Georgia State University

Si doped n-type GaAs/AlGaAs HEIWIP terahertz detector

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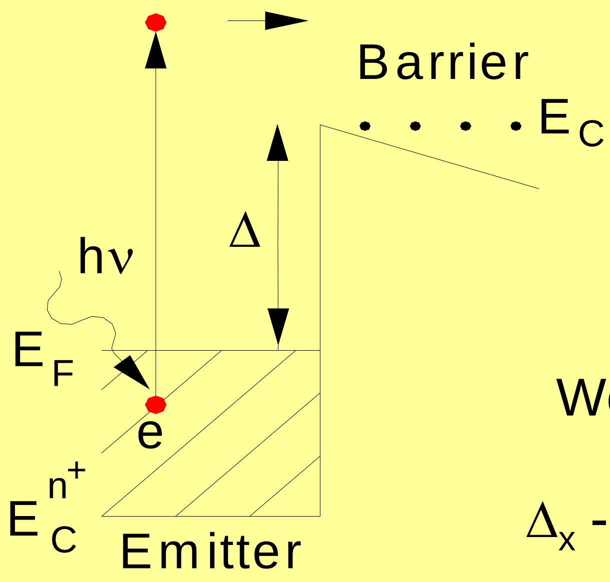
HEIWIP Detectors

HEterojunction **I**nterfacial **W**orkfunction **I**nternal **P**hotoemission Detector

- Detection mechanism in HEIWIP



Work function $\Delta = \Delta_x + \Delta_d$

Δ_x - Band offset between emitter and barrier

$\Delta_d = E_{narrow} - E_F$

Advantages

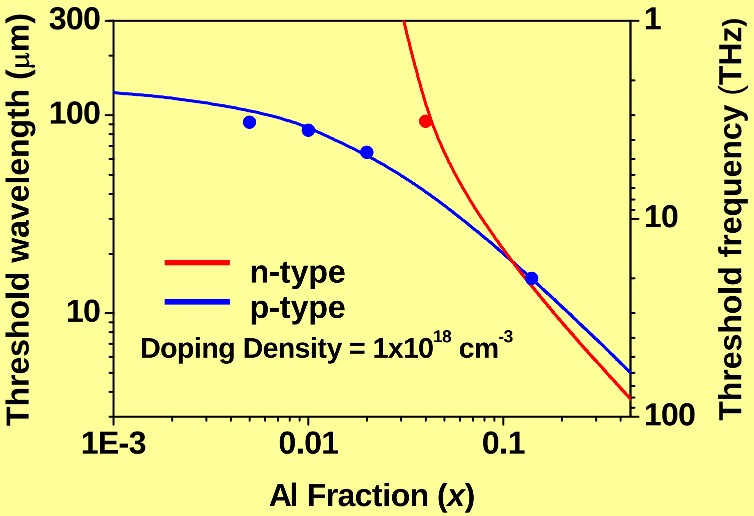
- Threshold freq (wavelength) tailorable over a wide range
- Normal incidence response
- Broadband response easily achieved
- High quantum efficiency
- Lower dark current [APL **78,** 224 (2001)]

p-type & n-type HEIWIP detectors

- Reported results are limited to p – type HEIWIP
- Easy to control the Fermi level and threshold frequency in p - type
- However, below 3 THz is difficult due to very low Al fraction (0.005) requirement[1]

Alternatives:

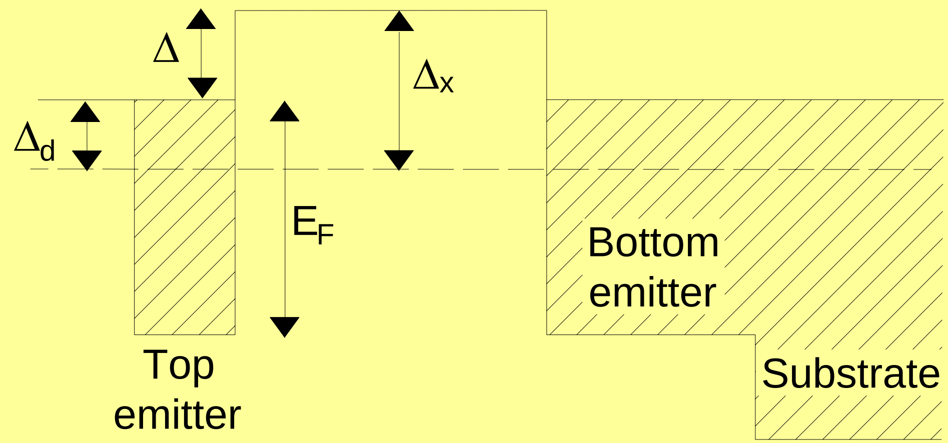
- doped AlGaAs emitter and undoped GaAs barrier: obtained 2.3 THz threshold[2]
- n-type HEIWIP detectors



