THz QWIP

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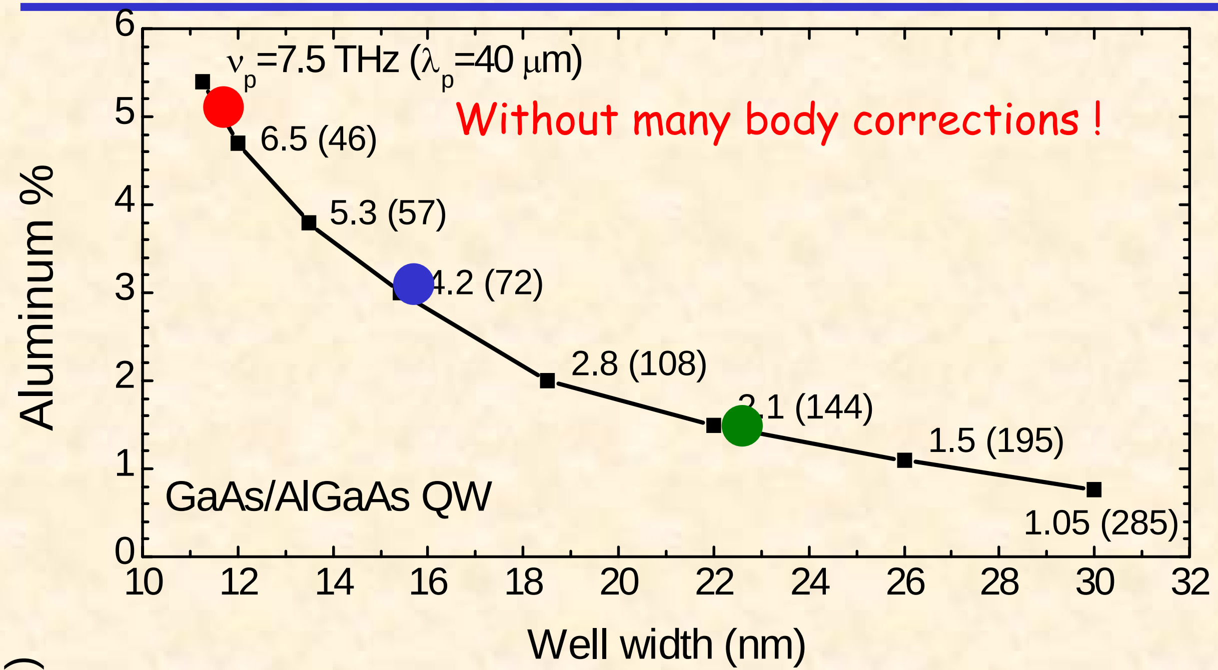
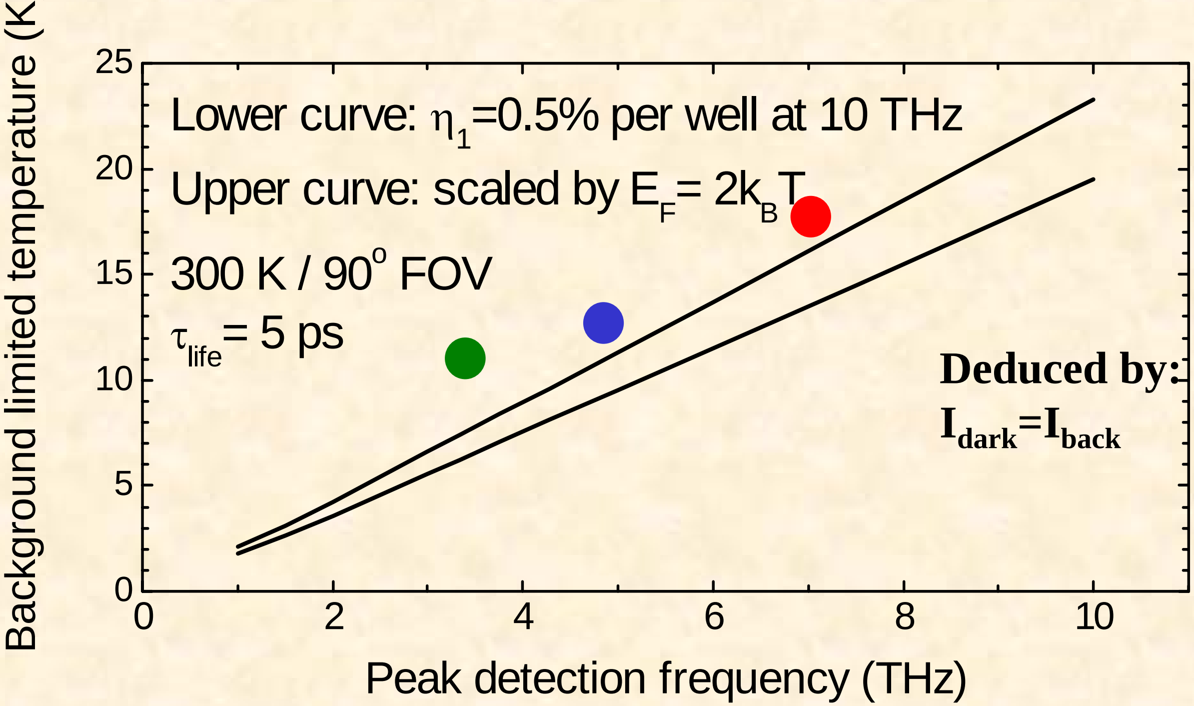
Terahertz quantum well photodetectors





