SAND2016-6757C

Single-Shot Charge Readout Using a Cryogenic HBT Preamplifier Inline with a Silicon SET at Millikelvin Temperatures

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CQuIC
Center for Quantum Information and Control

Motivation

- Previously demonstrated cryogenic preamplification at 4 K.

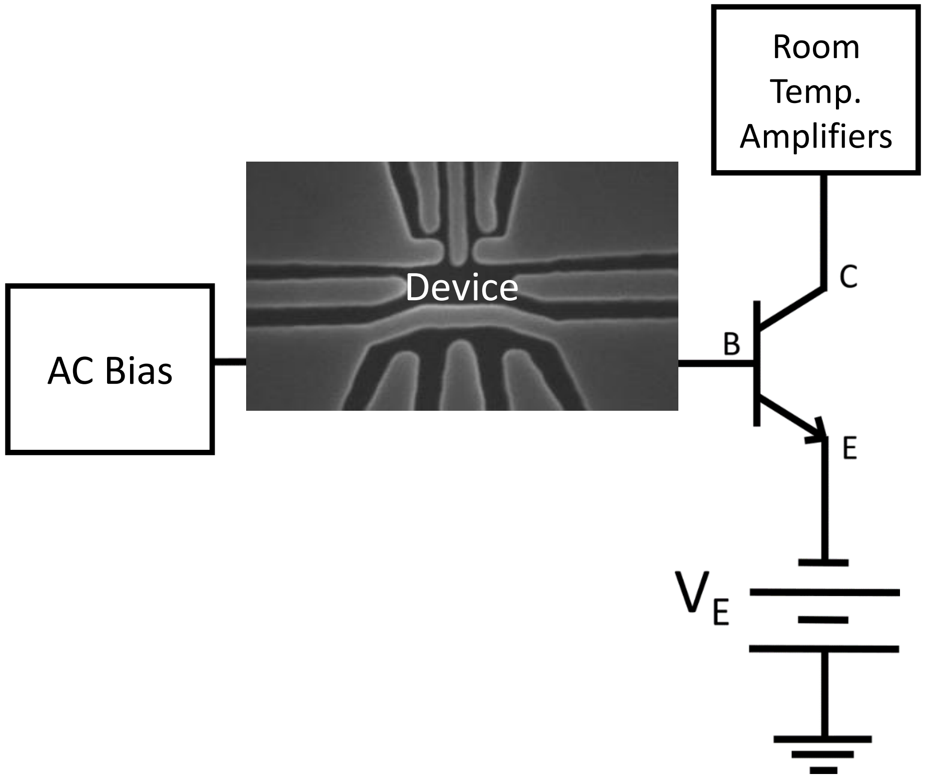
- **Goal:** Increase signal-to-noise ratio, bandwidth, and charge sensitivity of readout circuit **in dilution refrigerator.**

- **Approach:** Heterojunction-Bipolar-Transistor (HBT) as cryogenic preamplifier physically located on device PCB at base temperature (T = 15 mK).

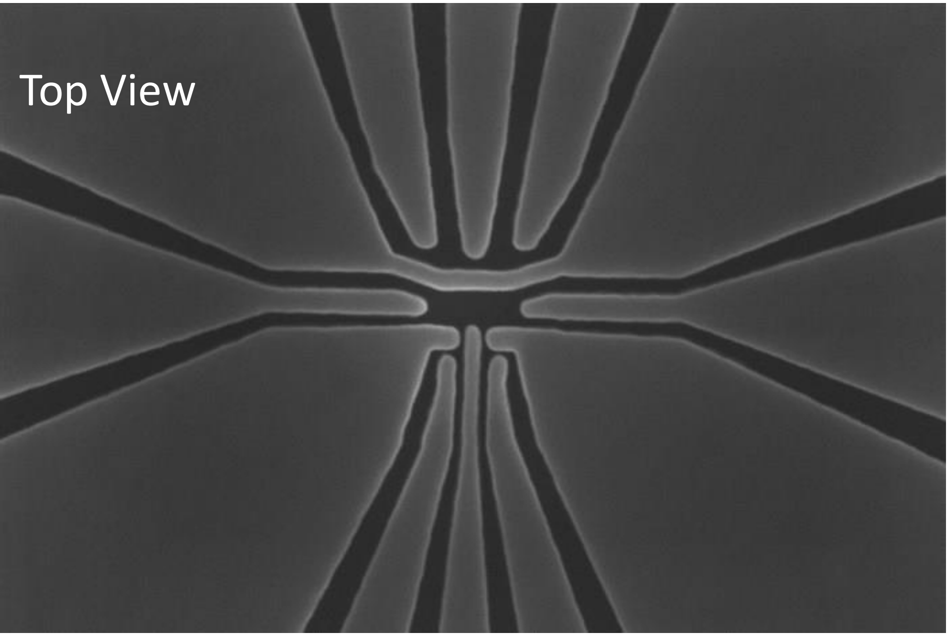
- **Challenges:** Power dissipation and noise.

- Why HBT cryogenic preamp?
  - Current input
  - Relatively simple implementation
  - Superior gain vs. power over HEMT
  - Low power (50 nW to 5 μW)
  - Low 1/f corner frequency

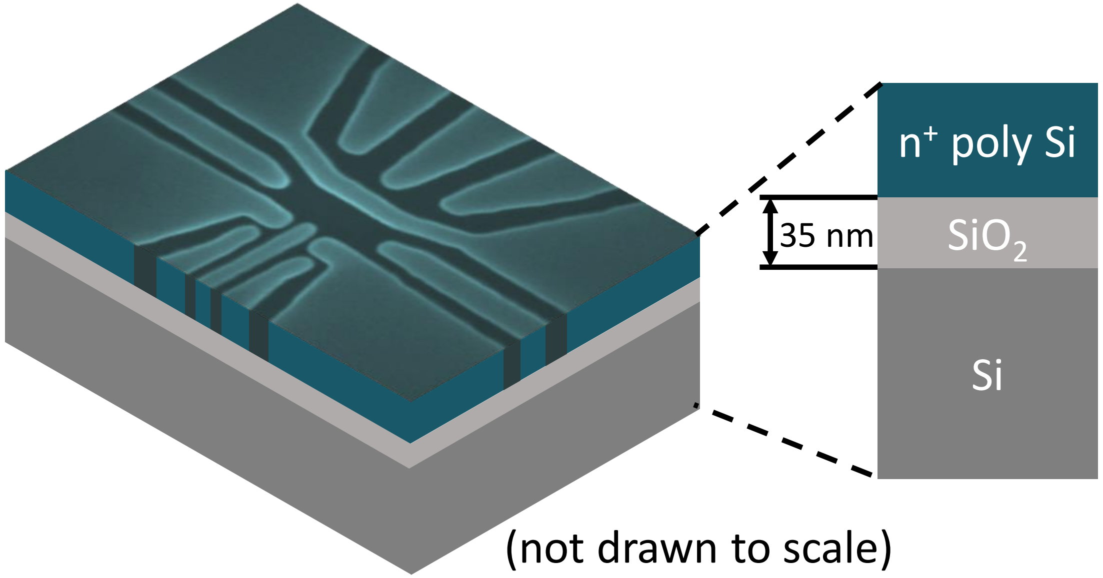
- **Take-home message:** Comparable time-domain charge sensitivity to RF techniques with low overhead.



Silicon Metal-Oxide-Semiconductor (MOS) Devices Fabricated at Sandia



Isometric View



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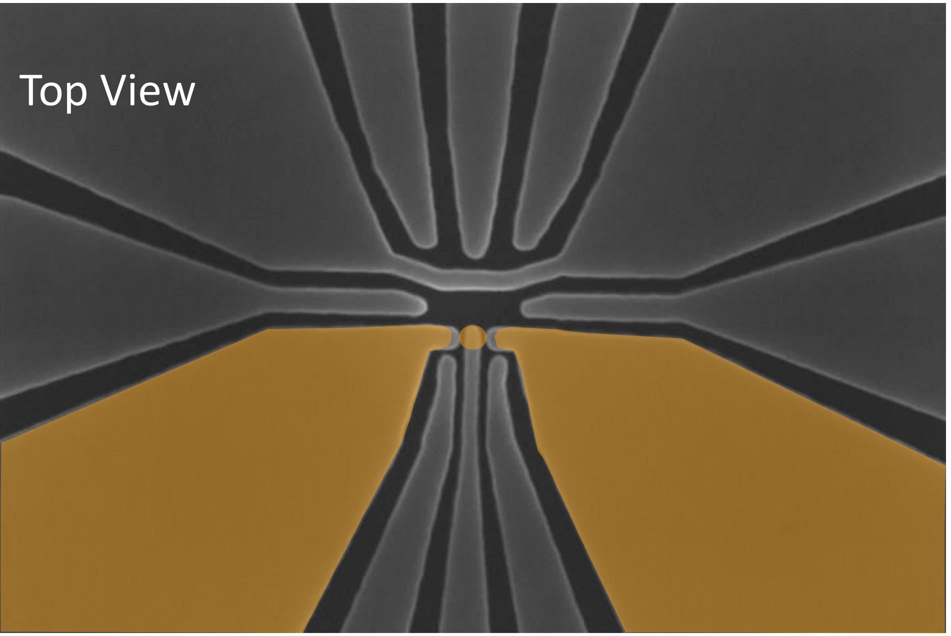

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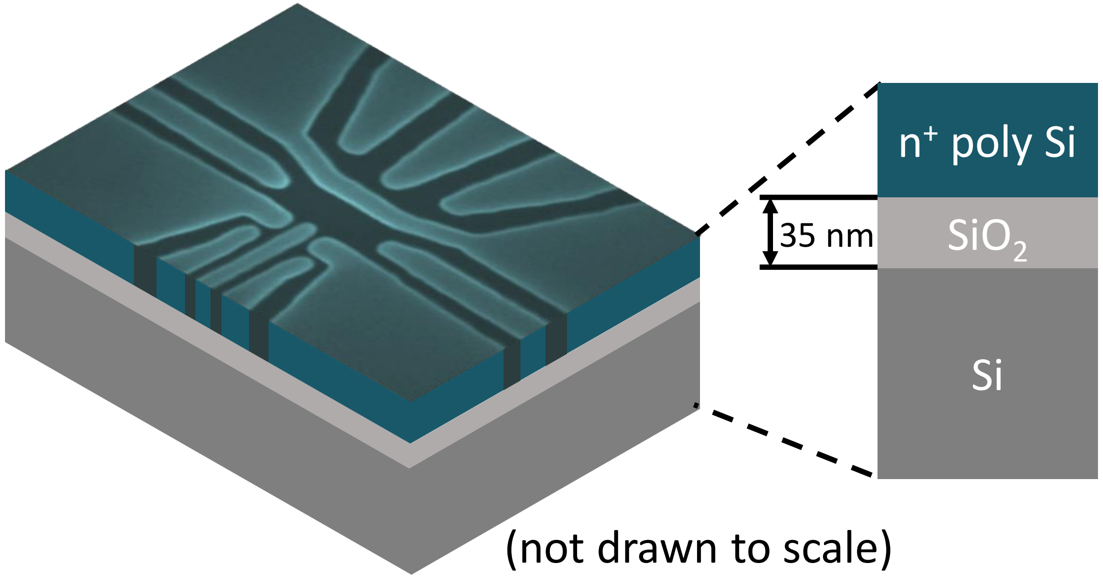

