

# APS Fabricated in a Standard 0.18 $\mu\text{m}$ CMOS Technology

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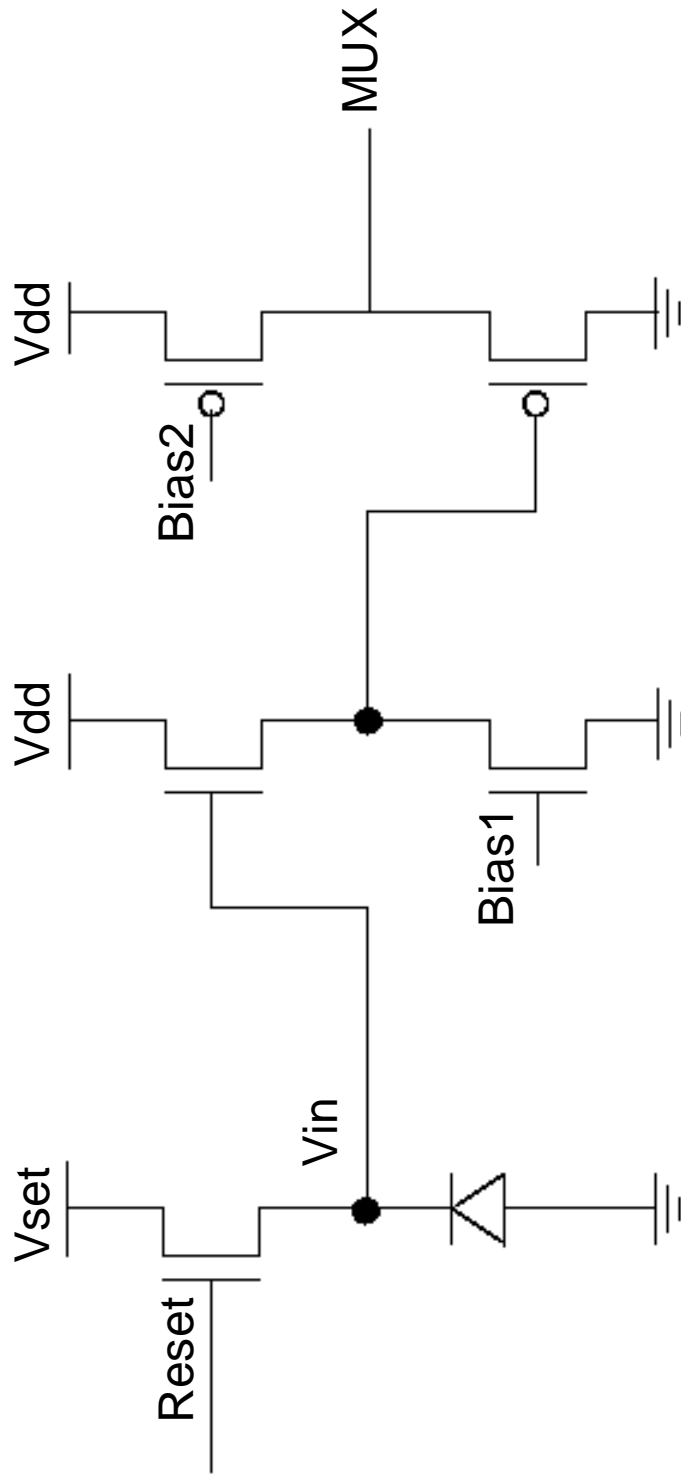
# Motivation

- CMOS image sensors benefited from scaling
  - Reduce pixel size
  - Increase fill factor
  - Integrate more circuitry
- CMOS image sensors harder to build using sub-quarter  $\mu\text{m}$  processes
  - Thin gate oxide
  - Shallow Trench Isolation
  - Highly doped retrograde well
  - Silicide