QWIP in the THz region: Predicted/projected Performance

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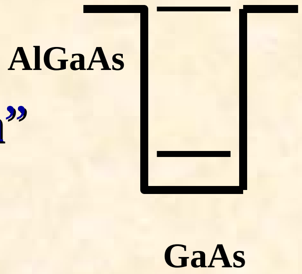
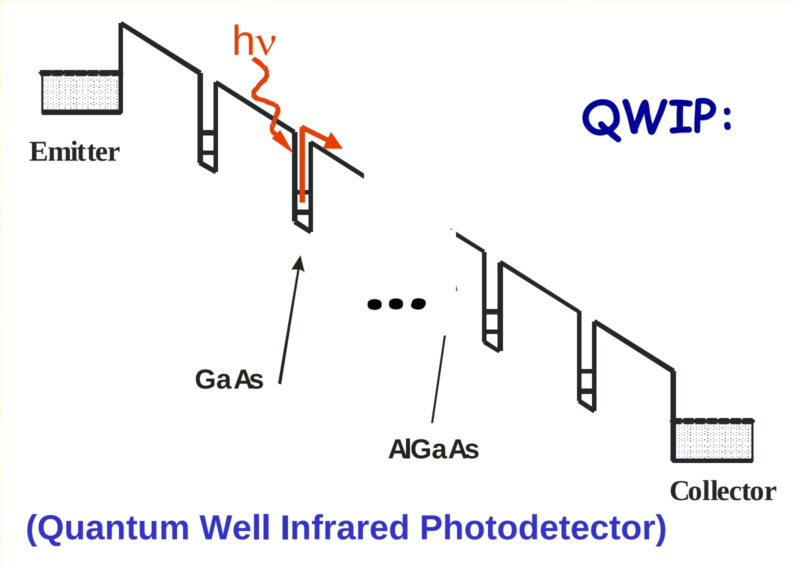
J. C. Cao

"Optimal Design"

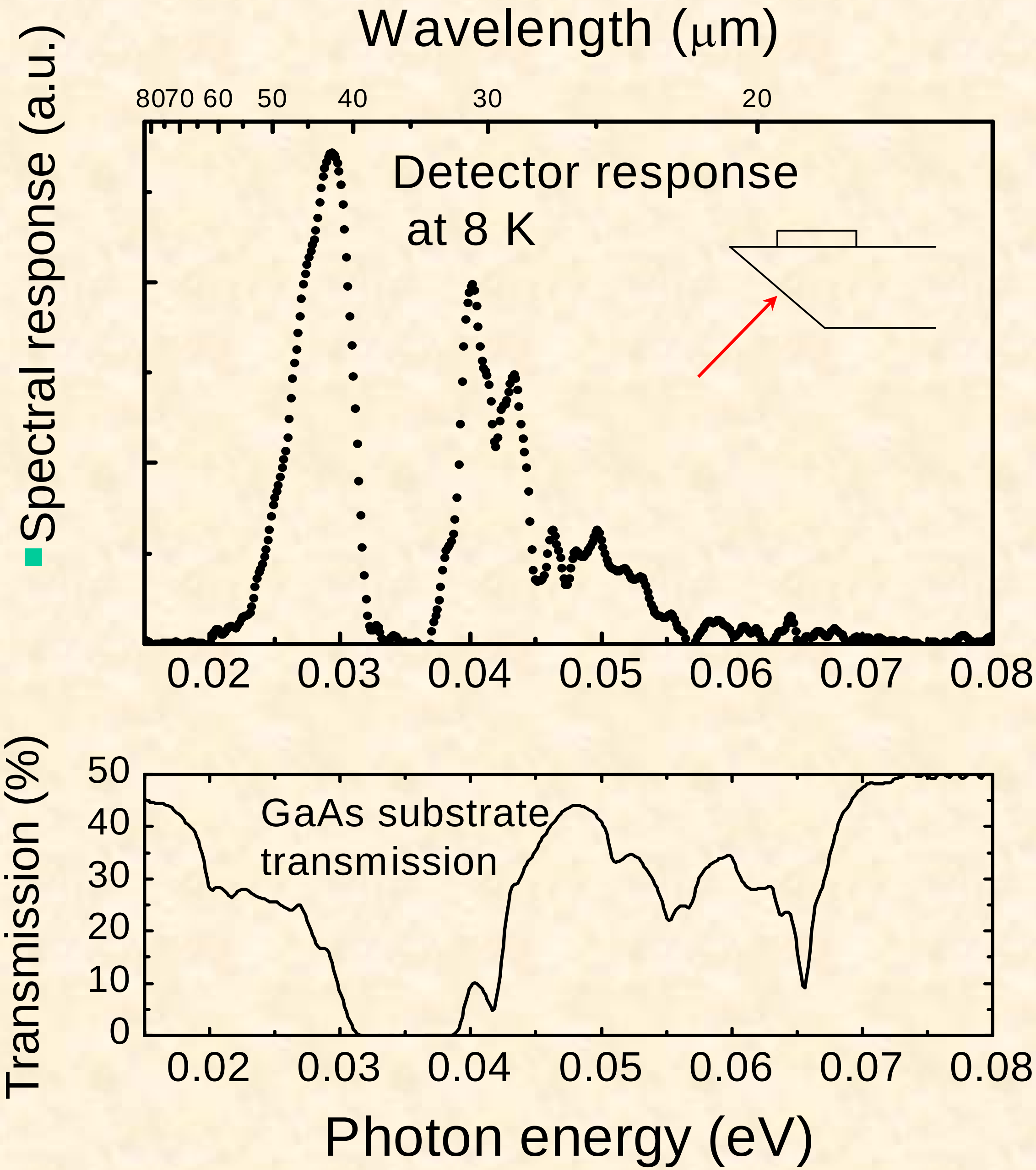




QWIP:

(Quantum Well Infrared Photodetector)

