2-micron, High QE Photodetector for Quantum Metrology

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LIGO-T1900380-v1

Overview

- **Brief Introduction of Gravitational Waves**
- **Role of Photodiodes**
- **Properties of Photodiode**
- **Photodiode Characterization Experiment**
  - Setup
  - Low Noise Electronics
    - Their noise budget
  - Photodiodes under test
    - Comparison between properties
- **Future Work**

Gravitational Wave Detector

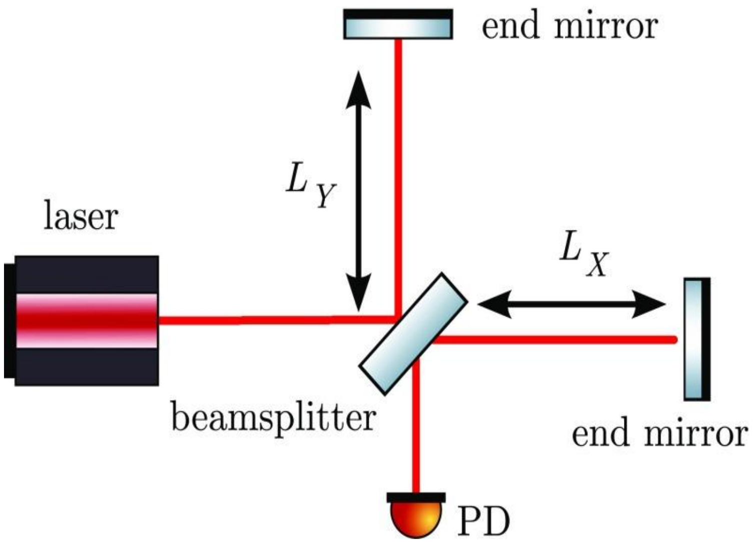
- Gravitational waves are ripples produced in space time fabric.

- Advanced LIGO has a strain sensitivity of 10^{-24} ~10^{-23} /√Hz

- **Voyager** will have a sensitivity of 4-5 factor above aLIGO.
  - some significant design changes,
    - **200kg, silicon test mass**
    - Mirrors coated with **amorphous silicon base**,
    - Lowering test mass temperature to **123K**,
    - Laser of **wavelength 2um**.

The role of Photodiode in GW detector

- The photodiode(PD) is used at the **dark port of detector**.
- It is also used to detect scattering.



- **Requirements for Voyager**
  - Need of PD **sensitive to 2um**.
  - Quantum efficiency**(QE) >98%**.

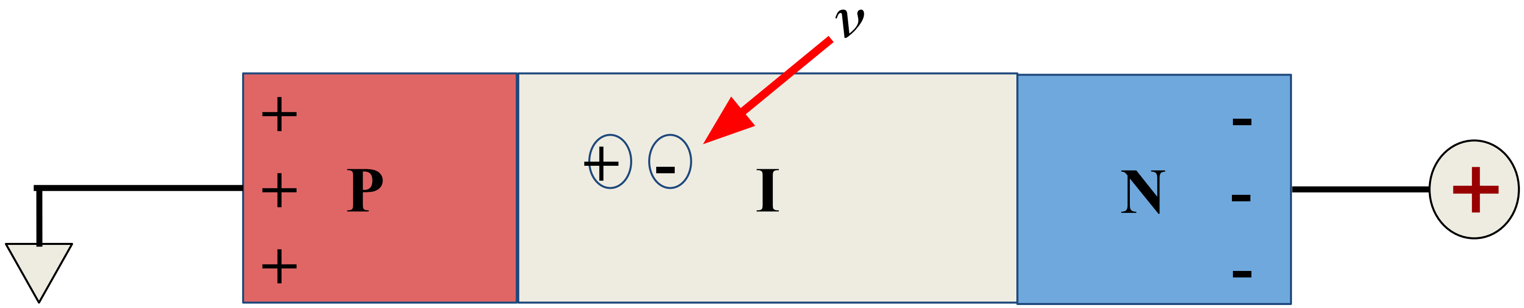
- **Status of Current Photodiodes**
  - Current InGaAs photodiodes **aren't sensitive to 2um** of wavelength.

Promising Photodiode Materials

We are planning to use the photodiode of following materials in Voyager:

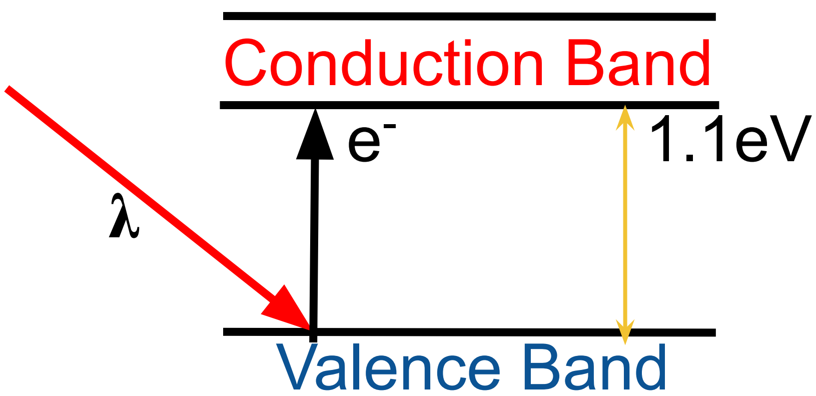
- **Extended Indium Gallium Arsenide** (ex-InGaAs)
- **Indium Arsenide Antimonide** (InAsSb)
- **Mercury Cadmium Telluride** (MCT or HgCdTe)

