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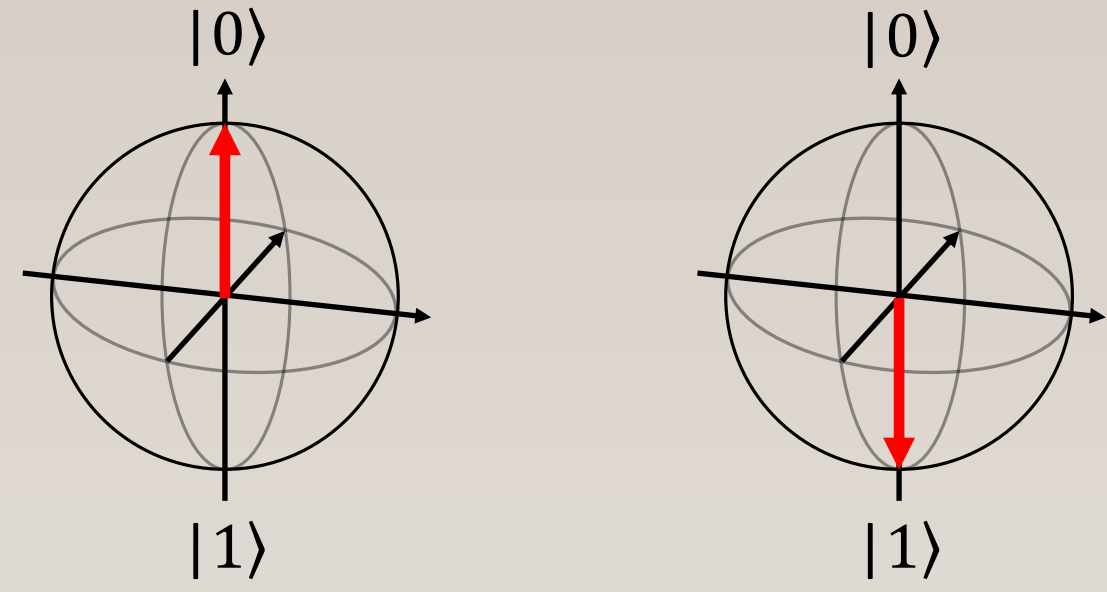


Single-Shot Charge Readout using a Cryogenic Heterojunction-Bipolar-Transistor Preamplifier Inline with a Silicon Single-Electron-Transistor at Millikelvin Temperatures

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Motivation

- Qubit states need to be read out.
- Single-shot readout is necessary in many implementations.
 - Readout fidelity is dependent on signal-to-noise ratio (SNR) and bandwidth (BW).
- Cryogenic preamplifier improves SNR and BW.
- Heterojunction-bipolar-transistor has many advantages as a cryogenic preamplifier:
 - Low power (50 nW to 5 μ W).
 - Relatively simple implementation.