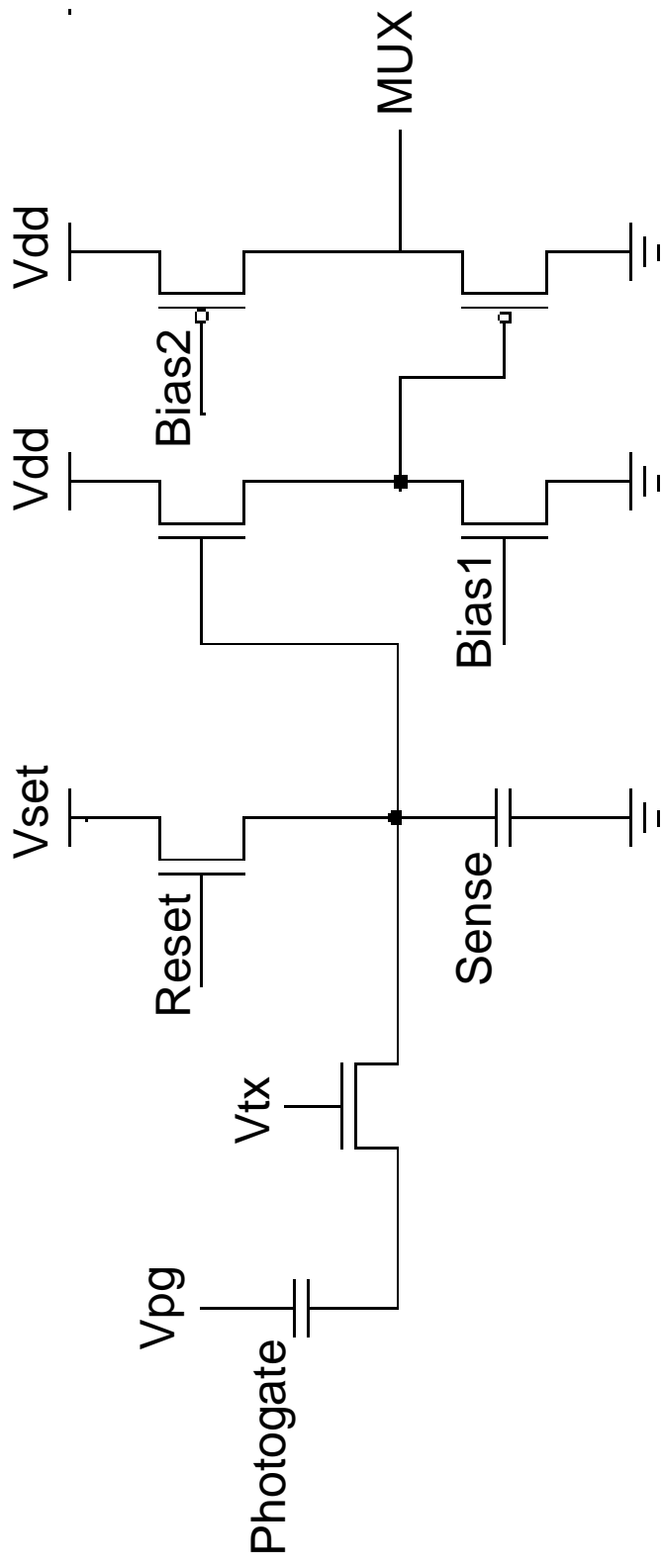
# Design Considerations

- **Gate leakage current density**
  - Higher than photodiode dark current density
  - Use thick oxide transistor (**3.3V**) to build follower
- **Transistor off-current**
  - Comparable to photo-current
  - Use long channel device to build reset transistor
- **Signal swing**
  - Reset use thick oxide transistor
- **Silicide**
  - Apply silicide block on photodiodes

