InGaAs/InP DHBTs in a planarized, etch-back technology for base contacts

Vibhor Jain, Evan Lobisser, Ashish Baraskar, Brian J Thibeault, Mark Rodwell
ECE Department, University of California, Santa Barbara, CA 93106-9560

D Loubychev, A Snyder, Y Wu, J M Fastenau, W K Liu
IQE Inc., 119 Technology Drive, Bethlehem, PA 18015

vibhor@ece.ucsb.edu, 805-893-3273

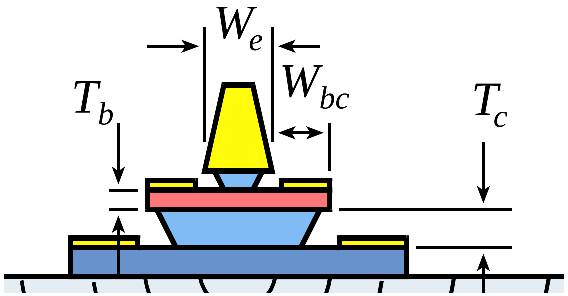
Outline

- HBT Scaling Laws
- Refractory base ohmics
- Fabrication
- DHBT – Epitaxial Design and Results
- Summary

Bipolar transistor scaling laws

$$\boxed{\frac{1}{2\pi f_\tau} = \tau_{tr} + RC}$$

$$\boxed{f_{\max} = \sqrt{\frac{f_\tau}{8\pi R_{bb,eff} C_{cb,eff}}}}$$



(emitter length L_e)

To ***double cutoff frequencies*** of a mesa HBT, must:

Keep ***constant*** all ***resistances*** and ***currents***
Reduce all ***capacitances*** and ***transit delays by 2***

$$\tau_b \approx T_b^2/2D_n + T_b/v_{exit}$$

$$\tau_c = T_c/2v_{sat}$$

Epitaxial scaling

$$C_{cb} = \varepsilon A_c/T_c$$

$$I_{c,\max} \propto v_{eff} A_e (V_{cb} + \phi_{bi})/T_c^2$$

Lateral scaling

$$R_{ex} = \rho_{contact}/A_e$$

$$R_{bb} = \rho_{sheet}\left(\frac{W_e}{12L_e} + \frac{W_{bc}}{6L_e}\right) + \frac{\rho_{contact}}{A_{contacts}}$$

Ohmic contacts

InP bipolar transistor scaling roadmap

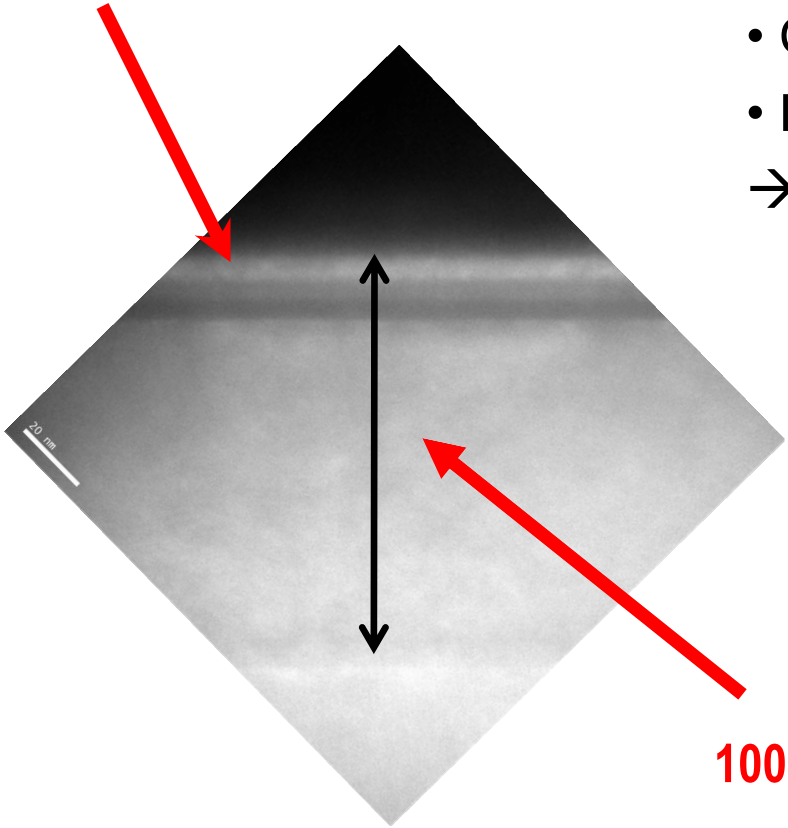
Design	**Emitter**	*256*	*128*	*64*	*32*	**Width (nm)**
		8	**4**	**2**	**1**	**Access ρ ($\Omega\cdot\mu m^2$)**
	Base	**175**	**120**	**60**	**30**	**Contact width (nm)**
		10	**5**	**2.5**	**1.25**	**Contact ρ ($\Omega\cdot\mu m^2$)**
	Collector	**106**	**75**	**53**	**37.5**	**Thickness (nm)**
Performance	**Current density**	**9**	**18**	**36**	**72**	**$mA/\mu m^2$**
	Breakdown voltage	**4**	**3.3**	**2.75**	**2-2.5**	**V**
	f_T	*520*	*730*	*1000*	*1400*	**GHz**
	f_{max}	*850*	*1300*	*2000*	*2800*	**GHz**

Rodwell, Le, Brar, Proceedings of IEEE, 2008

Contact diffusion

TEM by E Lobisser

Ashish Baraskar



15 nm Pd diffusion

100 nm InGaAs grown in MBE

- Pd contacts diffuse in base (p-InGaAs)
- Contact resistance ↑ for thin base
- Limits base thickness