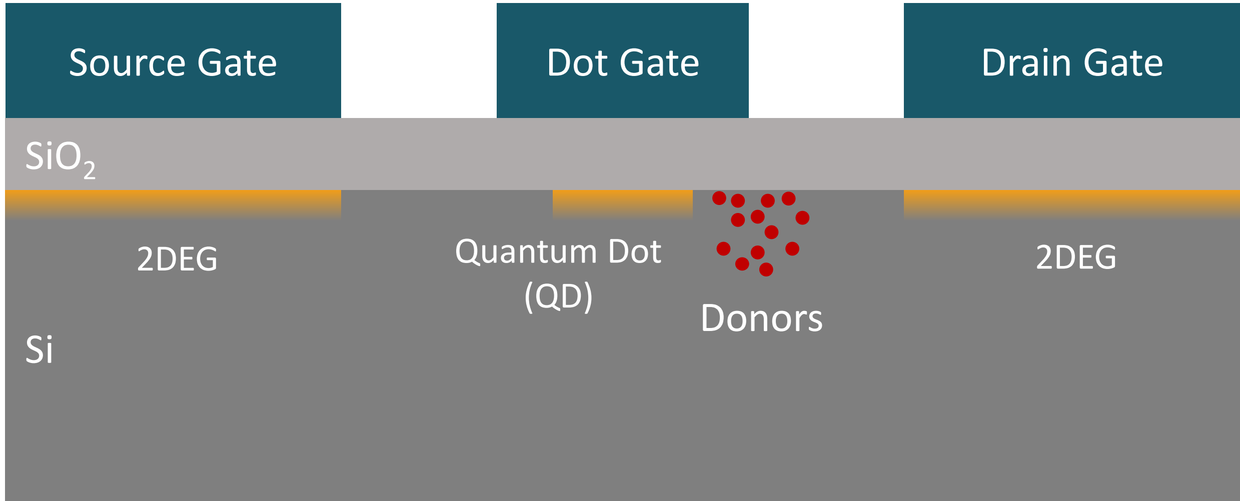

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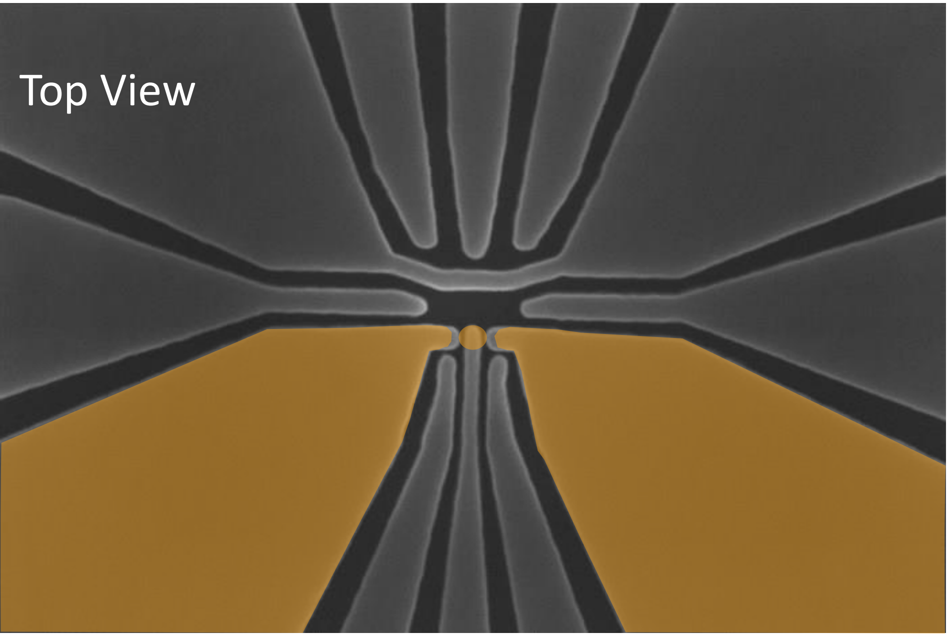

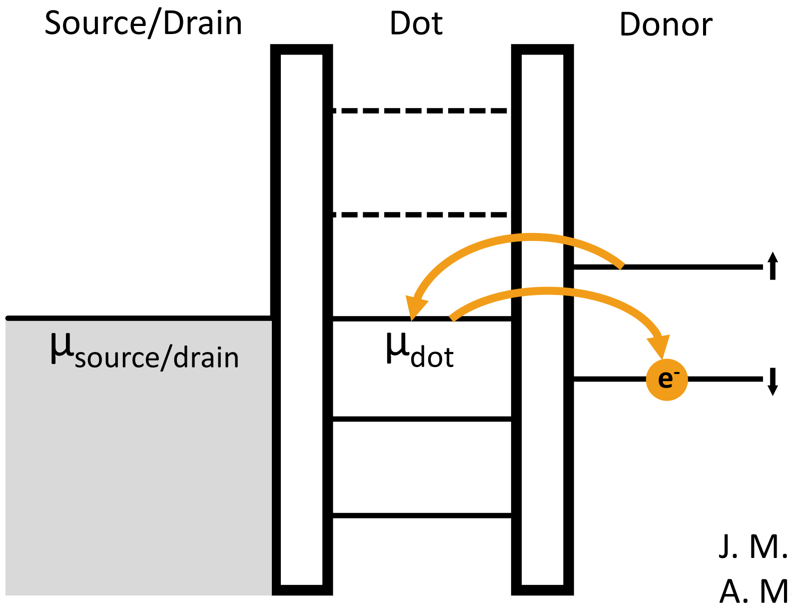

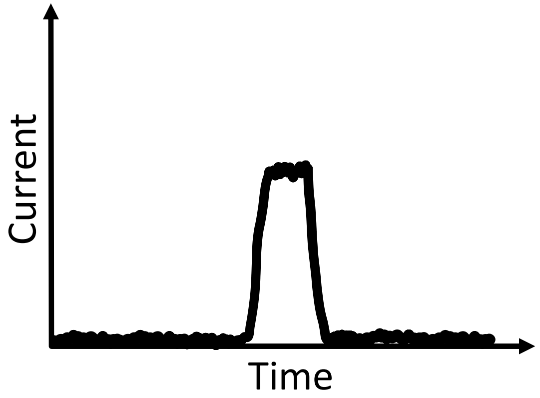

J. M. Elzerman, et al., Nature 430, 431 (2004)
A. Morello et al., Nature 467, 687 (2010)

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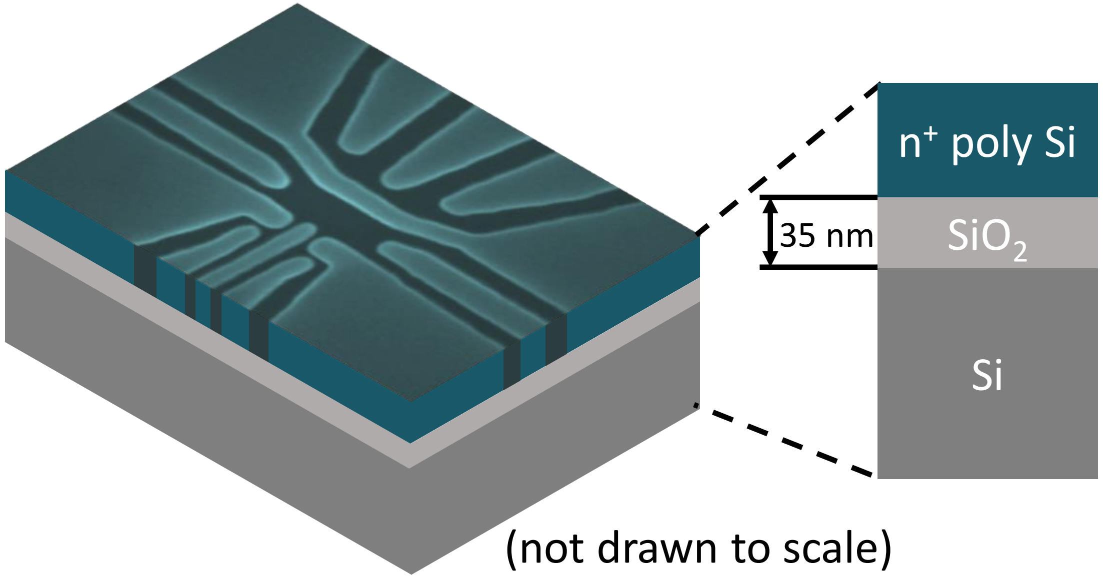
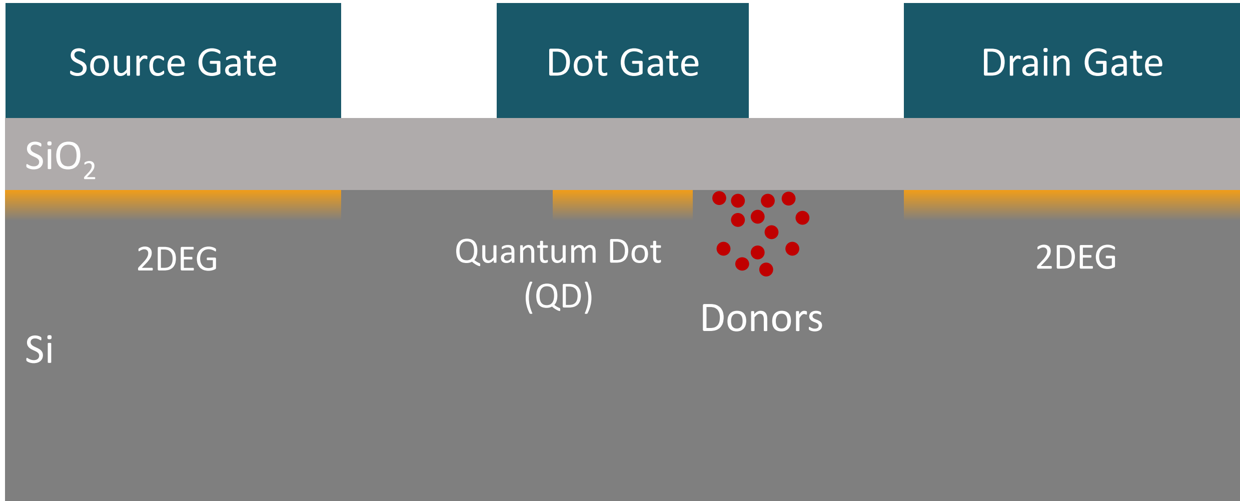
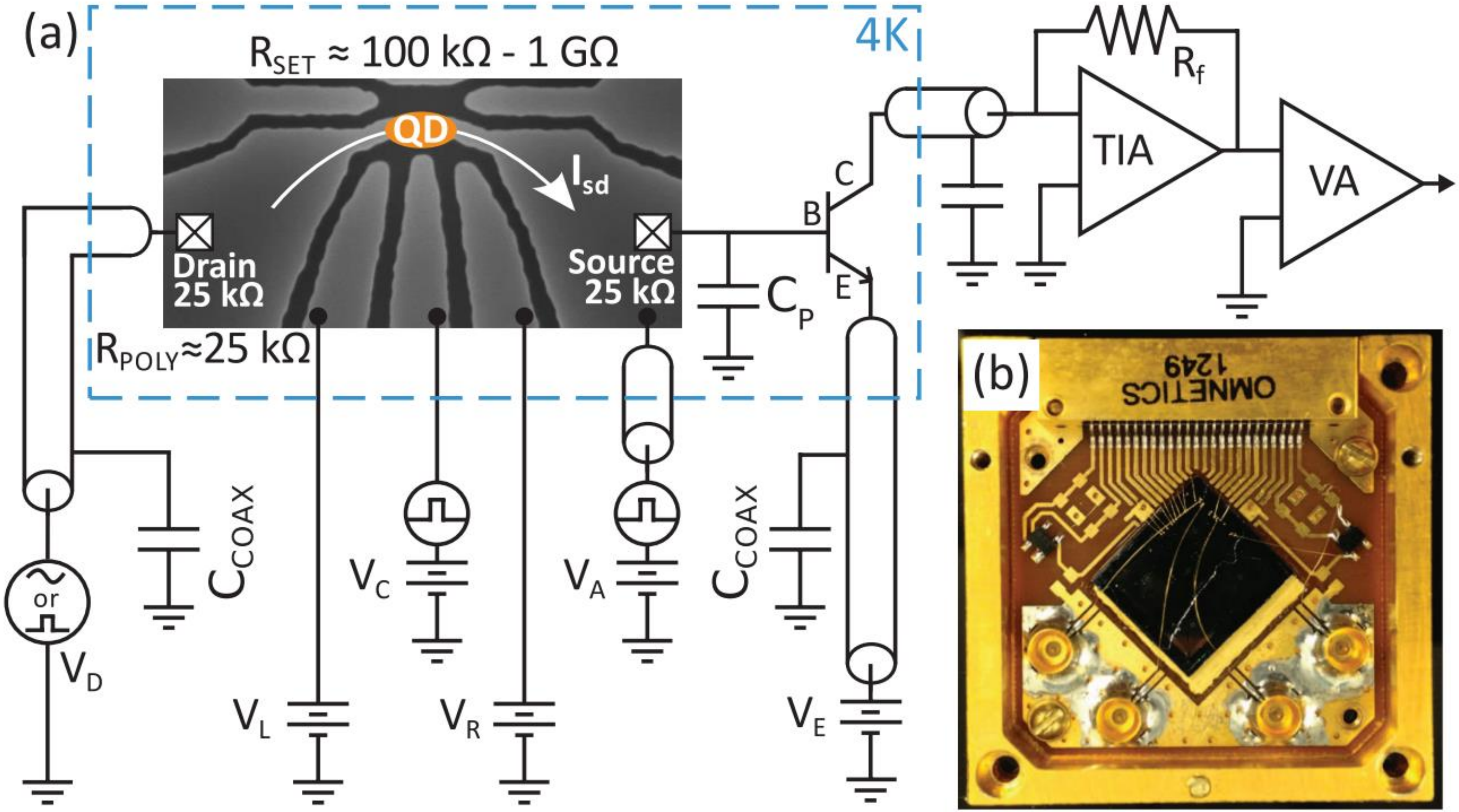