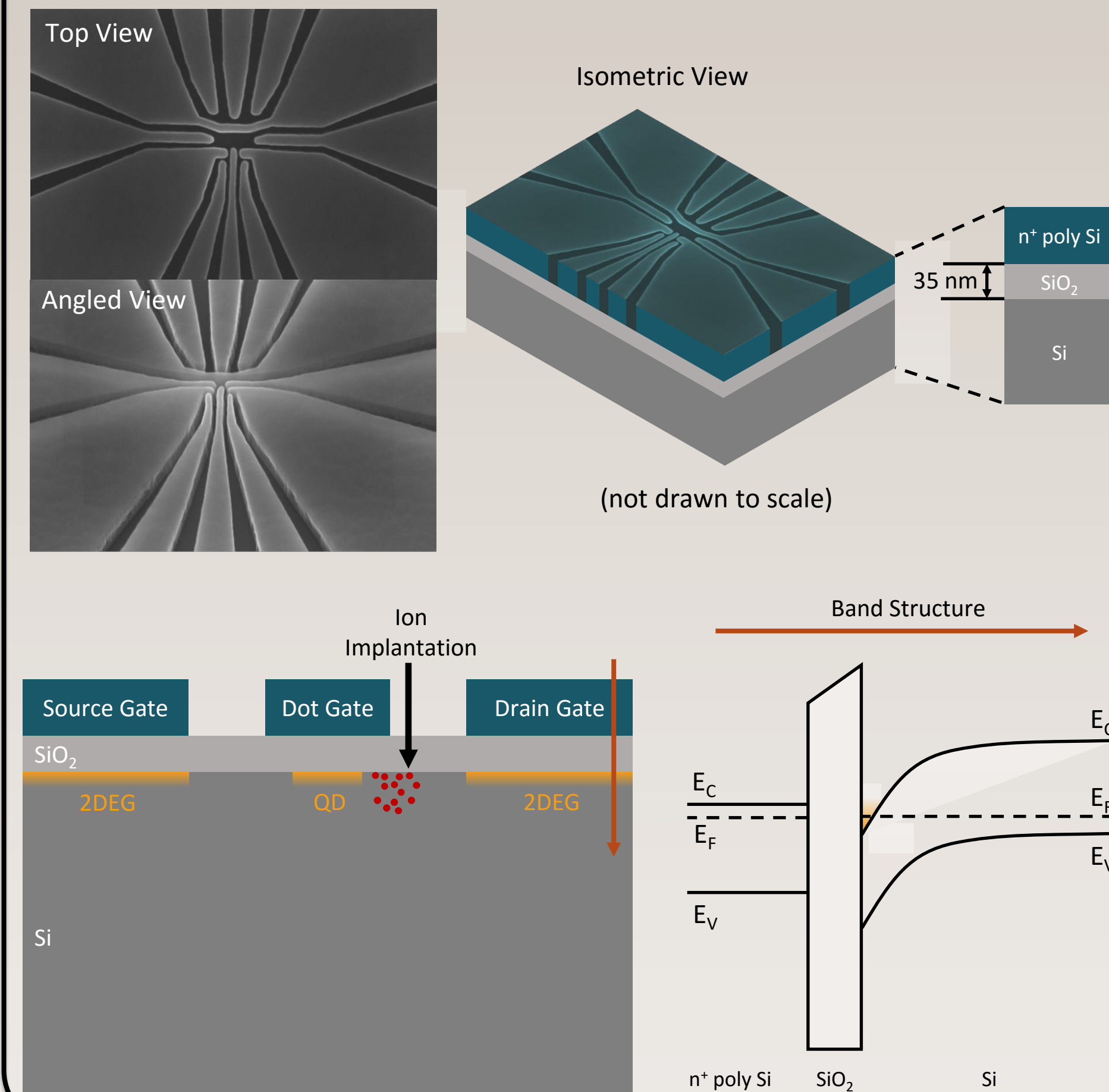


Time-Domain Single-Shot Readout: State of the Art

Single-Shot Readout Technique	Group	Reference	Carrier Frequency	Time-Domain Bandwidth	Time-Domain SNR	Charge Sensitivity (μ e/ $\sqrt{\text{Hz}}$)
HBT (Single-Stage)	Sandia/ UNM/ CQuIC	This Poster 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	Manuscript In Prep. (2015)	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