Photodiode Mechanism

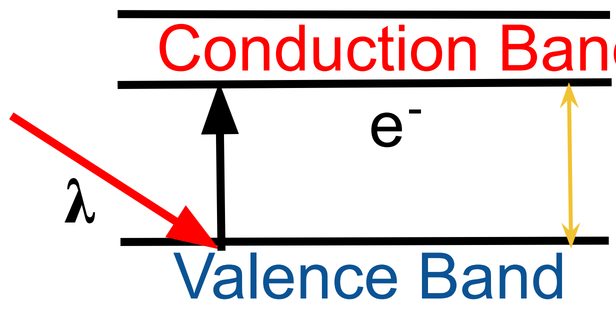


E_λ = 0.62eV @2um

(InGaAs: 0.75eV)
ex-InGaAs : 0.54eV
HgCdTe: 0.4 eV
InAsSb : 0.1 eV



Si Band Gap



New Materials' Band Gap

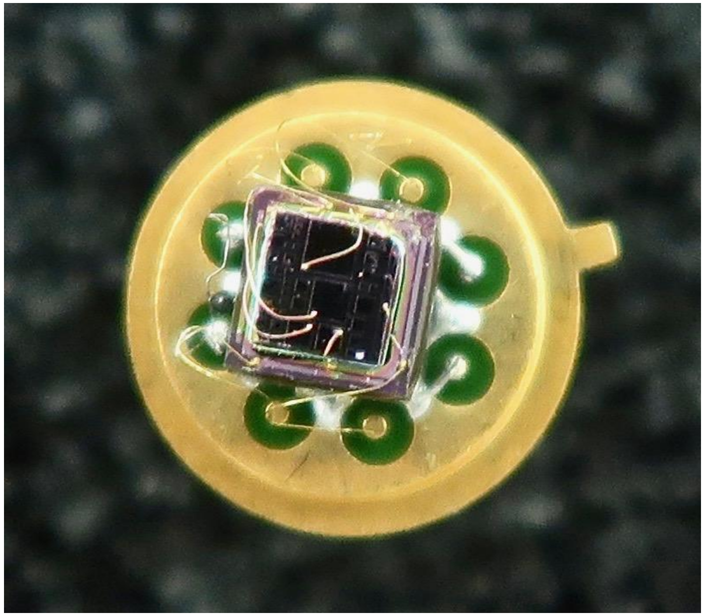
Properties of Photodiodes

- **Quantum Efficiency**
  - Fraction of incident photons that contribute to the photocurrent.
  - Linearity
    - Output Current as a function of incident light.

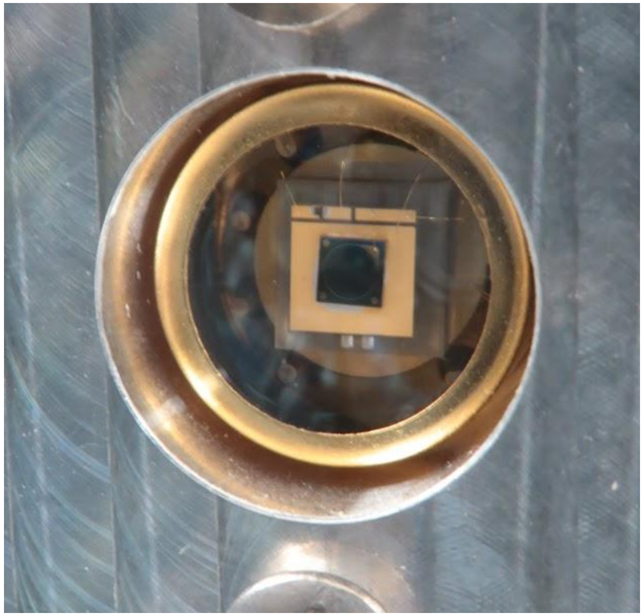
- **Dark Current**
  - Even in the absence of any optical power on the photodiode it can produce a small amount of signal current
  - Produced due to lattice mismatch

- **Dark Noise**
  - Photodiode dark noise arises due to dark current.