→ Scaling Limitation

Need for **non-diffusive**, **refractory** base metal

Refractory base ohmics

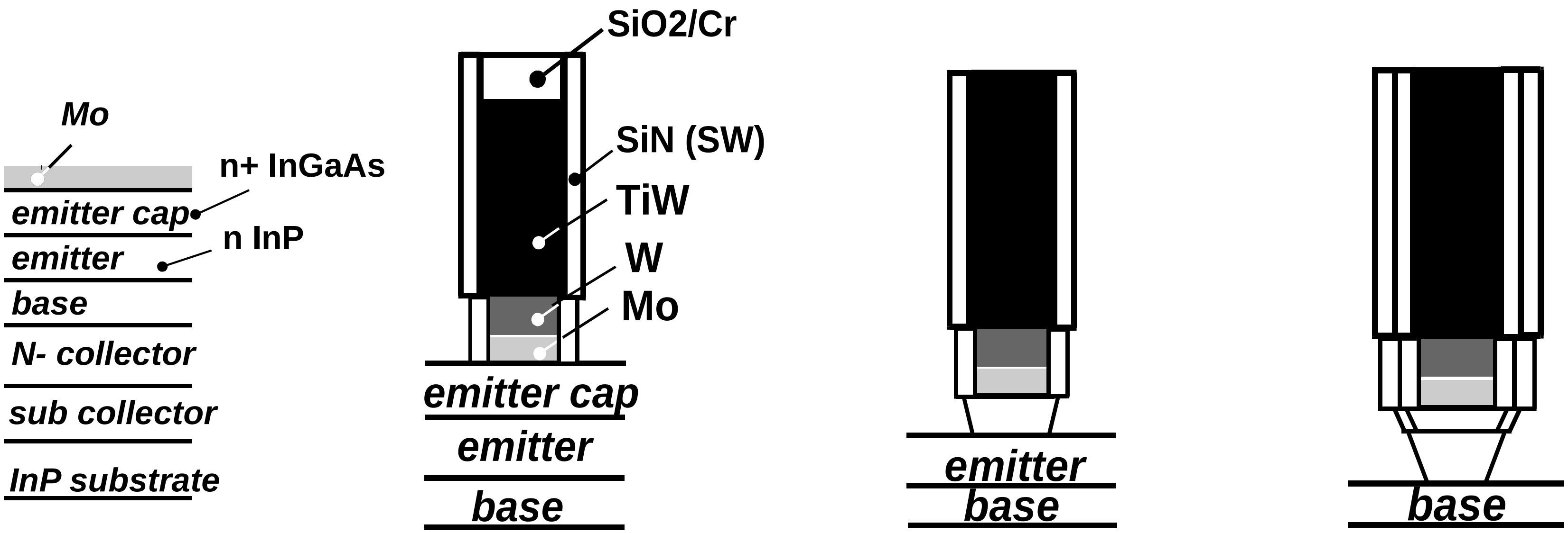
Ashish Baraskar *et al.*, EMC 2010
Ashish Baraskar *et al.*, Int. MBE 2010

Doping	Metal	Type	ρ_c (Ω-μm^2)
1.5E20	Mo	As deposited	2.5
1.5E20	Ru/Mo	As deposited	1.3
1.5E20	W/Mo	As deposited	1.2
1.5E20	Ir/Mo	As deposited	1.0
2.2E20	Ir/Mo	As deposited	0.6
2.2E20	Ir/Mo	Annealed	0.8

Refractory metal base contacts

Require a blanket deposition and etch-back process

Emitter process flow



Mo contact to n-InGaAs for emitter

W/TiW/SiO_2/Cr dep

SF_6/Ar etch

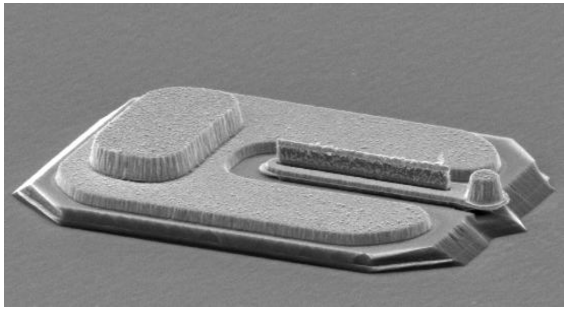
SiN_x Sidewall

SiO_2/Cr removal

InGaAs Wet Etch

Second SiN_x Sidewall

InP Wet Etch



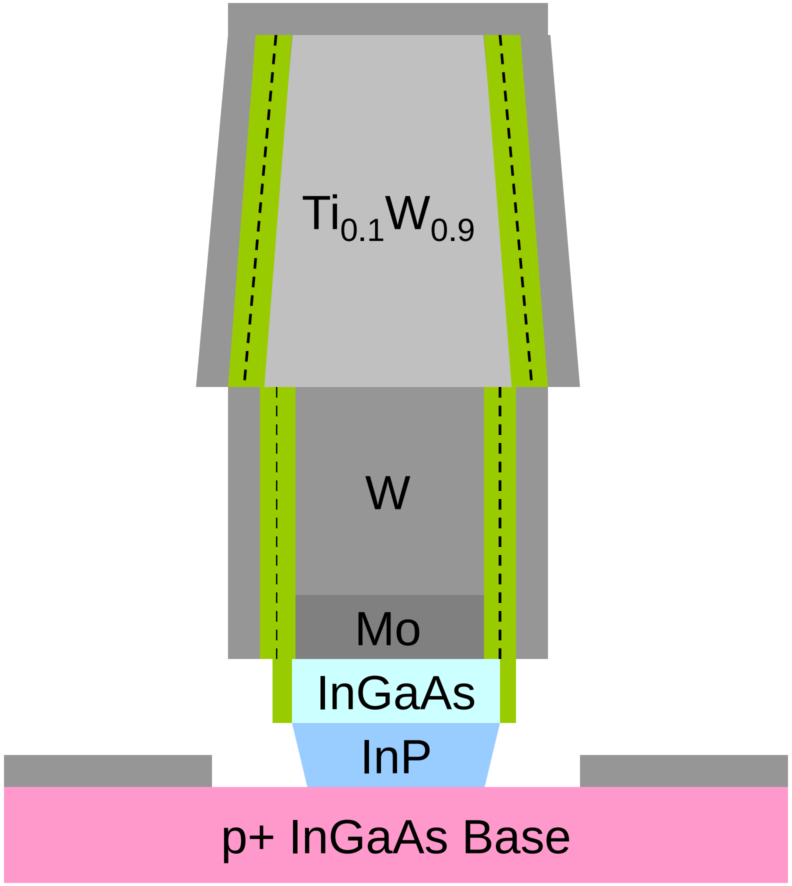
W/TiW interface acts as shadow mask for base lift off

