Multi-Color Tunneling Quantum Dot Infrared Photodetectors Operating at Room Temperature

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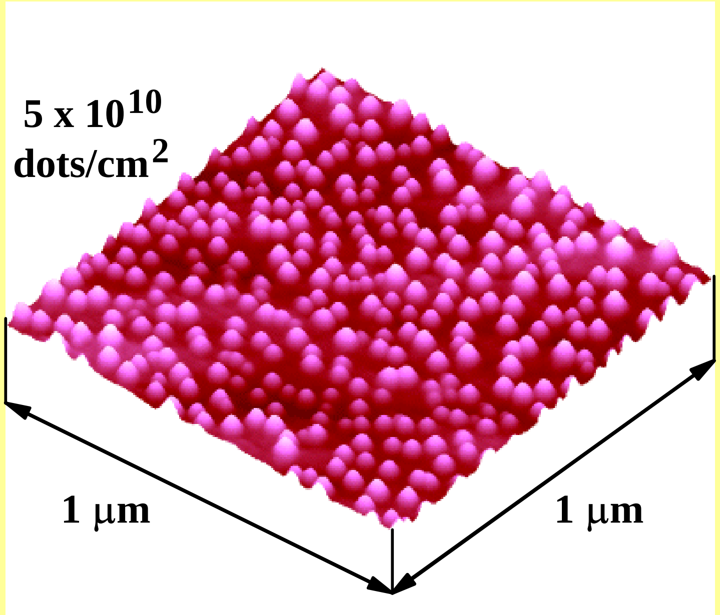
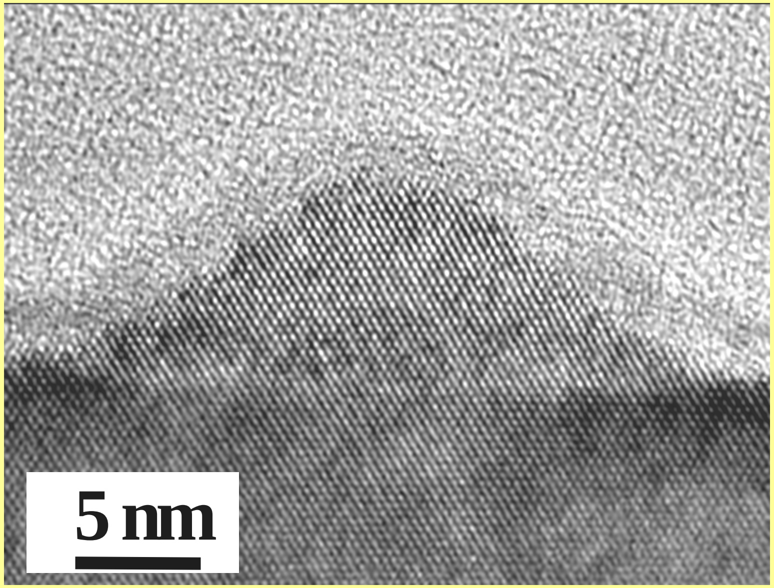
Introduction

- Quantum dot infrared photodetectors (QDIPs) grown by molecular beam epitaxy (MBE) at the University of Michigan.
- QDs- Self assembled
- Long lived excited states and superior carrier confinement.
- Expected to show low dark current, high detectivity and higher operating temperature.
- Normal incidence radiation is allowed, which is forbidden in n-type quantum well detectors.

Tunneling Quantum Dot Infrared Photodetector



AFM Image of InAs Quantum Dots

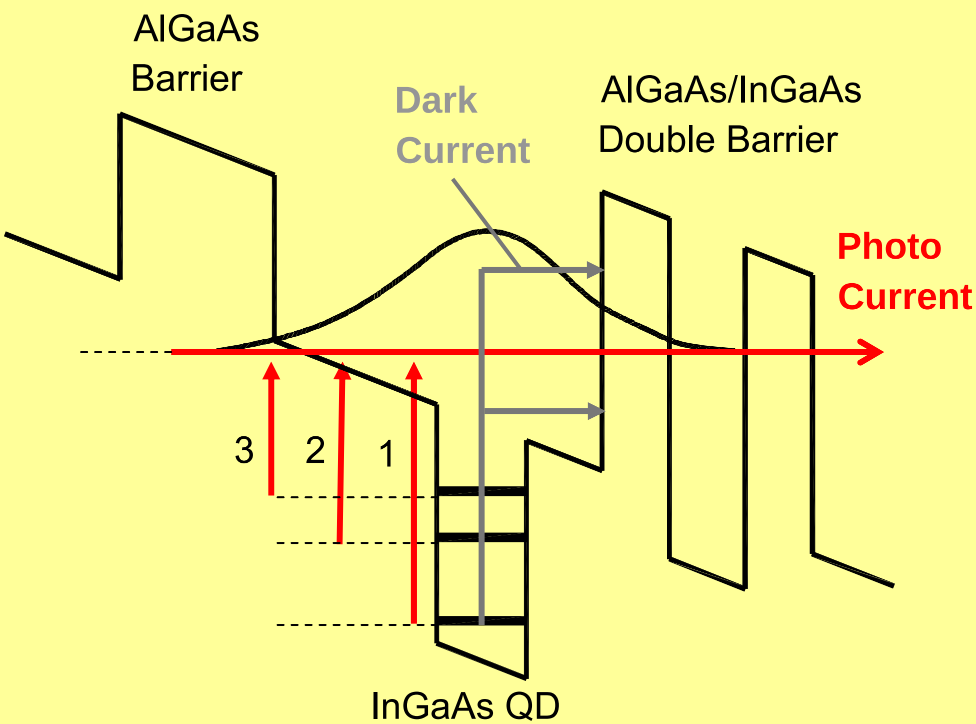


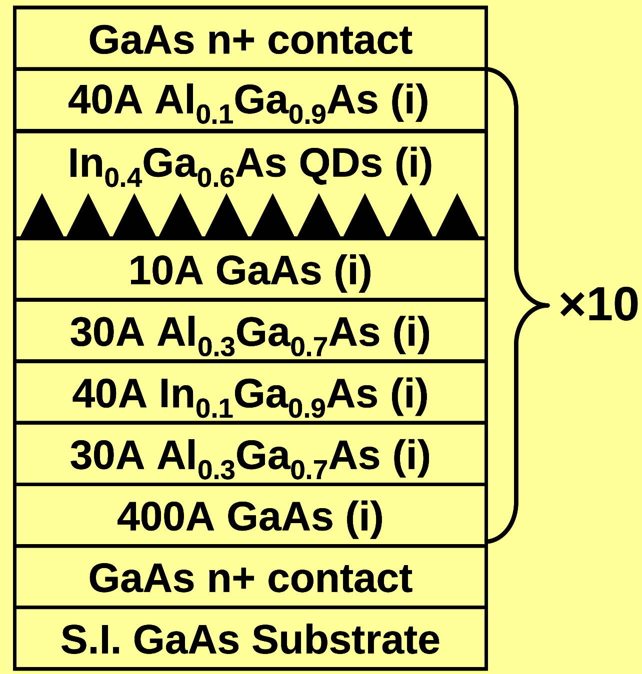
XTEM of an InGaAs QD

As pressure = 8×10^{-6} Torr
T_{Growth} (GaAs) = 600° C
T_{Growth} (InAs) = 520° C
InAs QDs ~ 2.6 ML
Growth rate (InAs) = 0.05ML/s
Growth rate (GaAs) = 2Å/s
Cap: 45Å $In_{0.15}Ga_{0.85}As$