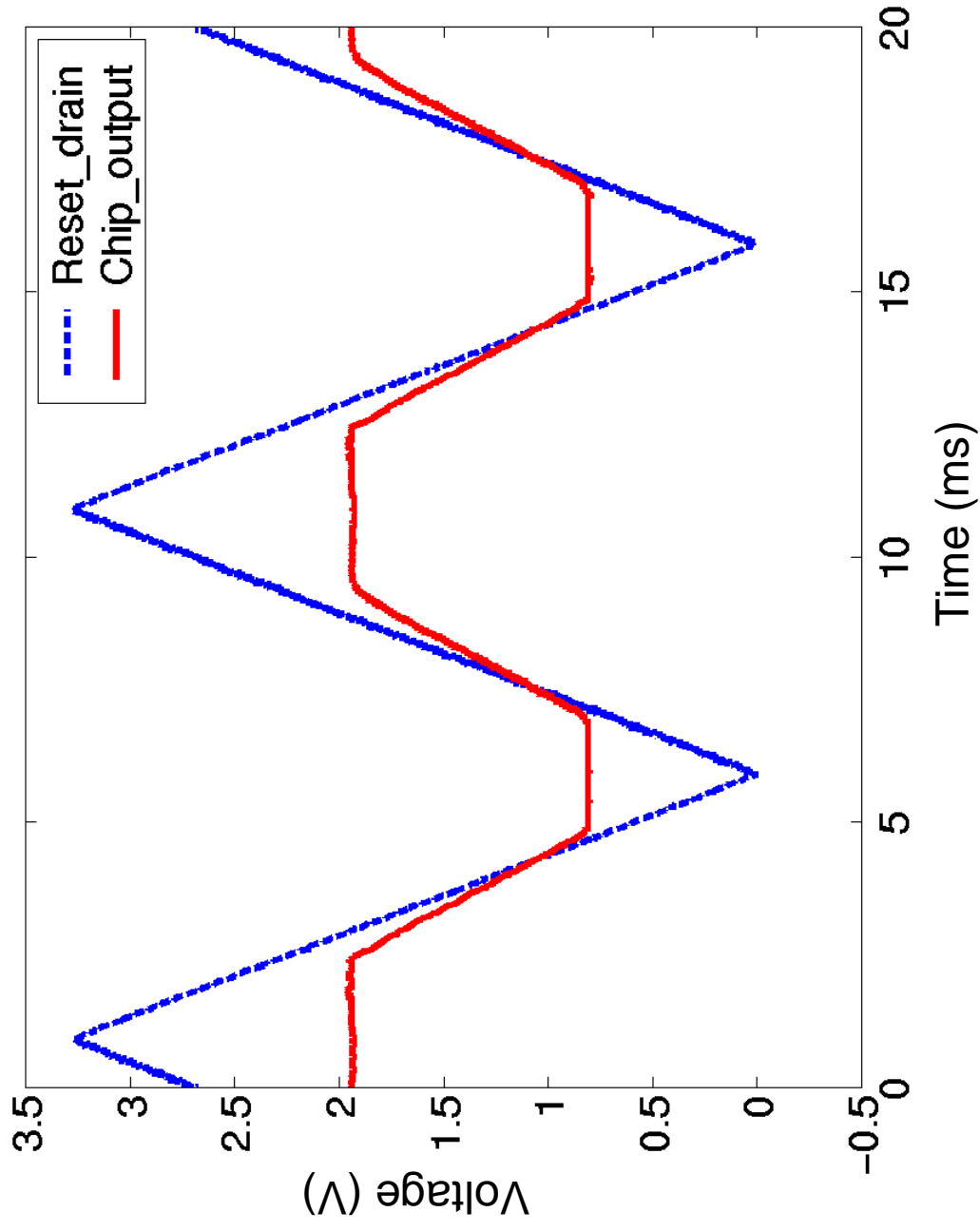
# Photodiode Test Structure



# Photogate Test Structure

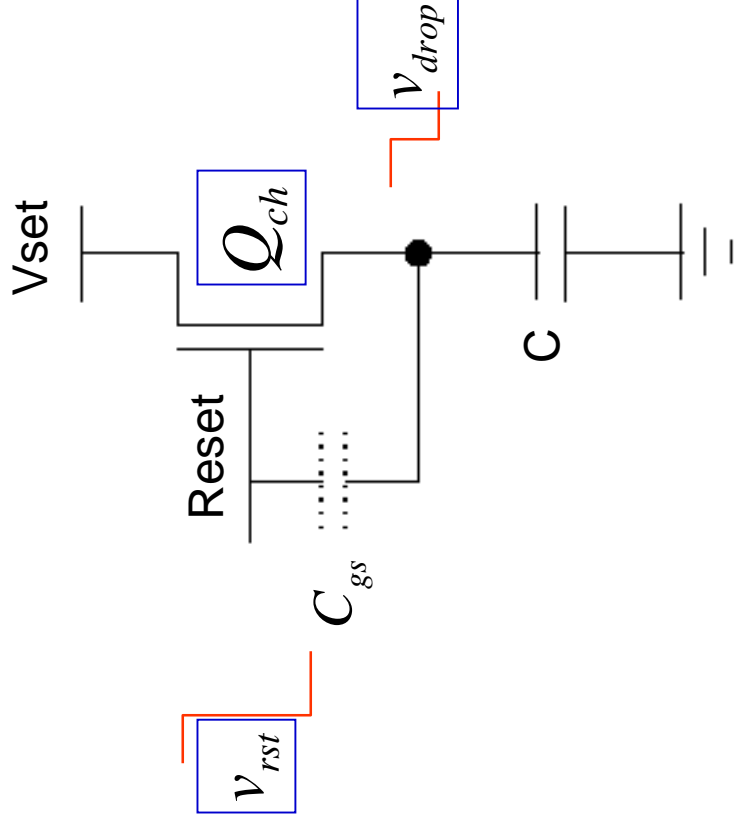


# Measured Readout Circuit Response



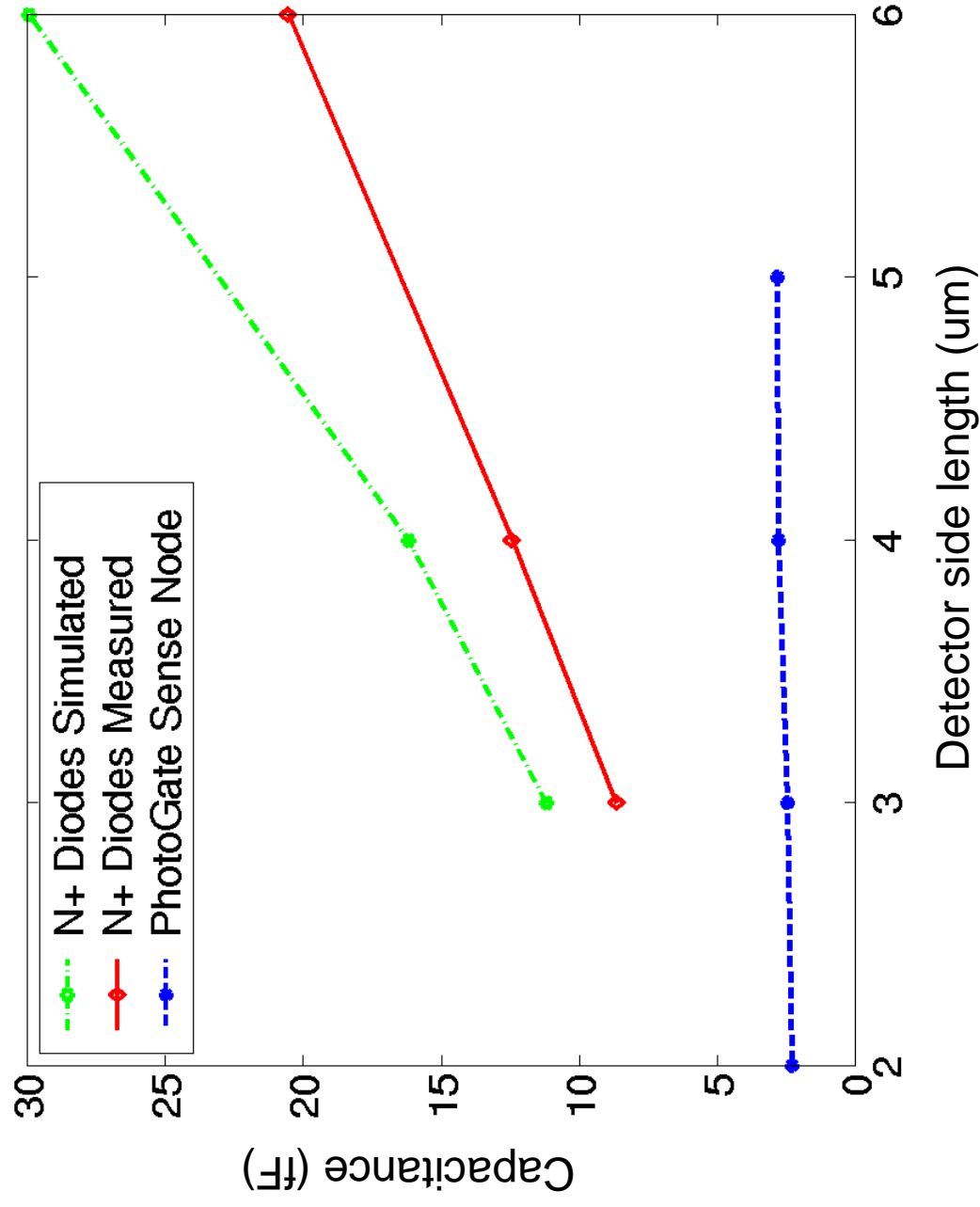