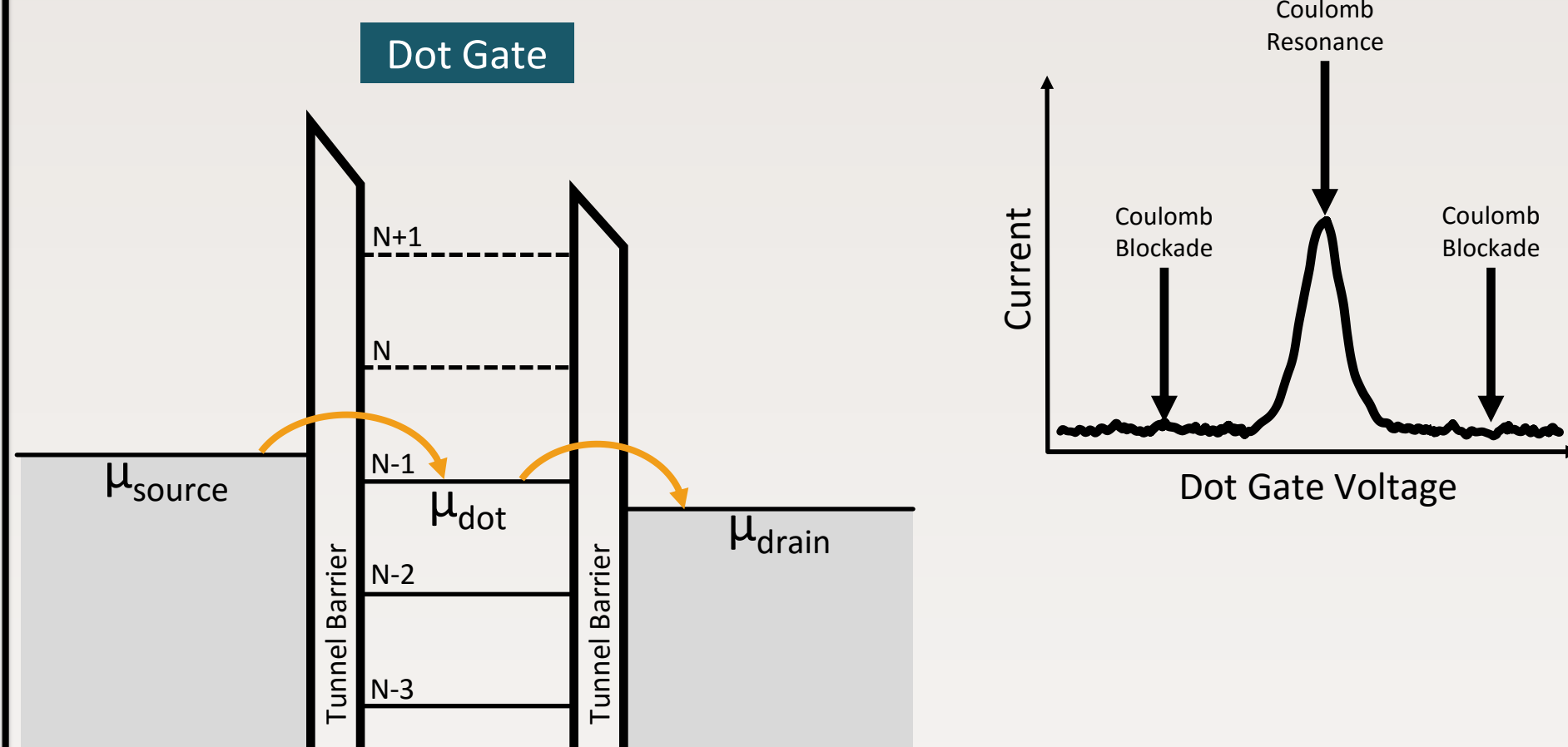
$$\text{Charge Sensitivity} \equiv \delta q \approx \frac{1}{(\text{SNR}) \cdot \sqrt{B}} \approx \frac{\sqrt{\tau_{\text{int}}}}{\text{SNR}} \left(\frac{e}{\sqrt{\text{Hz}}} \right)$$