1. *Matsik et.al., Appl. Phys. Lett., 82, (2003)*
2. *Rinzan et. al., Appl. Phys. Lett., 86, (2005)*

n-GaAs/$Al_xGa_{1-x}As$ HEIWIP Design

n^+ GaAs top emitter n = 1×10^{18} cm^{-3}	0.1 μm
$Al_xGa_{1-x}As$ barrier layer, x = 0.04	1 μm
n^+ GaAs top emitter n = 1×10^{18} cm^{-3}	0.7 μm
n^{++} GaAs substrate n = 5×10^{18} cm^{-3}	



Δ_x = 32 meV

E_F = 56 meV,

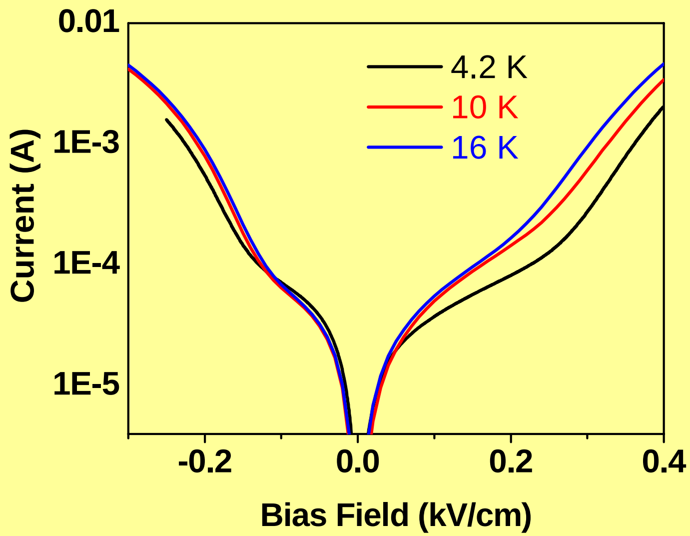
E_{narrow} ~ 36 meV,

Δ_d ~ - 20 meV

Δ ~ 12 meV

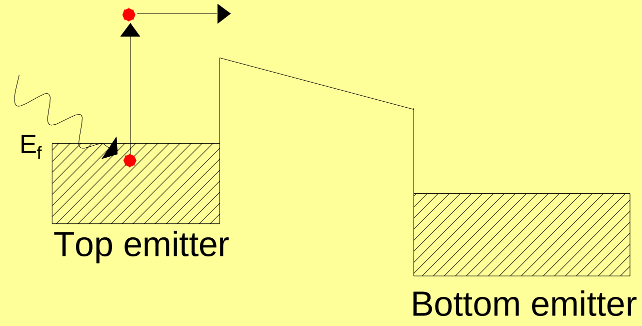
Characterization

- Dark current measurements

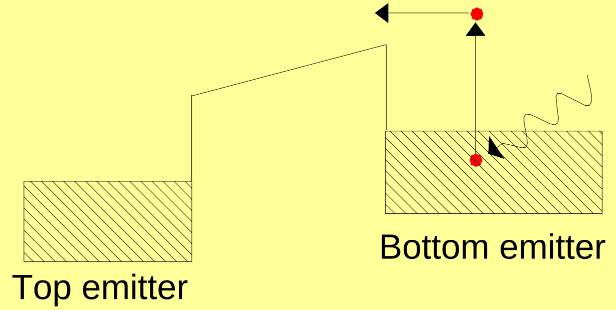


- Photoresponse measurements

(a) Emission from top emitter (reverse bias)