THz QWIP 1st experiment



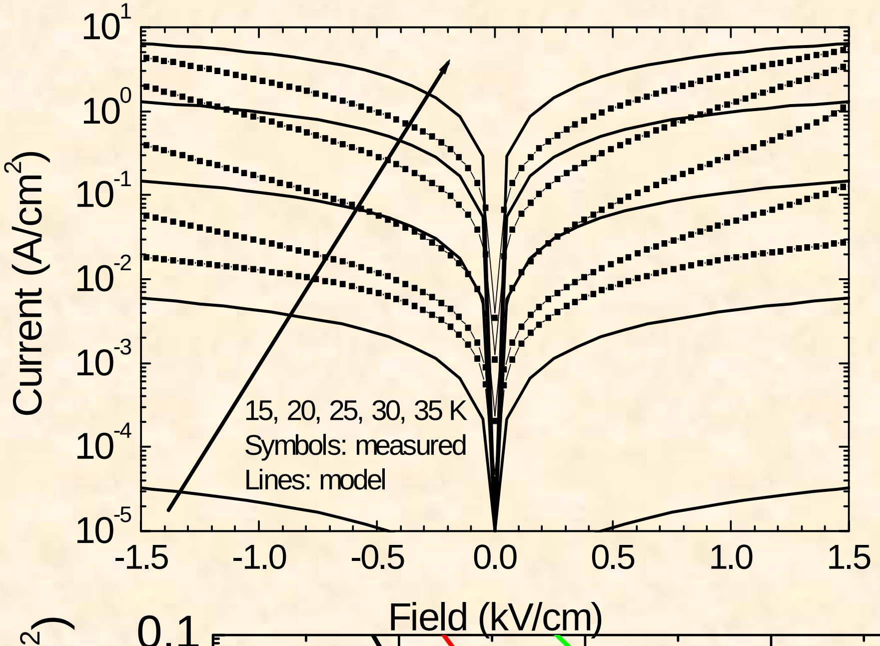
50 QWs
12/40nm GaAs/AlGaAs
Si doping: 1E11cm^{-2}
[Al]=5%
Bound-to-continuum or
phonon/polaron effect?

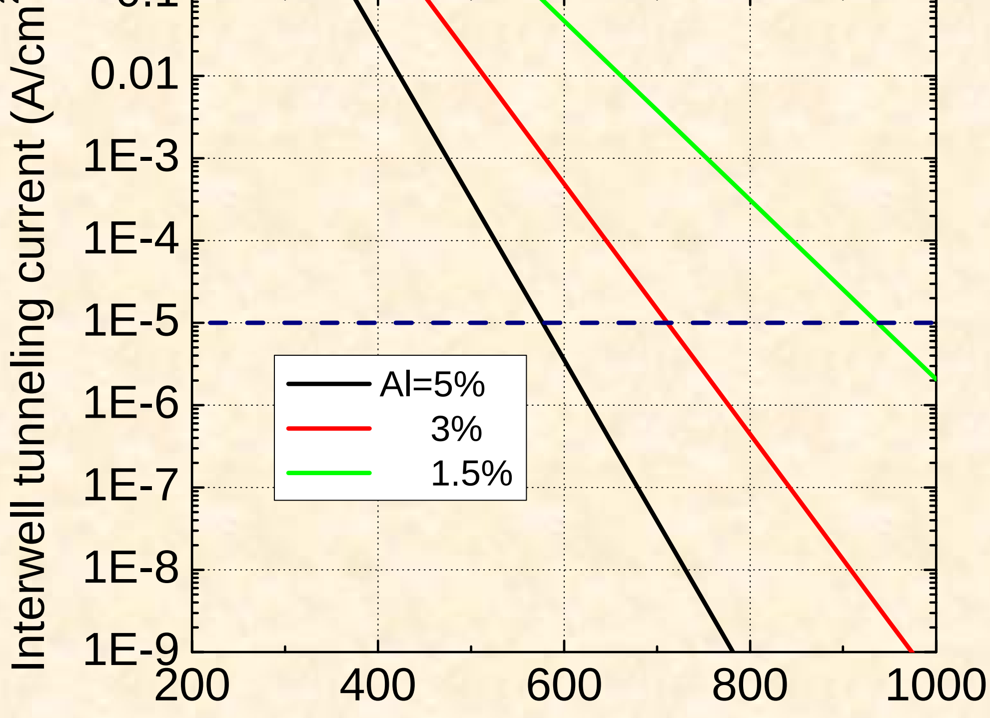
Noisy spectrum
45-deg facet geometry
P-polarized response

Optical phonon "dark" region
42meV – zone edge 2 phonon
45meV – AlAs-like phonon

Appl. Phys. Lett. 84, 4068 (2004)

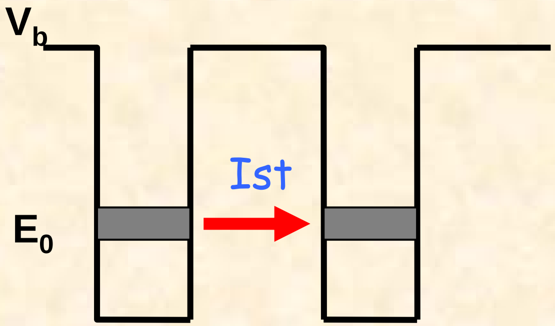
Problem: high dark current & Inter-well sequential tunneling





- Dark current stops decreasing for T<20K, ~ 10^{-2} A/cm^2, no BLIP operation.

- Main cause of high dark current for this device: sequential inter-well tunneling.

