Temperature Dependent Responsivity of Quantum Dot Infrared Photodetectors

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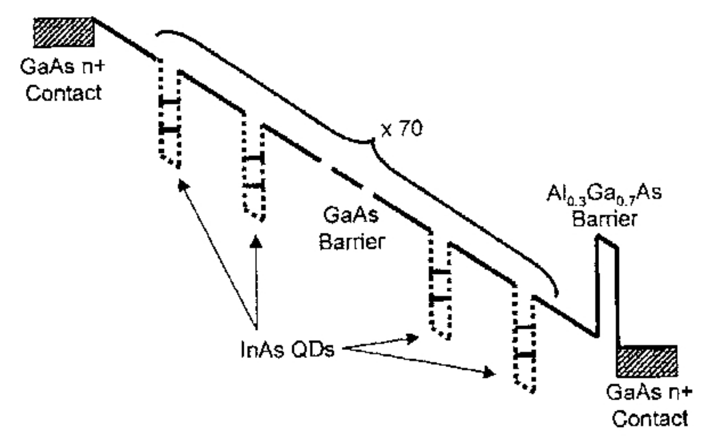
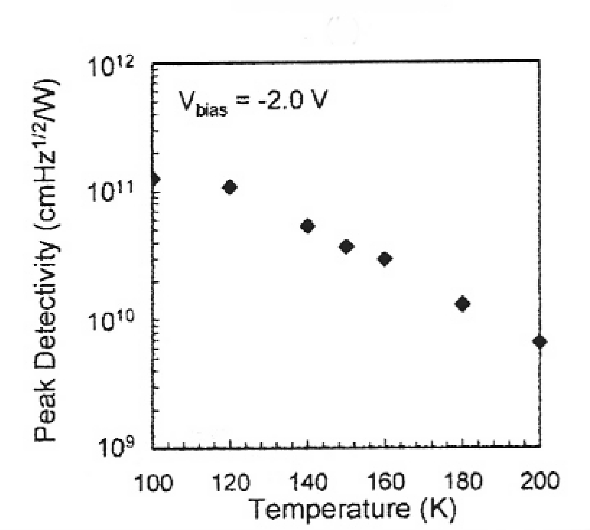
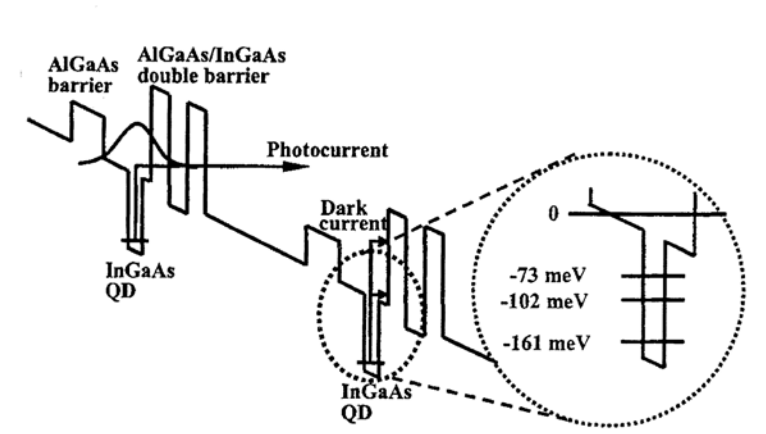
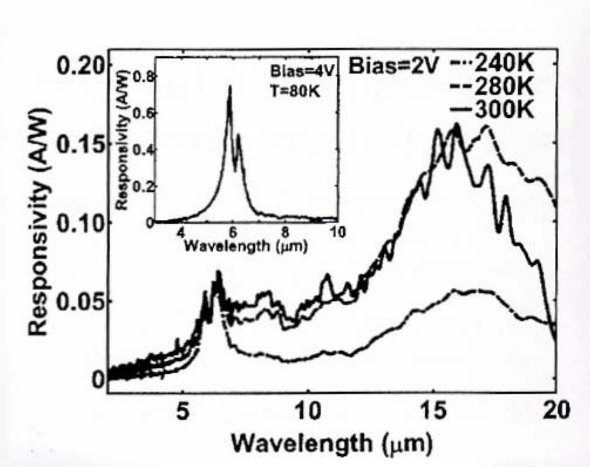
Progress in QDIPs