Tunneling Quantum Dot Infrared Photodetector

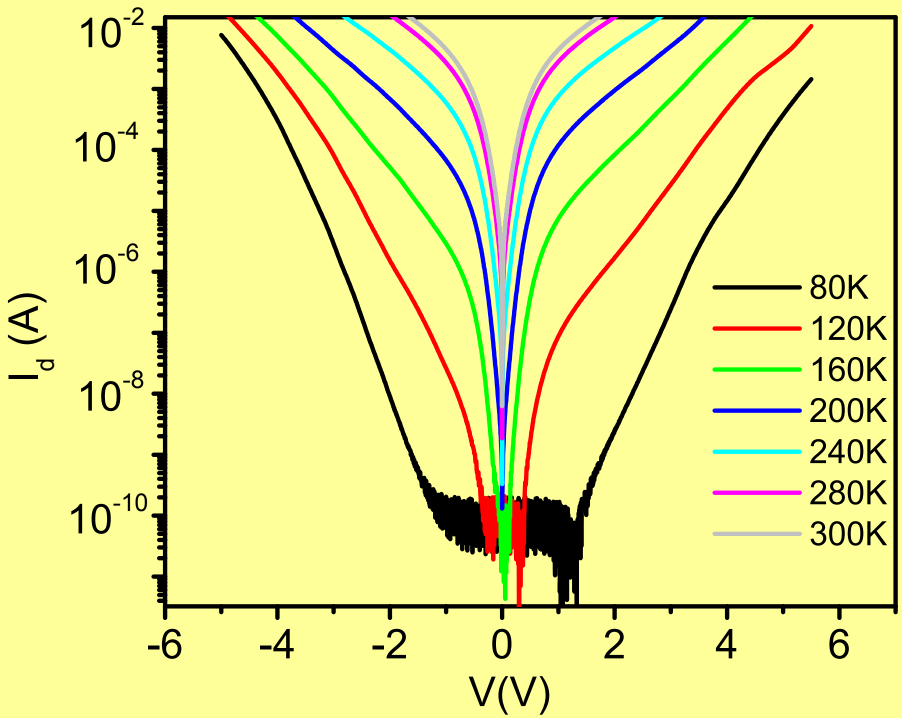
- The electrons contributing to the photocurrent are selectively collected from the quantum dots by resonant tunneling.

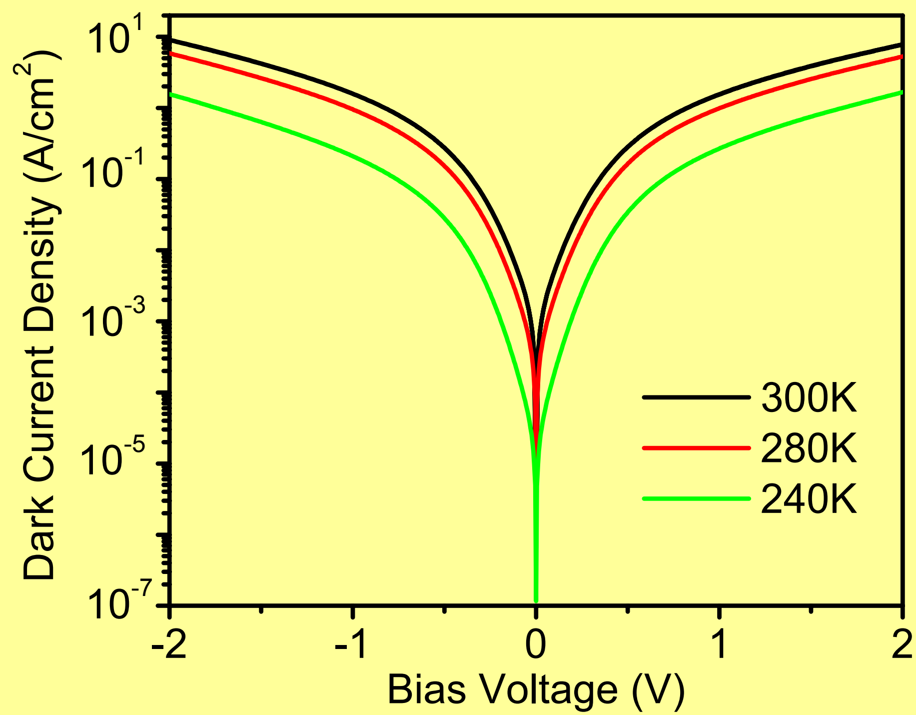




APL(**86**) 191106 (2005).

Dark Current Reduction





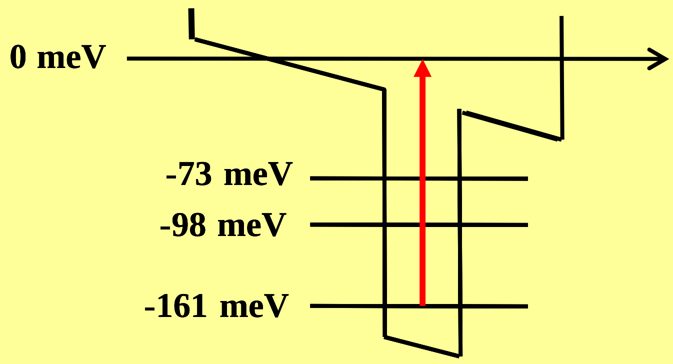
- A reduction of dark current by two orders of magnitude has been observed