Collector formed via ***lift off*** and ***wet etch***

BCB used to passivate and planarize devices

Base process flow – I

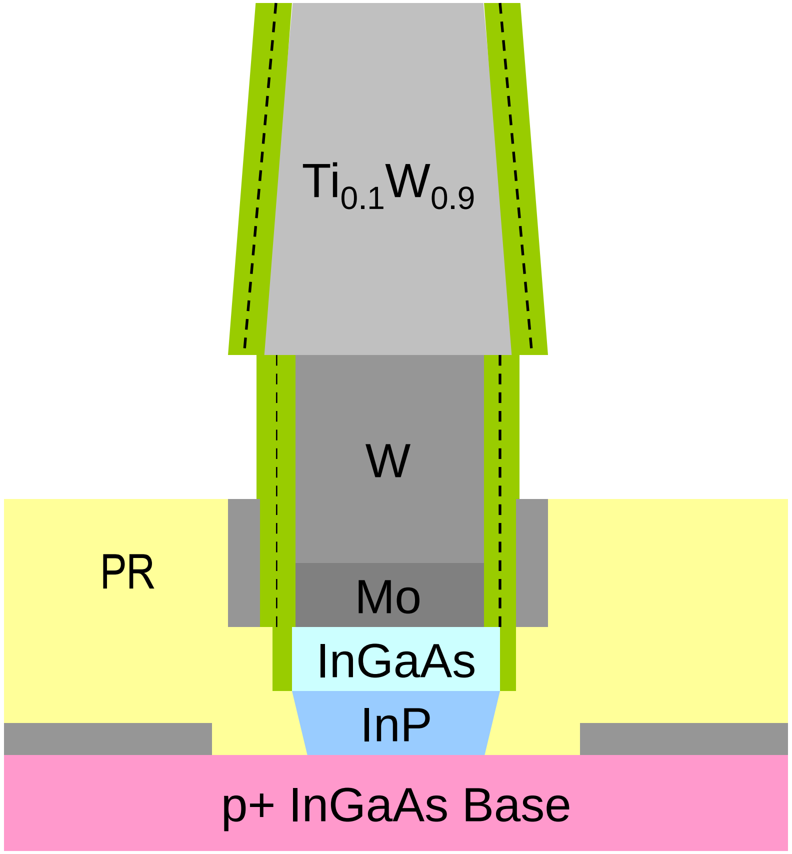
Blanket refractory metal



PR Planarization

Isotropic Dry etch of metal

Removes any Emitter-Base short



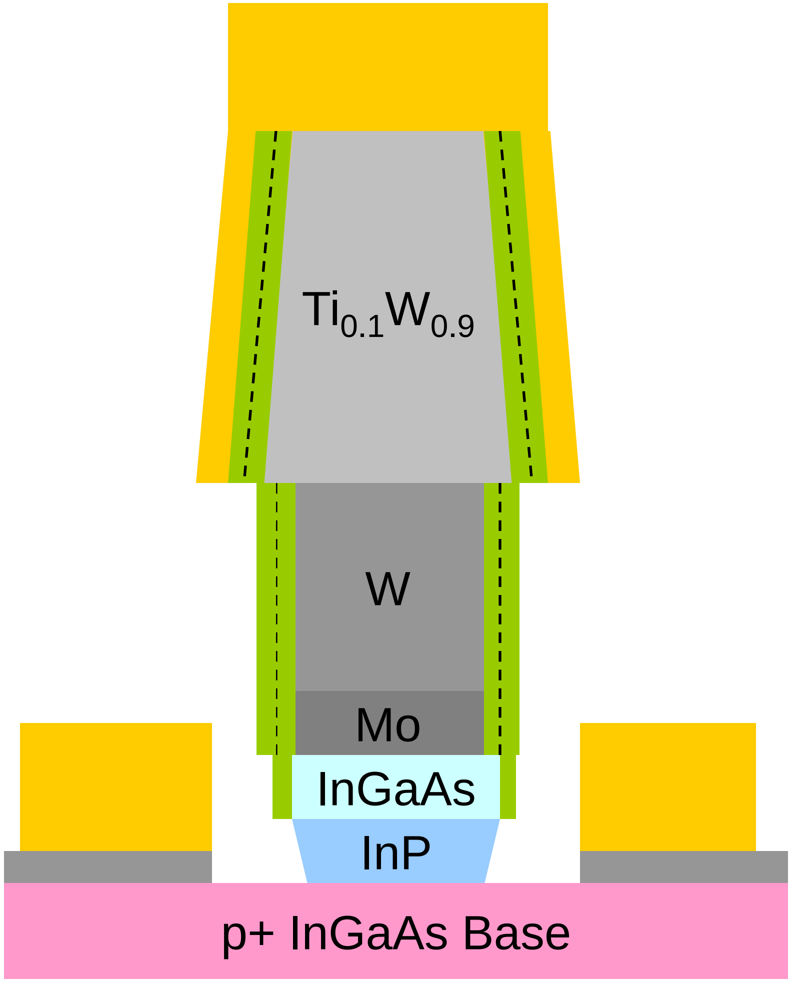
Base process flow – II

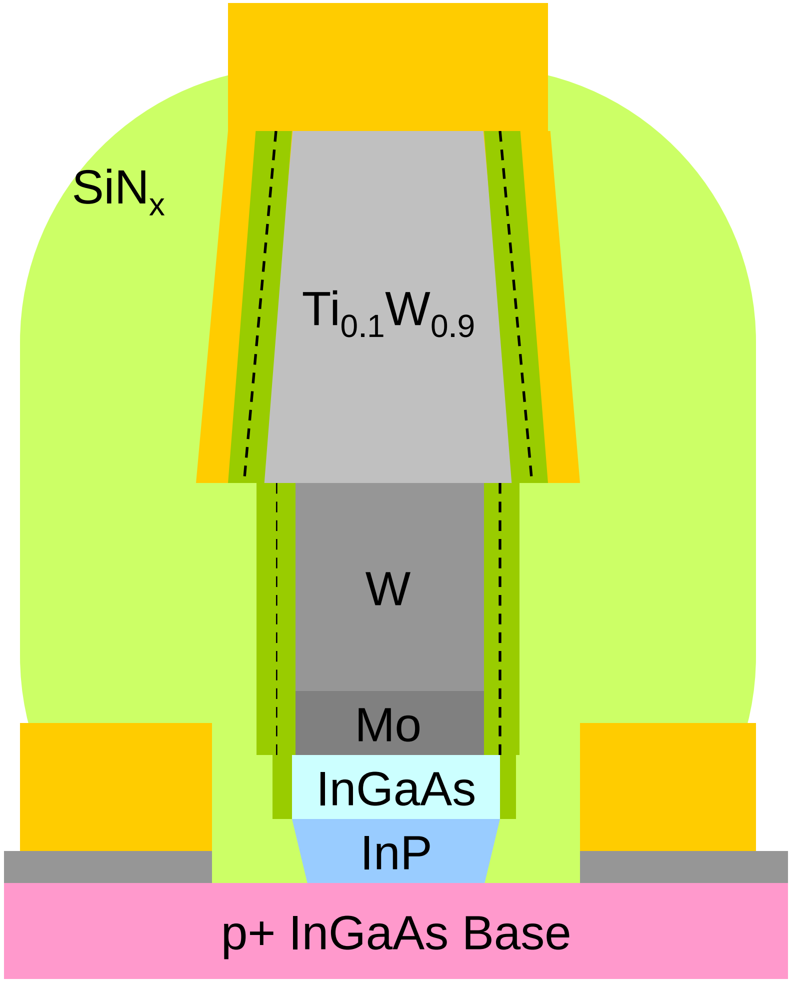
Lift-off Ti/Au

Low base metal resistance

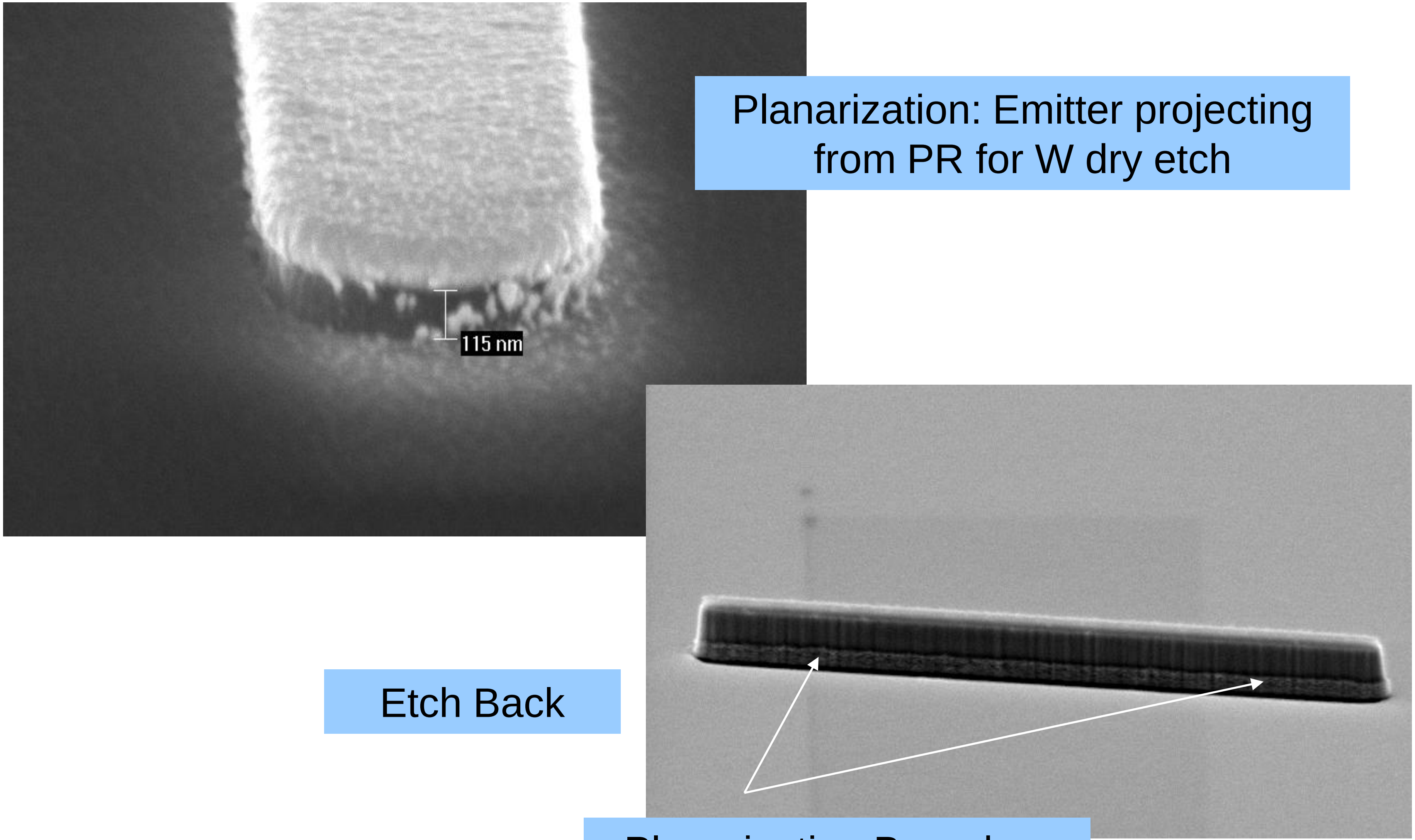
Blanket SiN_x mask

Etch base contact metal in the field





Base Planarization



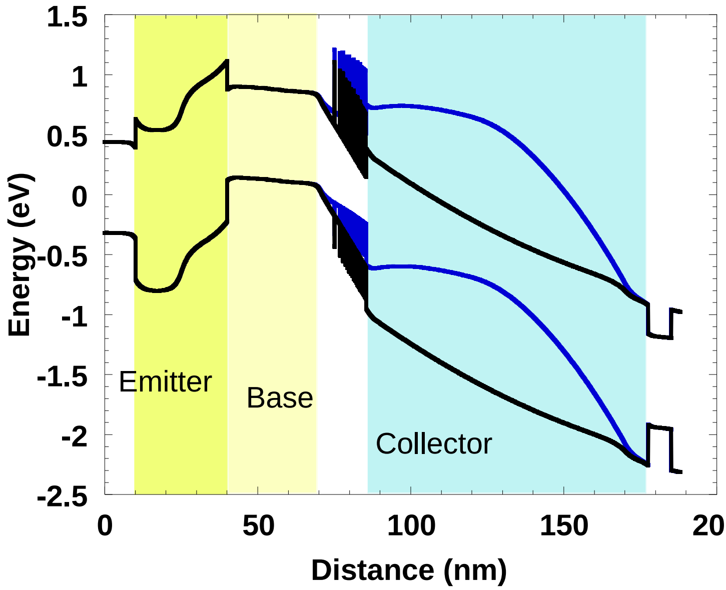
Planarization: Emitter projecting from PR for W dry etch

Etch Back

Planarization Boundary

Epitaxial Design

T(nm)	Material	Doping (cm^{-3})	Description
10	**$In_{0.53}Ga_{0.47}As$**	**$8\cdot10^{19}$: Si**	**Emitter Cap**
15	**InP**	**$5\cdot10^{19}$: Si**	**Emitter**
15	**InP**	**$2\cdot10^{18}$: Si**	**Emitter**
30	**InGaAs**	**$9\text{-}5\cdot10^{19}$: C**	**Base**
4.5	**$In_{0.53}Ga_{0.47}$ As**	**$9\cdot10^{16}$: Si**	**Setback**
10.8	**InGaAs / InAlAs**	**$9\cdot10^{16}$: Si**	**B-C Grade**
3	**InP**	**$6\cdot10^{18}$: Si**	**Pulse doping**
81.7	**InP**	**$9\cdot10^{16}$: Si**	**Collector**
7.5	**InP**	**$1\cdot10^{19}$: Si**	**Sub Collector**
7.5	**$In_{0.53}Ga_{0.47}$ As**	**$2\cdot10^{19}$: Si**	**Sub Collector**
300	**InP**	**$2\cdot10^{19}$: Si**	**Sub Collector**
Substrate	**SI : InP**		