Photodiodes tested

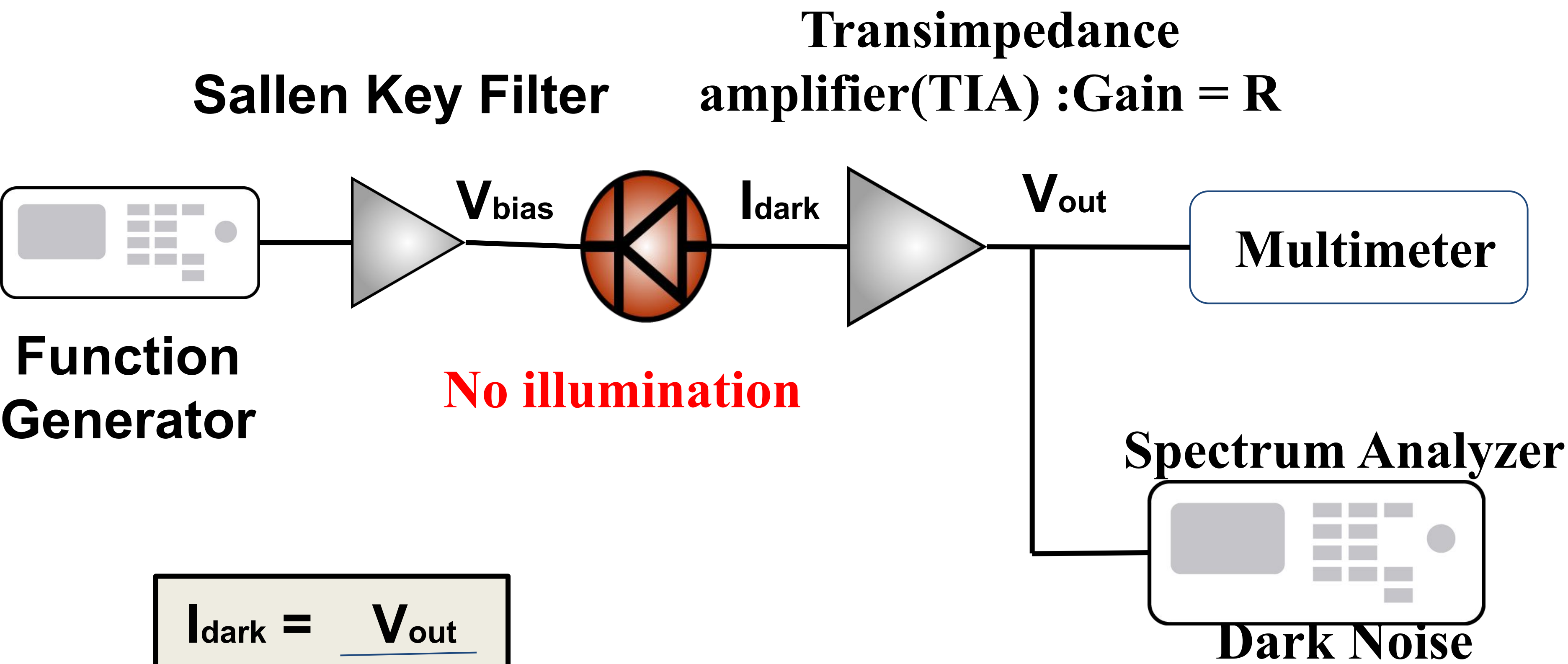


InAsSb (JPL NASA)
(500 um)^2
(750 um)^2
(1000 um)^2



Extended InGaAs
(LaserComponents)
IG22X2000T9
2 mm in dia.