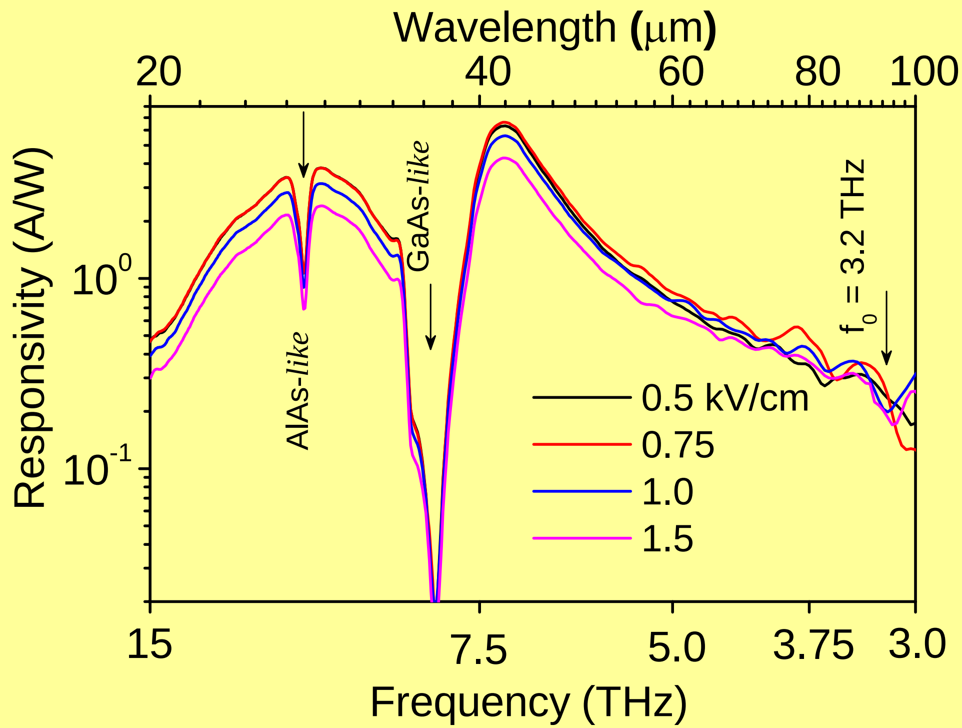


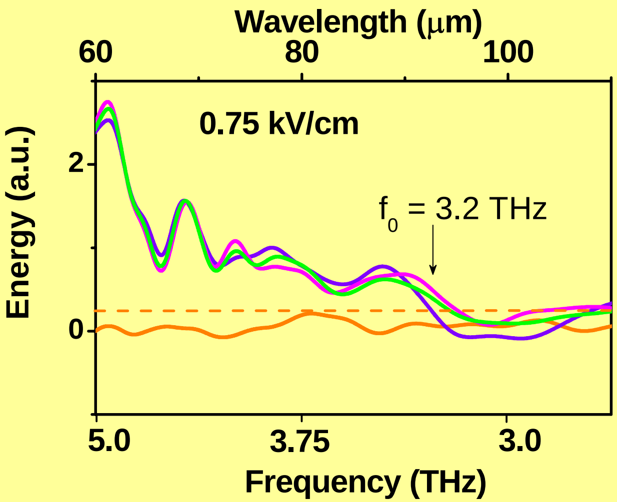
(b) Emission from bottom emitter (forward bias)