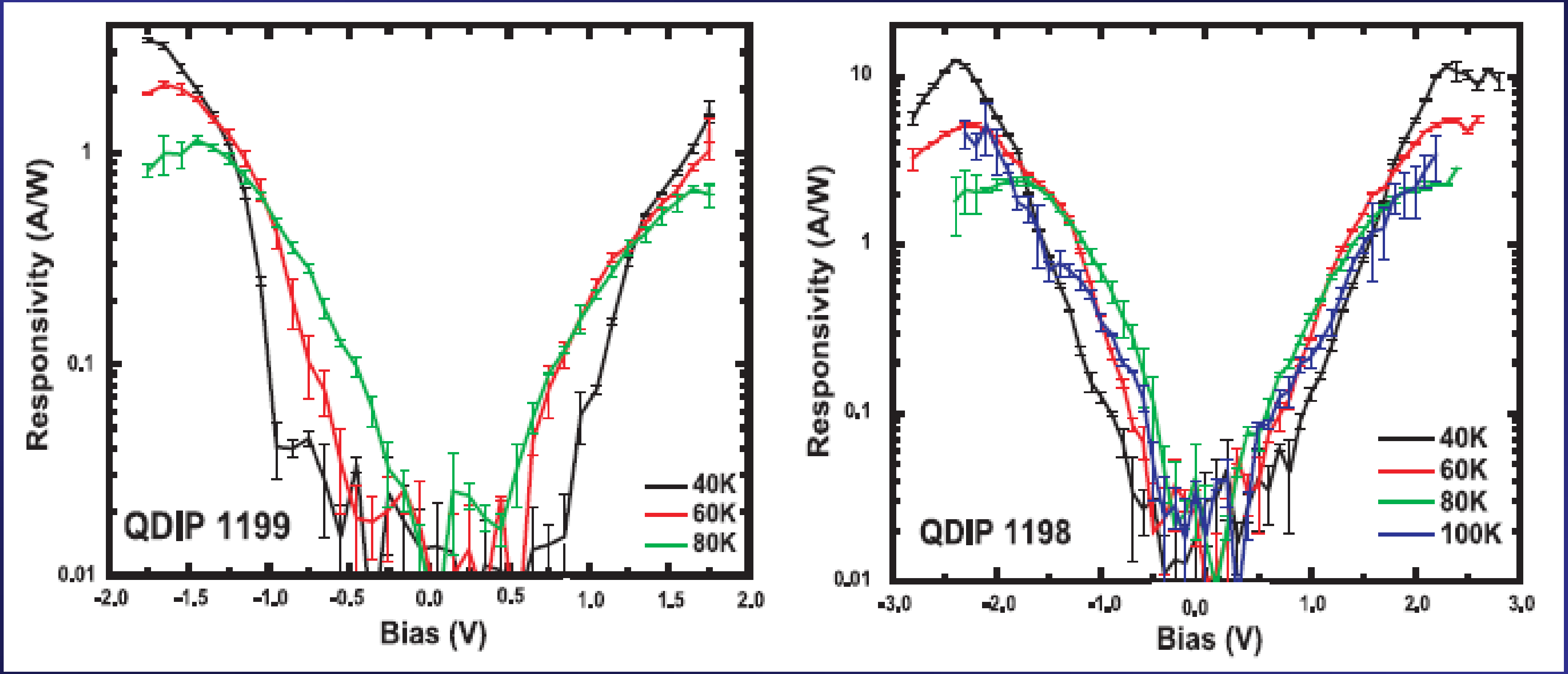






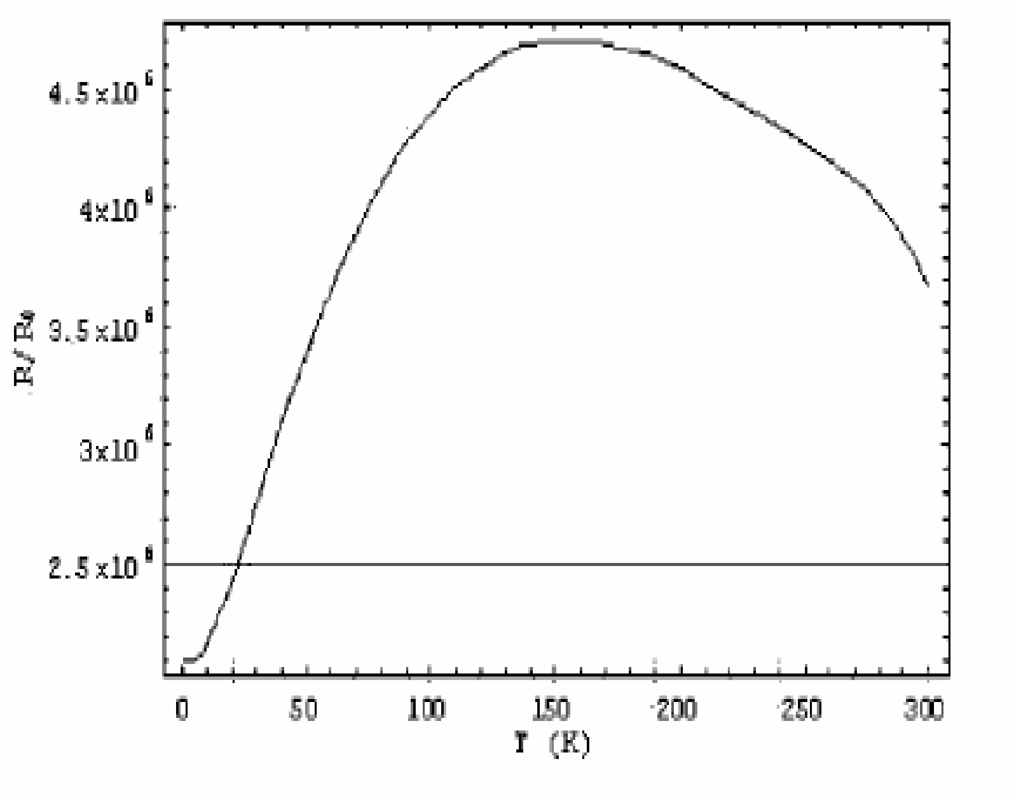
- S. Chakrabarti, et.al. *IEEE Photonics Technol. Lett,16,1361, 2004*
- *P. Bhattacharya, et. al. Appl. Phys. Lett., 86, 191106, 2005*

Responsivity vs. T



D. T. Le et.al. QWIP 2002 workshop

Responsivity vs. T



H. Lim et. al. Phys Rev B 72 (2005)

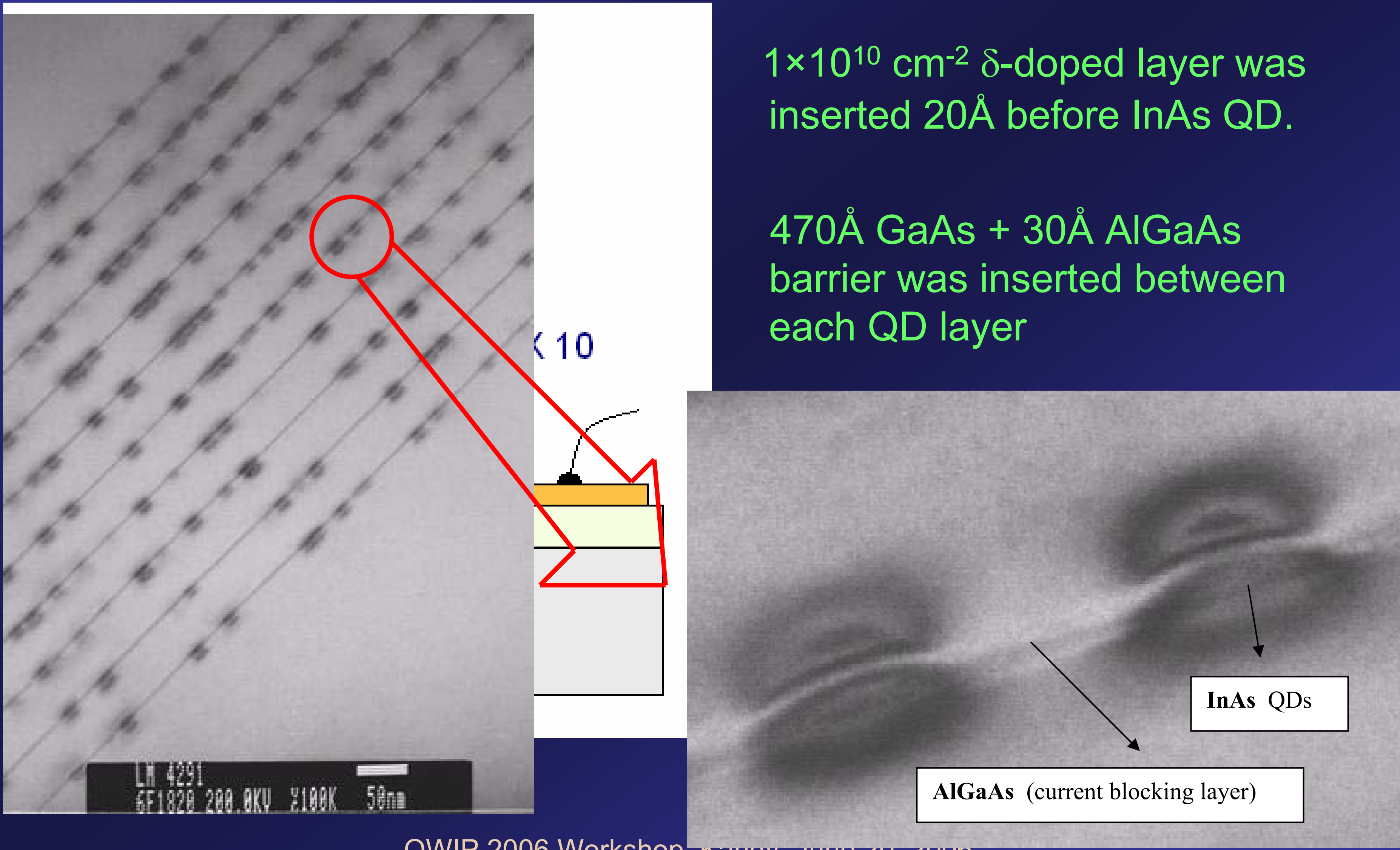
Quantum efficiency analysis:

Escape rate

State occupation probability

Excited carrier life time

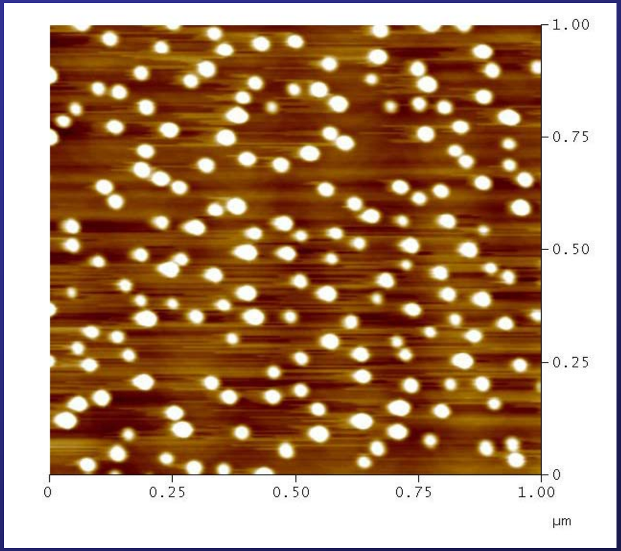
Sample structure



1×10^{10} cm^{-2} δ-doped layer was inserted 20Å before InAs QD.

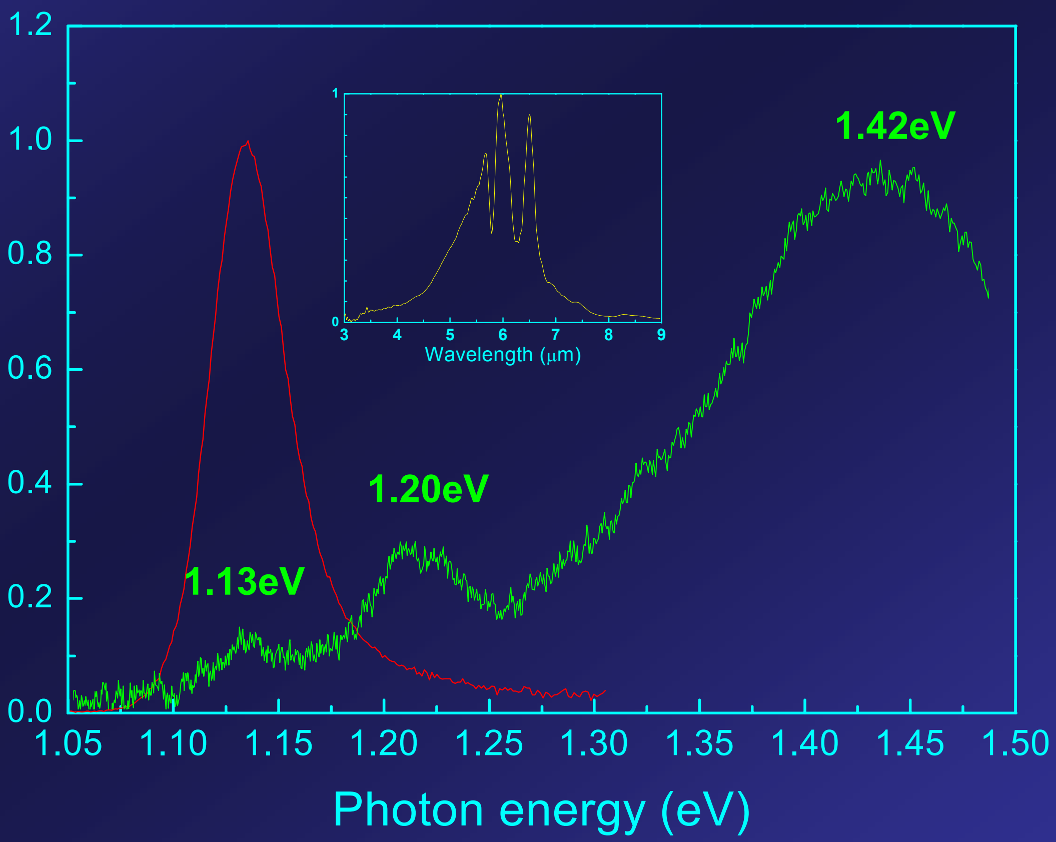
470Å GaAs + 30Å AlGaAs barrier was inserted between each QD layer