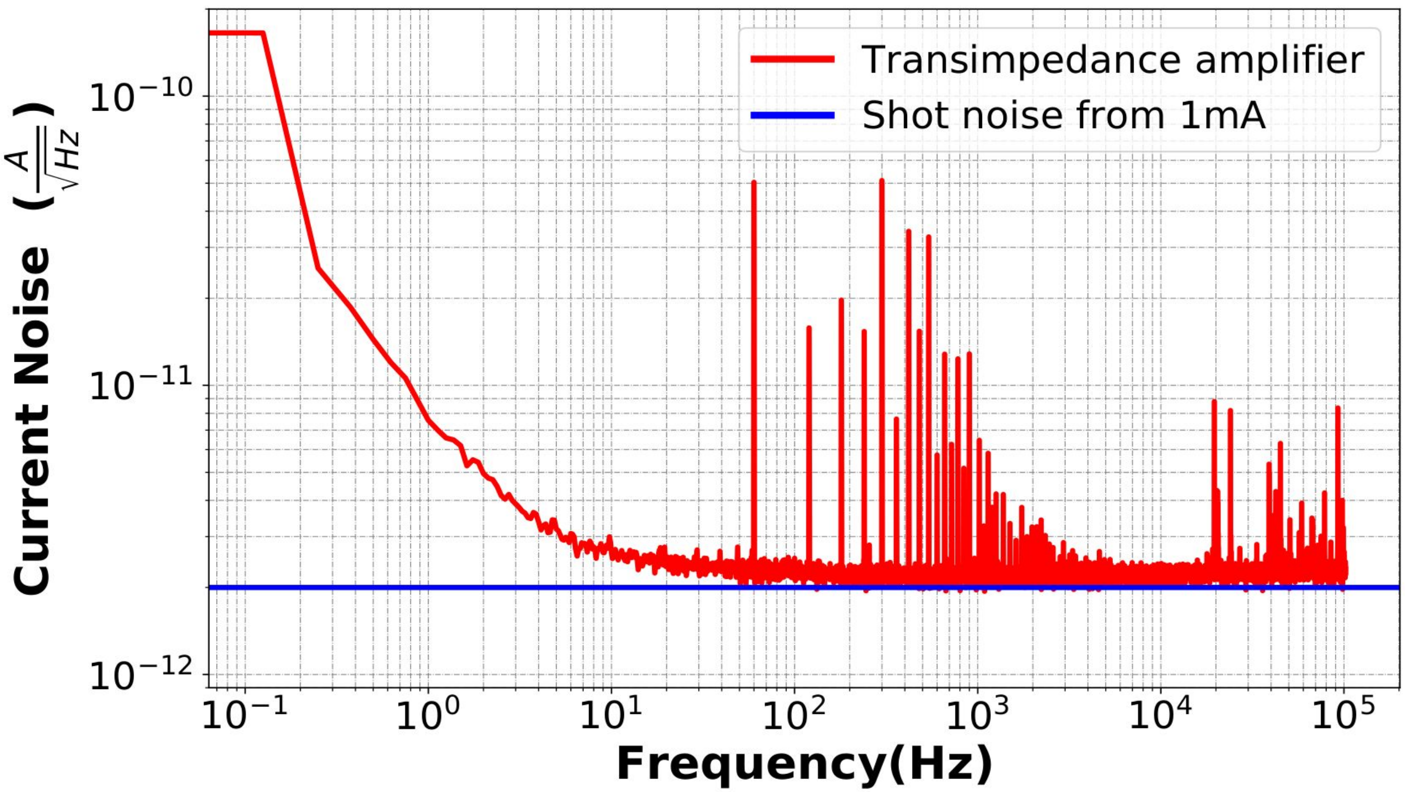
Dark Current and Dark Noise



$$I_{dark} = \frac{V_{out}}{R}$$

Low Noise Transimpedance Amplifier

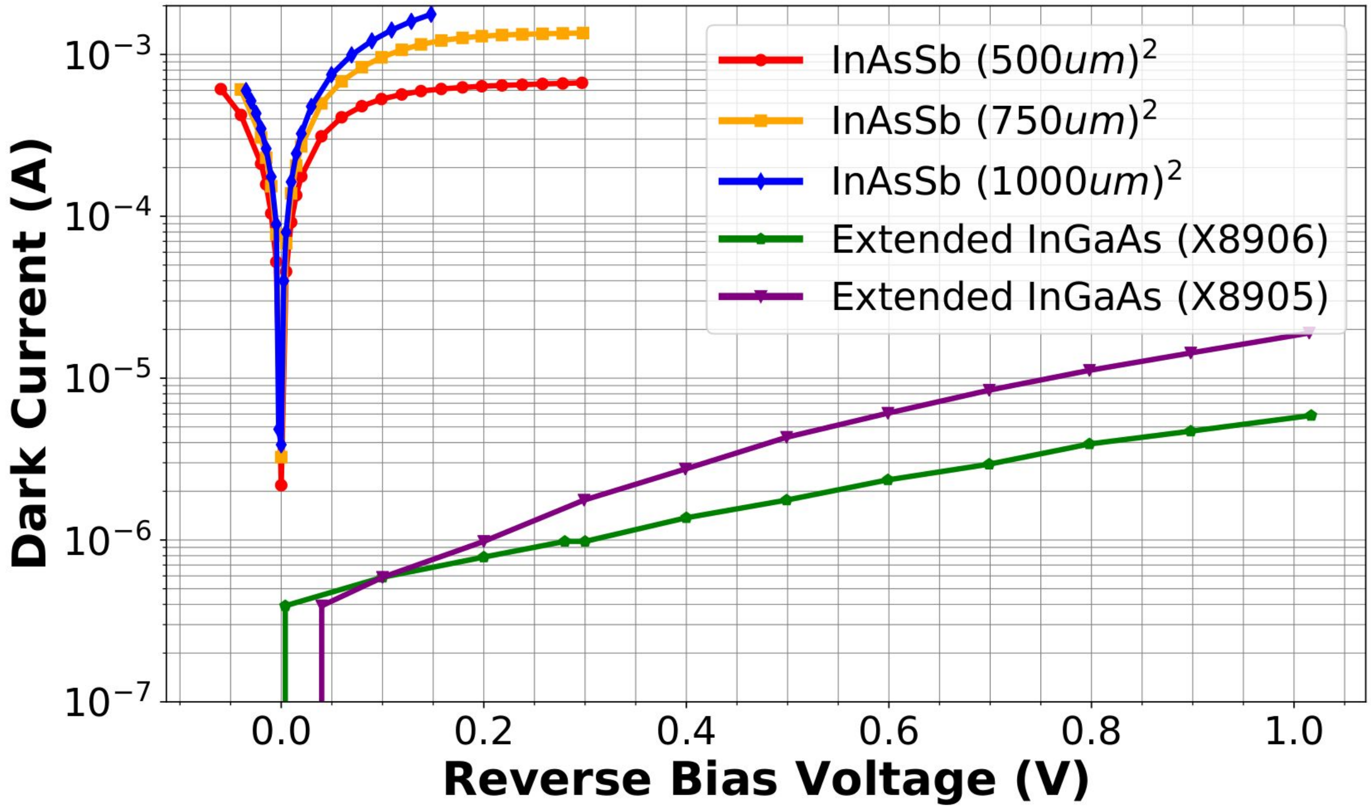
Transimpedance gain: 5.1kOhm / Opamp: OPA140



Achieved: current noise level of ~2pA/rtHz

(equivalent to the shotnoise current by 1mA DC)