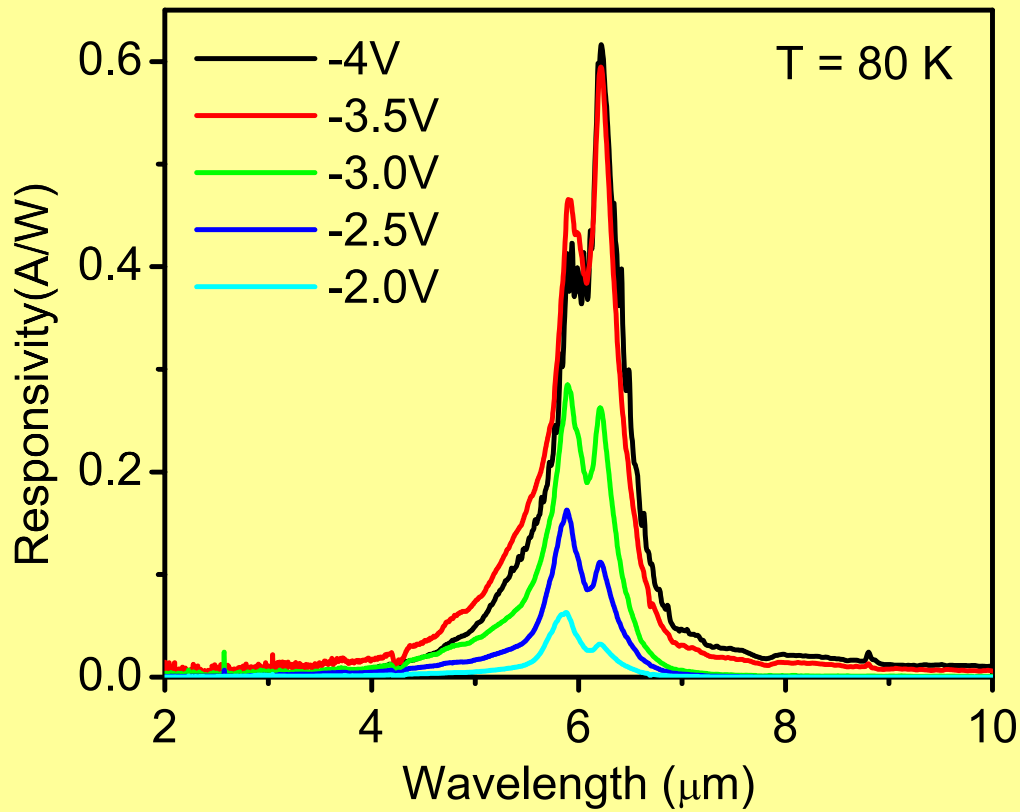
  TQDIP 3.06 X 10^{-5} A/cm^2 @ 120 K

  DWELL 1.60 X 10^{-2} A/cm^2 @ 100 K

- Low dark current density of 1.55 A/cm^2 at 300 K for 1 V bias.