Responsivity

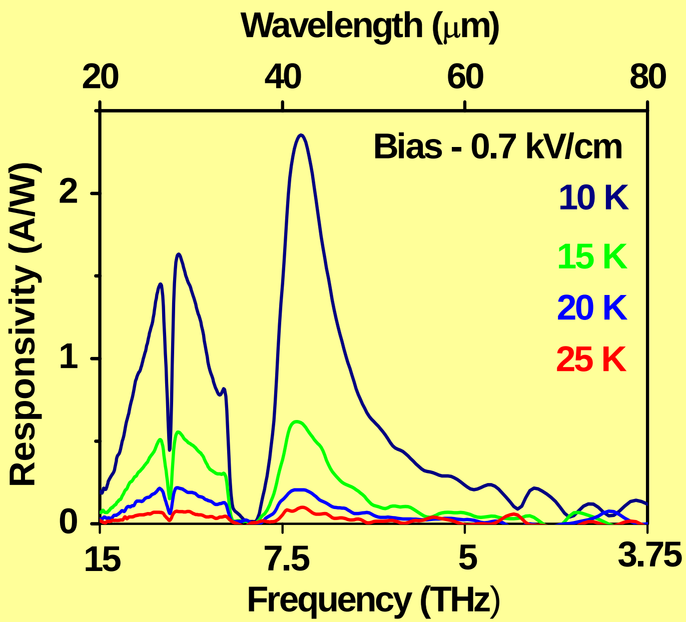
•Forward bias (Photoemission from bottom emitter)





- Spectra taken at 6 K
- Used Si composite bolometer to calibrate raw spectra
- Threshold frequency (f_0) – 3.2 THz (93 μm), R_{peak} = 6.4 A/W at 7.1 THz at 0.7 kV/cm

Responsivity



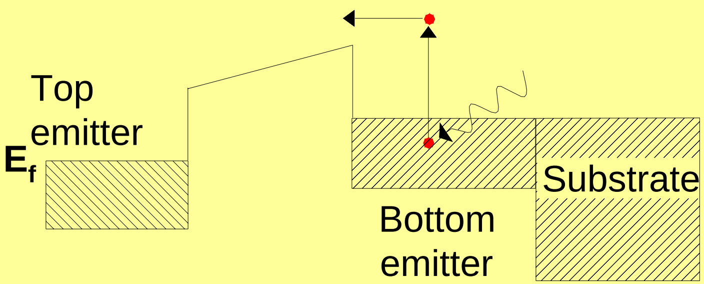
- Spectral response up to 25 K

At 6 K

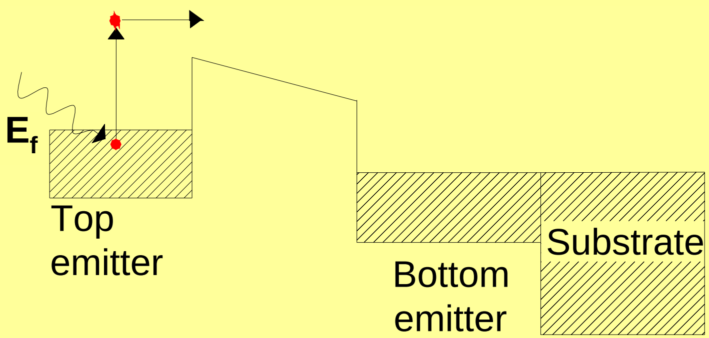
Bias (kV/cm)	R_{Peak}(A/W)	η_{Peak} (%)	$D^*_{Peak} \times 10^{10}$ (Jones)
0.2	3.0	8.9	5.1
0.5	6.1	18.2	4.4
0.7	6.4	18.9	3.4
1.0	5.5	16.4	1.7
1.5	4.1	12.3	1.5