Basic characteristics



6(H)×44(Ø) nm

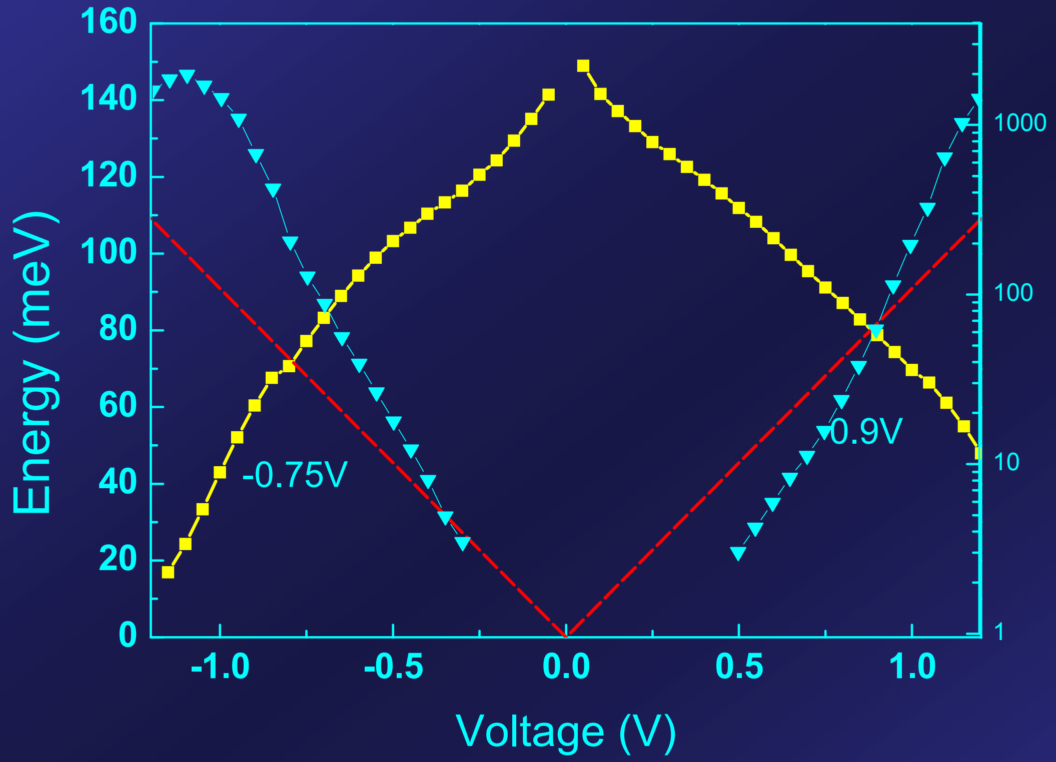
1.7×10^{10} cm^{-2}



B-B transition from ground state to the 1.42eV state.

Excited carrier is about 70meV lower than GaAs barrier.