MOS QD Architecture

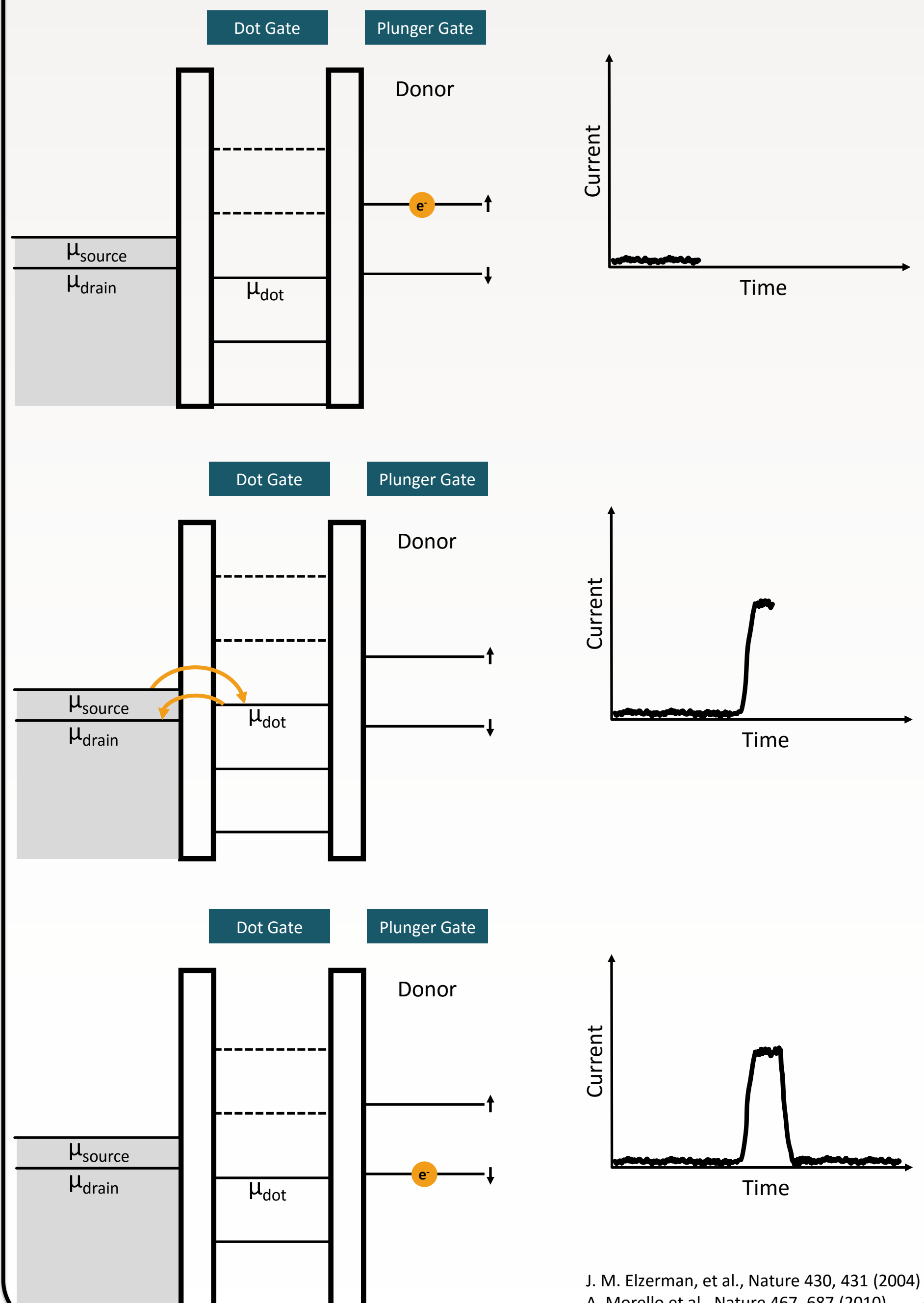


Spin-To-Charge Readout

Coulomb Blockade

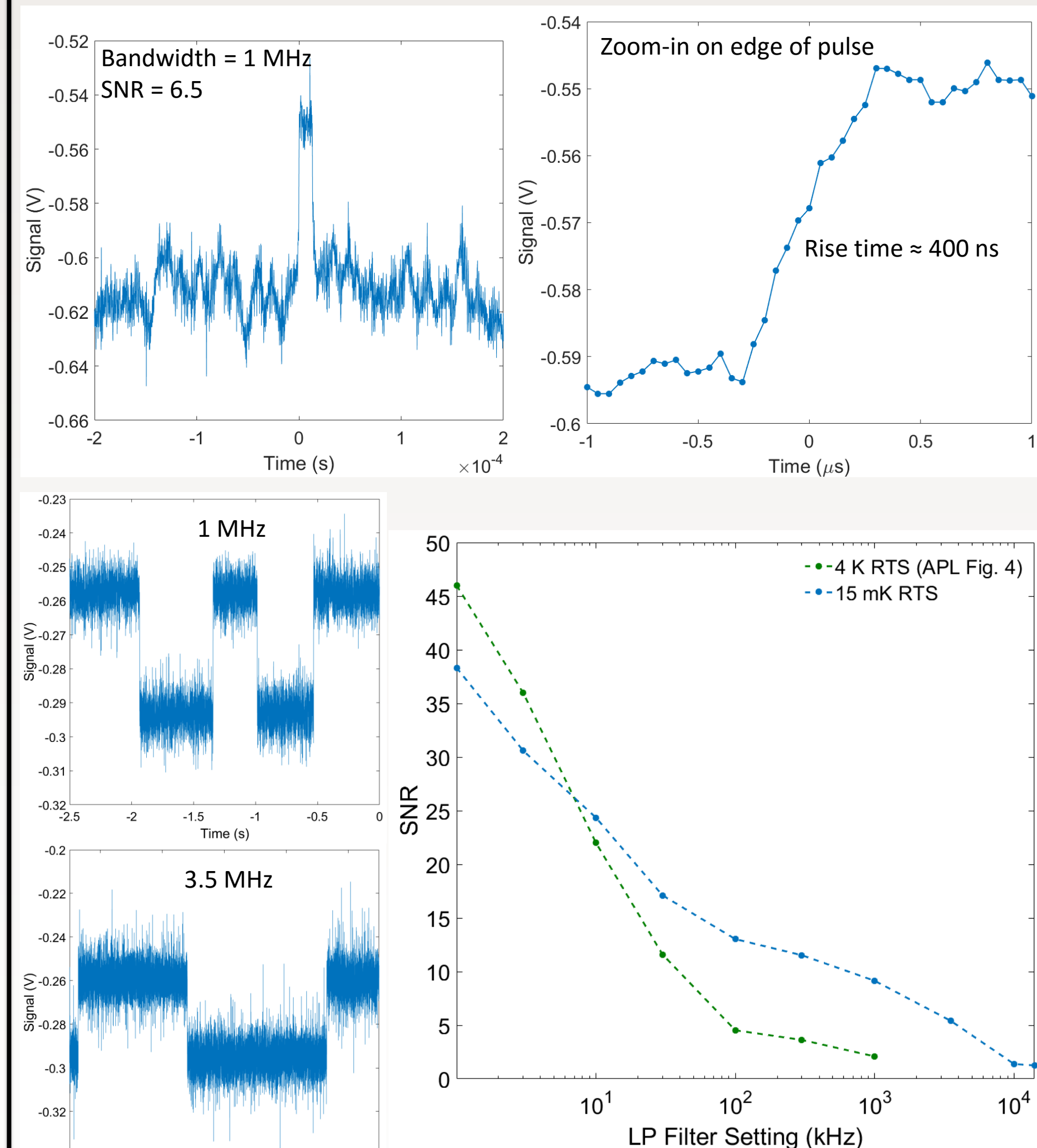