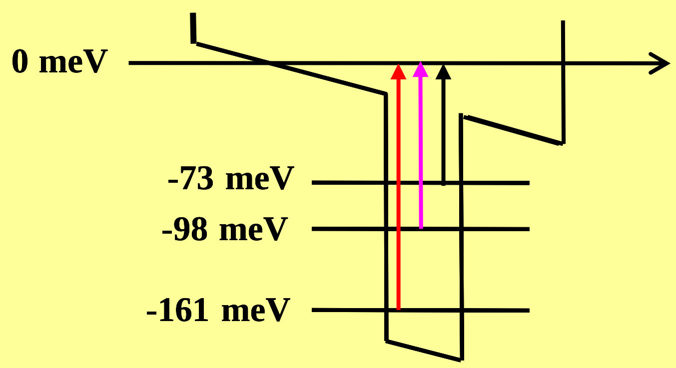
Response at 80 K

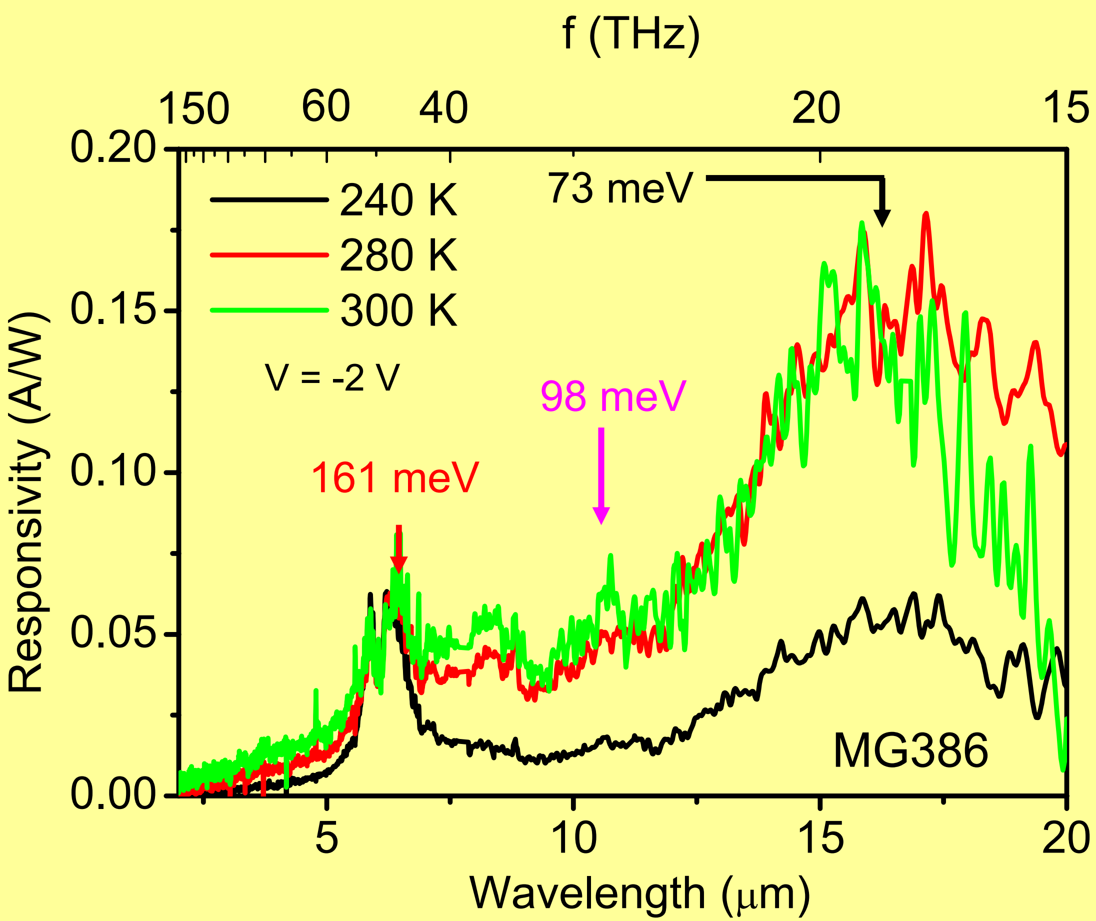




- 3 peaks expected at 6, 11, and 17 μm

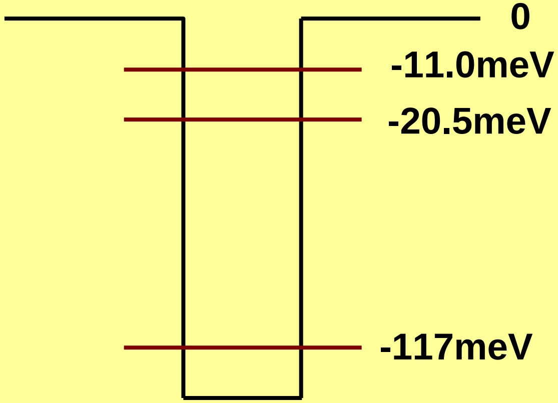
Room Temperature Response

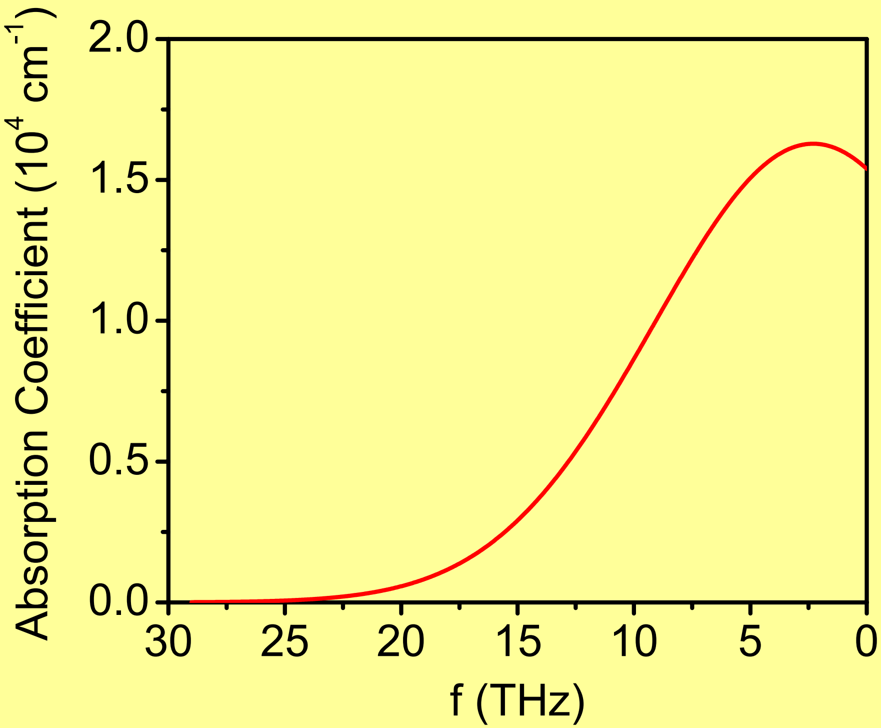




- The broad peak centered at 17 THz results from transitions from the second excited state of the dot to the well state (ΔE = 73 meV)

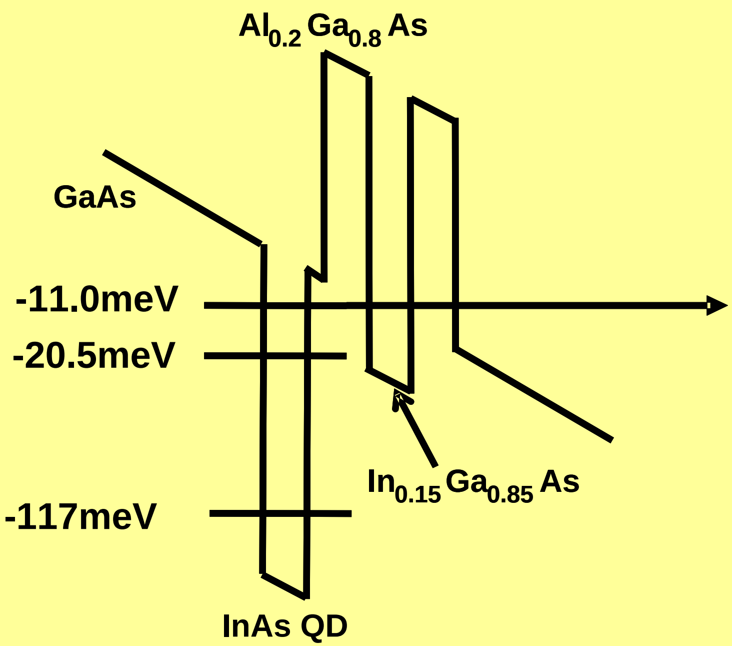
THz T-QDIP



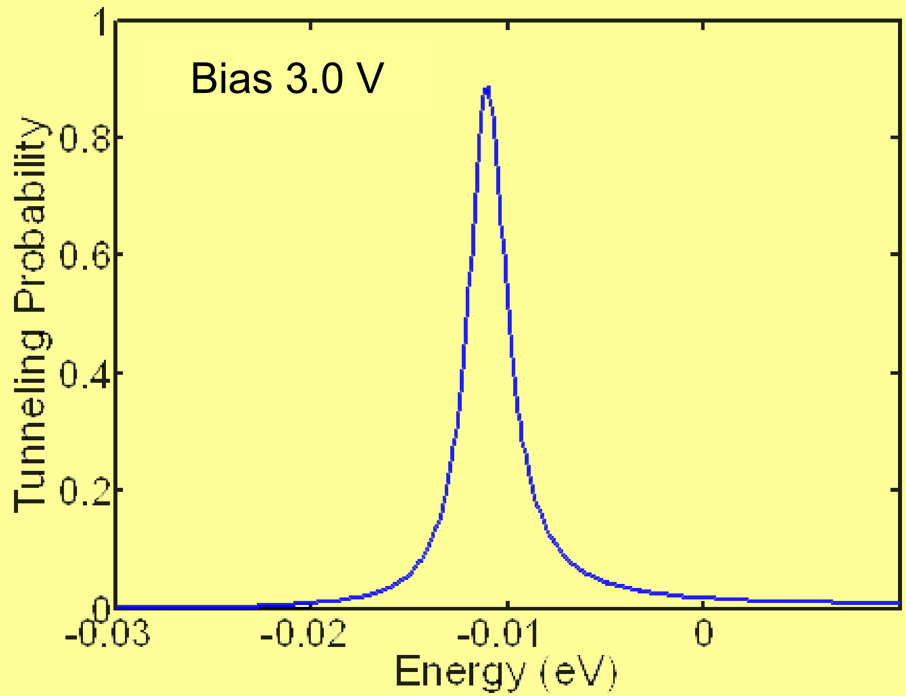


- Energy spacing between dot first and second excited states ~9.5 meV
- For the active region of the tunnel QDIPs, it is necessary to grow smaller dots (typically in the range height/width = 40Å/124Å)
- This will not only provide the smaller transition energy, but, for the same amount of adatom change, a large dot density

THz T-QDIP : Tunneling Probability



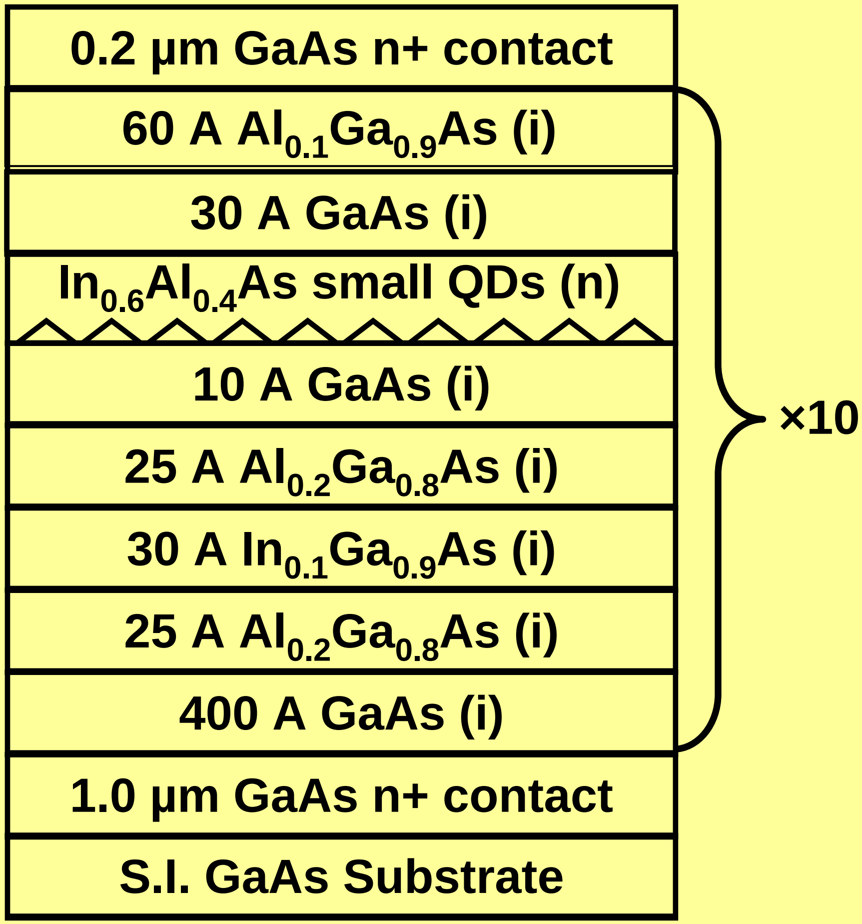
Schematic diagram of conduction band of terahertz T-QDIP.