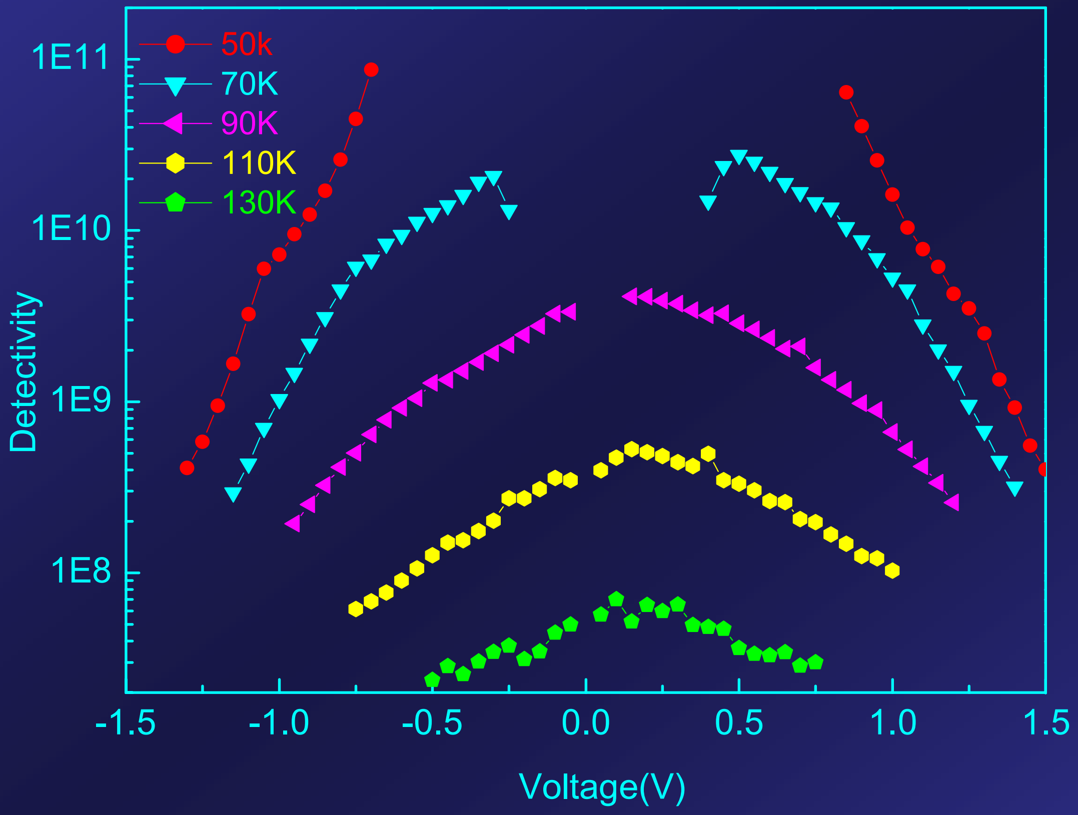
Impact ionization



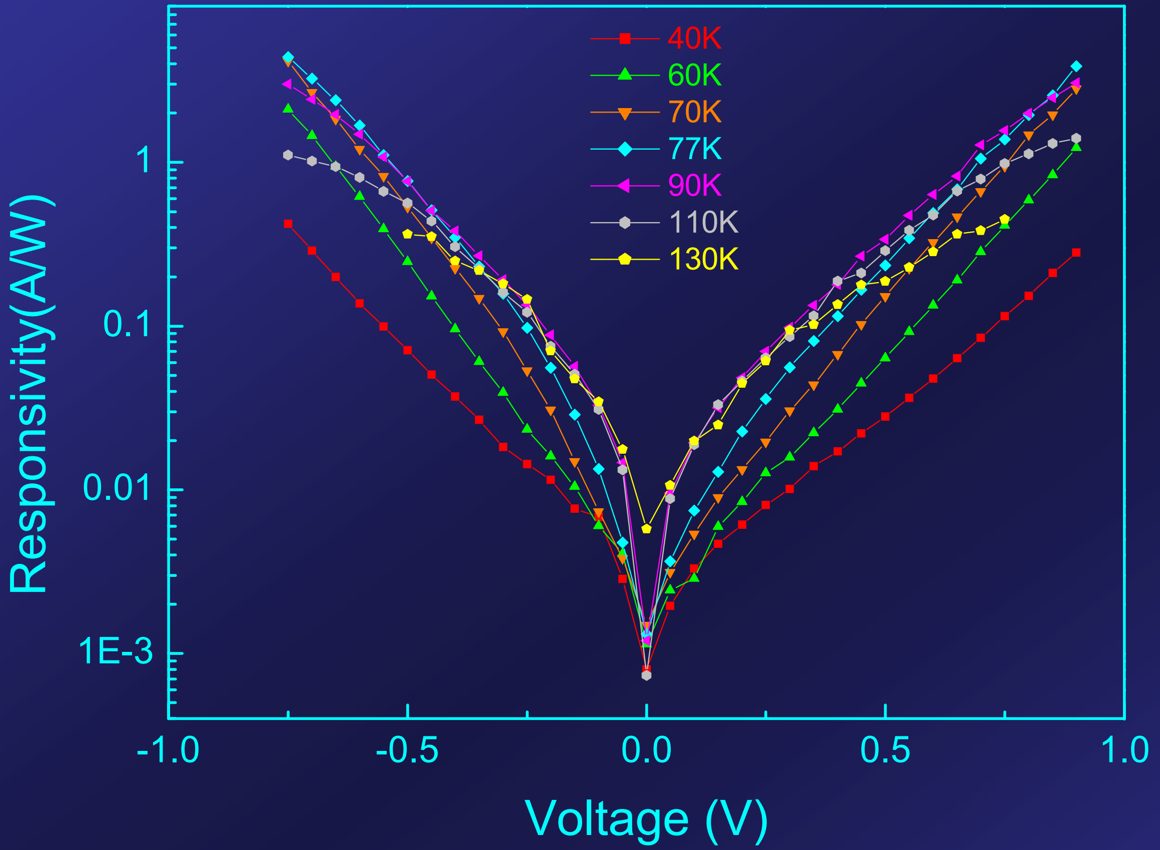
Impact ionization is possible if V > 0.9V or V < -0.75V.

Extra noise will be generated outside this bias region.

Impact ionization



Responsivity vs T



R changes more than 10 times from 40K to 90K.