Donor Electron Spin Readout: Spin-Up Example

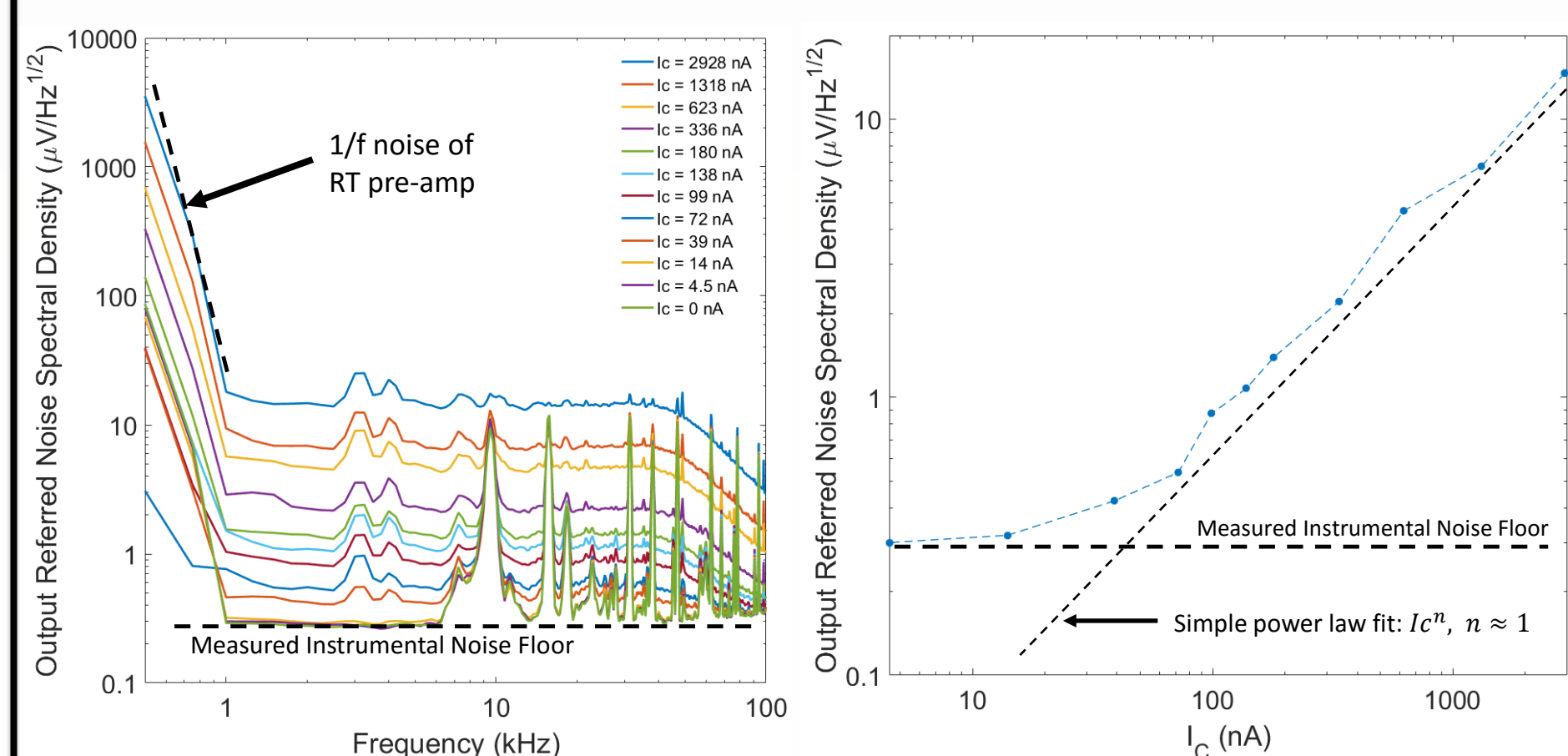


J. M. Elzerman, et al., Nature 430, 431 (2004)