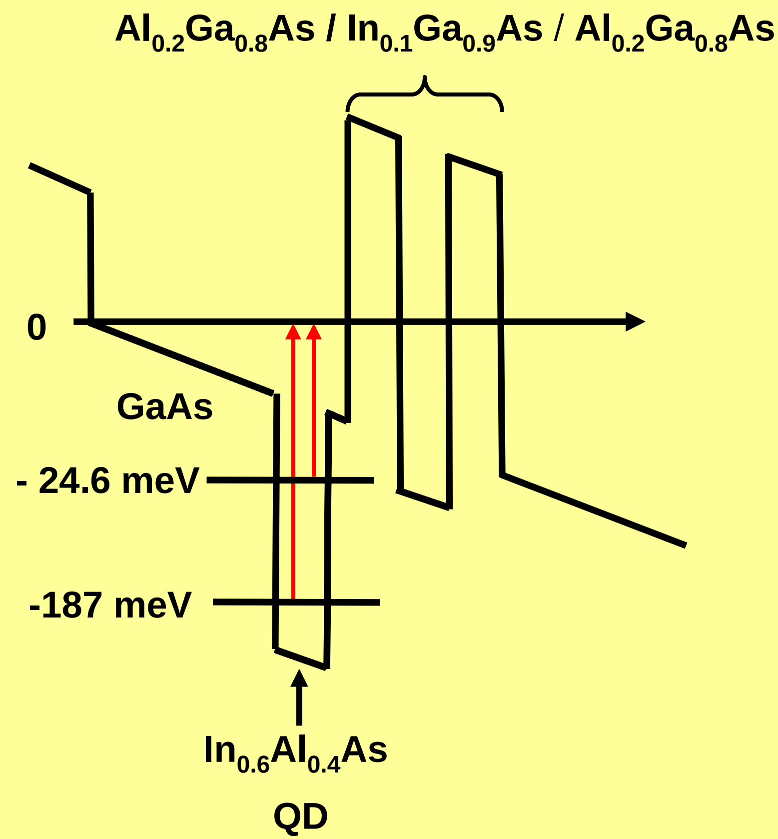


Calculated tunneling probability of THz T-QDIP as a function of energy.

