \mu eV$

$\Delta = 600\ \mu eV$



		A_n/A_3		$\gamma\ (10^{-3})$		ν		T (m K)	
n	g_{ph} (W/m^2 K^4)	A	B	A	B	A	B	A	B
1	40	32	90	5	5	0.88	0.94	598	571
2	40	8	17	2	1.6	0.94	0.98	196	161
3	160	1	1	0.8	0.6	0.96	0.98	89	91