Responsivity from top and bottom emitters

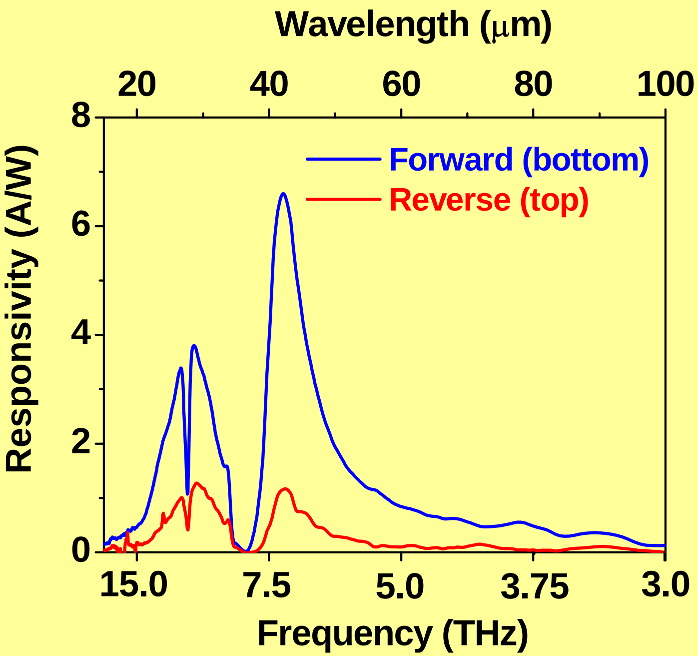
- Forward Bias



- Reverse Bias

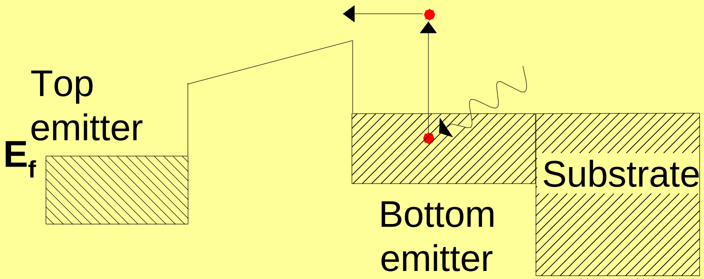


Responsivity from top and bottom emitters

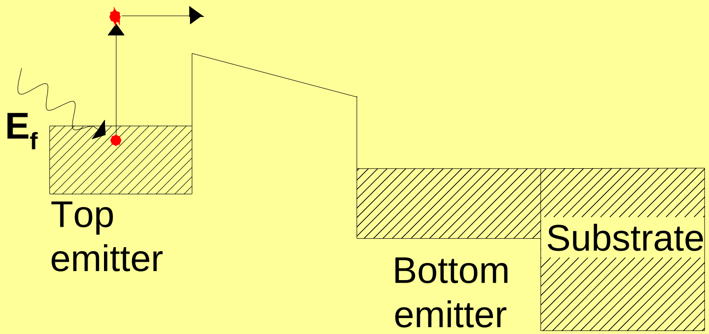


Responsivity from top and bottom emitters

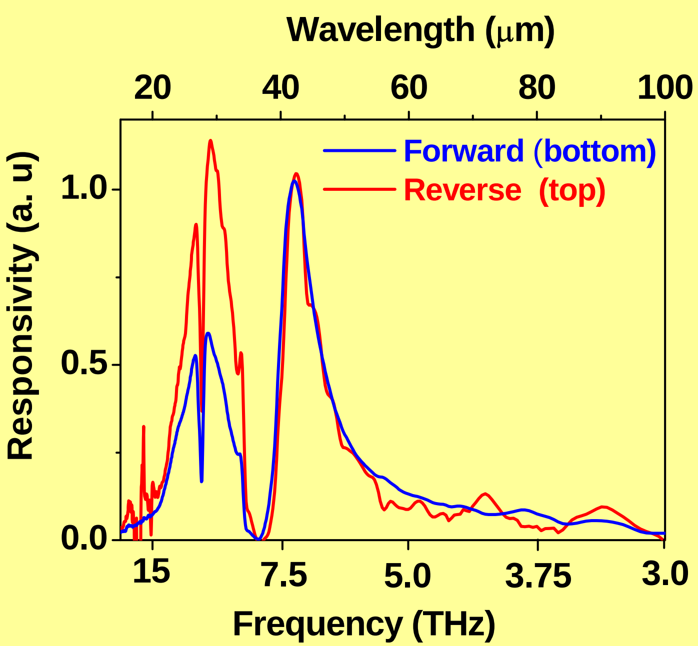
- Forward Bias



- Reverse Bias