- Tunneling probability has been calculated by the transfer matrix method

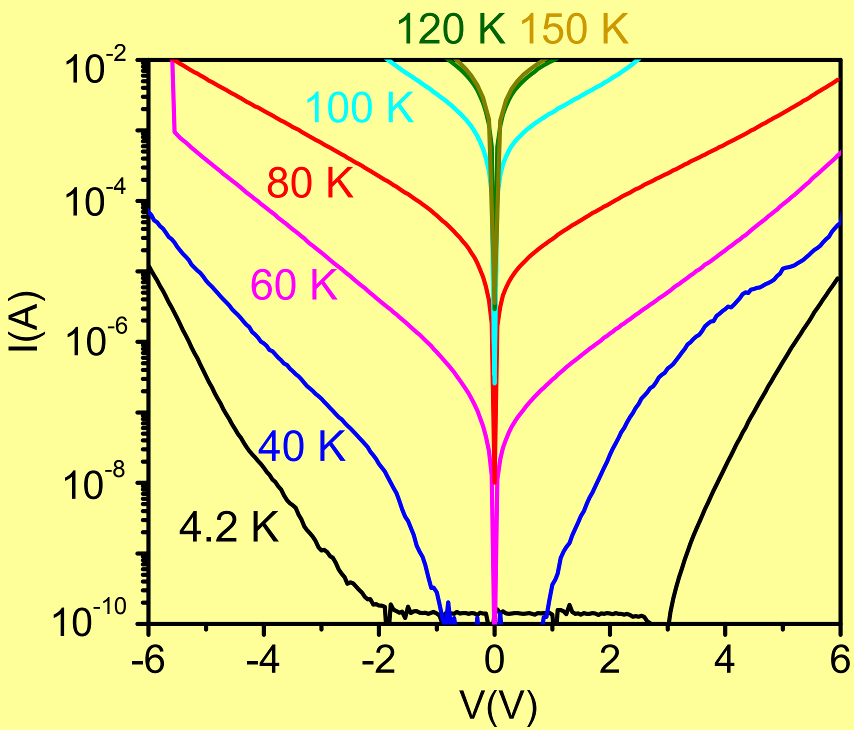
THz T-QDIP Structure

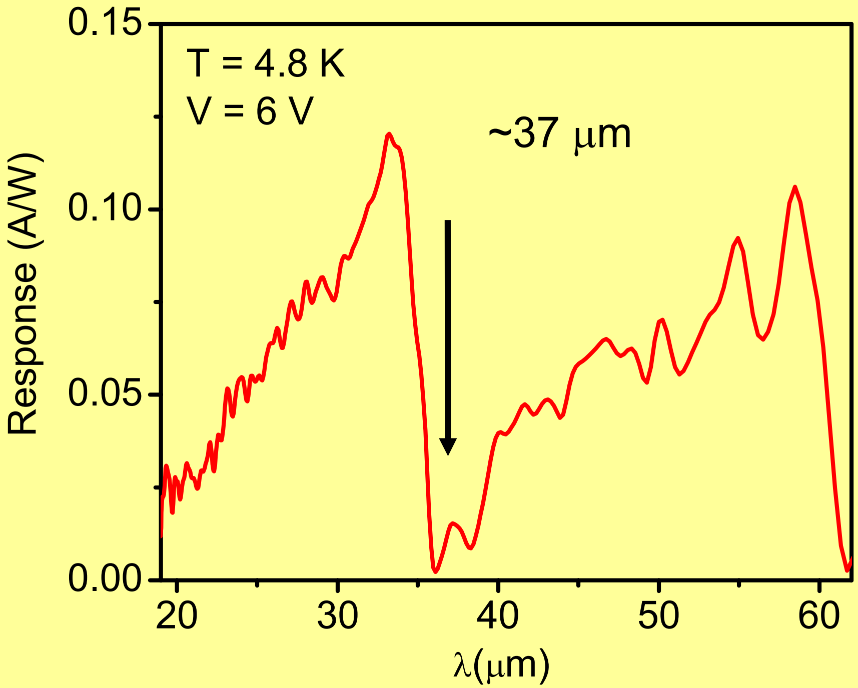




QDs >> n-type Si doped to 2×10^{18} cm^{-3}

THz T-QDIP

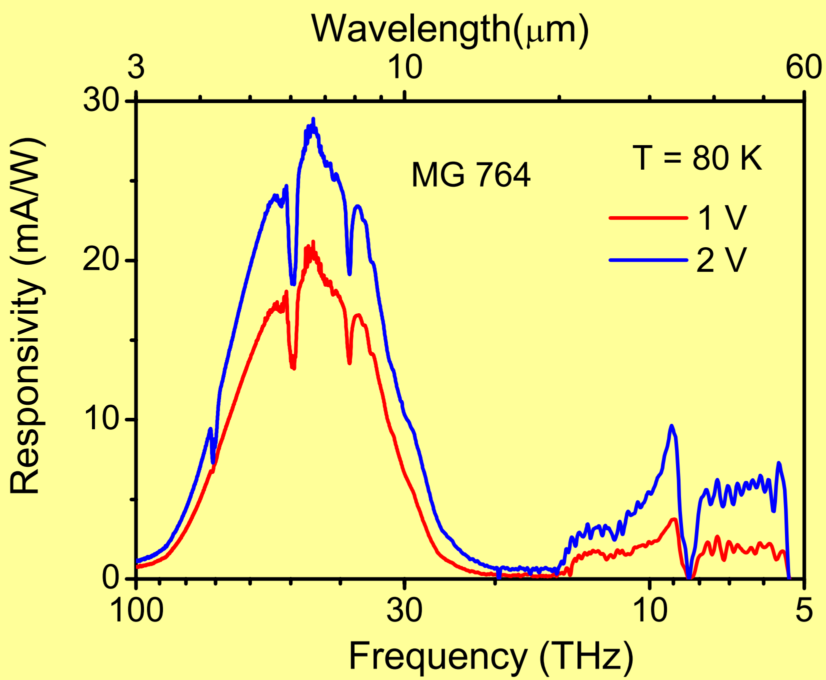


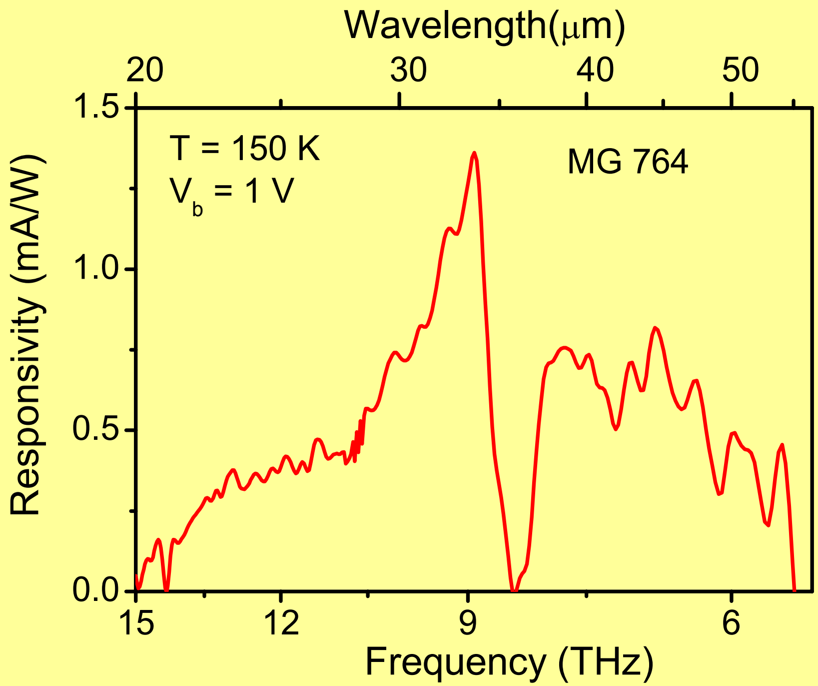