# Measuring Capacitance

Use charge injection due to reset



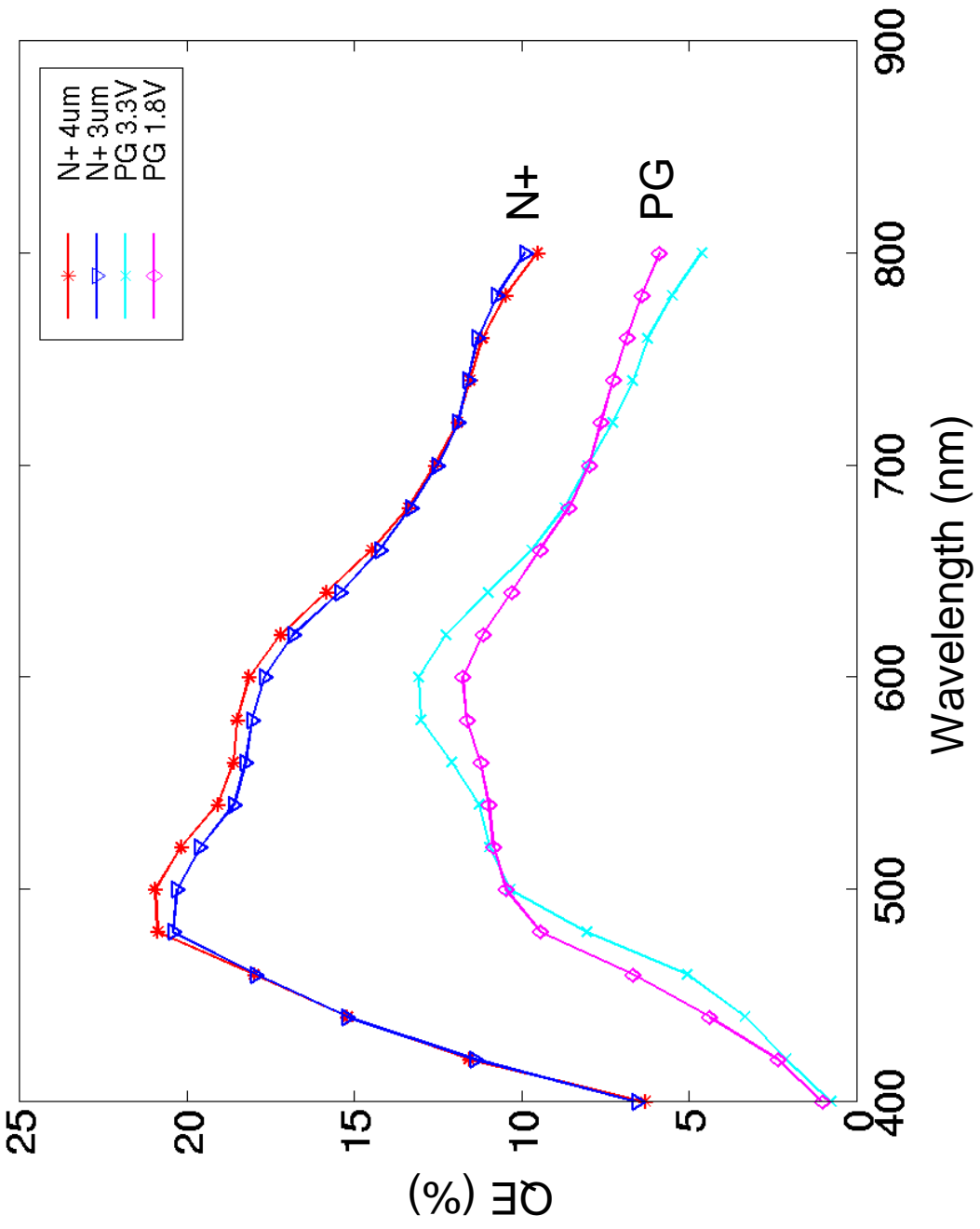
$$v_{drop} = v_{ch} + v_{fd} \approx \frac{\alpha Q_{ch} + v_{rst} C_{gs}}{C} = \frac{Q_{eff}}{C}$$