(not drawn to scale)

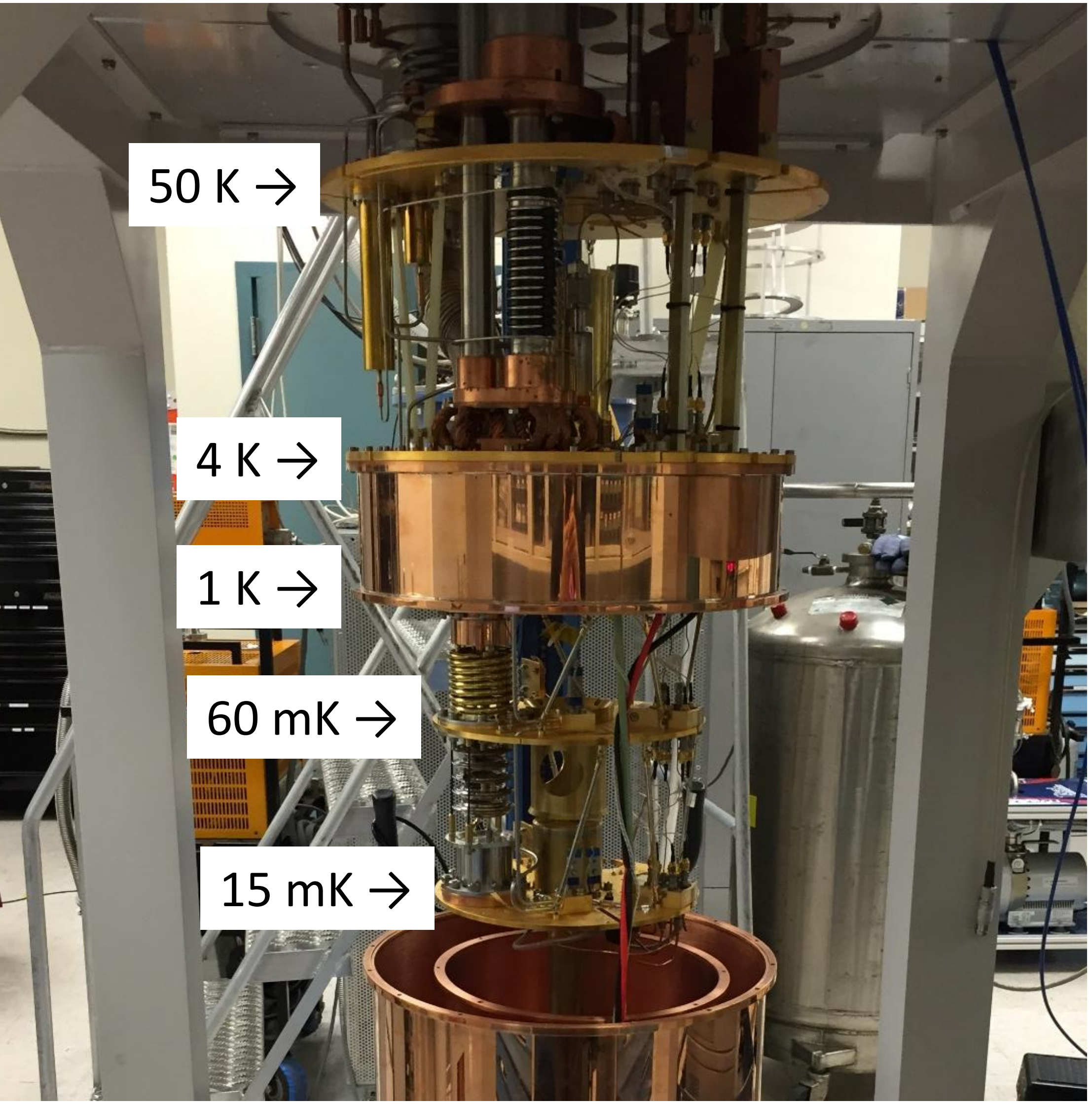


Cryogenic Preamplification Using a Heterojunction Bipolar Transistor (HBT) T = 4 K

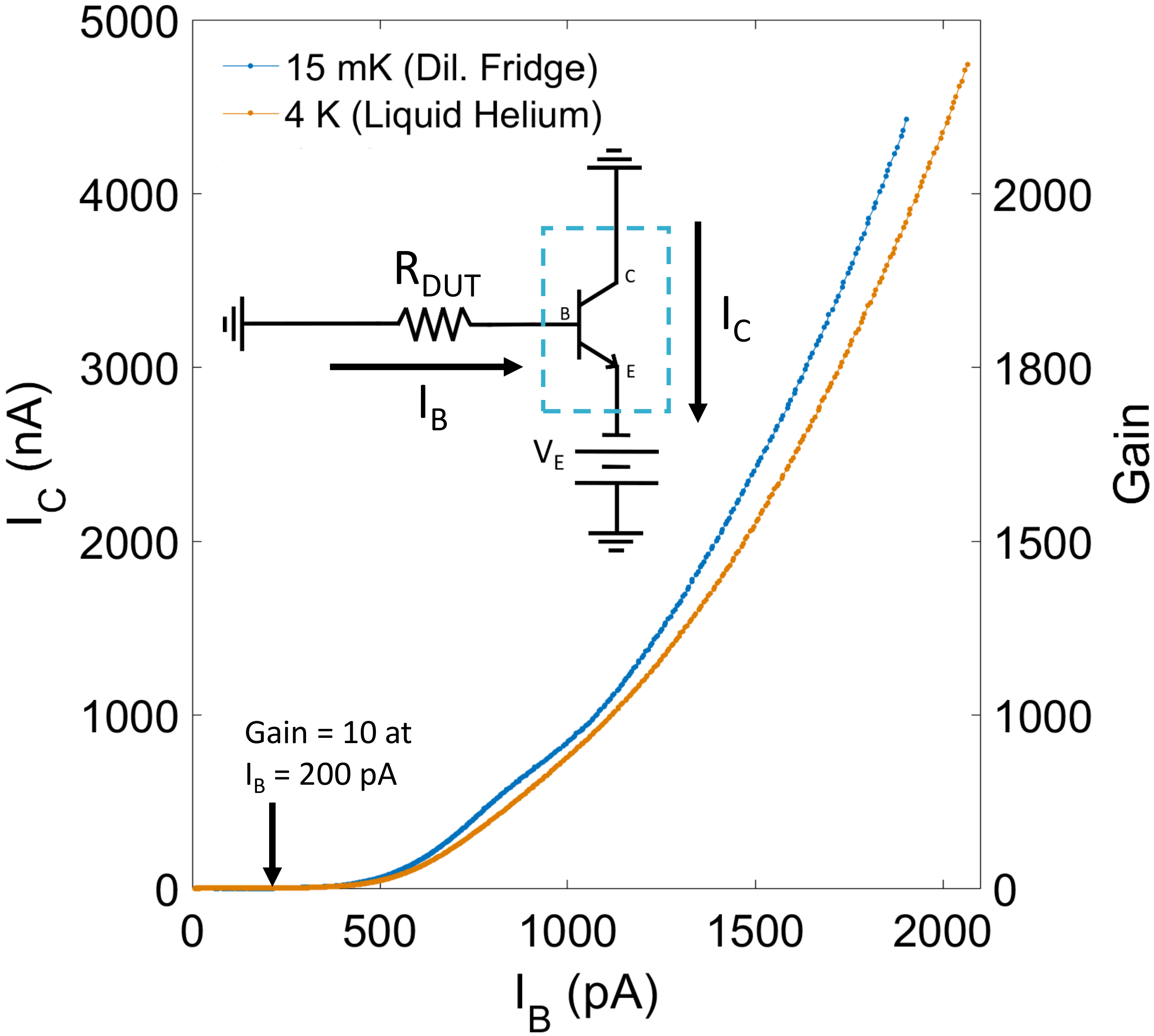


M.J. Curry et al., Applied Physics Letters 106 203505 (2015)