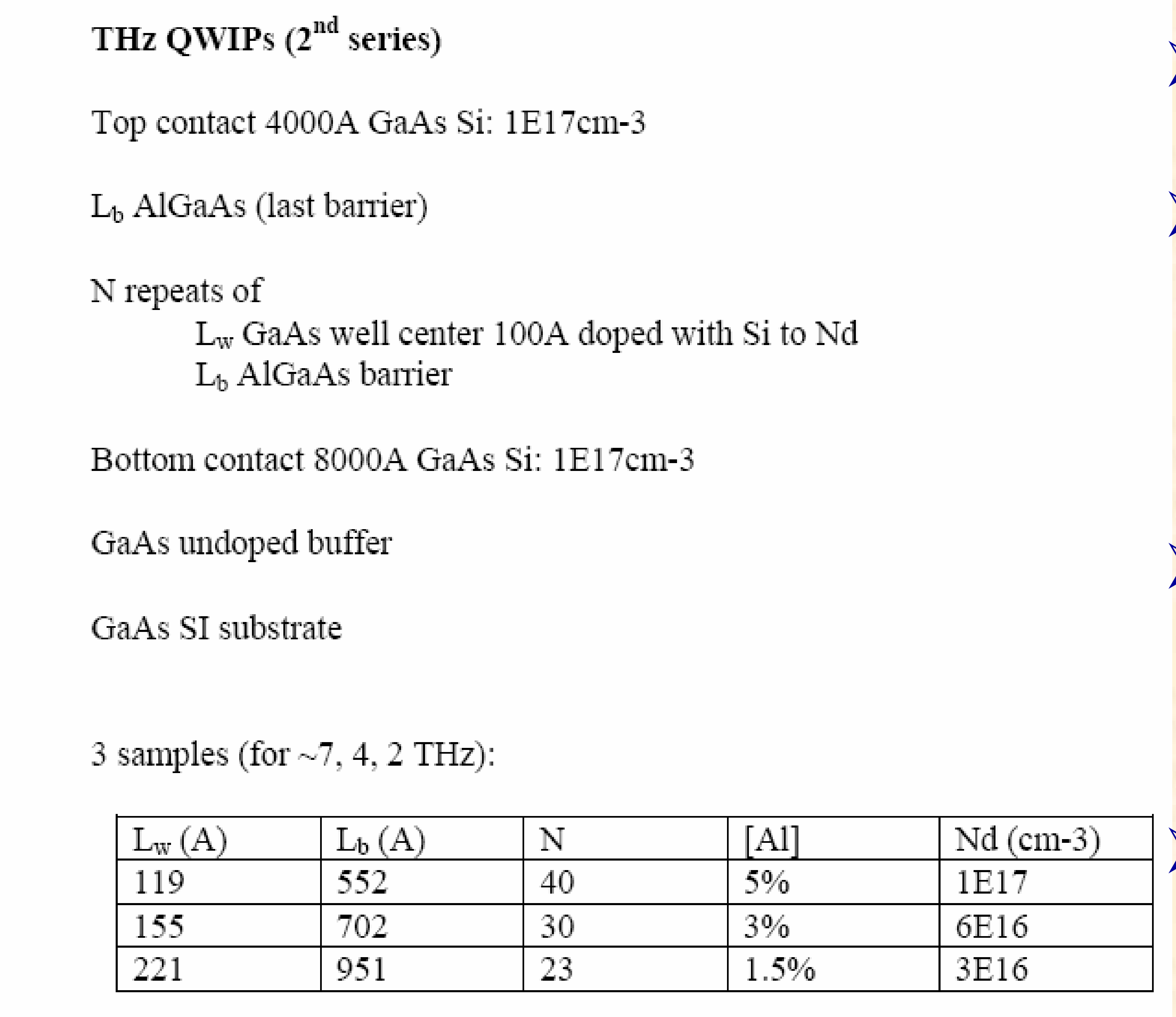


$$j_{st} \sim \frac{q n_{2d}}{\tau_{st}}$$

$$= \frac{q n_{2d} v_0}{L_w} \exp\left\{ - \frac{2\sqrt{2m^*(V_b - E_0)}}{\hbar} L_b \right\}$$

$$v_0 = \sqrt{\frac{2E_0}{m^*}}$$

THz QWIP Design (2nd Series)



THz QWIPs (2nd series)

Top contact 4000A GaAs Si: 1E17cm-3

L_b AlGaAs (last barrier)

N repeats of
    L_w GaAs well center 100A doped with Si to Nd
    L_b AlGaAs barrier

Bottom contact 8000A GaAs Si: 1E17cm-3

GaAs undoped buffer

GaAs SI substrate

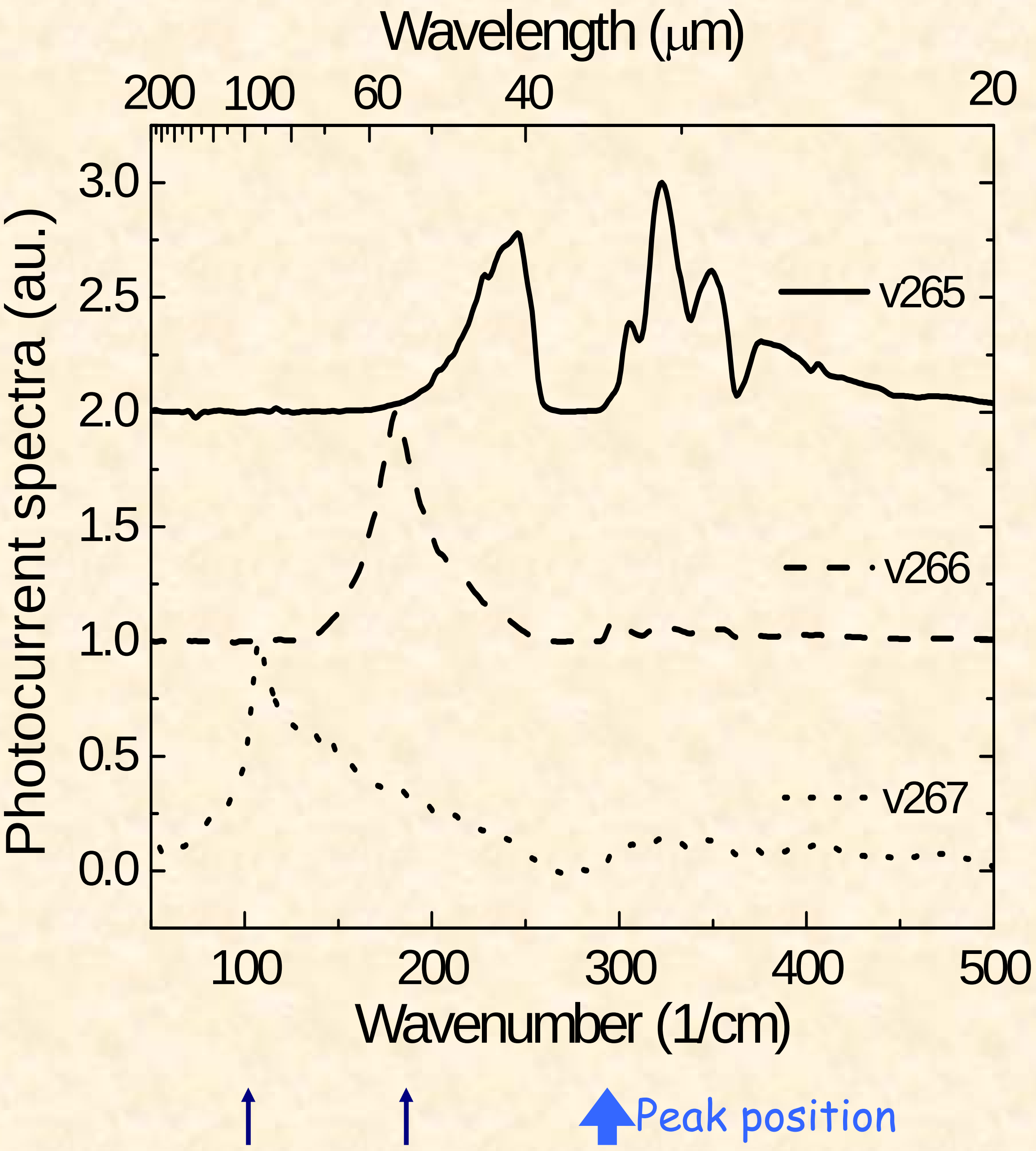
3 samples (for ~7, 4, 2 THz):