R saturated and then dropped for T>100K.

R increases as escape probability increases.

Current gain

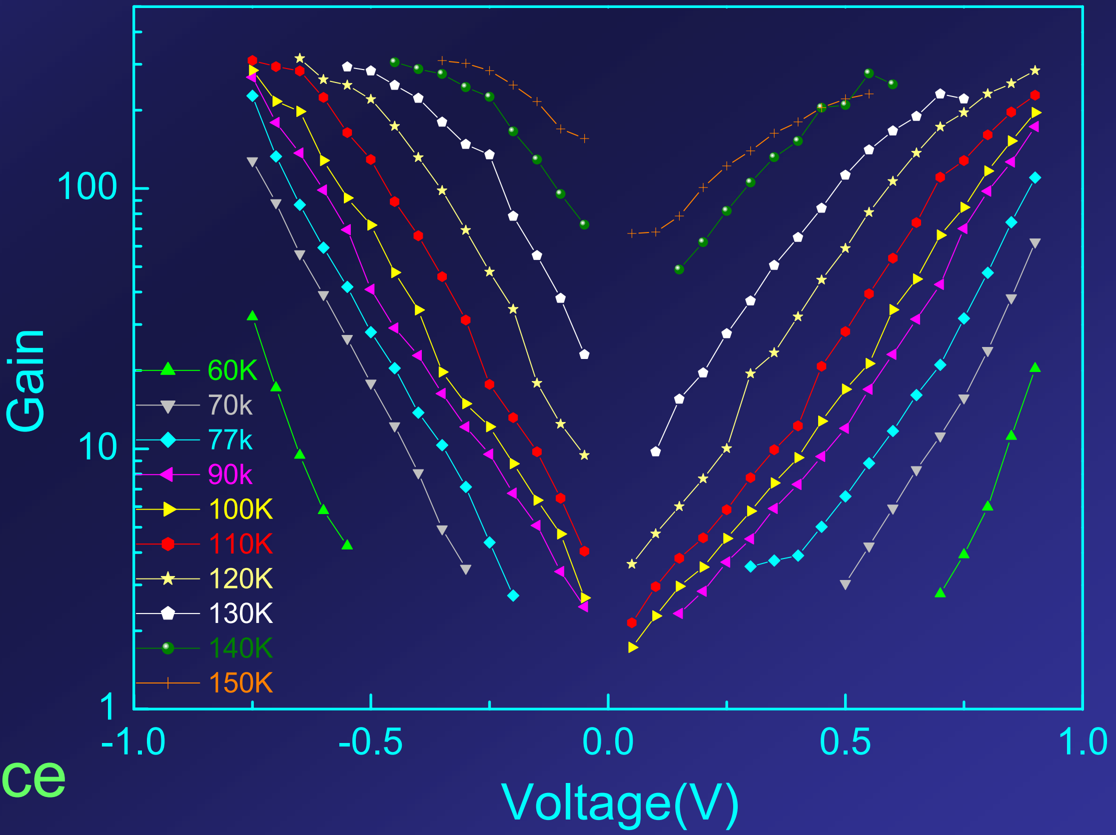
G-R noise dominates

$$g = \frac{I^2_{n,G-R}}{4qI_d}$$

Limitation of the noise measurement:

3×10^{-13} A/Hz$^{1/2}$

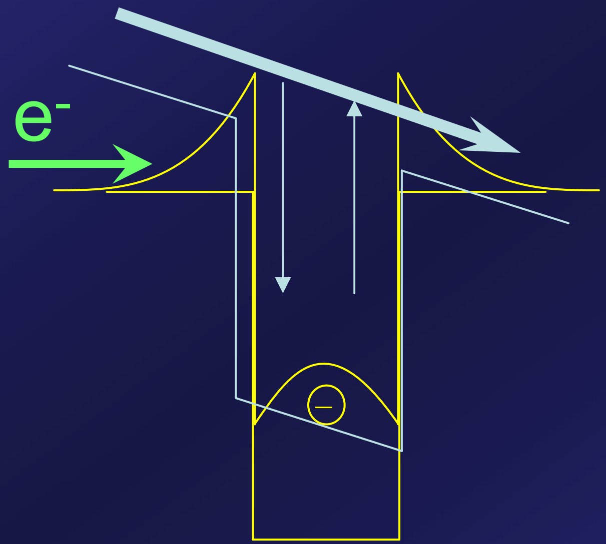
Gain dominates the temperature dependence