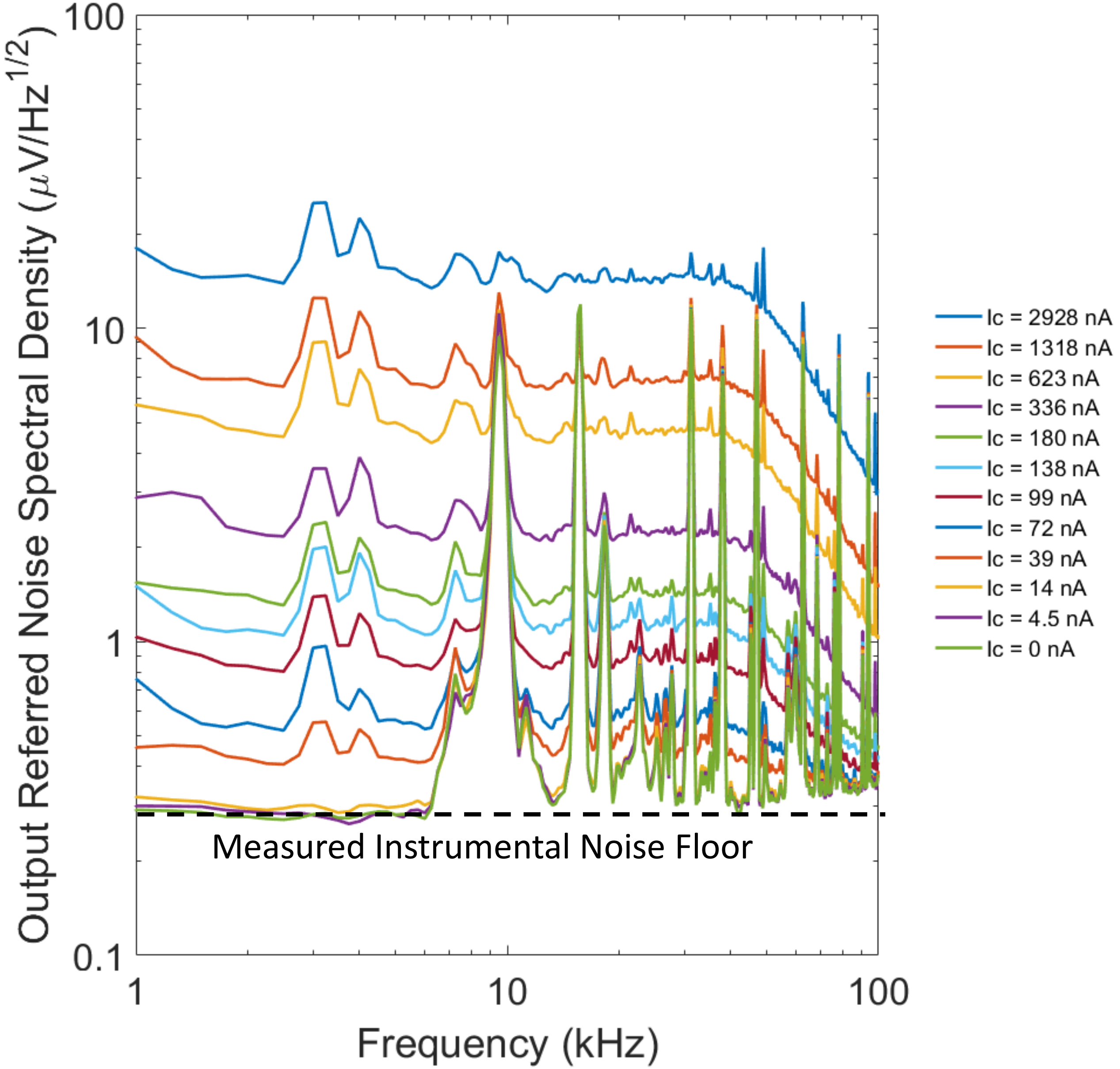
HBT DC Biasing at T = 4 K and T = 15 mK



Inside of Dilution Refrigerator



Readout Circuit Output-Referred Noise Spectral Density T = 15 mK



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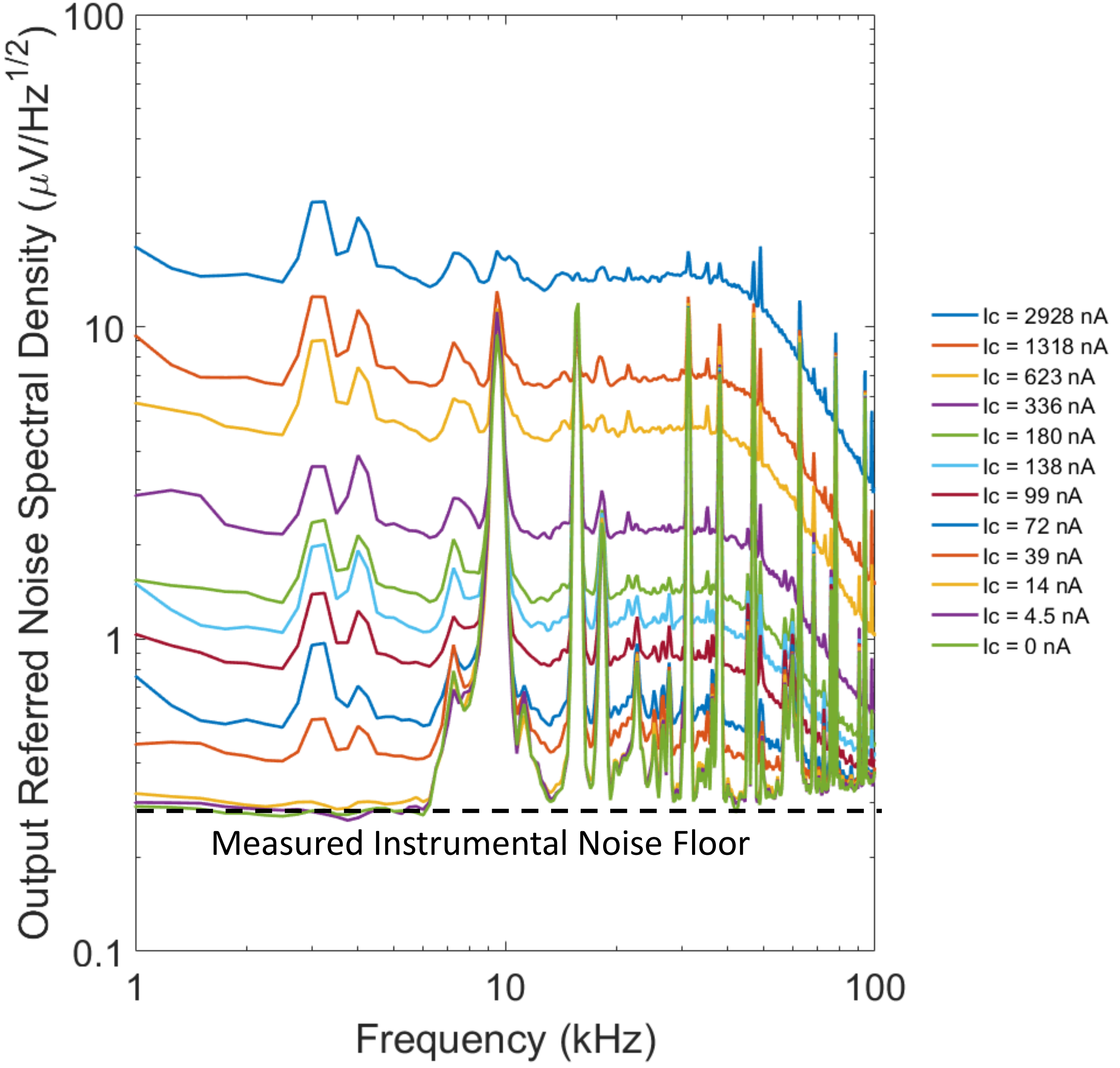

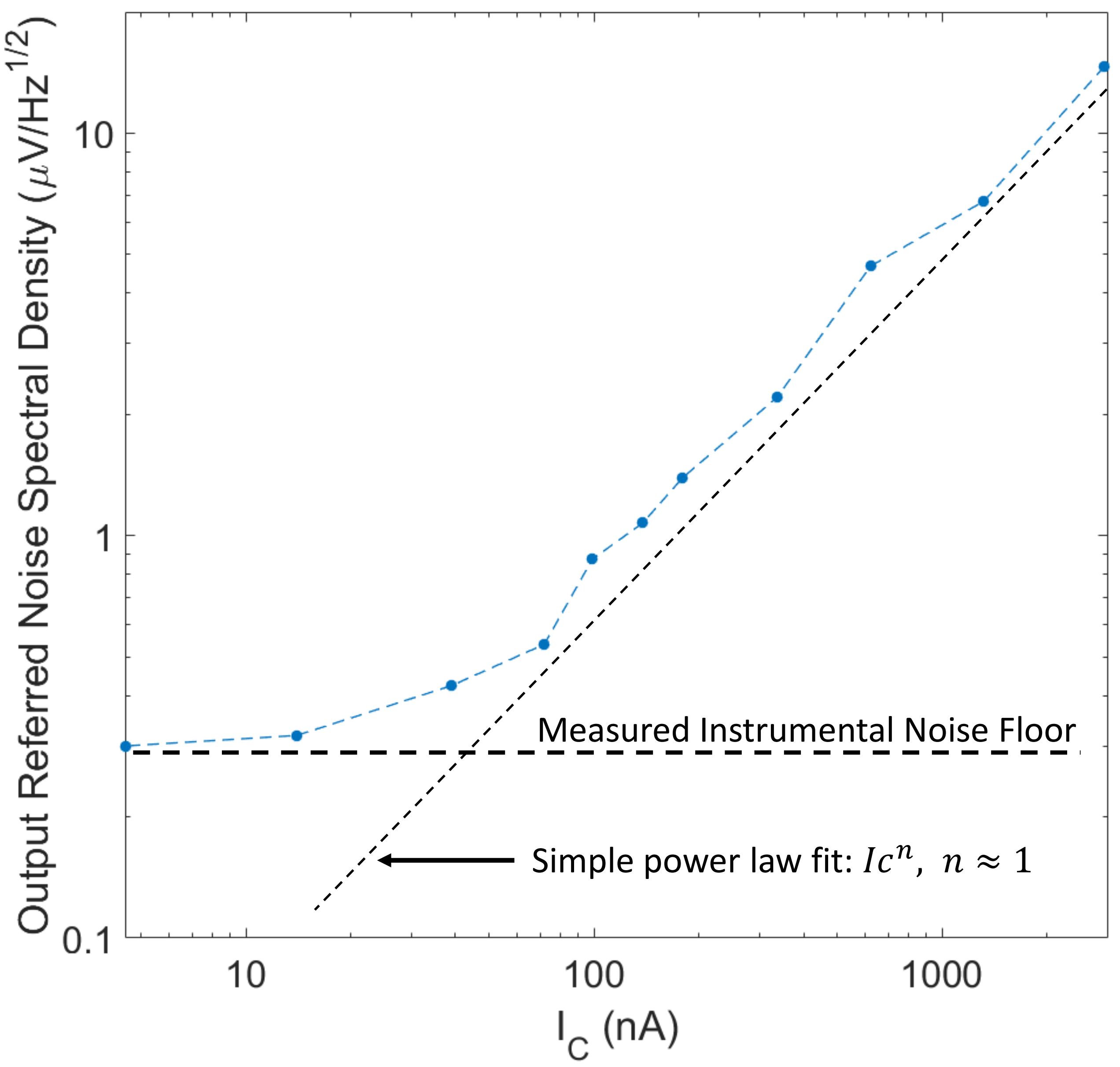

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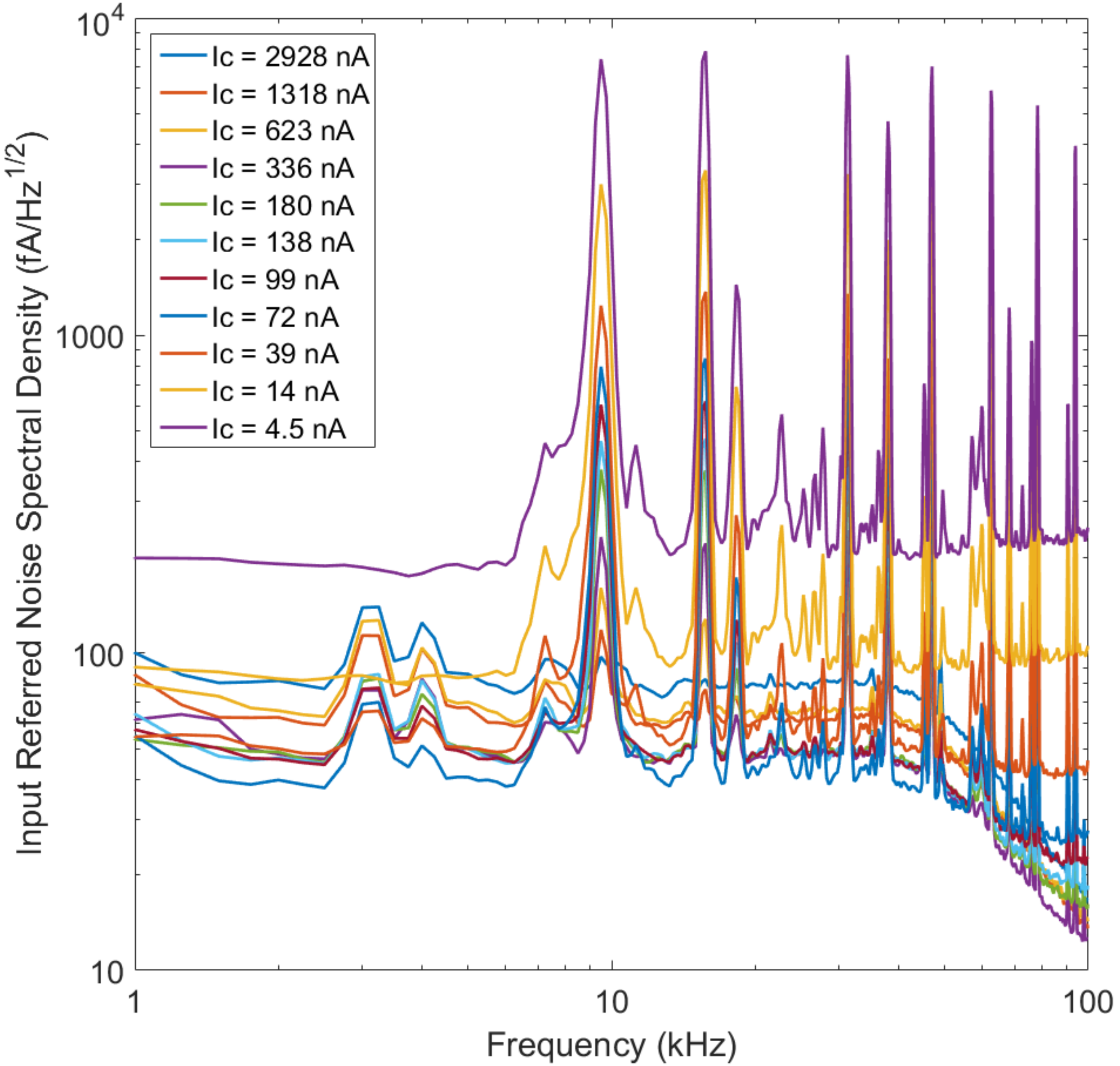