A. Morello et al., Nature 467, 687 (2010)

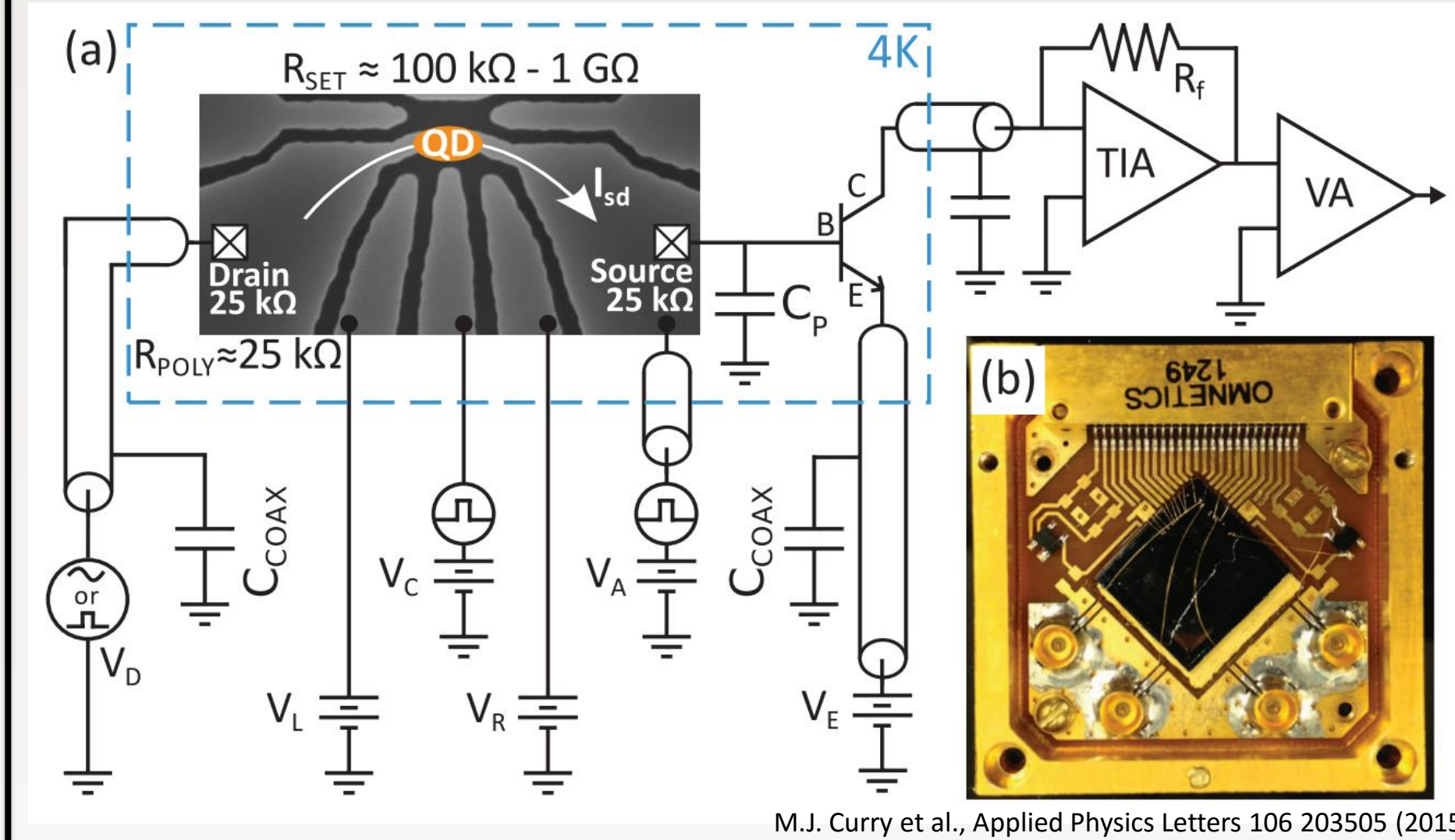
Experimental Results