Dark Current Measurement

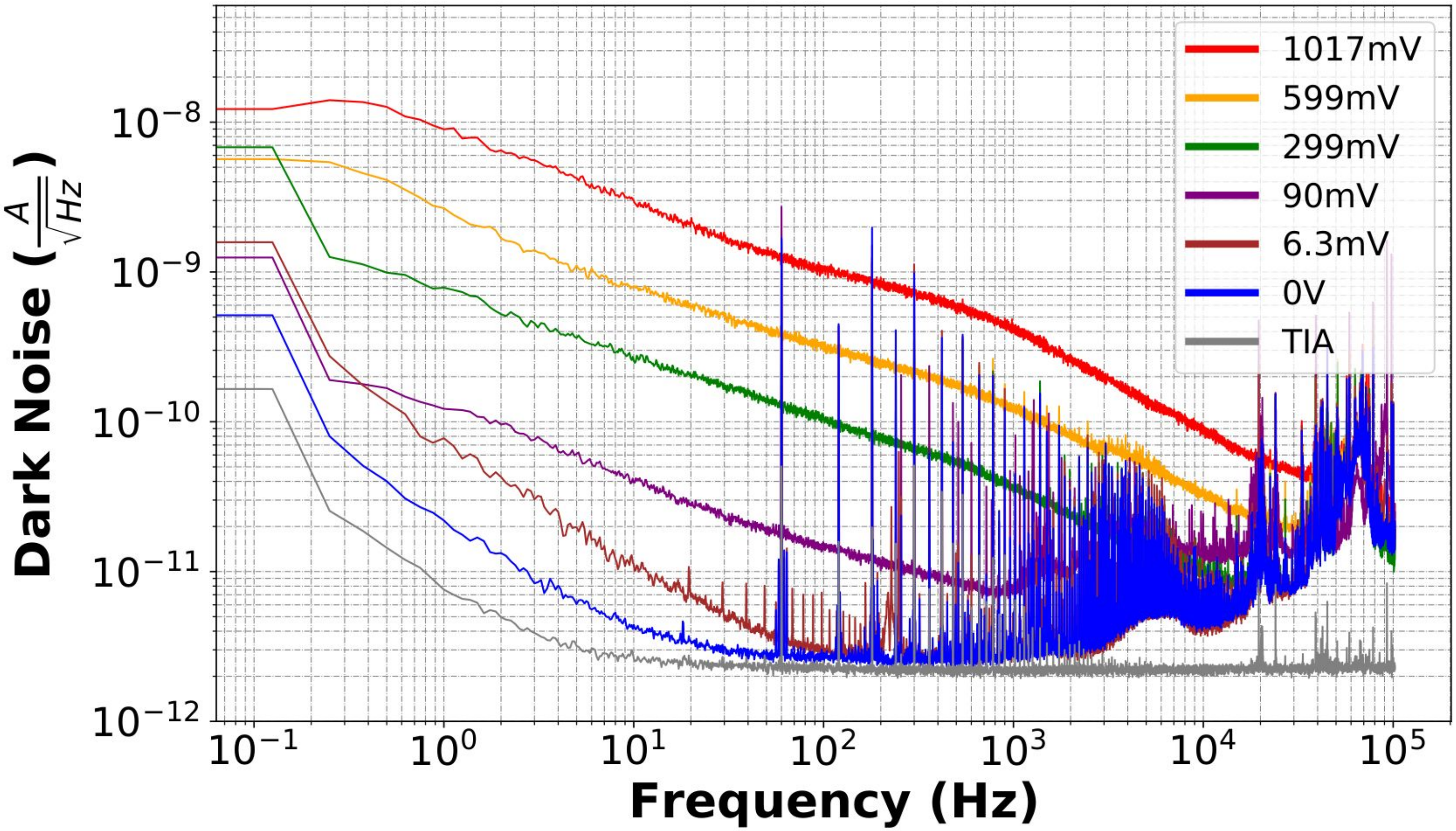


Note: Room Temp measurements

In general, I_{dark}(InAsSb) >> I_{dark}(ex-InGaAs)