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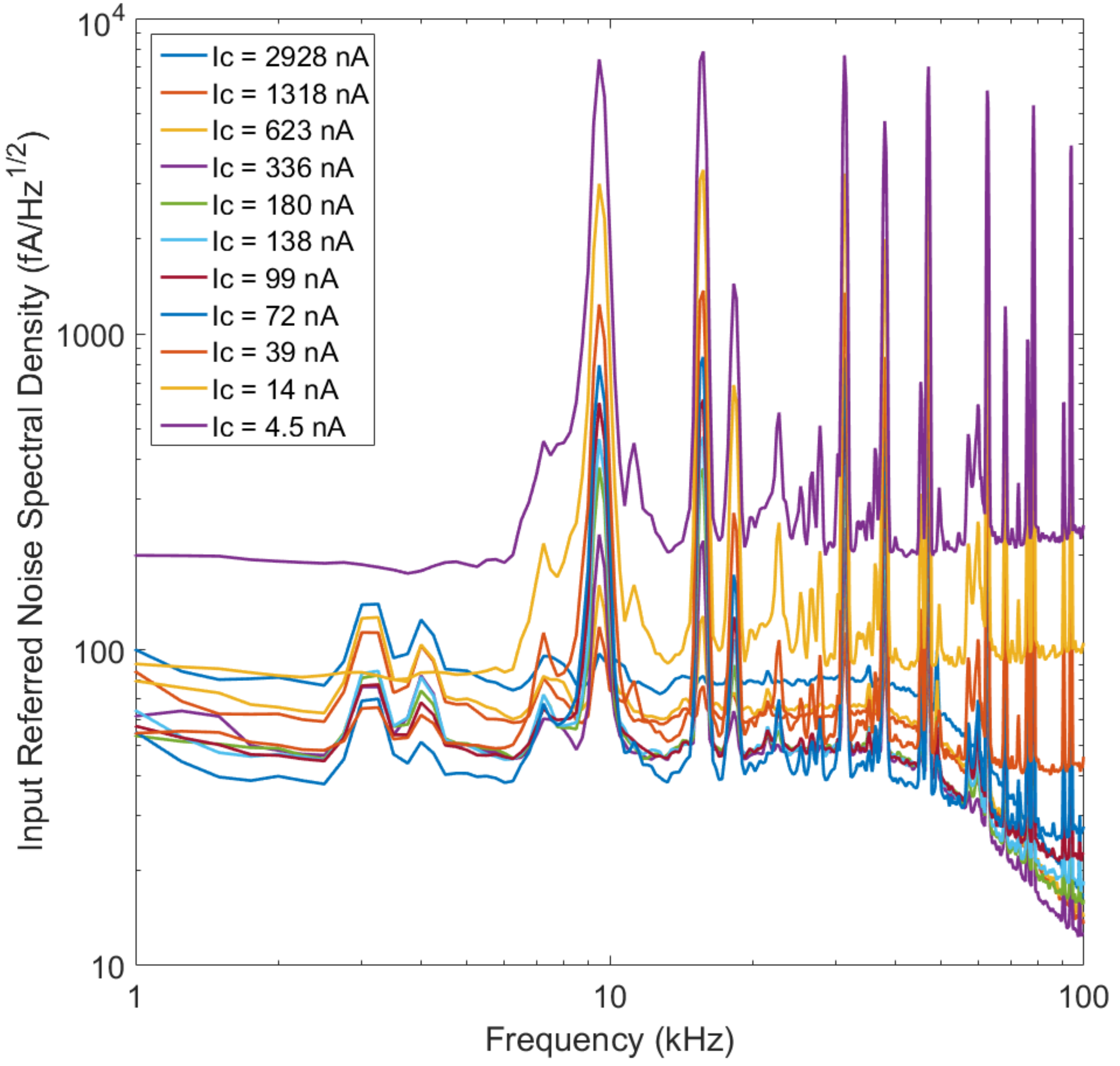
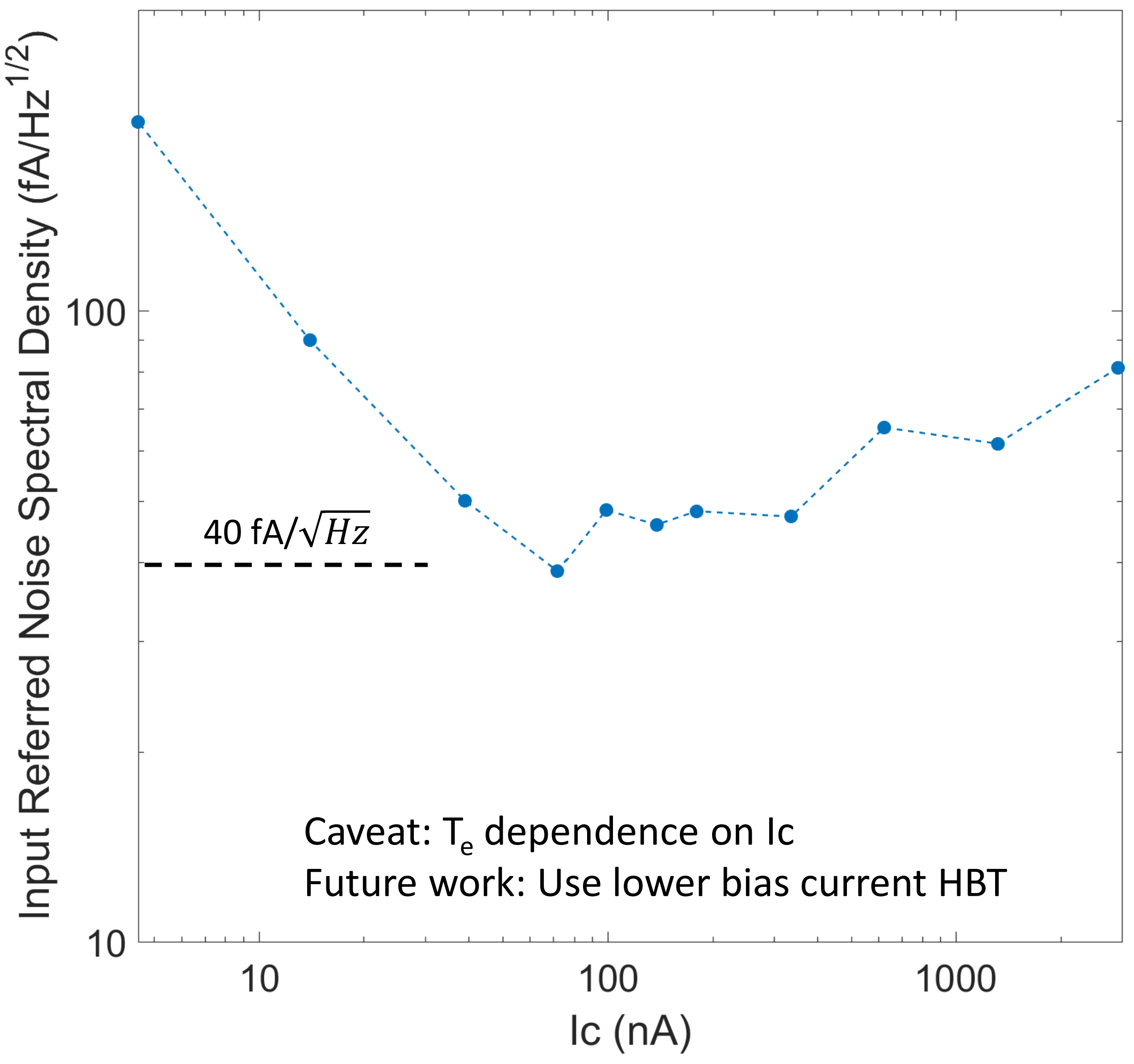
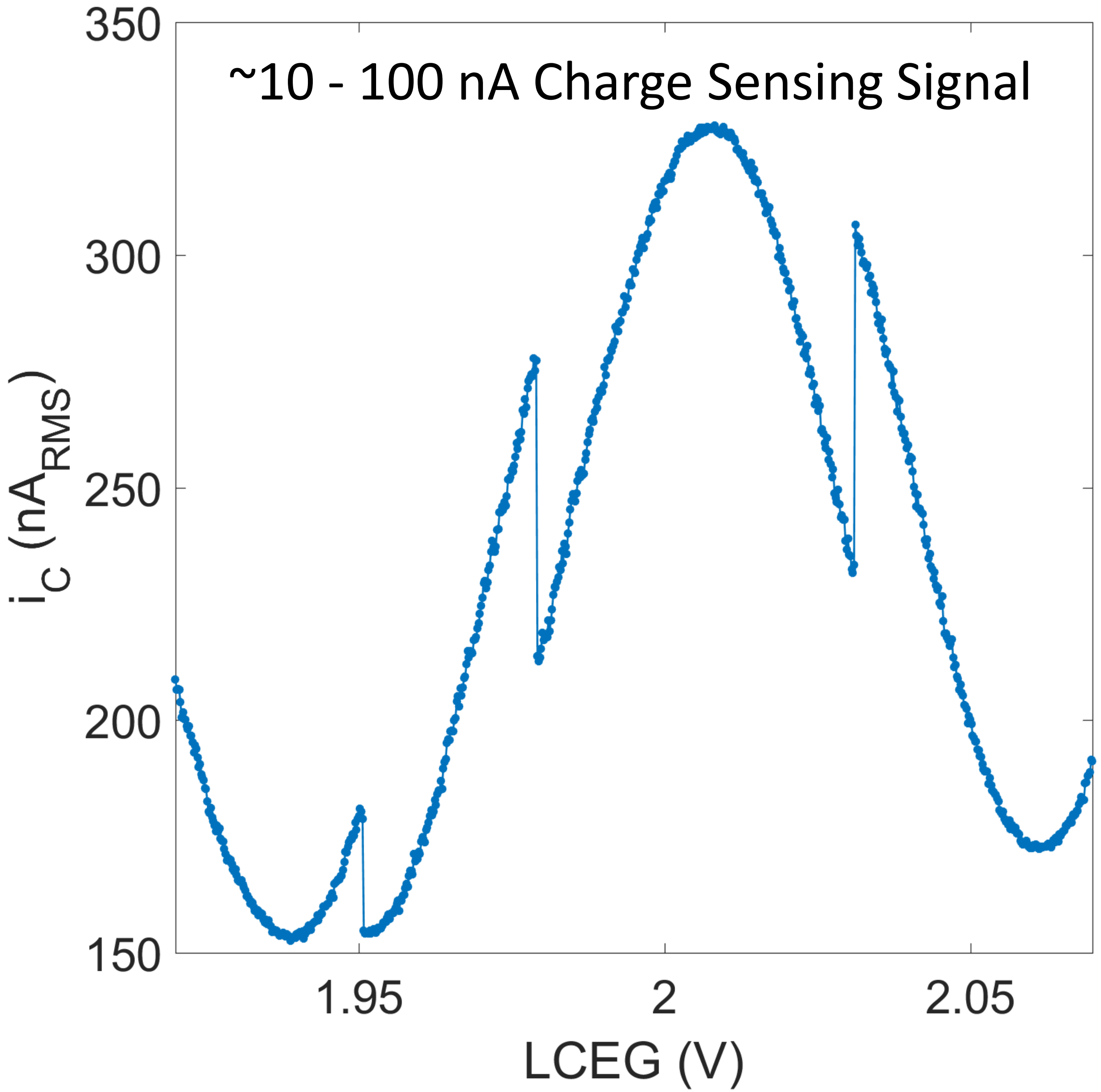
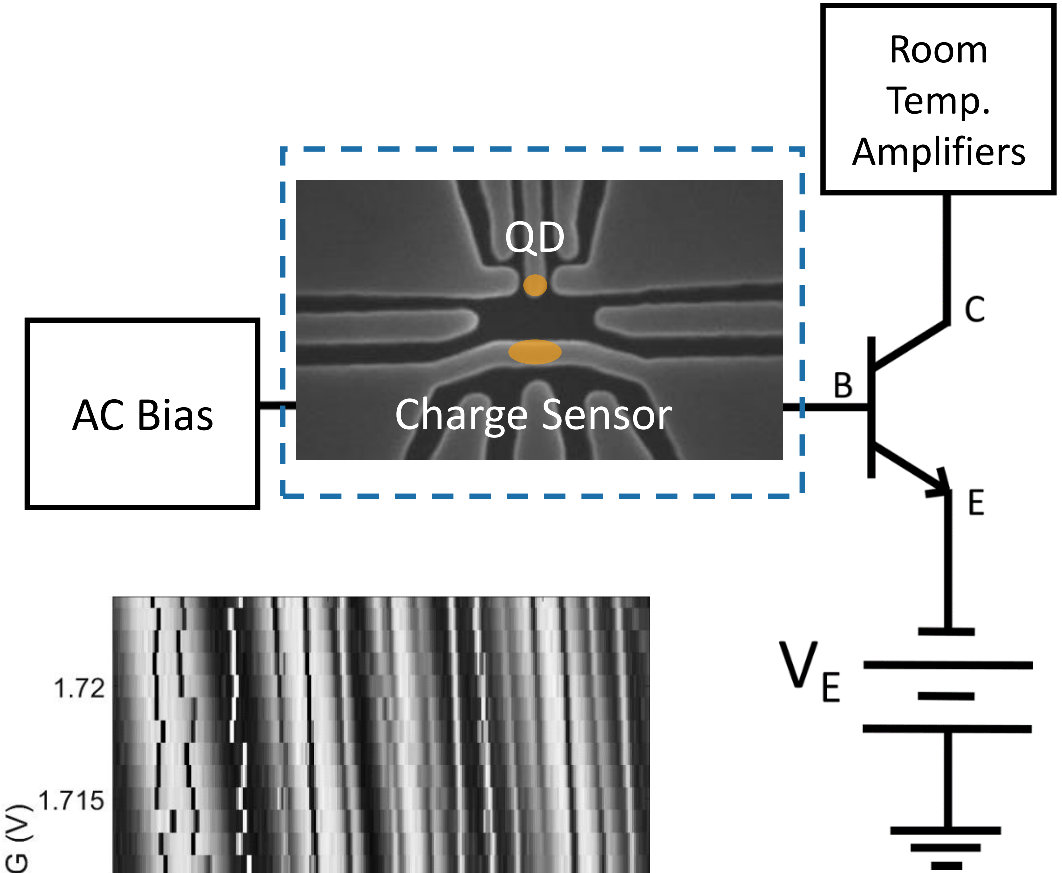
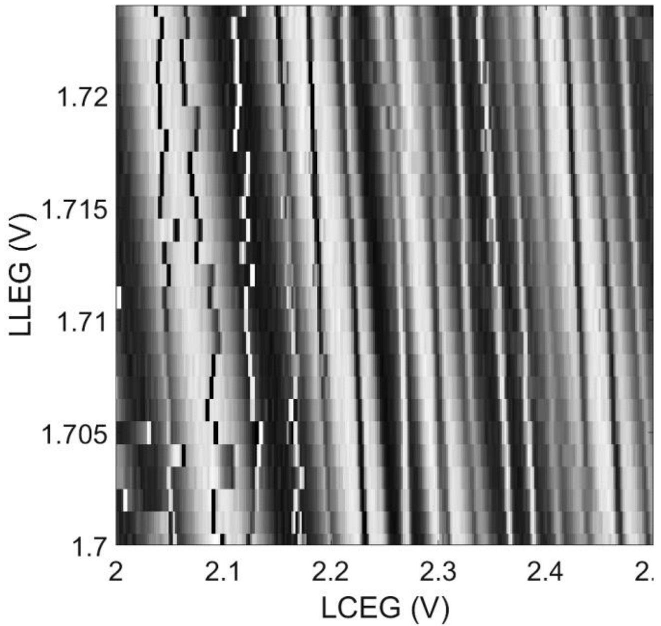