V_{be} = 1 V, V_{cb} = 0.7 V, J_e = 25 mA/μm^2

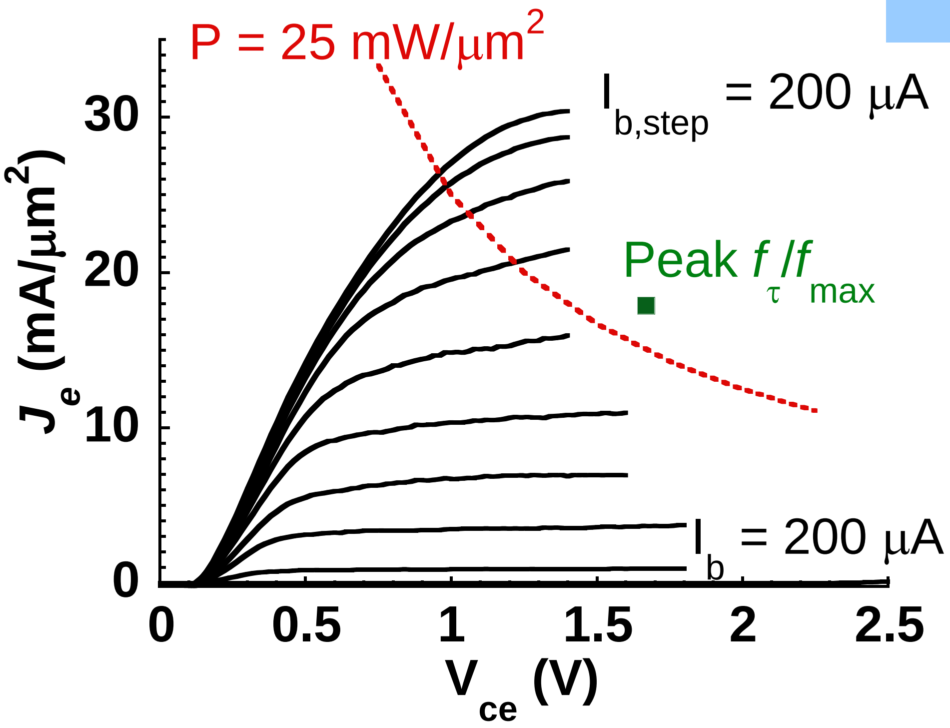
Low Base doping

→ Good refractory ohmics not possible

→ Pd/W contacts used

Results - DC Measurements

Common emitter I-V



@Peak f_τ,f_{max}

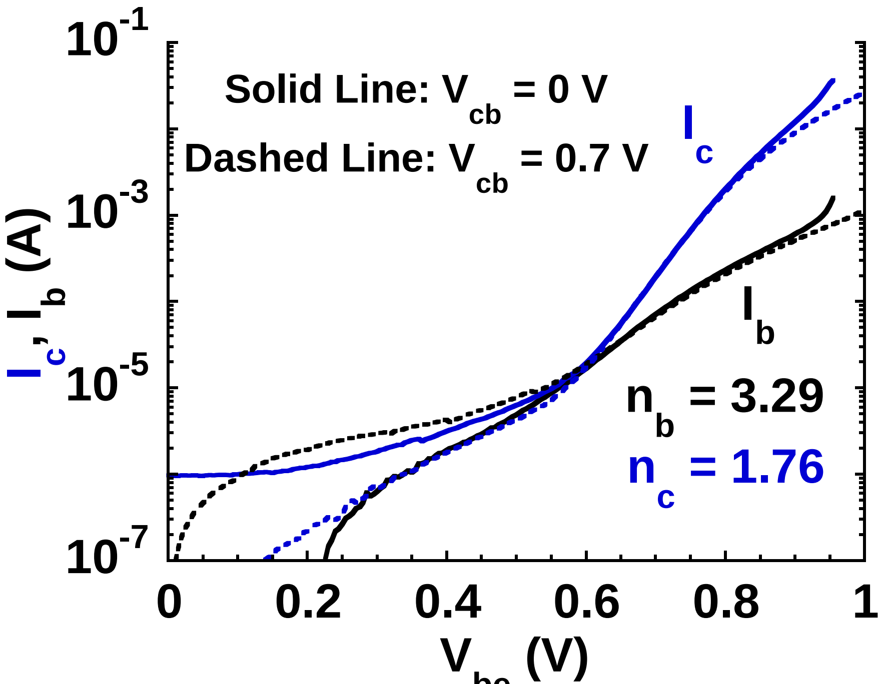
J_e = 17.9 mA/μm²

P = 30 mW/μm²