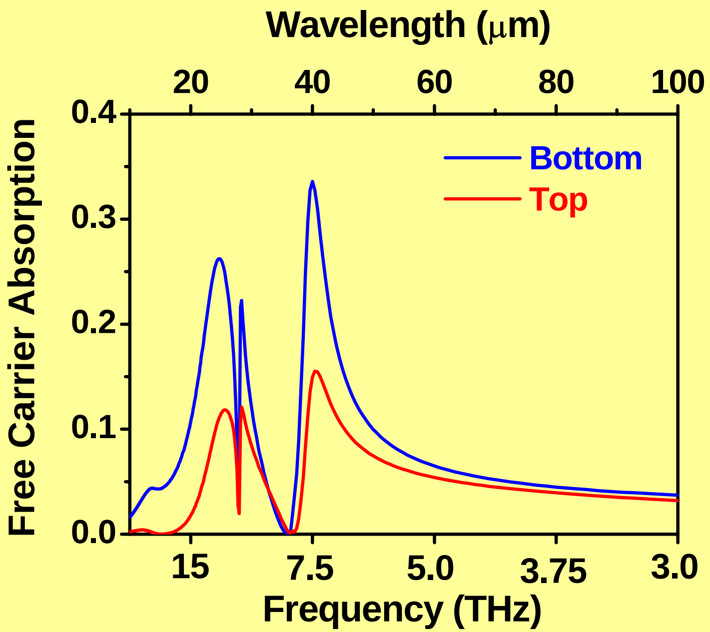


Responsivity from top and bottom emitters



Modeling

Calculated photo absorption in top and bottom emitters



Absorption probability

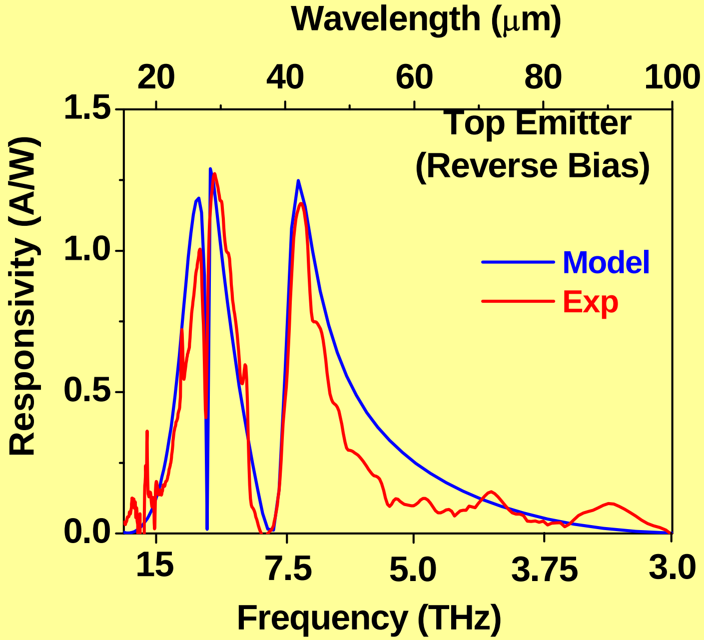
$$\eta_a = 2\tilde{I}\frac{\omega}{c}\mathrm{Im}\{\varepsilon\}W$$

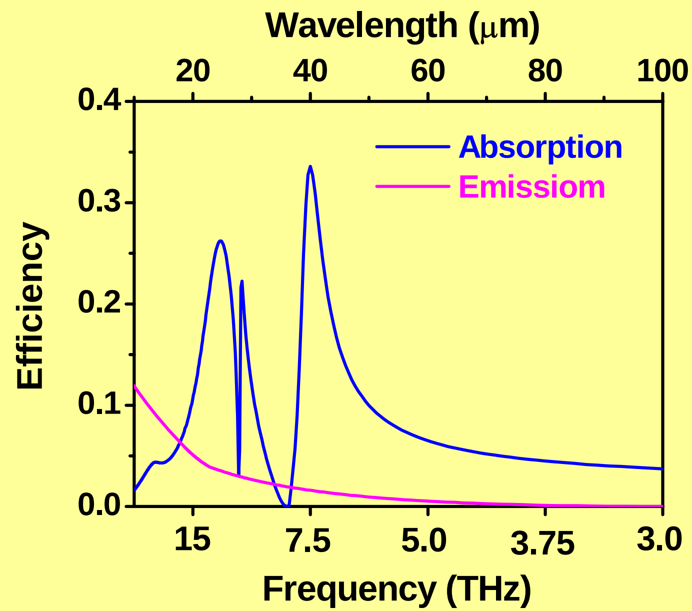
➢ The maximum absorption around 7.5 THz in both top and bottom emitters