Charge Sensing With HBT In Dilution Refrigerator T = 15 mK

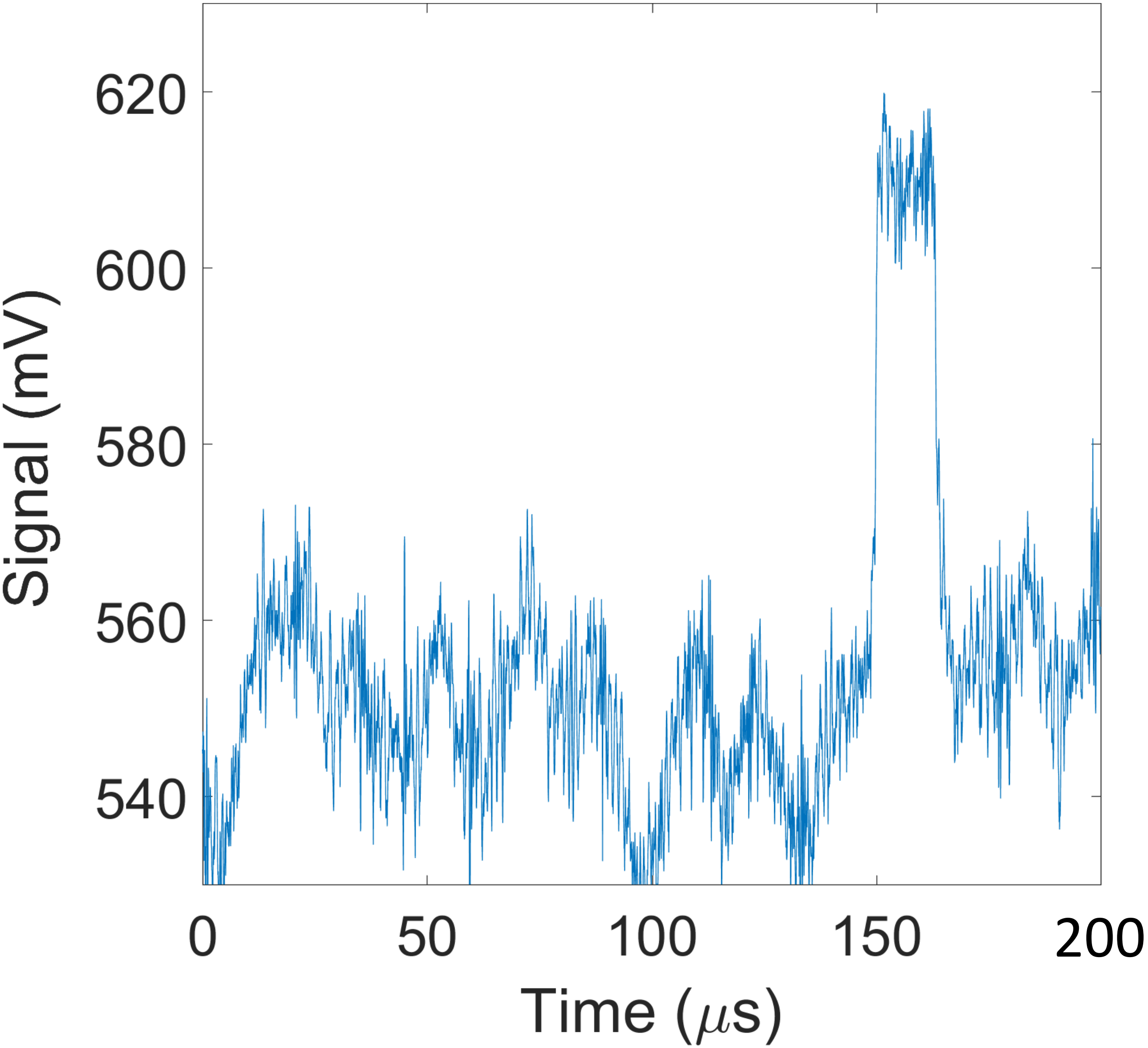






RTS Measurements With HBT Inline In Dilution Refrigerator T = 15 mK

Bandwidth = 1 MHz
SNR = 7



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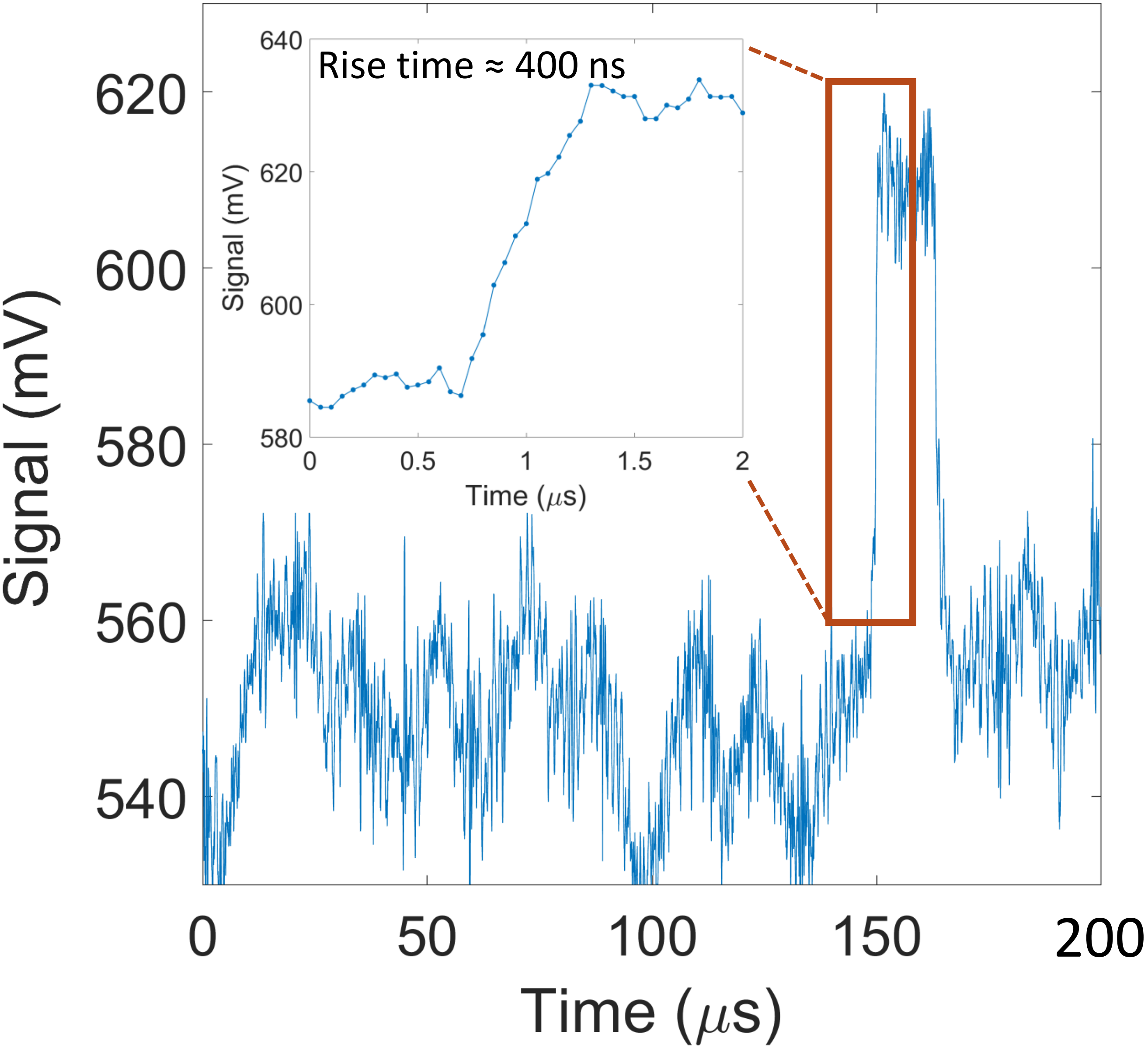