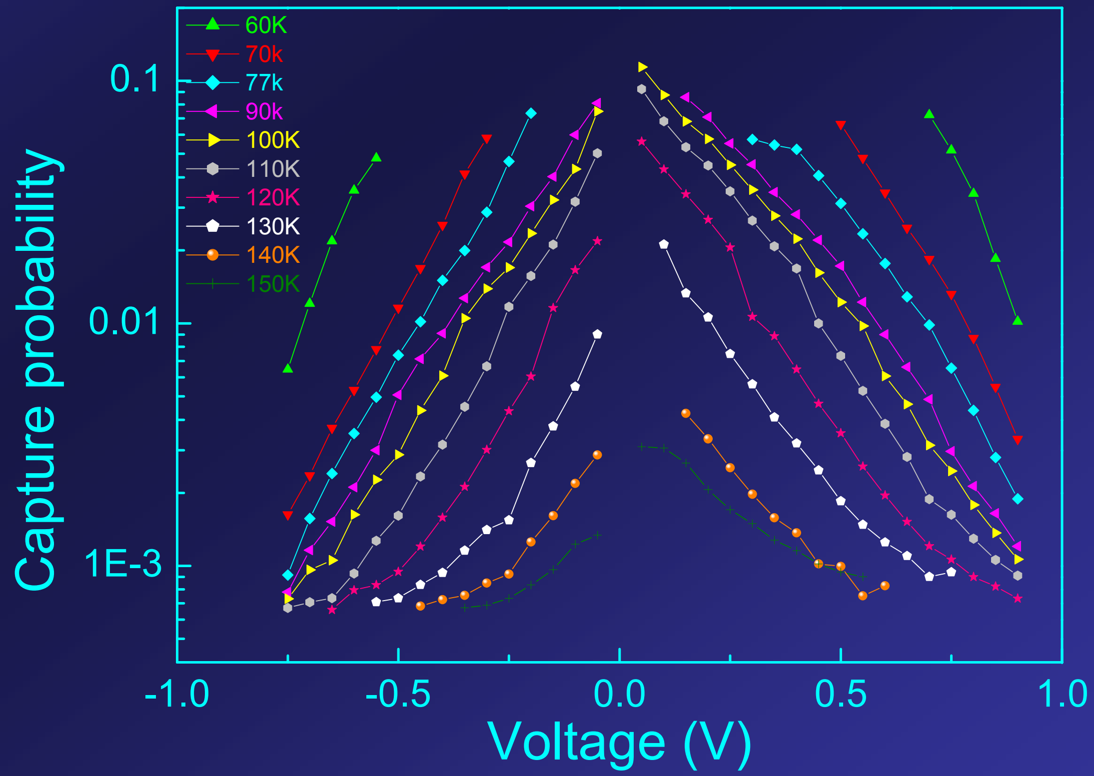


Repulsive barrier in charged QDs

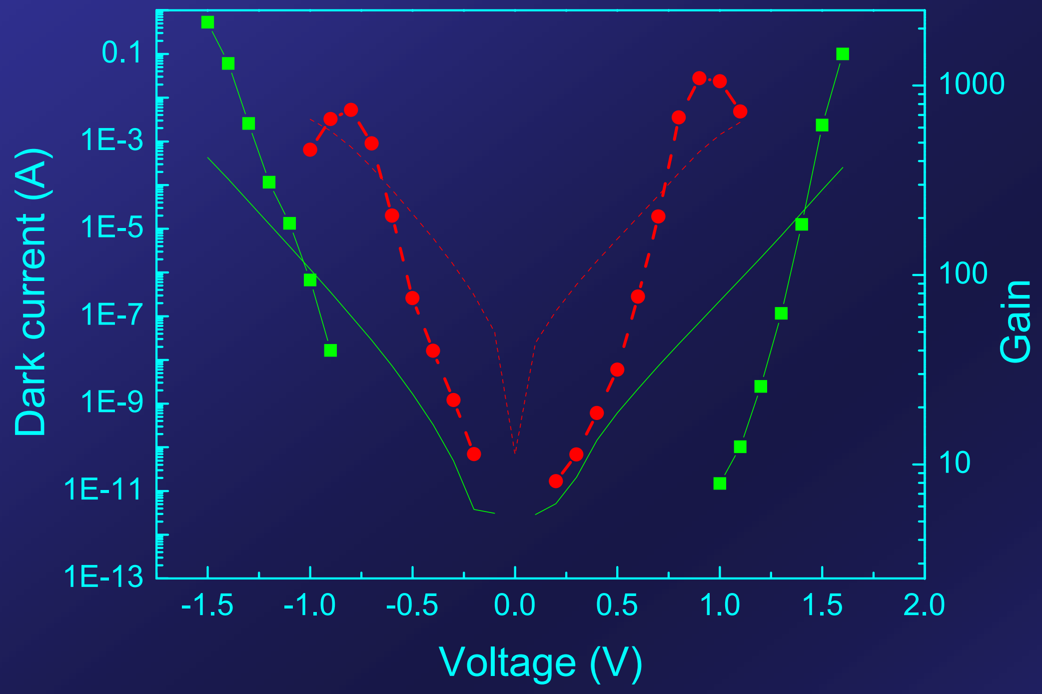
Assuming uniform electric field

$$g = \frac{1}{NFP_c}$$





Two samples with different doping



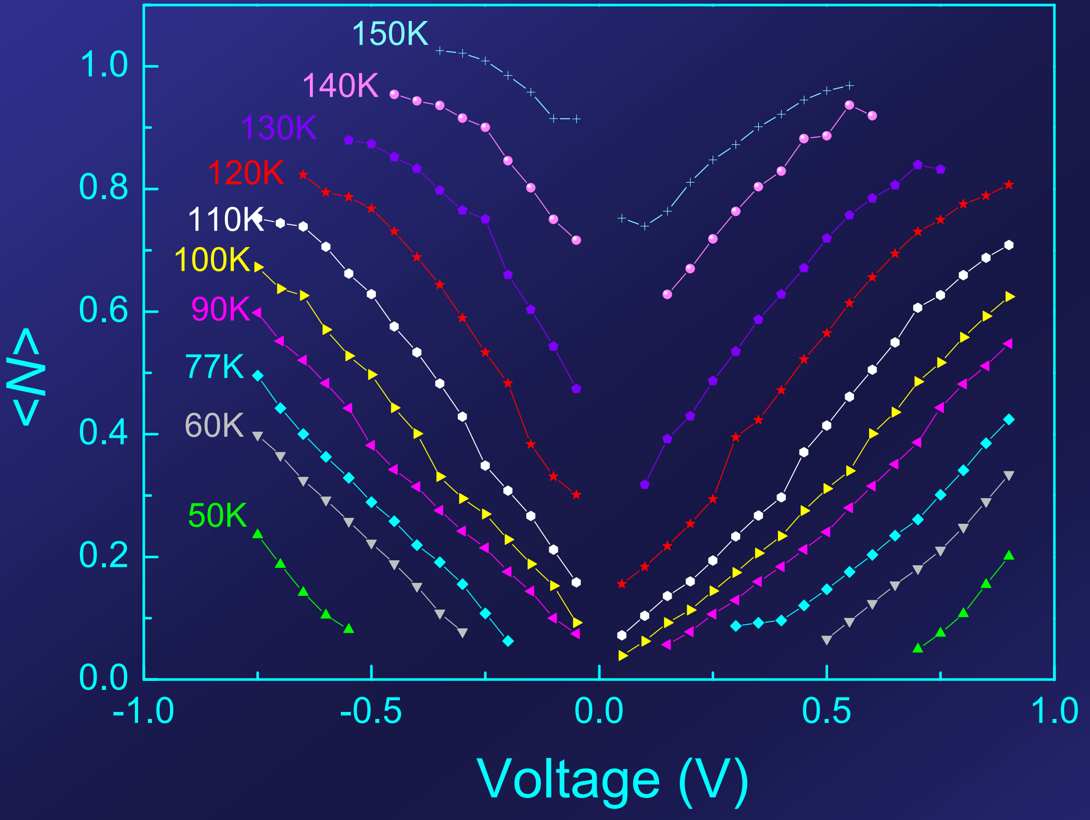
Identical device structure.

Dark current is much higher in the high doping sample.

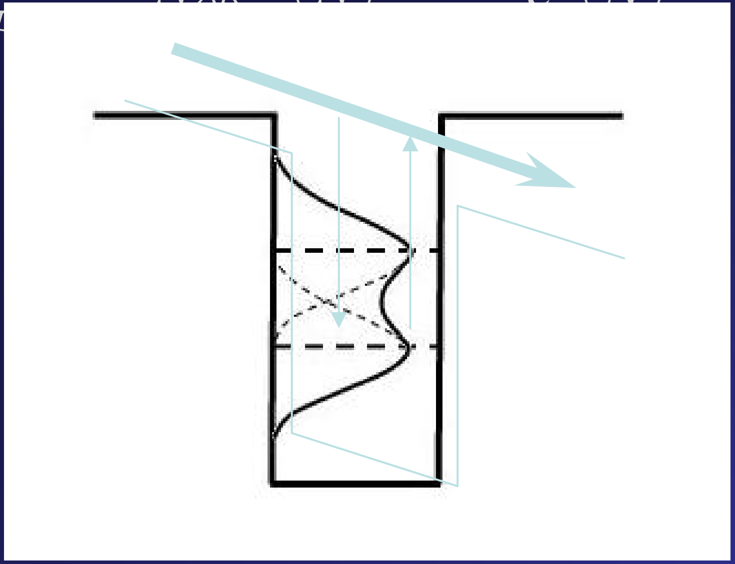
Gain is also much higher due to the carrier filling.