# Measured Capacitance

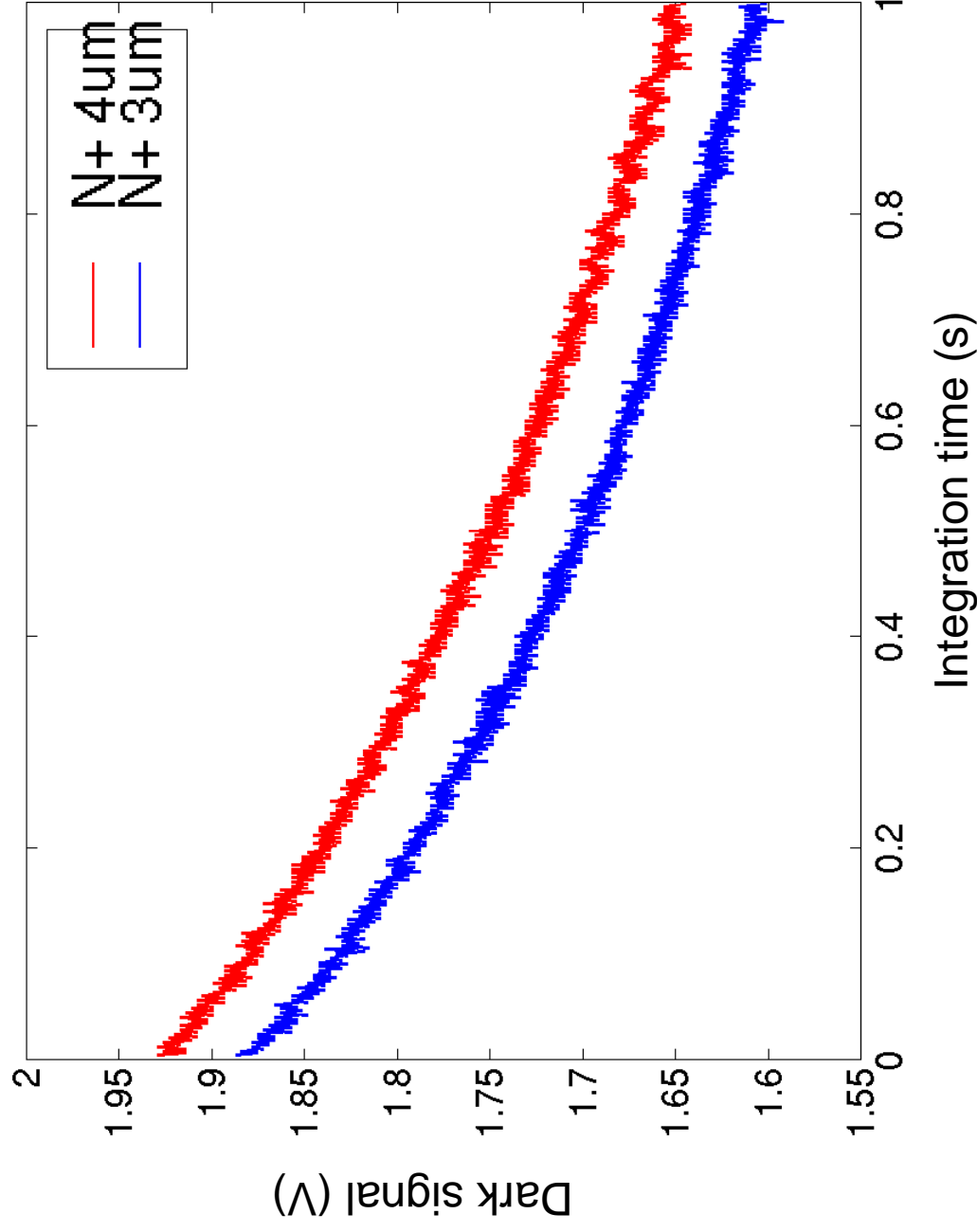




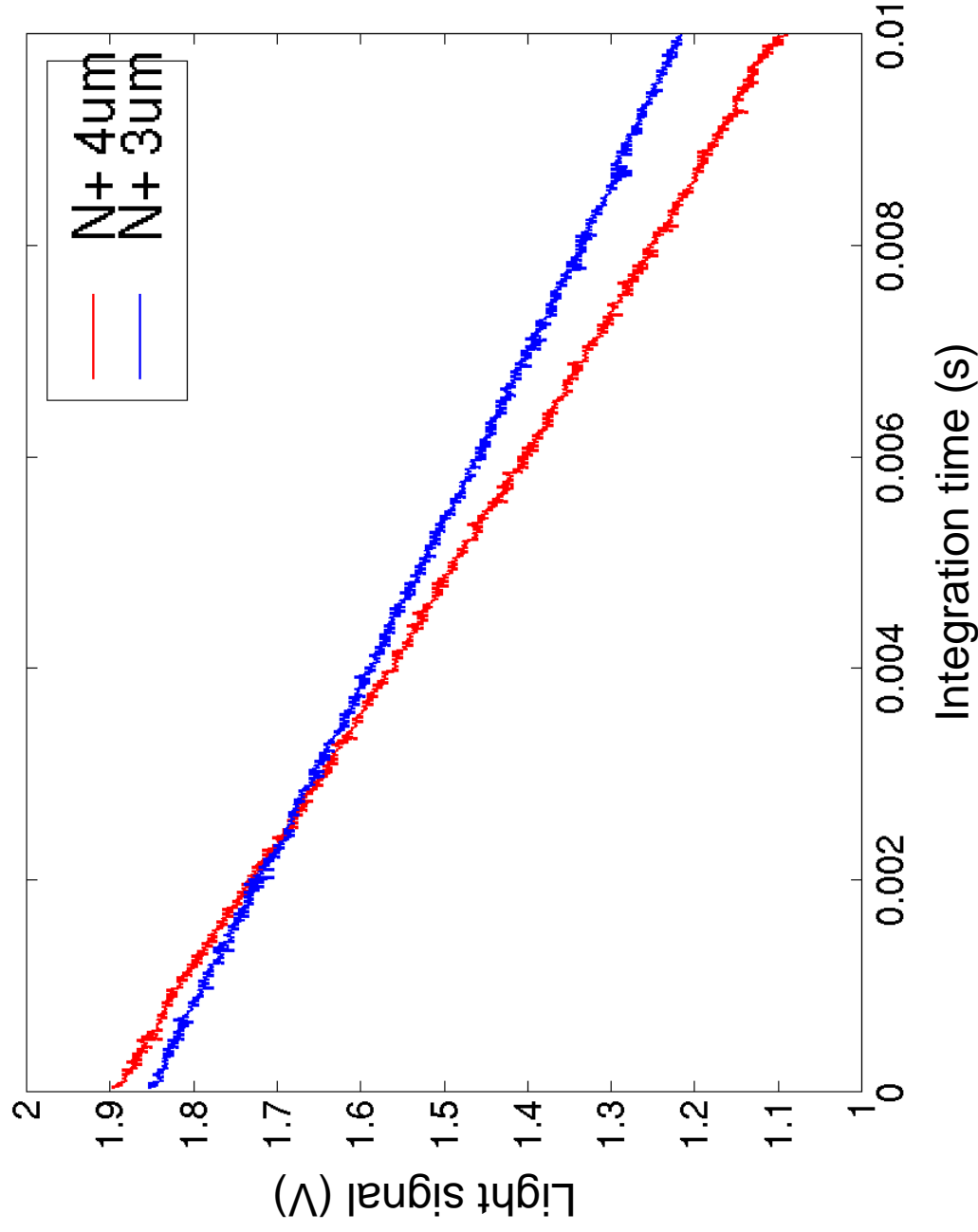
# Measured Quantum Efficiency



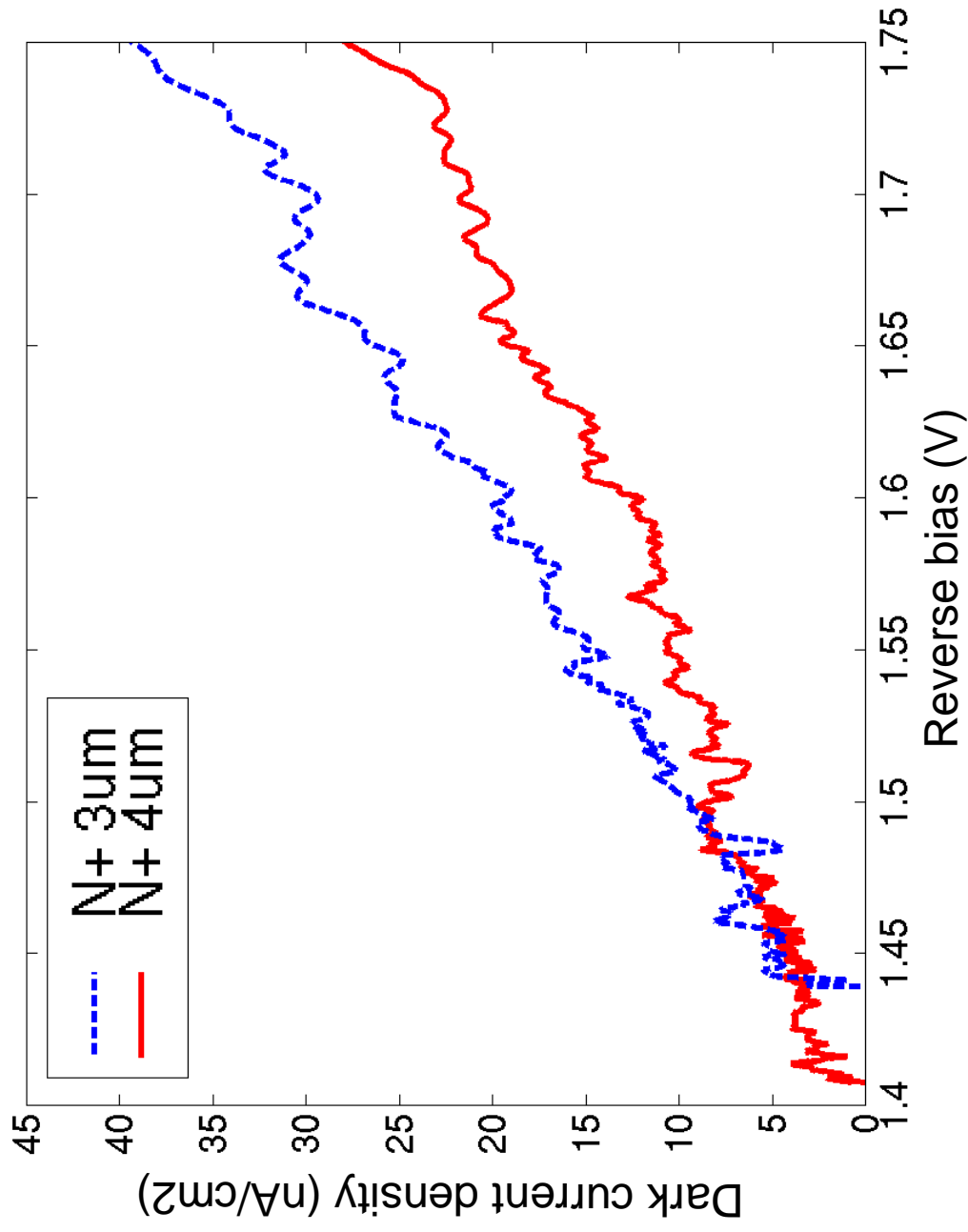
# Photodiode Dark Response



# Photodiode Light Response



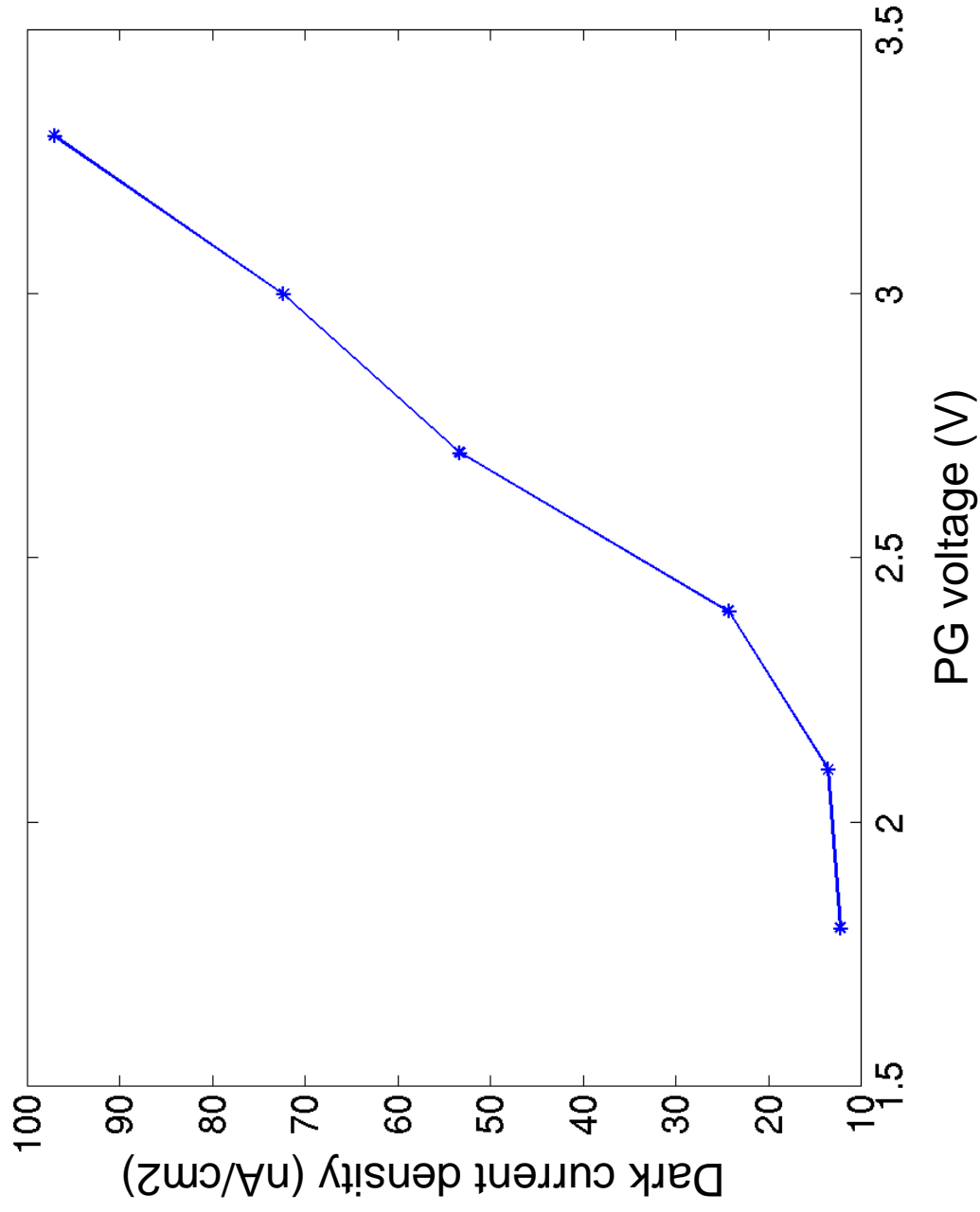
# Photodiode Dark Current



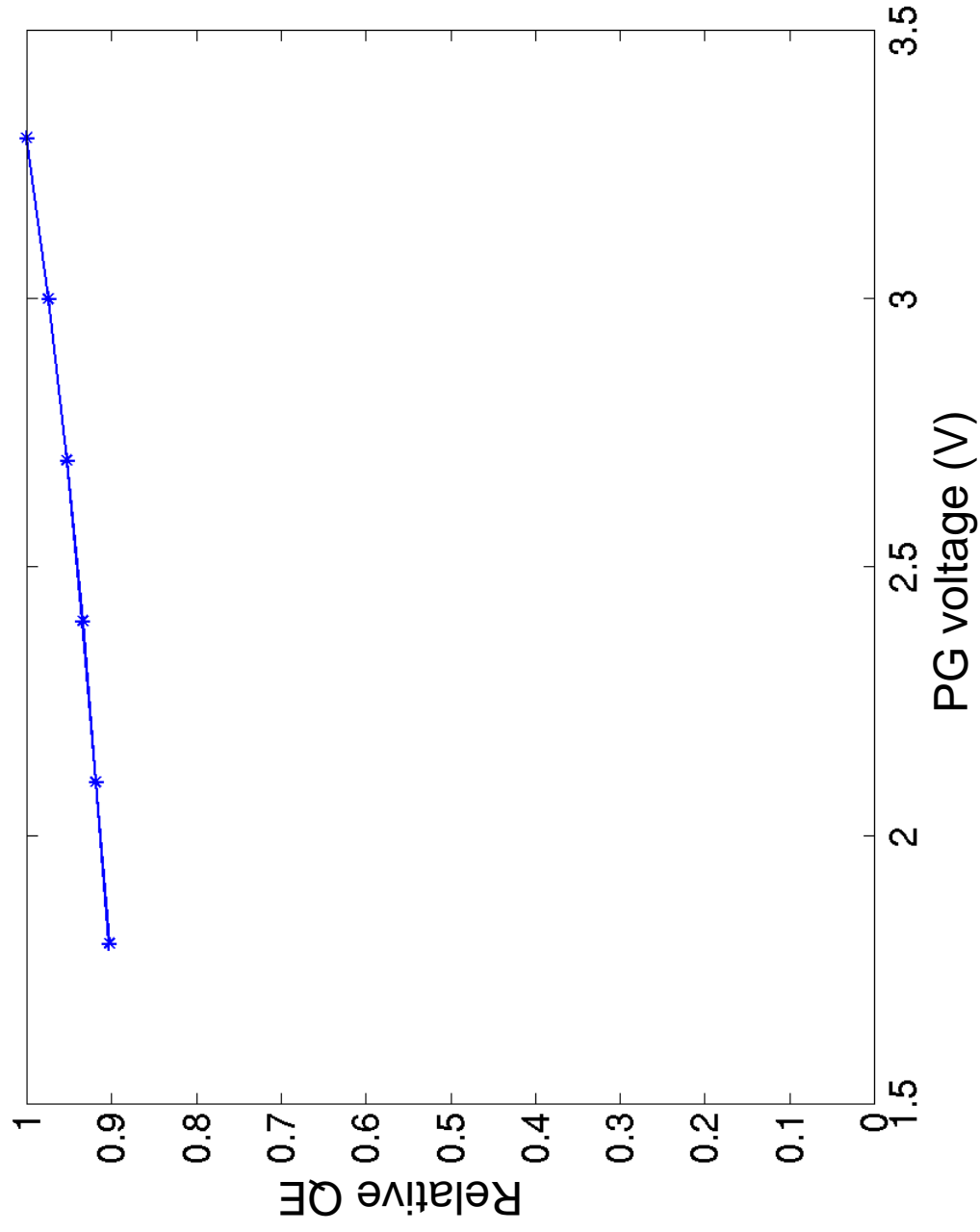