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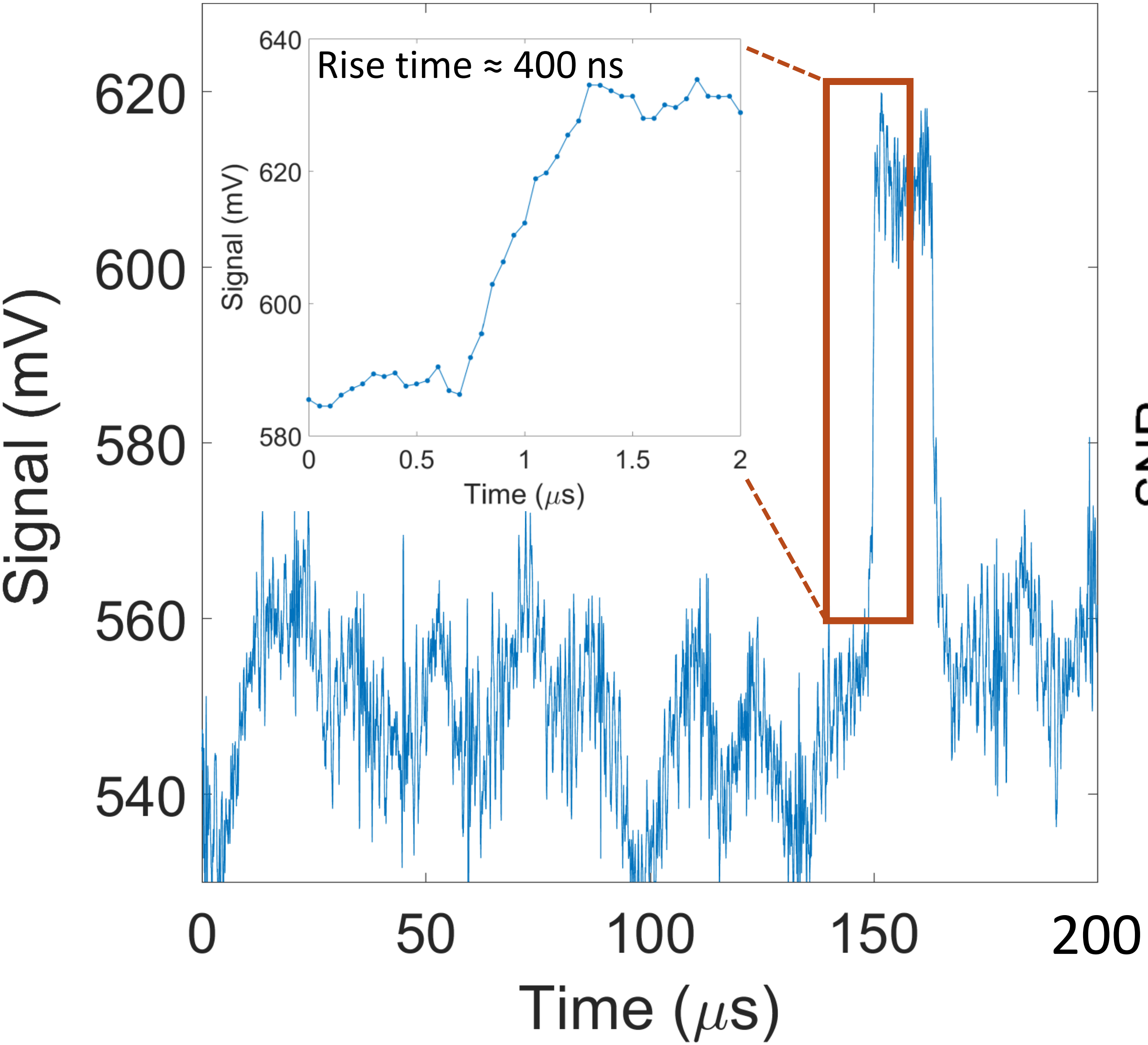

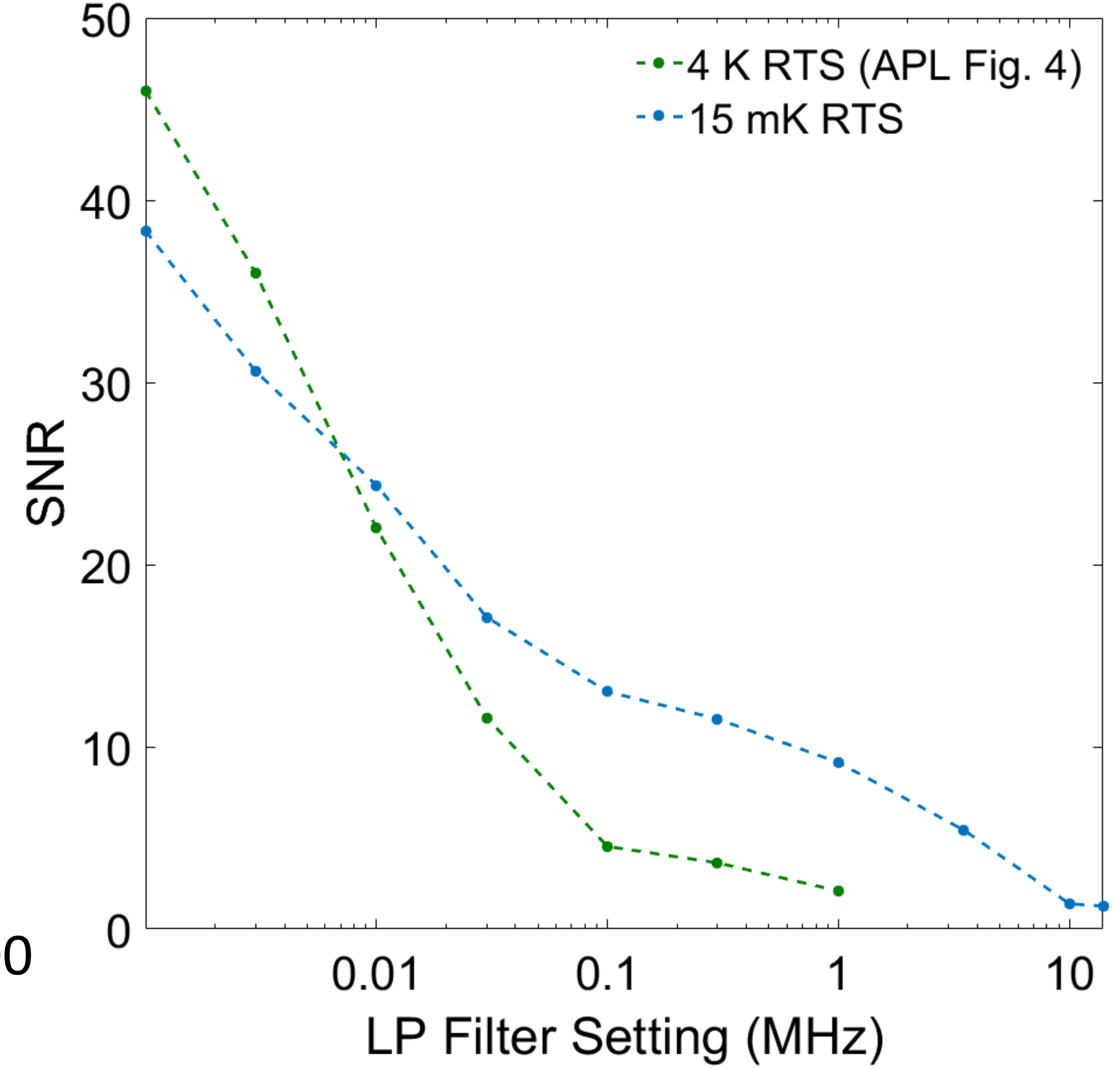

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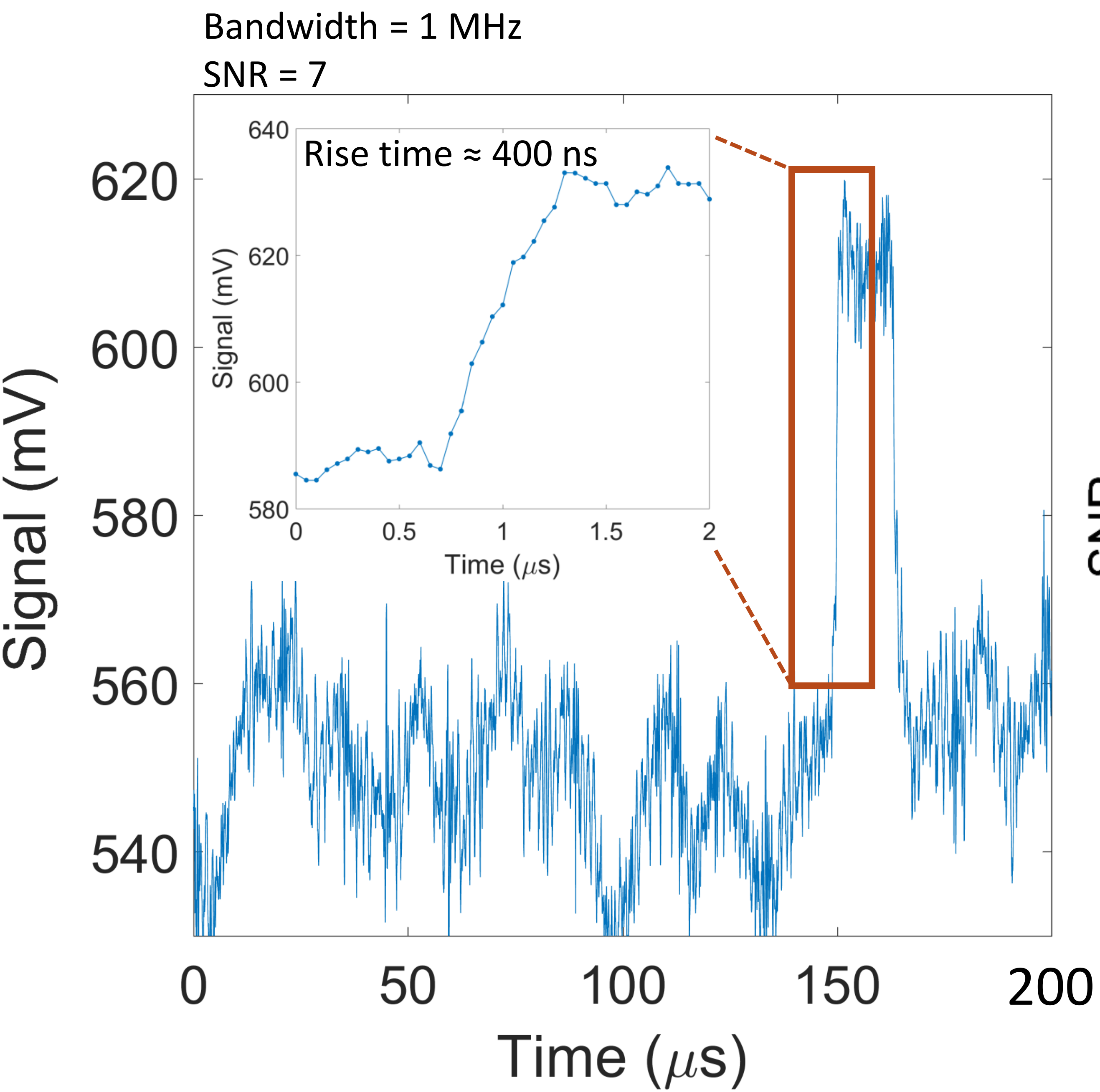