FWHM = 25 meV

This is due to inhomogeneous size distribution of QDs

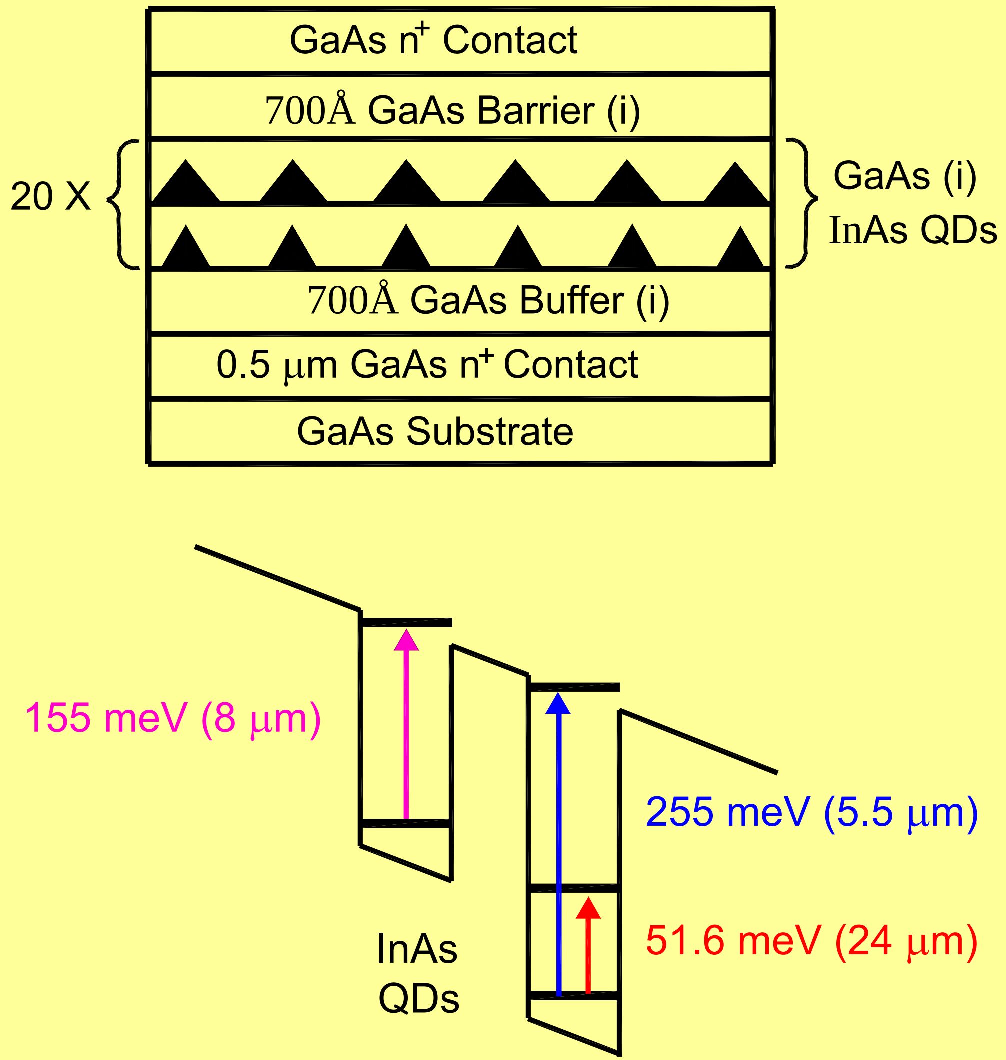
High Temperature Operation: THz T-QDIP



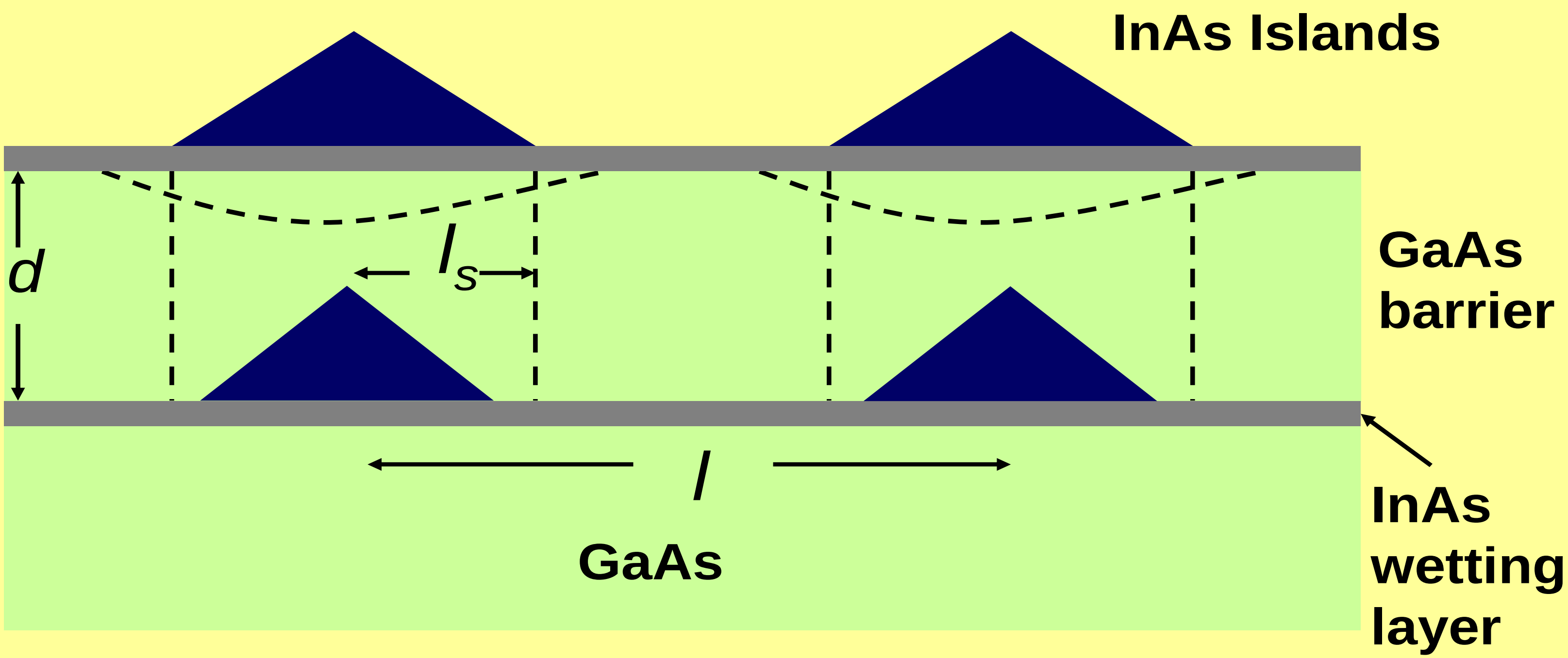


Bias (V)	D* (cm Hz$^{1/2}$/W) @ 80 K
1	4.3×10^{8} @ 7 µm
2	3.4×10^{8} @ 7 µm
1	5.0×10^{7} @ 50 µm
2	8.0×10^{7} @ 50 µm