High dark current increase the charge inside the QDs

Average extra carrier number



F $N_{QD}-\langle N\rangle$ $e^2\langle N\rangle$



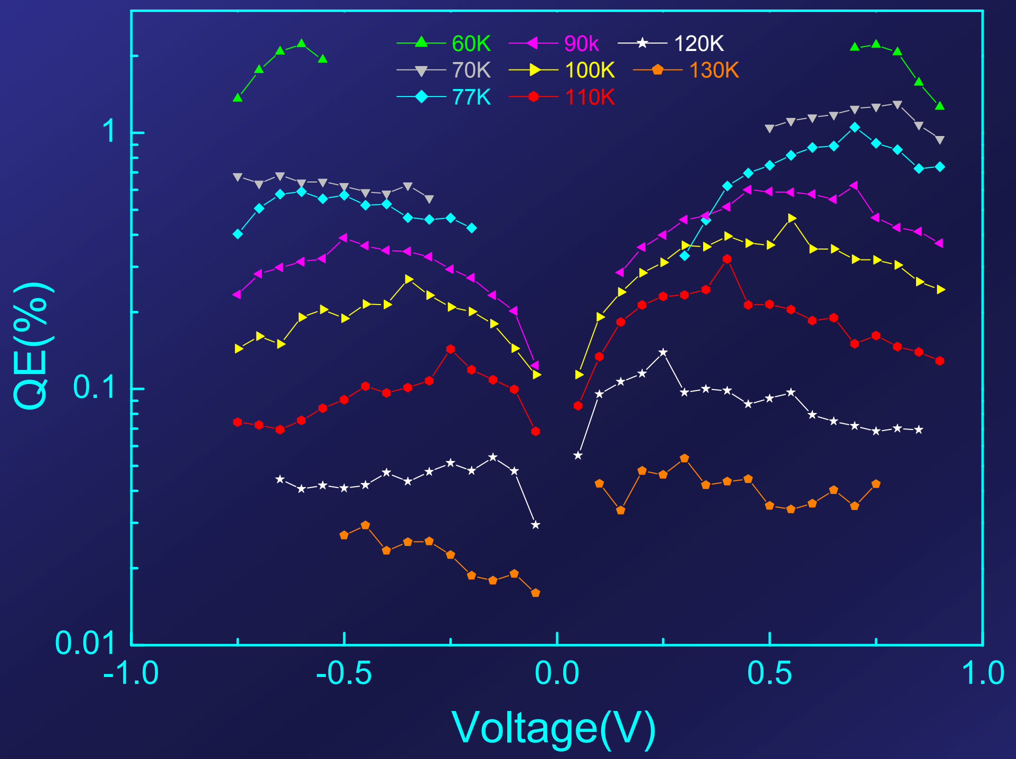
$$\mu = 2000 cm^2/V/s$$

$$v_{sat} = 1\times10^6 cm/s$$

$$\tau_c = 5ps$$

$$J_{QD} \propto \exp\frac{E_f - E_c}{kT}$$

Quantum efficiency

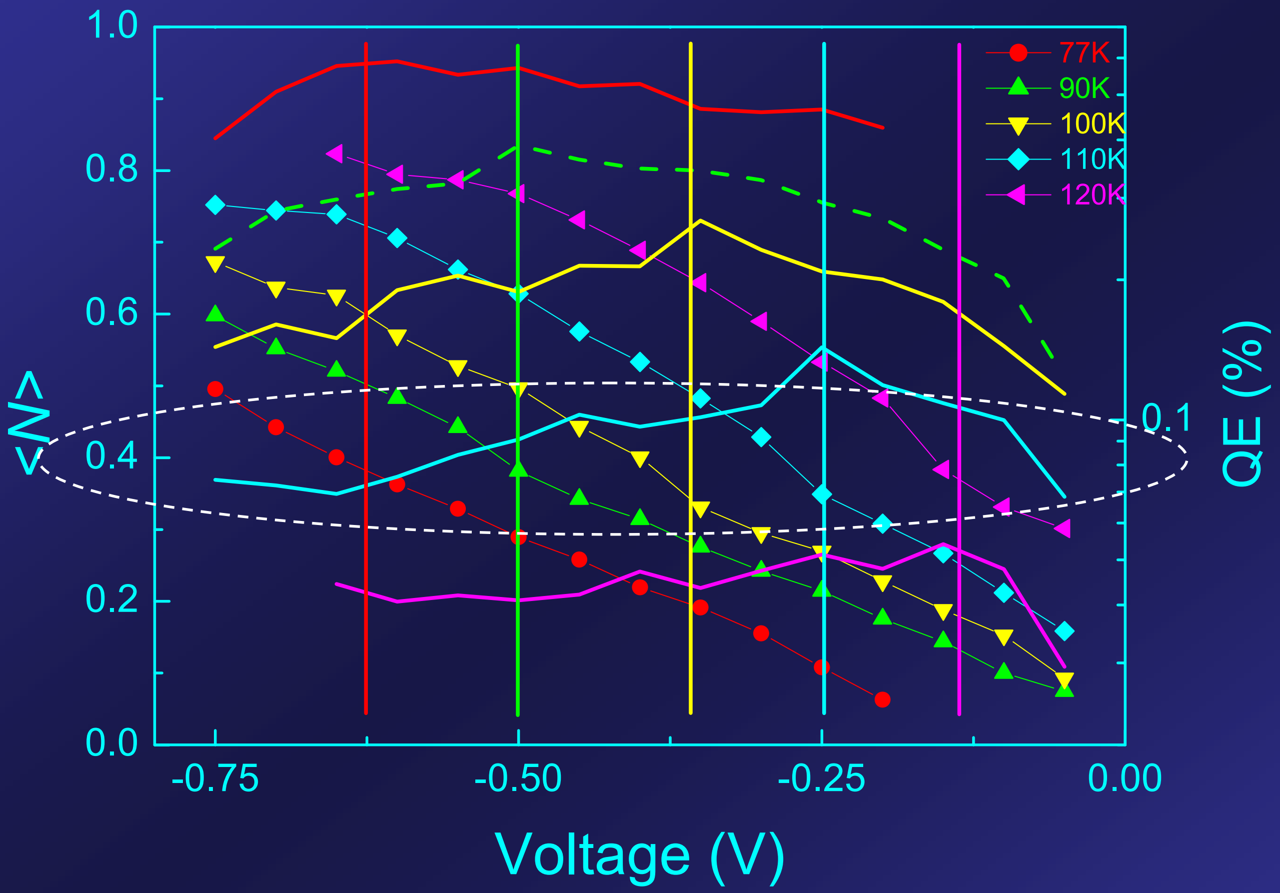


$$\eta \propto n_g (1 - n_e) P_e$$

$V(QE_{peak})$ ↓ as T ↑

QE_{peak} ↓ as T ↑

Doping concentration

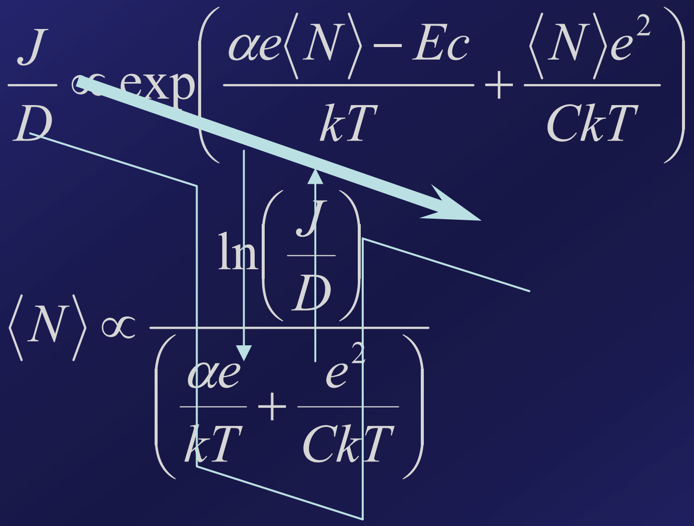


The peak quantum efficiency happens around <N>=0.4

Original doping is 1.6e-/QD. Close to nominal 1.2e-/QD

Minimize the <N>

$$\frac{JP_c}{D} = A\exp\frac{E_f - E_c}{kT}$$



$$\frac{J}{D} \propto \exp\left(\frac{\alpha e\langle N\rangle - Ec}{kT} + \frac{\langle N\rangle e^2}{CkT}\right)$$

$$\langle N\rangle \propto \frac{\ln\left(\frac{J}{D}\right)}{\left(\frac{\alpha e}{kT} + \frac{e^2}{CkT}\right)}$$

Smaller size QDs

with higher density

<N>↓as D↑& C↓

more stable <N>

Change in QDs density for 10 times

<N> will be more than 3 times smaller

Summary

- The change of current gain dominates the behavior of responsivity in QDIPs

- Extra carriers/charge inside the QDs play an important role in the gain and QE of QDIPs

- Given the same of InAs nominal thickness, smaller QD with higher density provides a smaller change in <N>. QDs with smaller size are favorable.