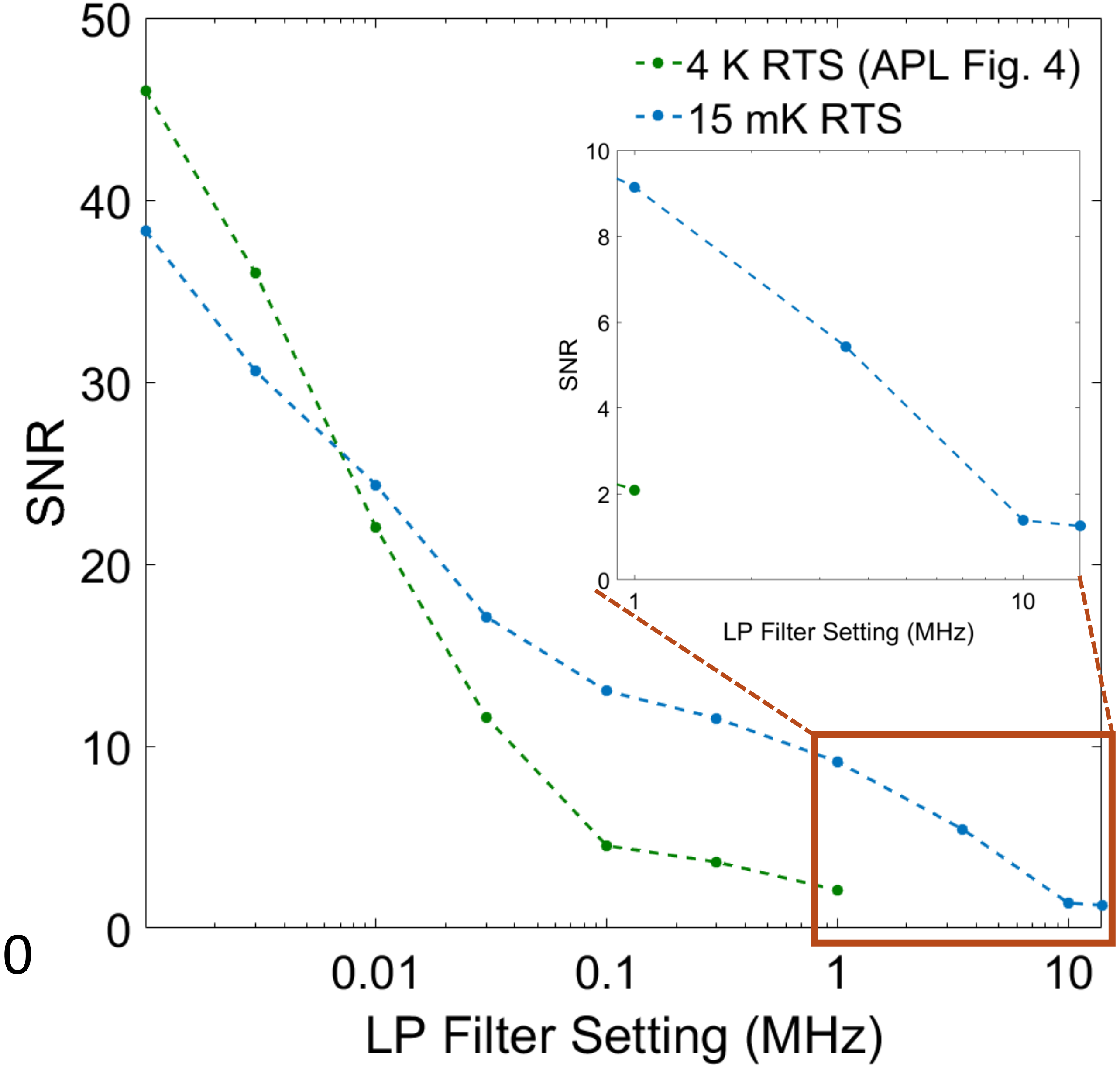

Time-Domain Single-Shot Readout: State of the Art

$$\begin{matrix}Charge\\Sensitivity\end{matrix} \equiv \frac{1}{(SNR)\cdot\sqrt{B}} = \frac{\sqrt{\tau_{int}}}{SNR} \quad \left(\frac{e}{\sqrt{Hz}}\right)$$

Single-Shot Readout Technique	Group	Reference	Carrier Frequency	Time-Domain Bandwidth	Time-Domain SNR	Charge Sensitivity (μe/$\sqrt{Hz}$)
HBT (Single-Stage)	Sandia/UNM/CQuIC	This Presentation Also: APL 106, 203505 (2015)	N/A	30 kHz 100 kHz 1 MHz 3 MHz	13 10 7 4	400 300 100 100
HEMT (Single-Stage)	Delft	APL 91, 123512 (2007)	N/A	800 kHz	3	400
HEMT (Dual-Stage)	Sandia	APL 108, 063101 (2016)	300 kHz	100 kHz	10	300
RF-QPC	Harvard CQC2T NRC Canada	PRB 81, 161308(R) (2010) APL 91, 222104 (2007) Physica E 42, 813 (2010)	220 MHz 332 MHz 763 MHz	5 MHz 500 kHz 1 MHz	2 7 7	200 200 100
RF-SET	Harvard Wisconsin/Dartmouth	PRB 81, 161308(R) (2010) APL 101, 142103 (2012)	220 MHz 936 MHz	10 MHz 2 MHz	4 4	80 100
Gate-Dispersive RF	ARC Sydney	PRL 110, 046805 (2013)	700 MHz	30 kHz	1	6000
RF Transmission SC Cavity + JPA	Princeton	PR Applied 4, 014018 (2015)	7.88 GHz	2.6 MHz	9	80

Conclusion

- Single-shot charge readout demonstration in dilution fridge.

- HBT cryogenic preamp benefits:
  - Relatively simple implementation
  - Low power (50 nW to 5 μW)
  - Low 1/f corner frequency

- **Take-home message:** Comparable time-domain charge sensitivity to RF techniques with low overhead.

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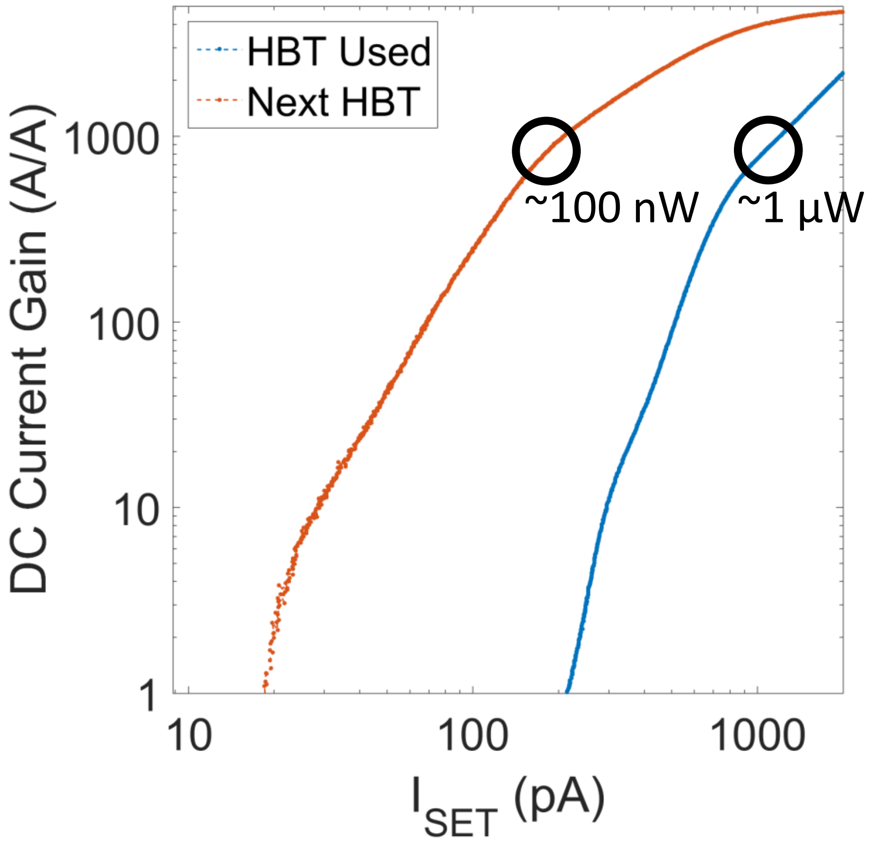

Future Work: Minimize Te with lower bias current HBT

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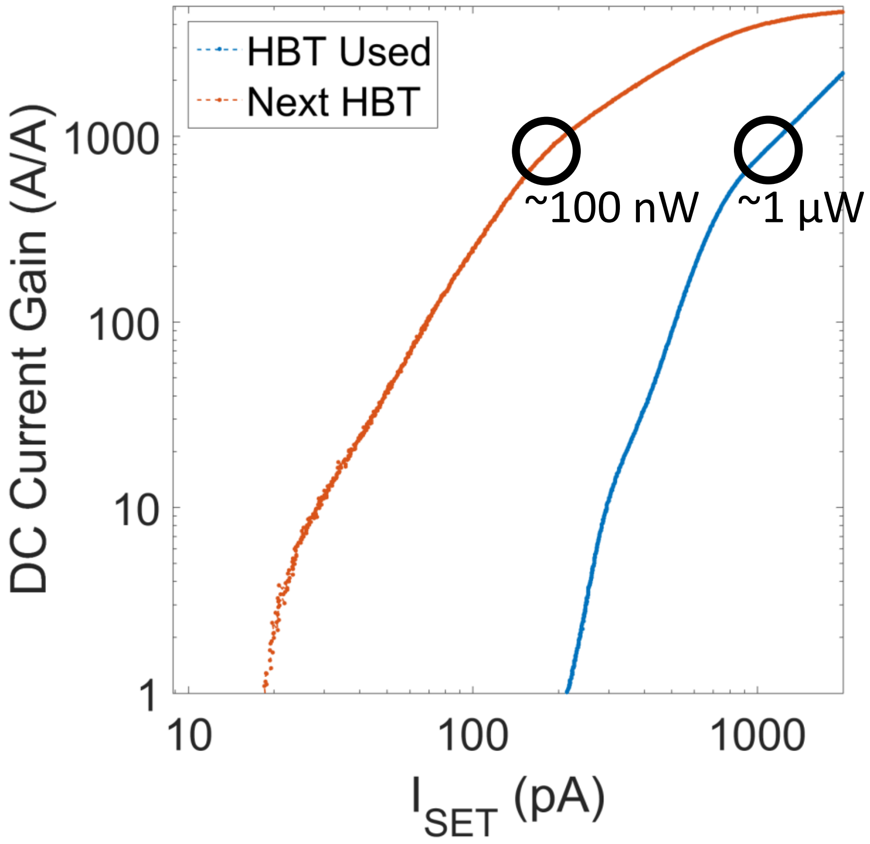

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Questions?