L_w (A)	L_b (A)	N	[Al]	Nd (cm-3)
119	552	40	5%	1E17
155	702	30	3%	6E16
221	951	23	1.5%	3E16

- L_b: Ist~10^{-5} A/cm^2, ~background I_{ph}
- Well doping for adequate peak absorption (1E11 ~ 3E10 cm^{-2}) ~0.2% per well
- Low contact doping to reduce free carrier absorption (plasma~90cm^{-1})
- Total epilayer thickness ~ 3.5um

Appl. Phys. Lett. 86, 231103 (2005)

Summary of Spectra



- ➢ Peak wavelength shorter than design -> many body effects

Sample	V0265	V0266	V0267
Wavenumber (1/cm)	290	180	108
Energy (mev)	36.0	22.4	13.4
Wavelength (um)	34	56	93
Freq. (THz)	8.7	5.4	3.2
Design (THz)	6.5	3.8	1.9

Many body effects

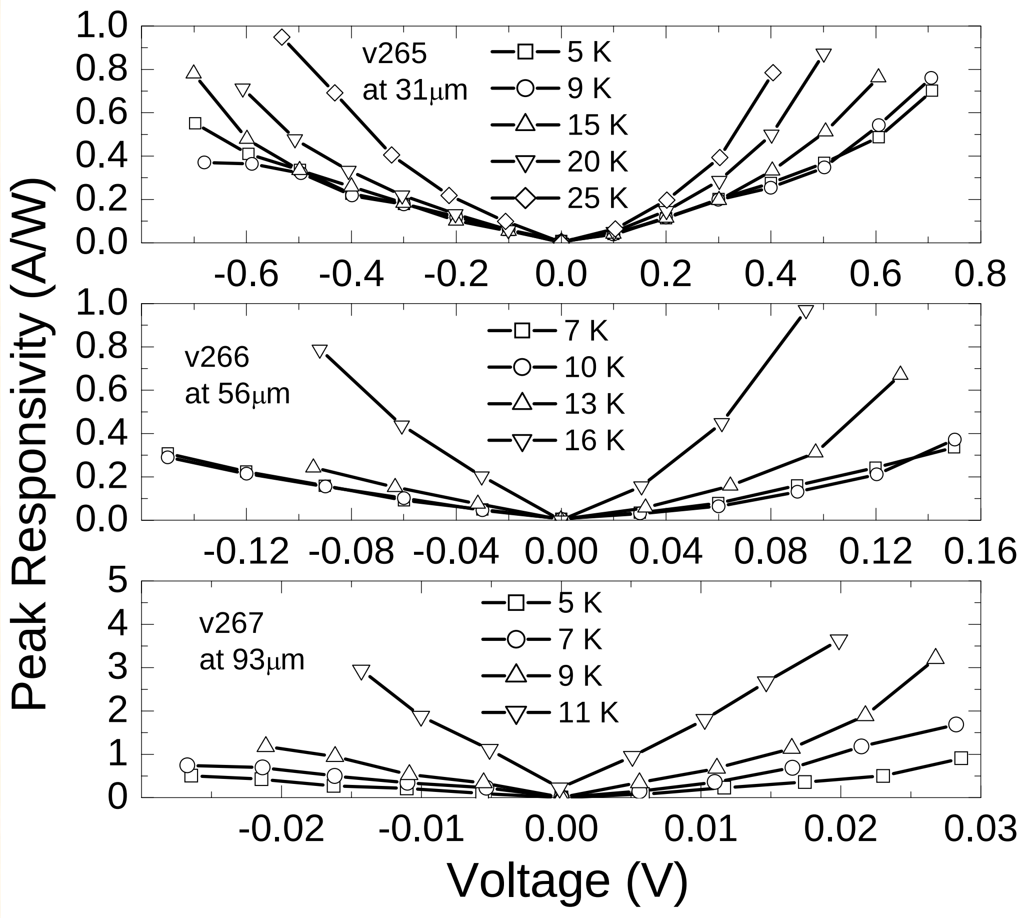
Device parameters

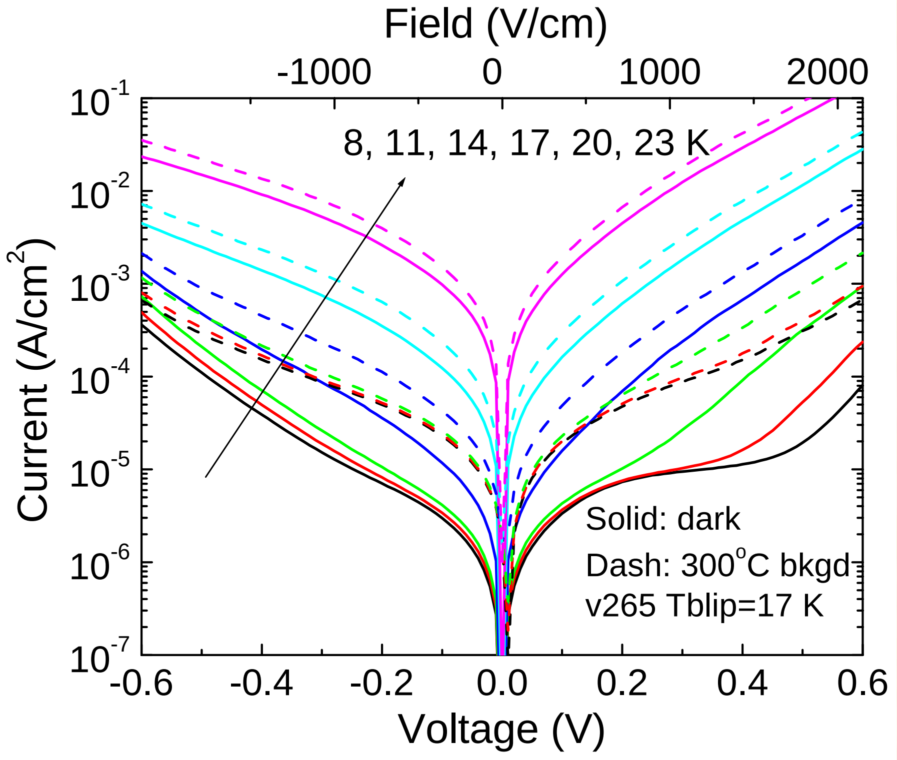
Wafer	L_w (nm)	L_b (nm)	N	[Al]	N_d (cm^{-3})	n_{2D} (cm^{-2})