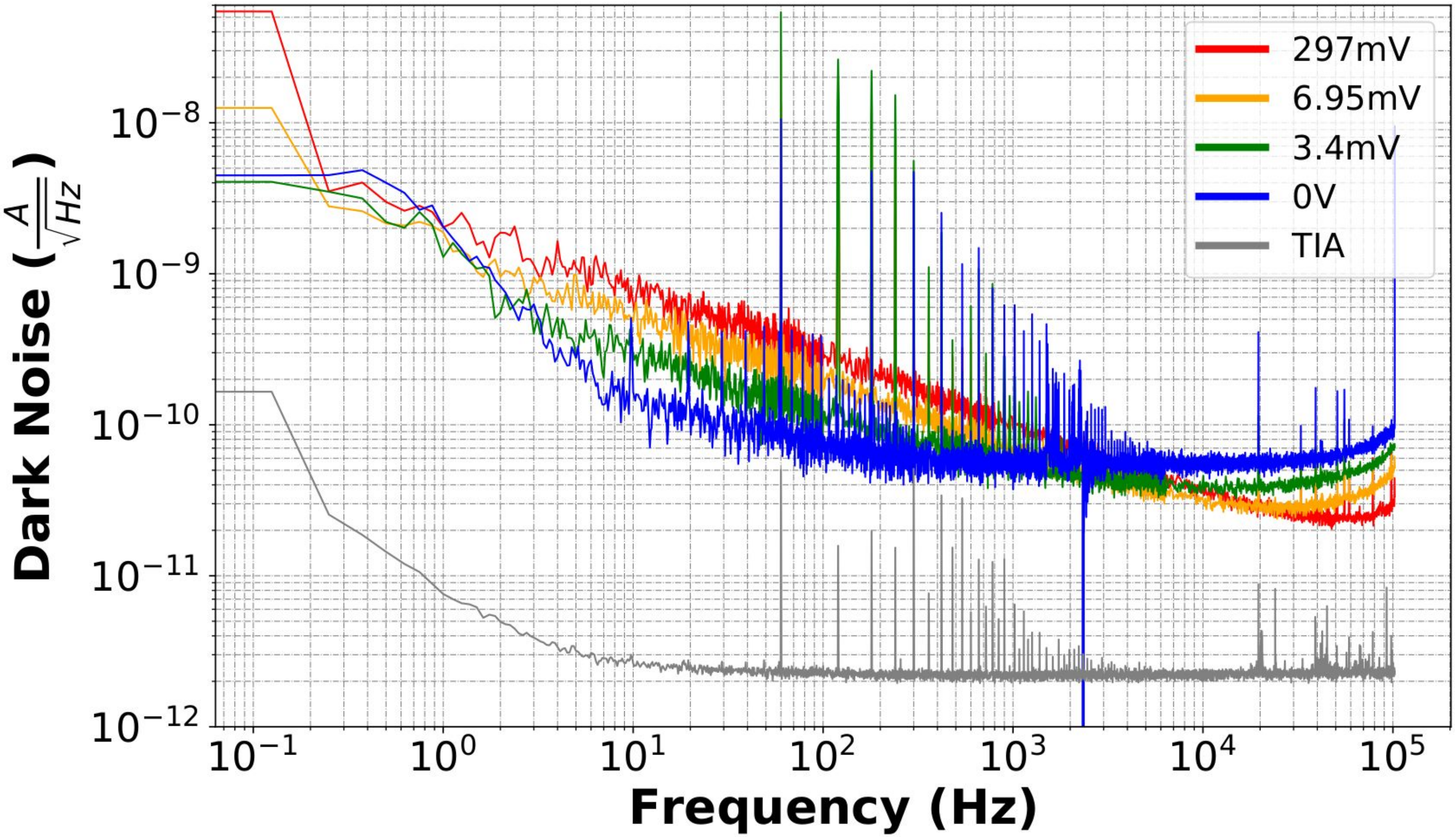
ex-InGaAs(X8906) showed less dark noise

Dark Noise of ex-InGaAs



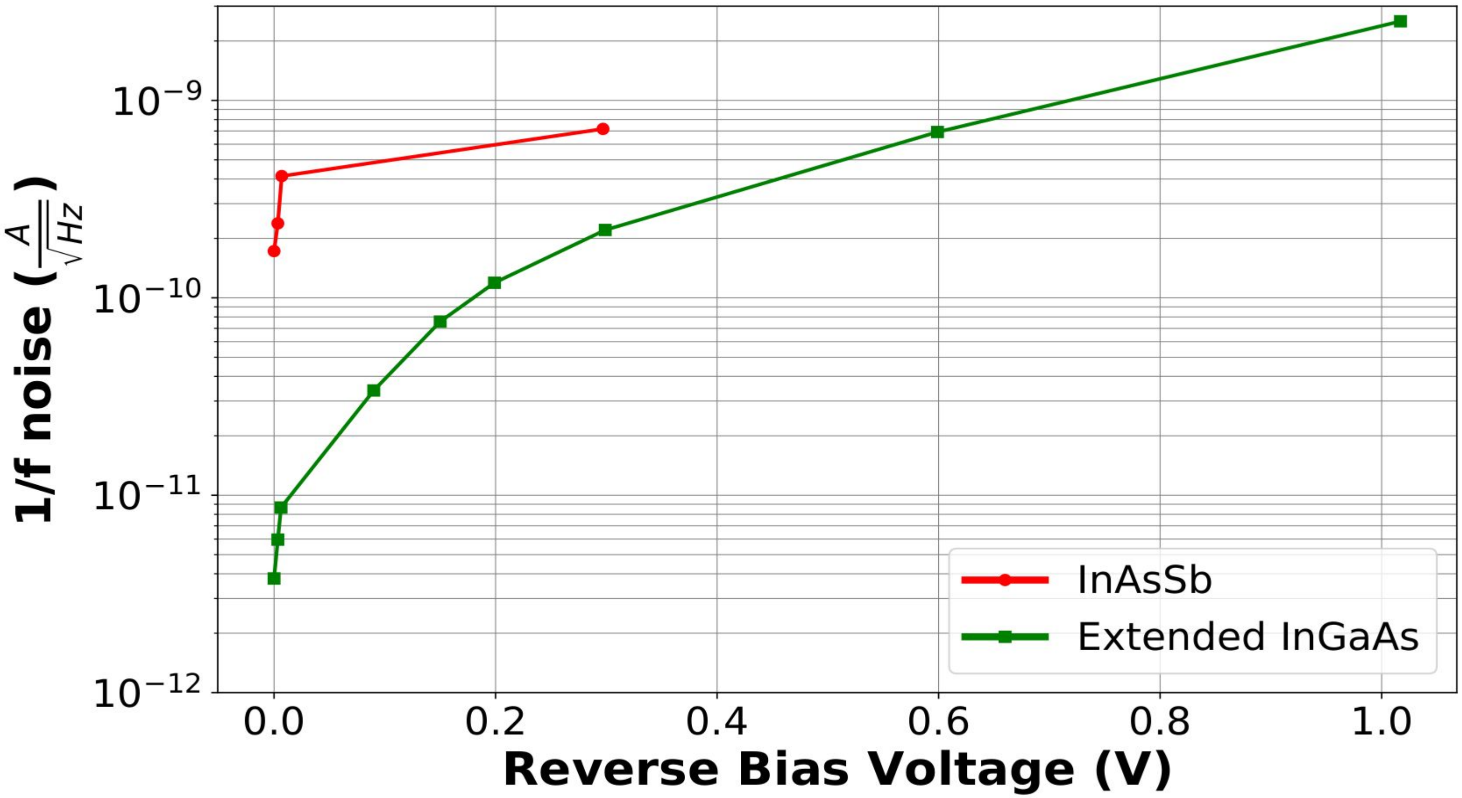
The dark noise decreases with decrease in bias voltage.