BV_{ceo} = ***2.4 V*** @ J_e = 1 kA/cm²

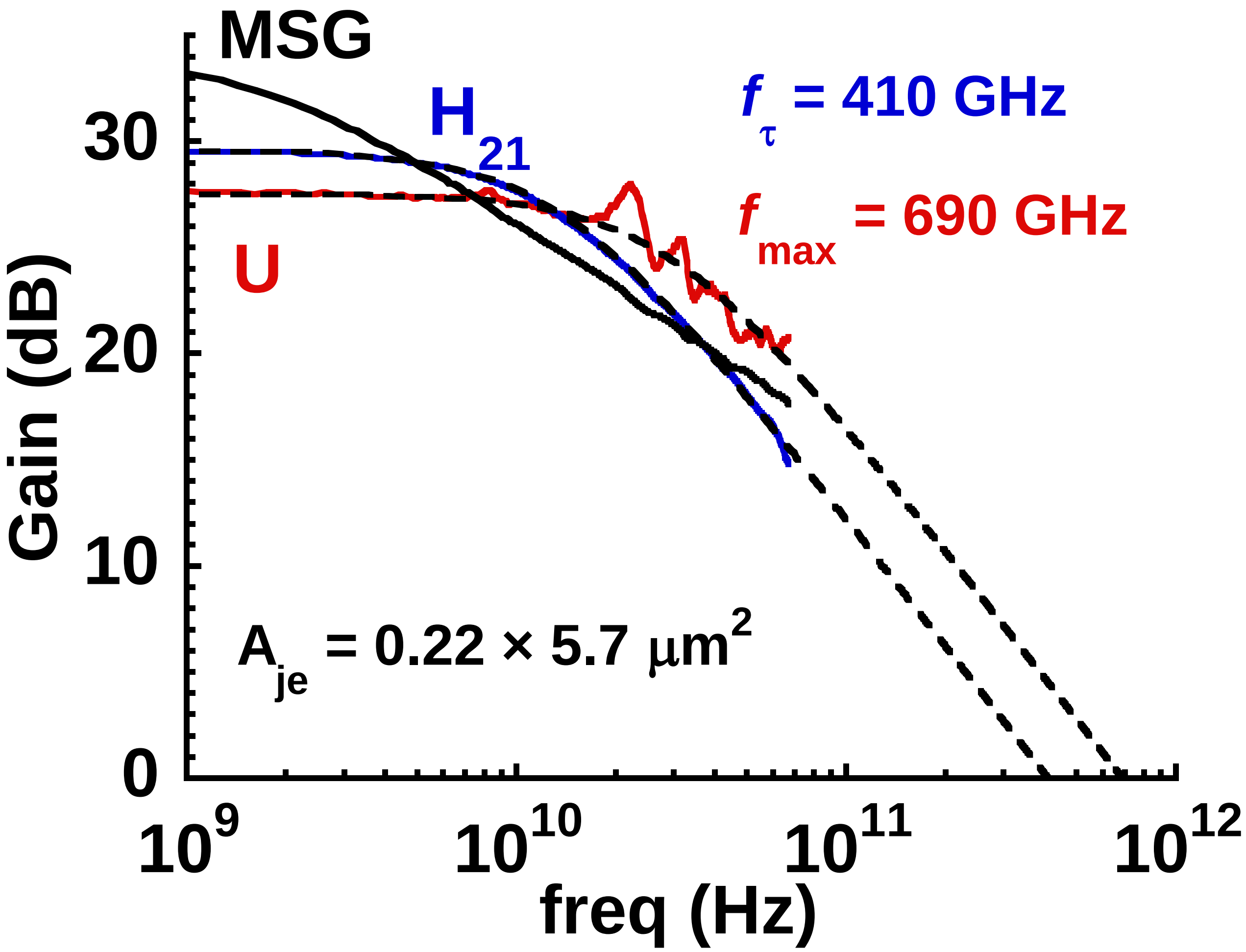
β = ***26***

J_{KIRK} = 21 mA/μm²



Gummel plot

1-67 GHz RF Data



I_c = 22.4 mA

V_{ce} = 1.67 V

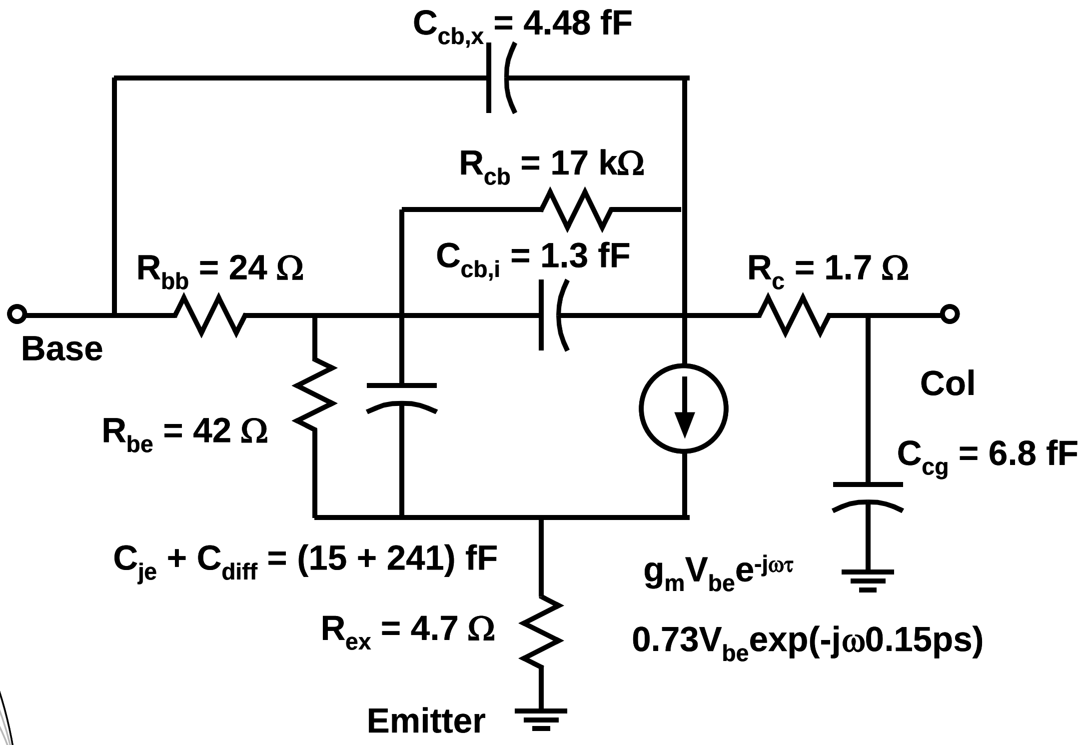
J_e = 17.9 mA/μm^2

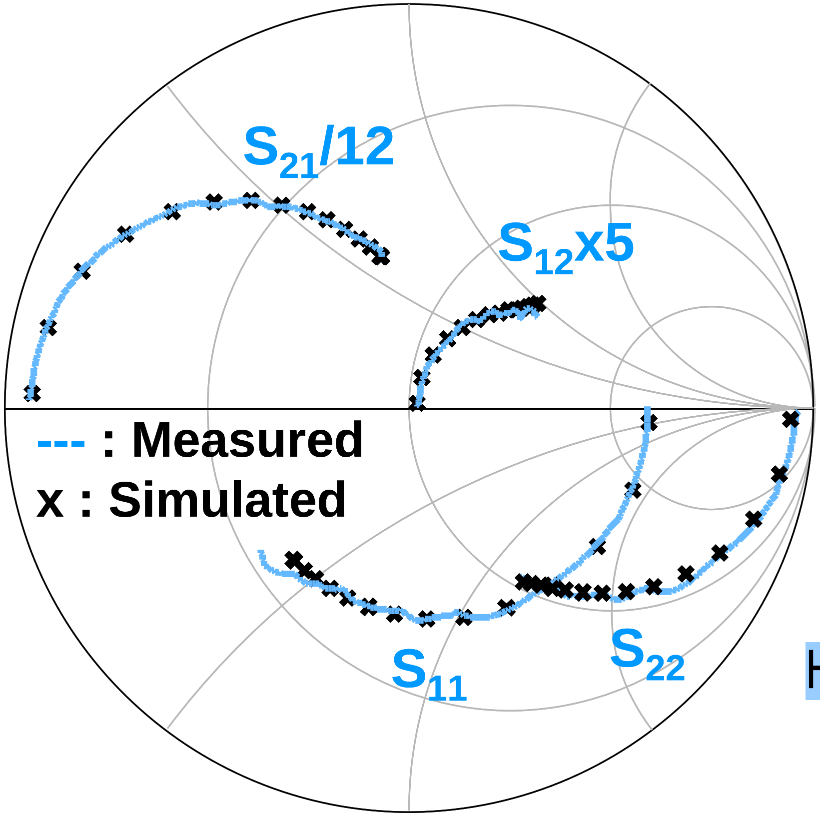
V_{cb} = 0.7 V

Single-pole fit to obtain cut-off frequencies