V265	11.9	55.2	40	5%	1E17	1E11
V266	15.5	70.2	30	3%	6E16	6E10
V267	22.1	95.1	23	1.5%	3E16	3E10

Comparison

Wafer	E_1 (meV)	E_2 (meV)	E_{ex-co} (meV)	E_{depol} (meV)	**Theory peak (meV)**	**Exp peak (meV)**
V265	14.31	43.21	4.71	2.2	**35.81**	**~36**
V266	8.58	26.93	3.65	1.6	**23.60**	**22.3**
V267	4.25	12.92	2.50	1.0	**12.17**	**13.4**

Background Limited IR performance





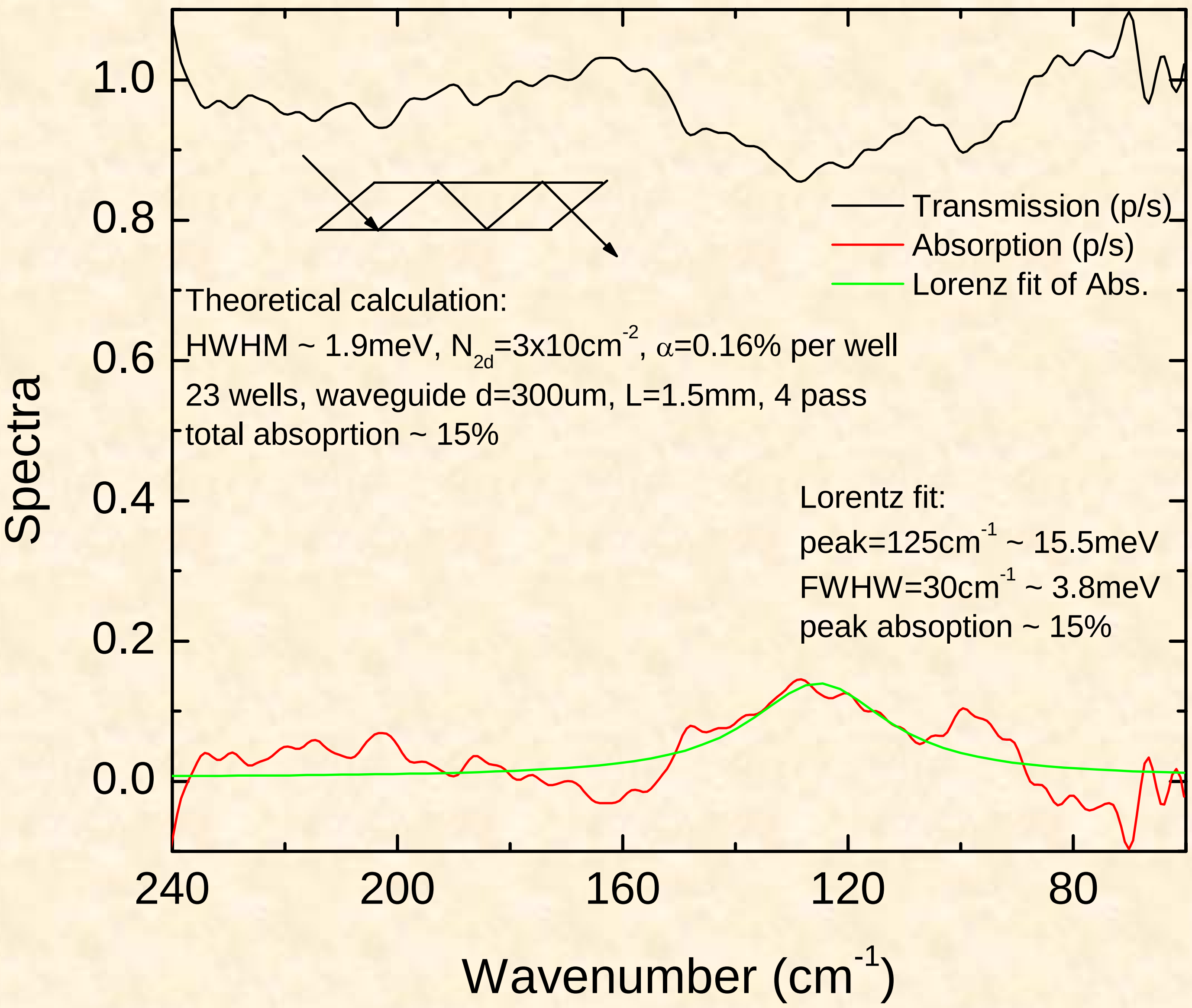
- ➢ Responsivity R = 0.5 ~ 1 A/W, similar to Mid-IR QWIP.
- ➢ Transition temperature correlates with BLIP temperature: 17, 13, 12 K

Summary

- ❑ Wider barrier can be employed to effectively reduce inter-well tunneling current and enable BLIP operation.
- ❑ BLIP was demonstrated at 17, 13, 12 K for peak response at 9, 5.4, 3.2 THz.