# Dark Current Mechanism

- Super-linear increase cannot be attributed to widening of depletion region
- Direct tunneling ?
  - Doping density not high enough
- Poole-Frenkel Effect
  - Carrier emission rate of traps increases significantly in high electric field

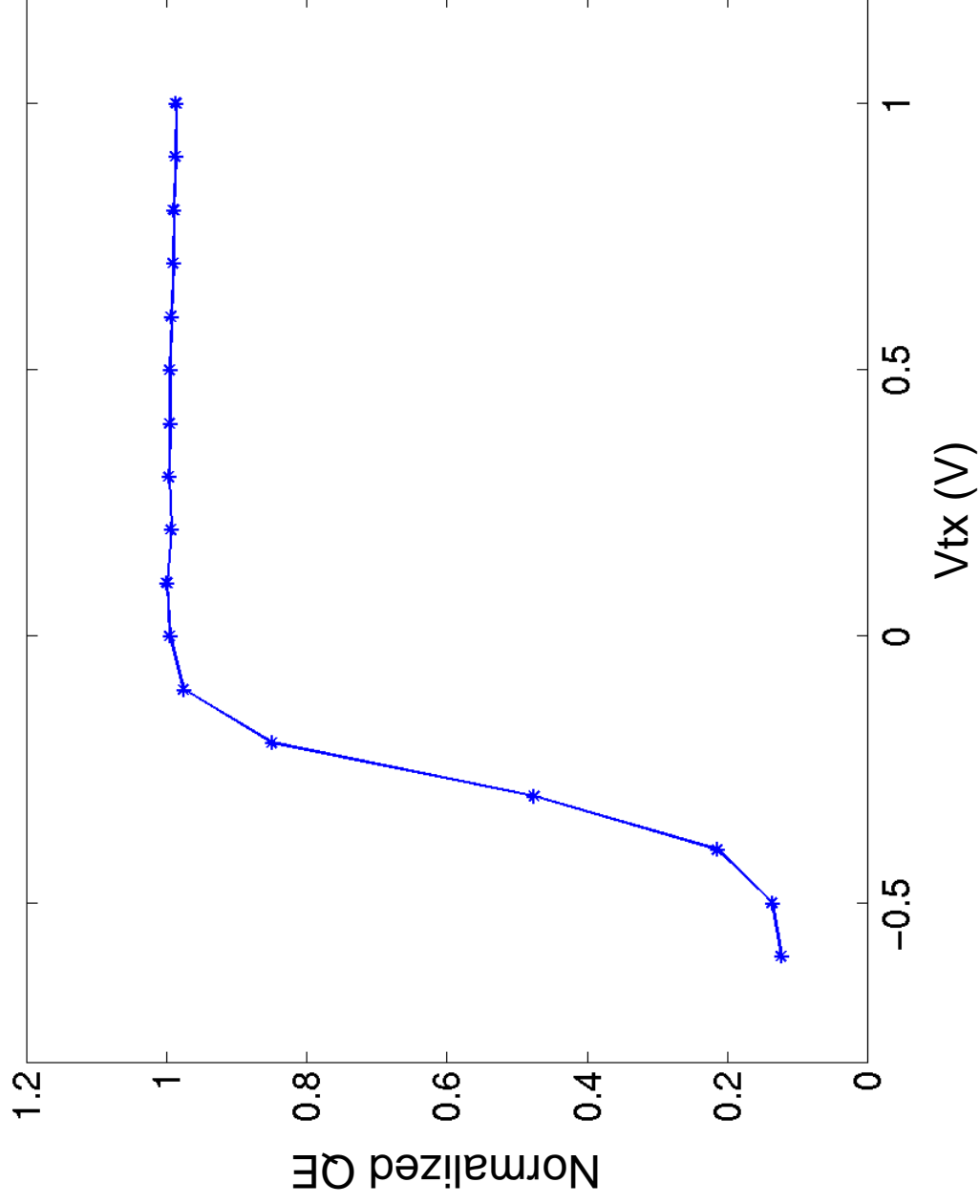
# PG Dark Current



# PG Normalized QE



# Transfer Gate Off-current





# Photogate operation

- **Switching PG and Tx**
  - Transfer gate can only be turned off by negative voltages
- **Switching PG, Tx fixed bias**
  - Charge injection due to PG switching adversely affects analog CDS
- **Fix both PG and Tx**
  - 4T photodiode APS mode
- **Similar QE achieved for all modes**

# Conclusion

Measured key imaging parameters for standard 0.18  $\mu\text{m}$  process

- **Dark current very high**
  - Dark current decreases super-linearly in bias voltage
    - Lower photodiode reverse bias desired
- **Quantum efficiency low**
  - High p-well doping density
- **Photogate operation**
  - Transfer gate cannot be turned off
  - Analog CDS not effective