Dark Noise of InAsSb



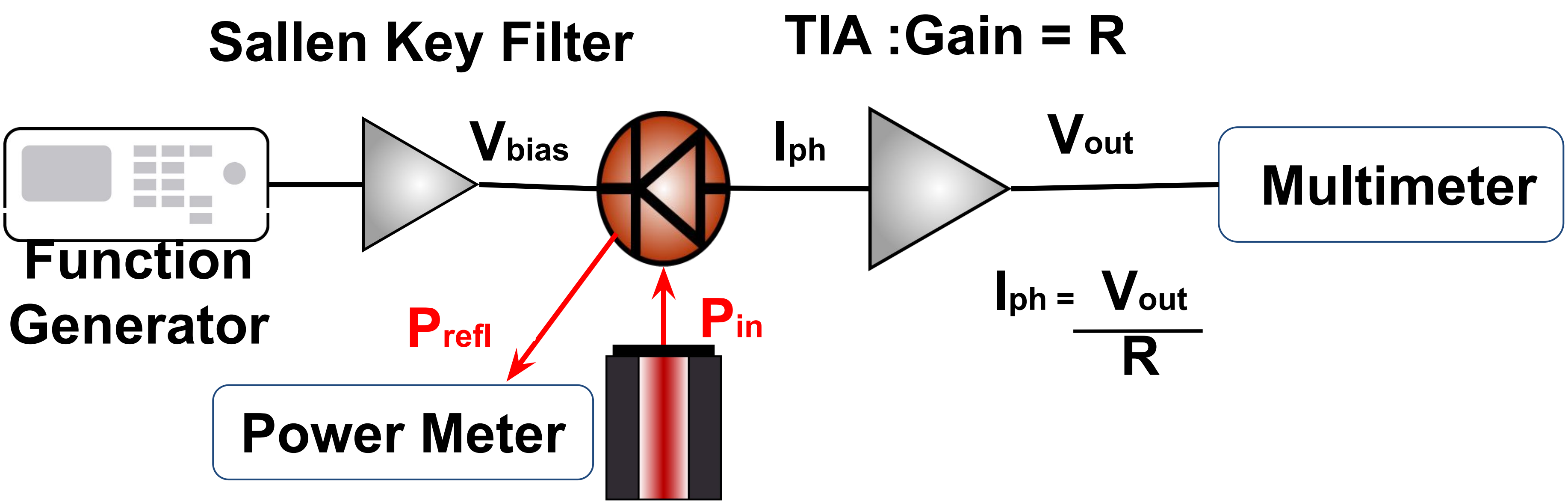
Similar behavior / In general, the noise was larger than ex-InGaAs

1/f noise comparison (at 10Hz)



The ex-InGaAs has lower 1/f noise at room temperature.

Quantum Efficiency (Q.E.)