Future: Absorption needs to be improved

V267 THz QWIP absorption at room temperature



Theoretical calculation:
HWHM ~ 1.9meV, $N_{2d}=3\times10cm^{-2}$, $\alpha=0.16\%$ per well
23 wells, waveguide d=300um, L=1.5mm, 4 pass
total absoprtion ~ 15%

Lorentz fit:
peak=$125cm^{-1}$ ~ 15.5meV
FWHW=$30cm^{-1}$ ~ 3.8meV
peak absoption ~ 15%

Absorption in our detector:

~7.5% for polarized light

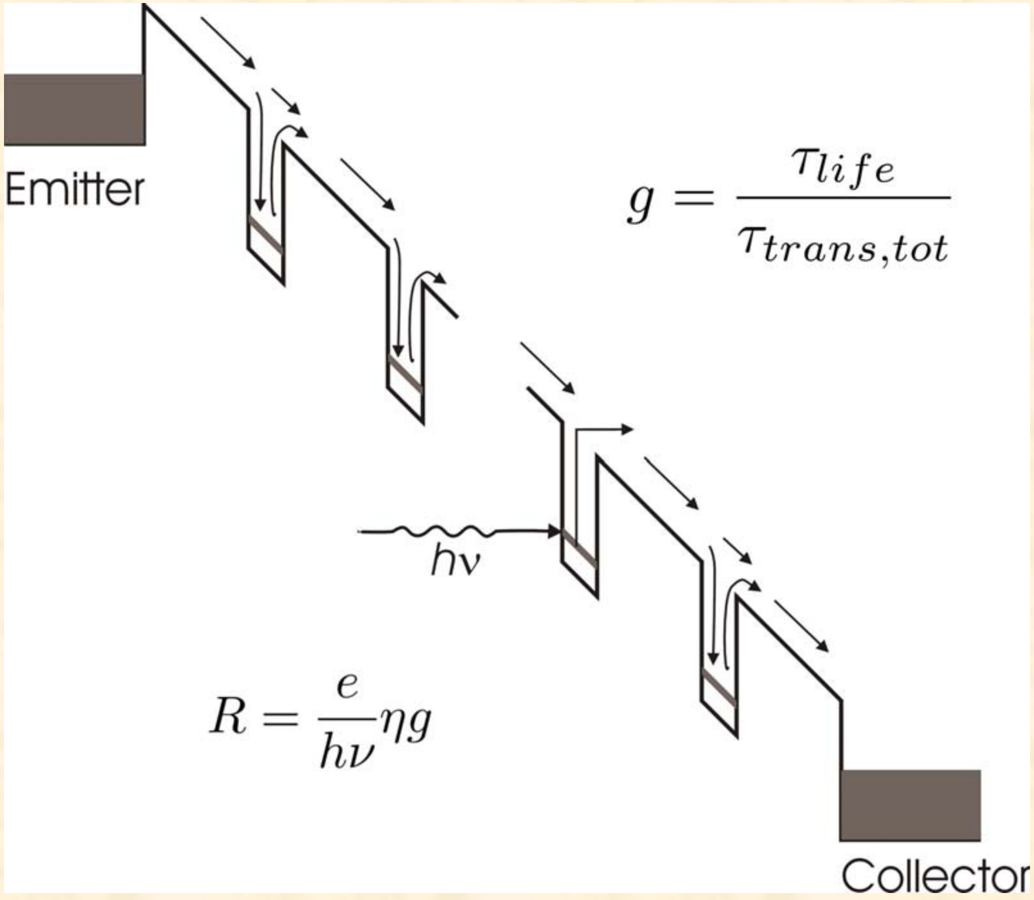
On-going:

Improve absorption by

- Higher doping
- More wells

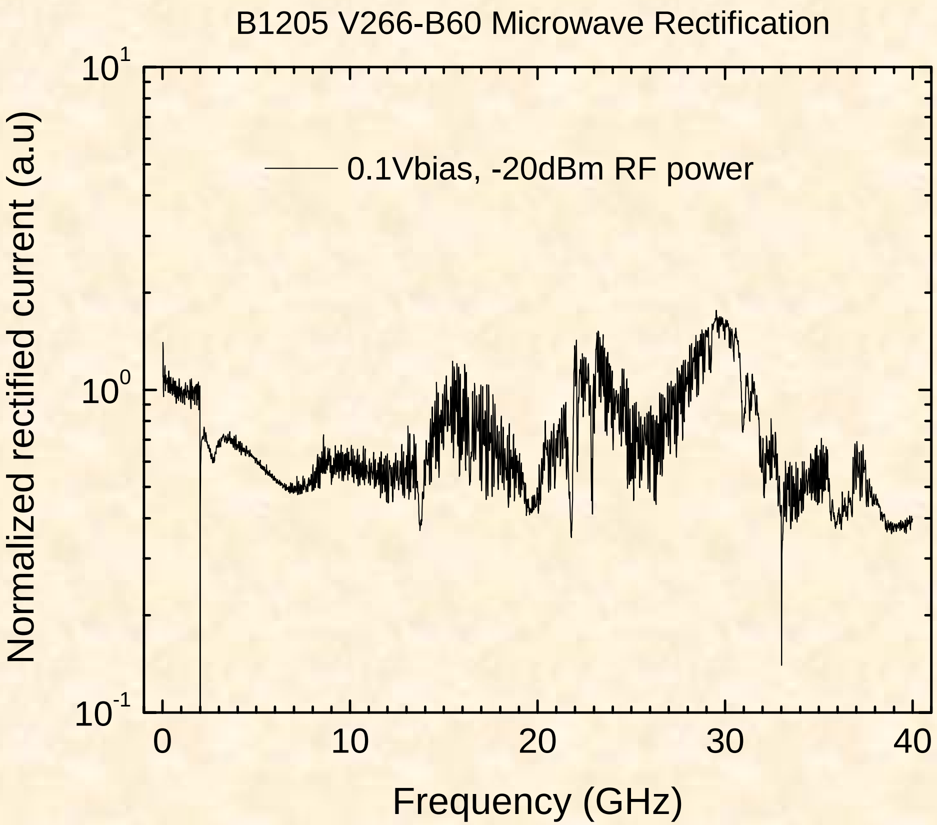
Goal: Absorption > 50%

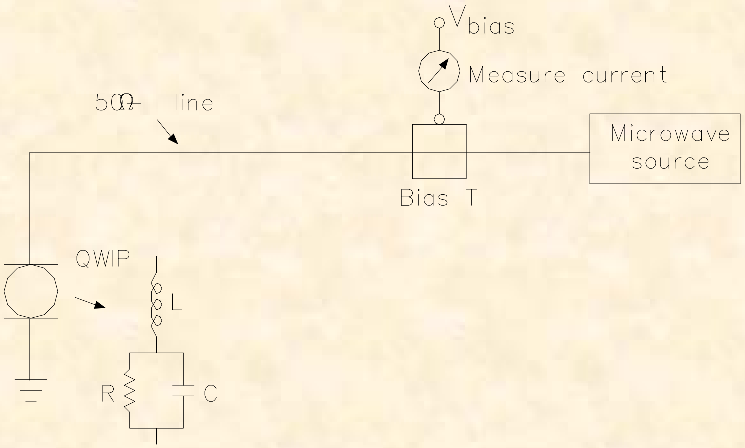
Future: High Speed Characteristics



$$g = \frac{\tau_{life}}{\tau_{trans,tot}}$$

$$R = \frac{e}{h\nu}\eta g$$


B1205 V266-B60 Microwave Rectification

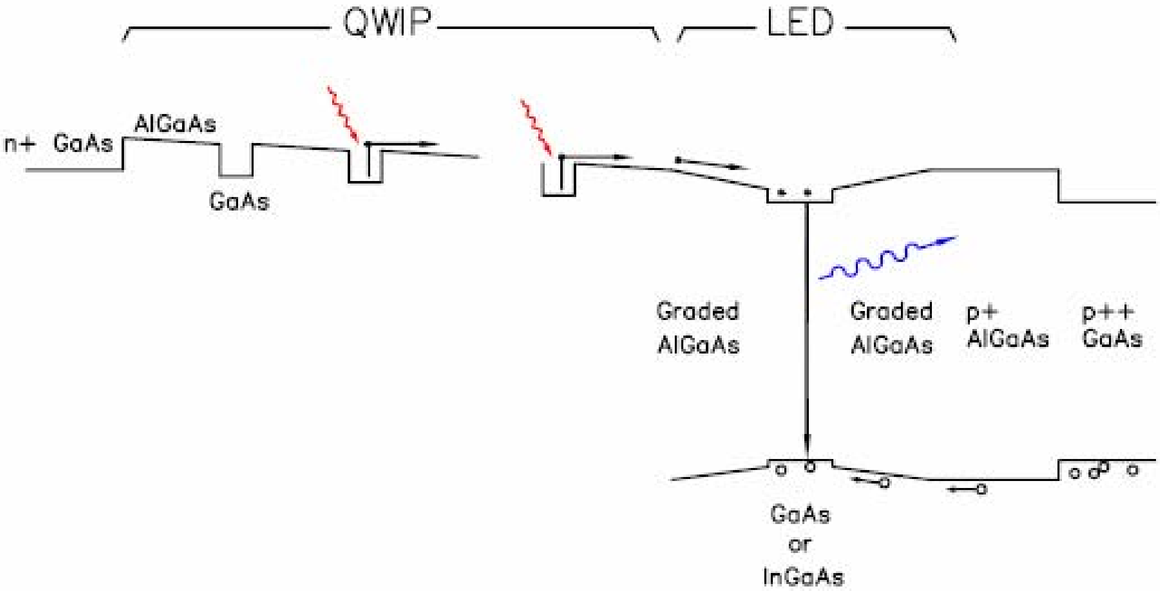


Goal: Flat response to 30 GHz

Application: THz heterodyne receiver

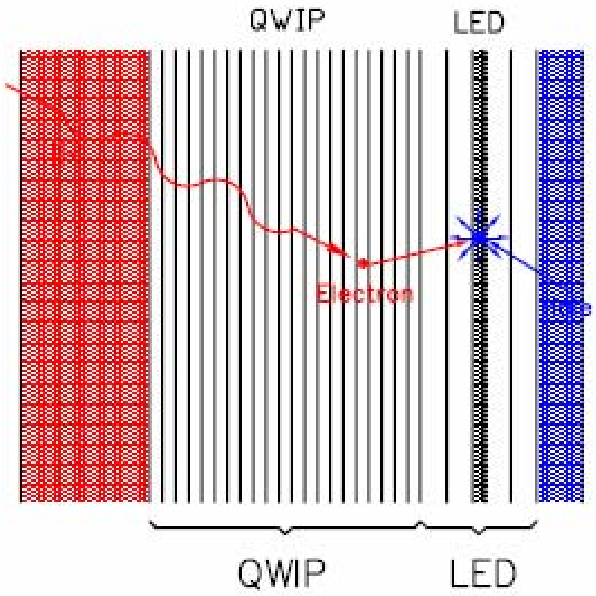
Future: THz Imaging Device

Long wavelength to near IR converter



Electron. Lett. 31, 832 (95)

QWIP–LED stack is thin pixellation may not be necessary



Key feature: thin active layer

Electron. Lett. 33, 378 (97)

Goal: Background limited performance imaging in THz region