Bi-layer QDIP

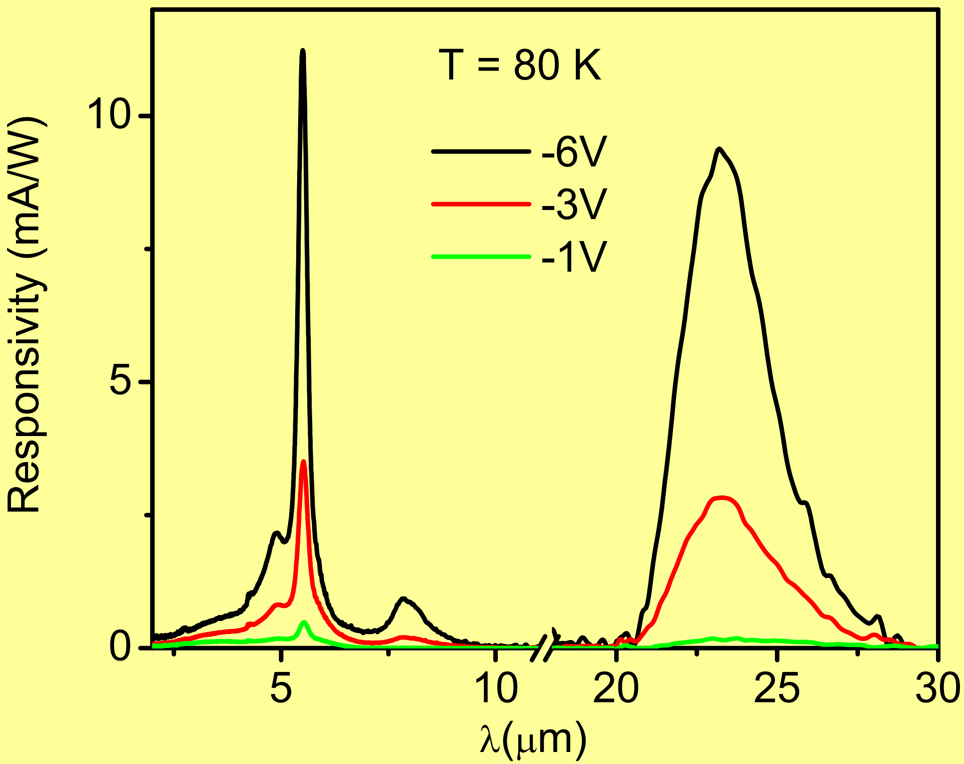


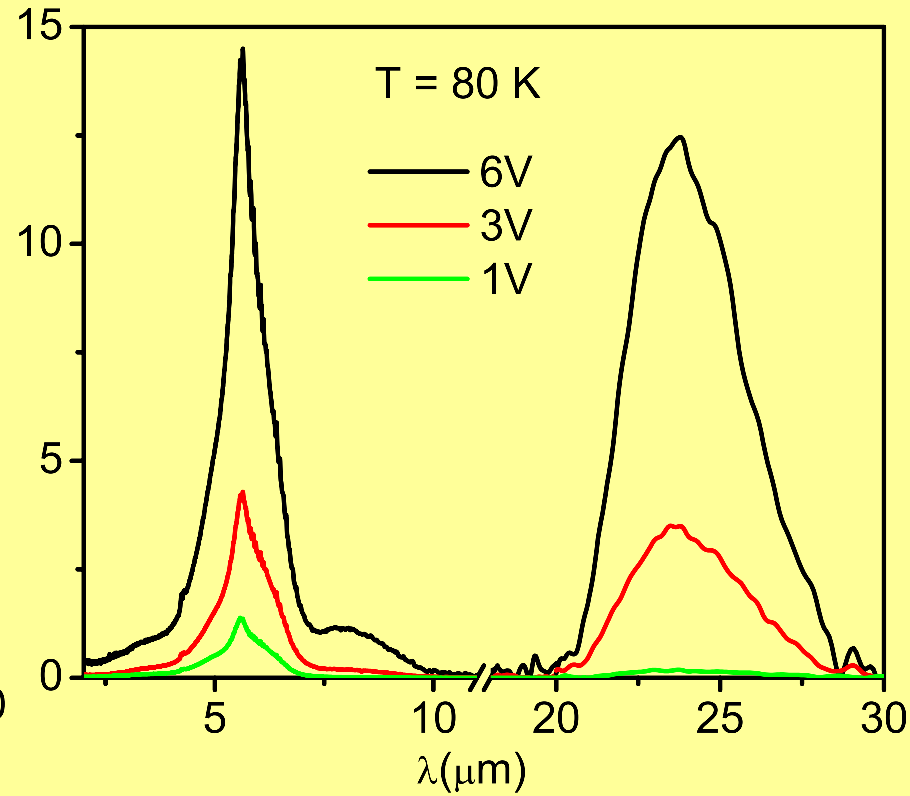
Bi-layer QDIP



For perfect vertical coupling: $2l_s \geq l$

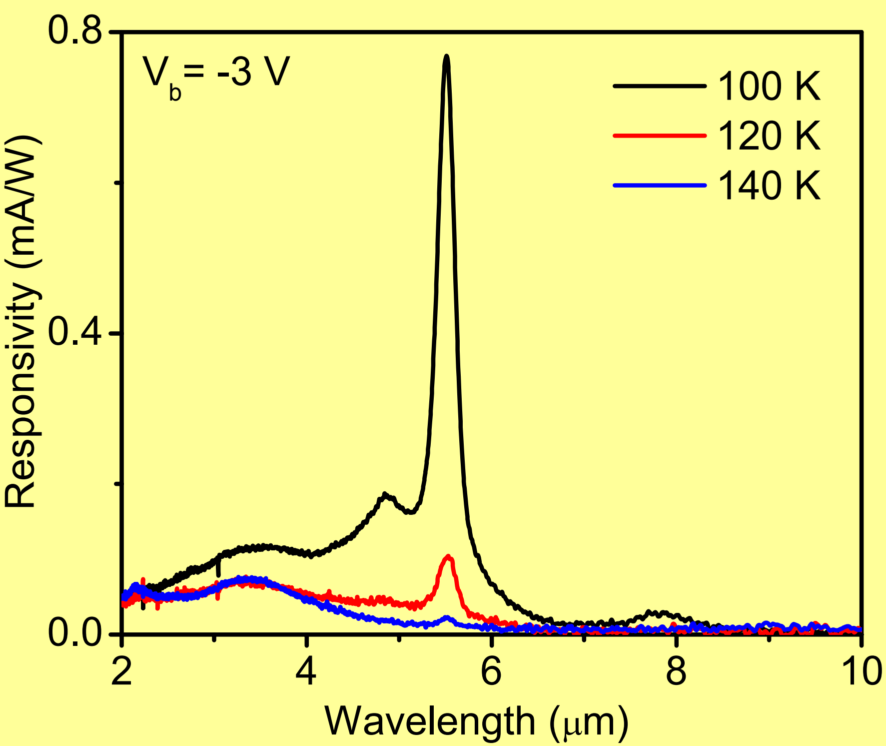
MIR response of Bi-layer QDIP

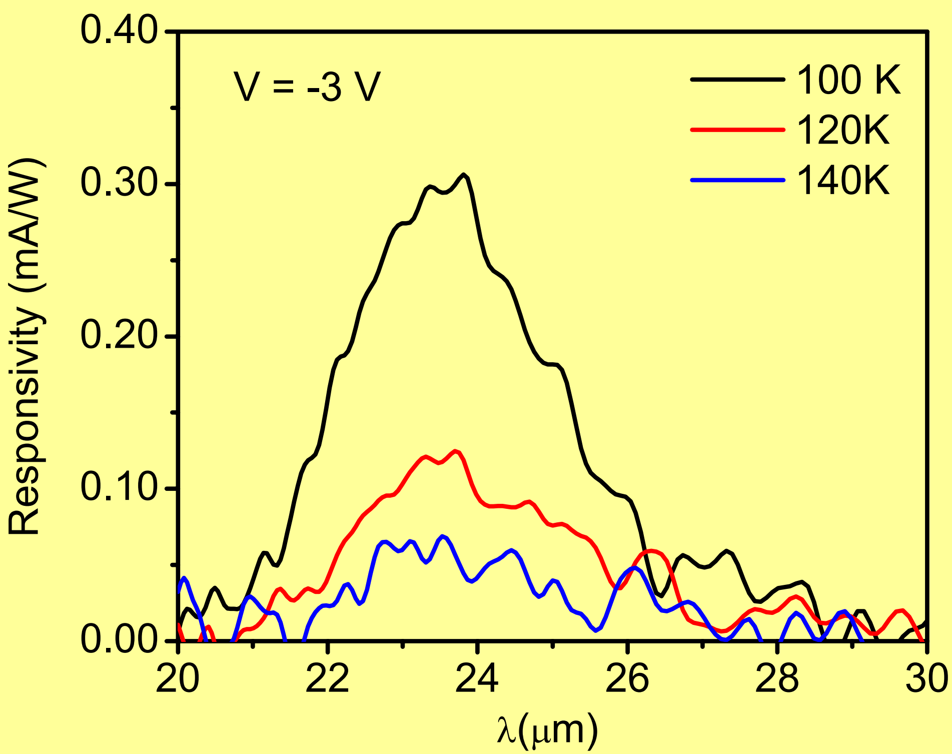




Bias (V)	D* (cm Hz$^{1/2}$/W) @ 5.5 μm
-6	1.5×10^{9}
-3	4.3×10^{8}
3	5.5×10^{8}
6	1.7×10^{9}

FIR Response of Bi-layer QDIP





Conclusion

- A novel QDIP with a tunneling barrier.
- Photoexcited carriers are selectively collected from InGaAs quantum dots through resonant tunneling, while the dark current is reduced by using AlGaAs blocking barriers placed right before contacts.
- Two distinct absorption peaks ~ 6 μm and 17 μm and a weak response around 11 μm.
- Higher operating temperature.
- Demonstration of THz operations of T-QDIP
- Multi-color detectors from bi-layer QDIP