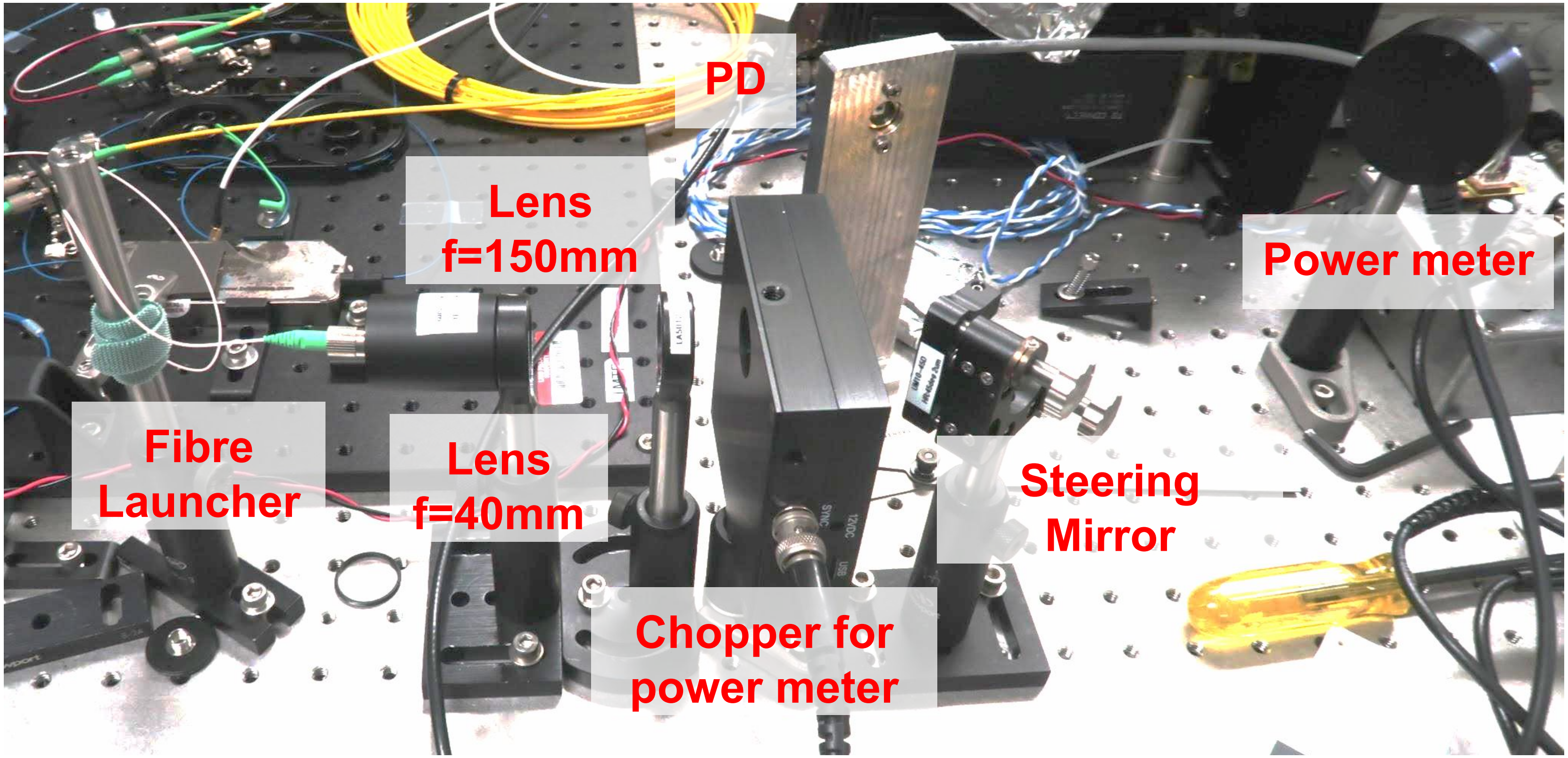


$$\text{External Q.E} = \frac{(I_{ph} / e)}{(P_{in} / h\nu)}$$

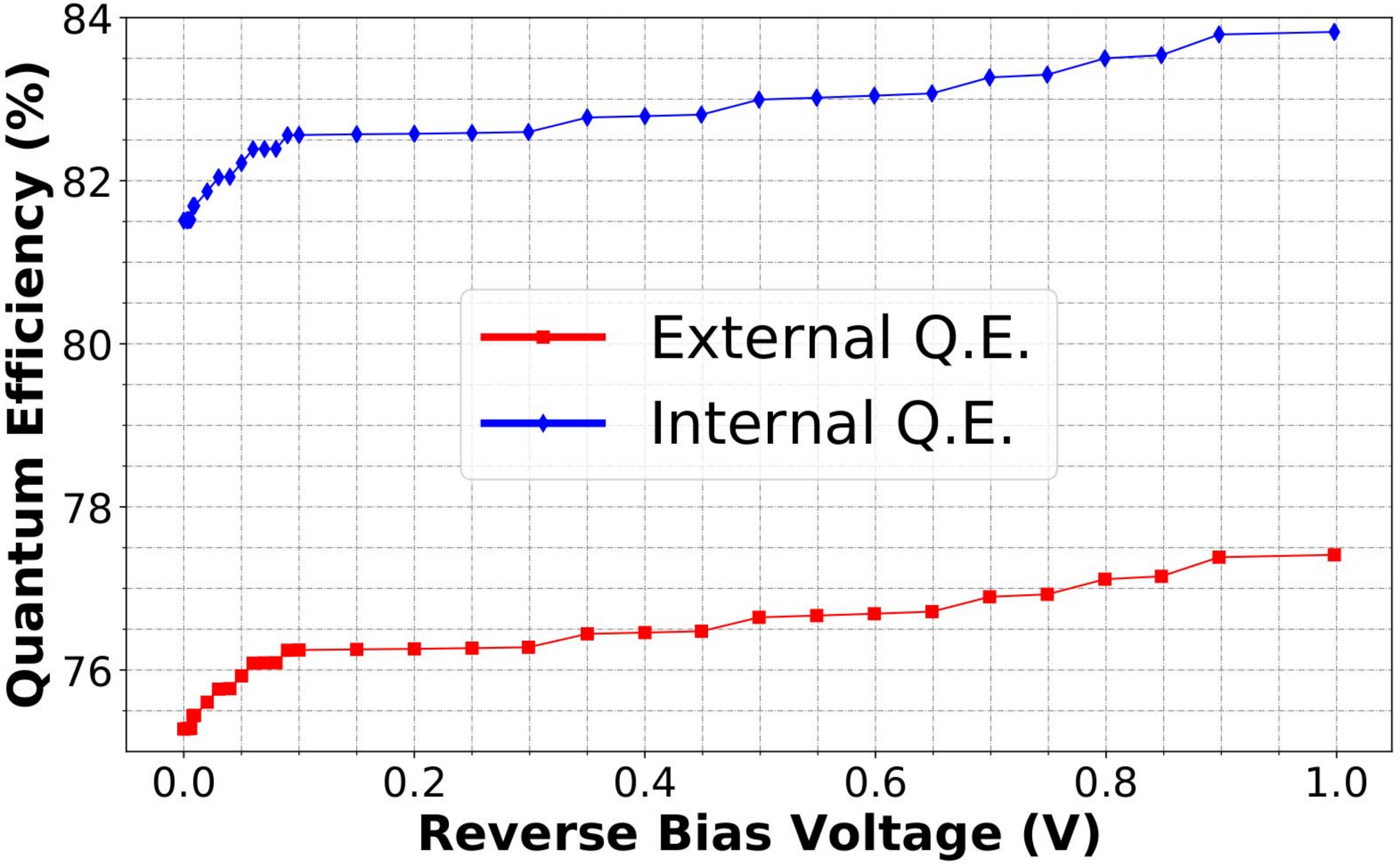
$$\text{Reflectivity} = \frac{P_{refl}}{P_{in}}$$

$$\text{Internal Q.E} = \frac{\text{External Q.E}}{1 - \text{Reflectivity}}$$

Q.E Measurement Setup



Q.E.: ex-InGaAs (X8906)



External Q.E.: 77.4% / Internal Q.E.: 83.8% at Vbias = 1V (max)

Summary

- **Work Done**
  - Dark current and dark noise measurements at room temp
  - Quantum Efficiency of ex-InGaAs PDs.

- **Future Work**
  - Q.E. vs V_{bias}
  - Q.E., dark current/noise vs temperature
  - Test HgCdTe photodiode

Thanks for your time!