Modeling

Photoemission

- Used escape cone model for photo emission[1]
- Assumed L_p = 20 nm, L_e = 0.4 µm





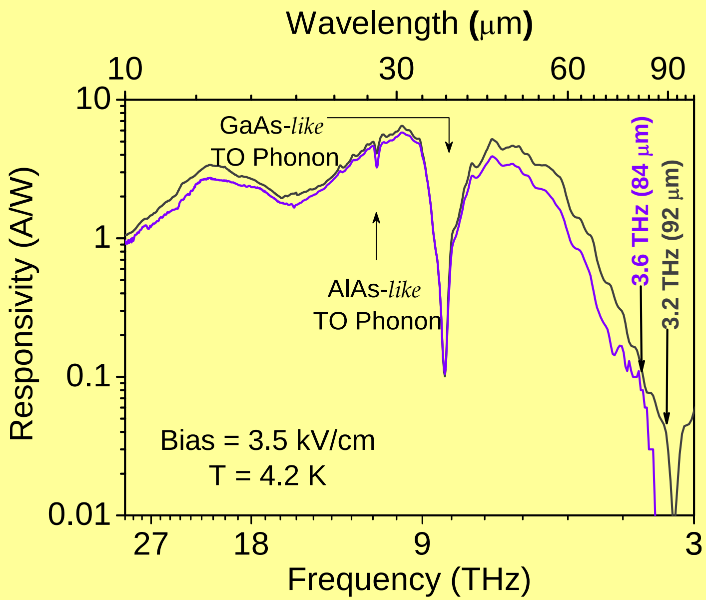
Higher energy electrons (> 8 THz) undergo a phonon emission giving a lower photoemission efficiency (> 8 THz)

1. J. M. Mooney and J. Silverman, IEEE Trans. Electron. Devices, **33**, (1985)

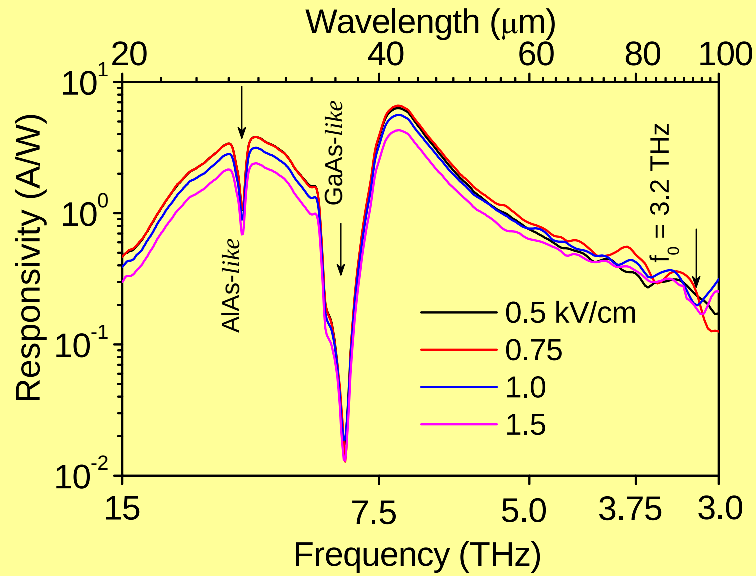
Comparison with p- type HEIWIP

- Threshold frequency - 3.2 THz (92 µm)[1], Al fraction used – 0.005
- R_{peak} = 6.0 A/W at 10 THz (30 µm).

p - type



n – type with doped substrate



	p-type	n-type
f_0 (THz)	3.2	3.2
R_{peak} (A/W)	6.0	6.4
Al fraction	0.005	0.04

1. Matsik et.at., Appl. Phys. Lett., 82, (2003)

Conclusions

- n-type HEIWIP terahertz detector with 3.2 THz (93 µm) threshold frequency has been successfully demonstrated.
- Al fraction used in the barrier is 0.04. Therefore, threshold frequency smaller than 3 THz can be achieved easily while keeping doping concentration in the emitter low (~1E18 cm^{-3})
- R_{peak} = 6.4 A/W at 7.1 THz (30 µm) was obtained at 0.7 kV/cm.
- It may be possible to go below 3 THz with n-type HEIWIP