Readout Circuit Output-Referred Noise Spectral Density

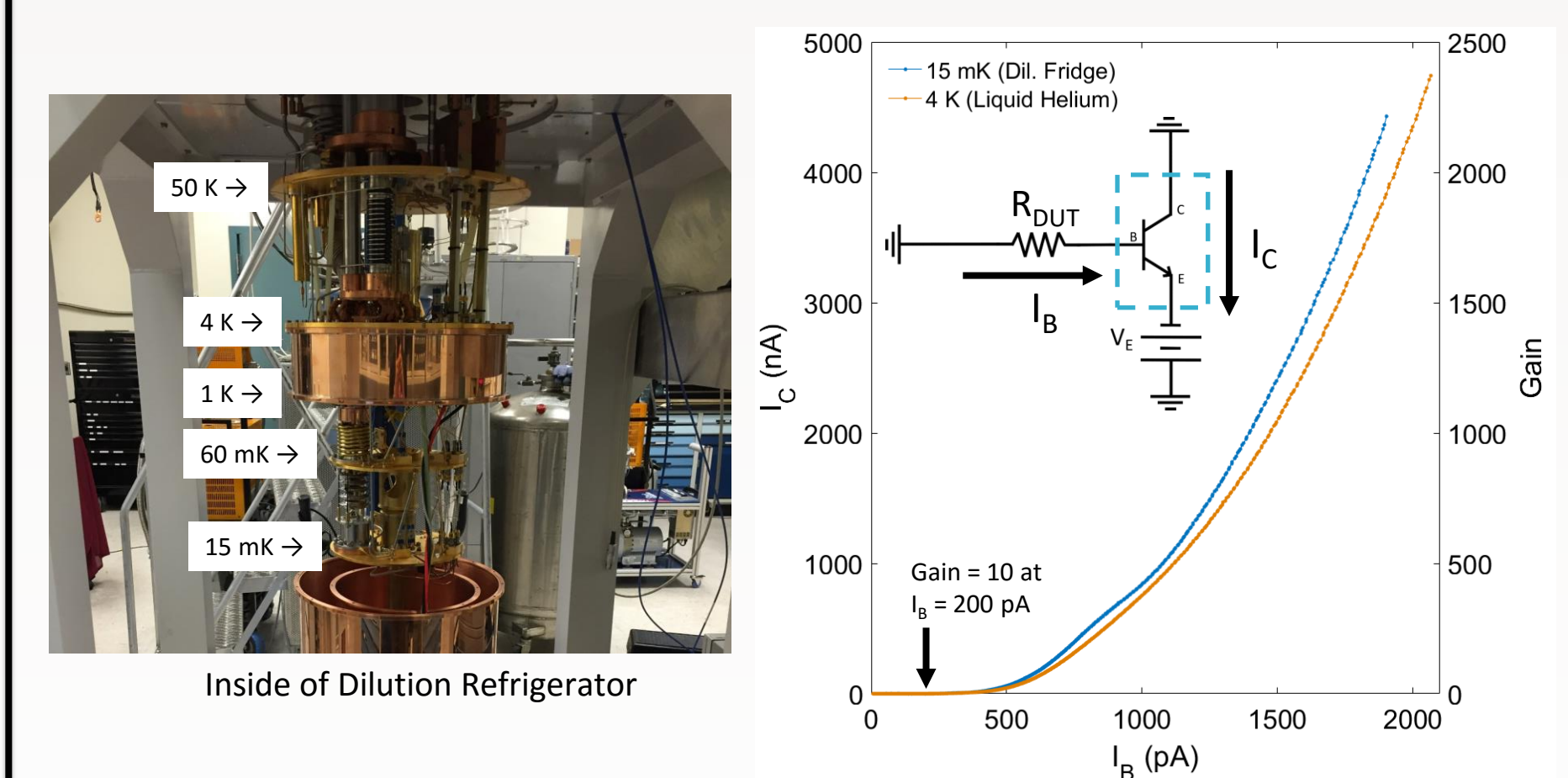


Cryogenic Preamplification



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

HBT DC Characterization at 4 K and 15 mK



Charge Sensing With HBT In Dilution Refrigerator