Equivalent Circuit

R_{ex} = 6 $\Omega\cdot\mu m^2$





Hybrid-π equivalent circuit from measured RF data

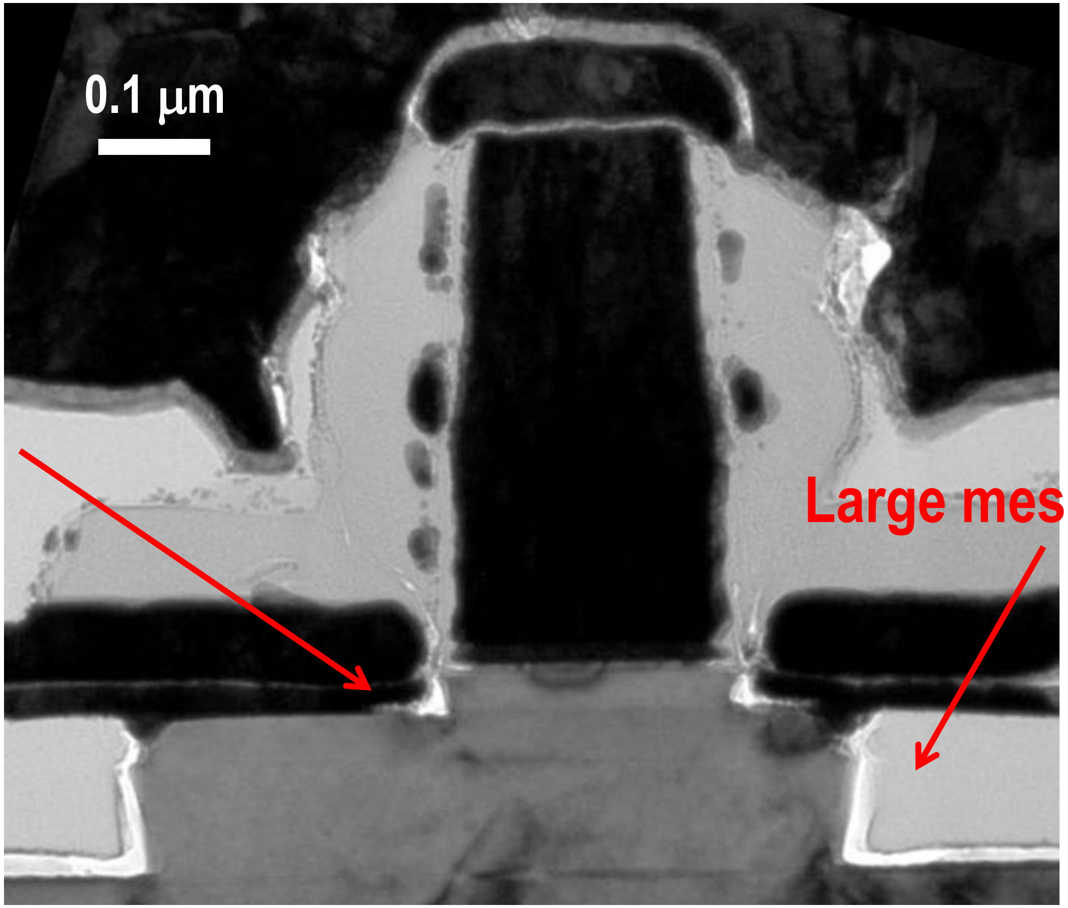
TEM

Large undercut in base mesa

Pd/W adhesion issue

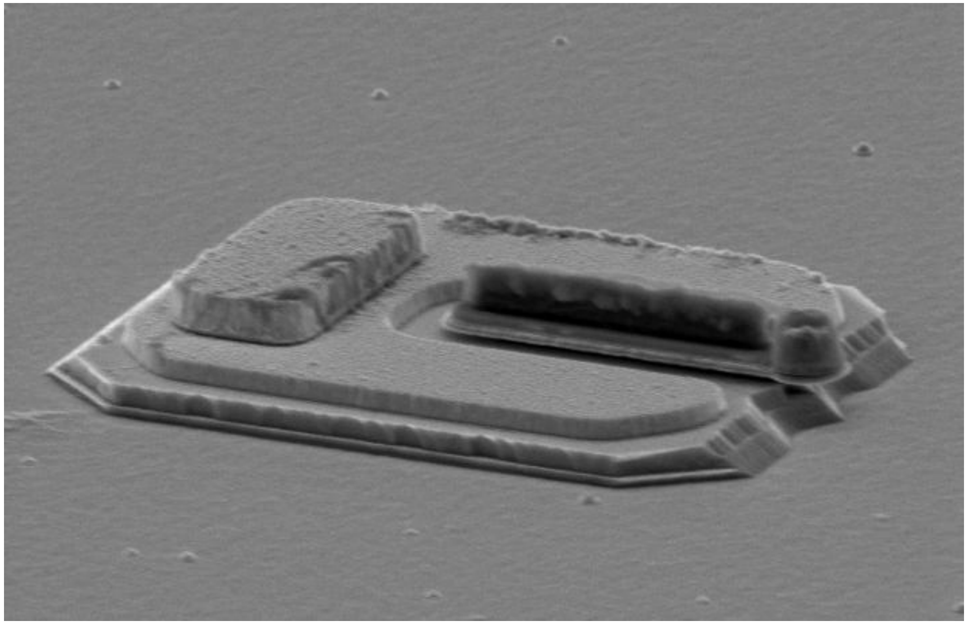
→ High R_{bb}

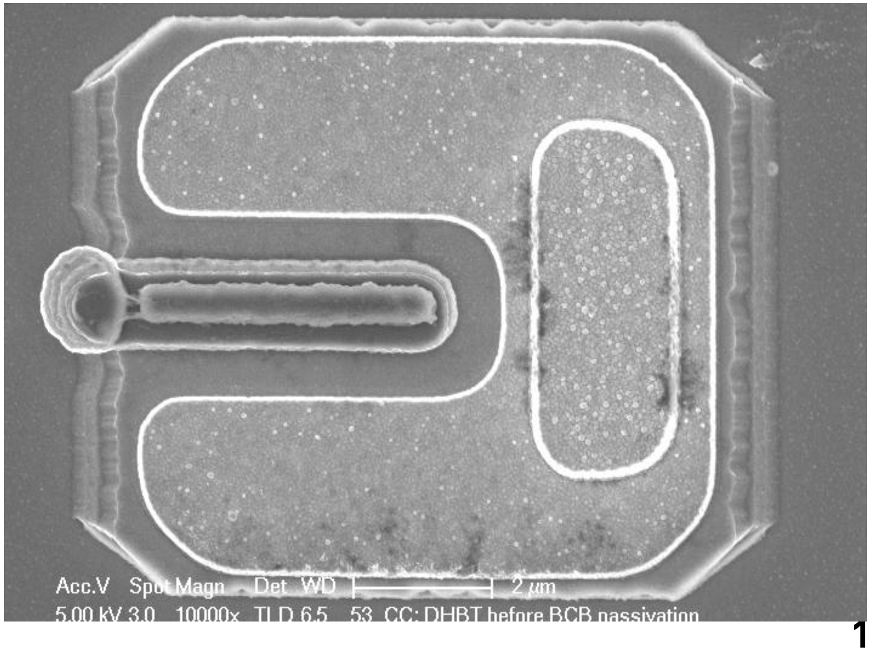
→ Low f_{max}



Summary

- Demonstrated a **planarized, etch back process** for **refractory base contacts**
- Demonstrated DHBTs with peak f_τ / f_{max} **= 410/690 GHz**
- **Higher base doping, thinner base and refractory base ohmics** needed to enable higher bandwidth devices





Thank You

Questions?

This work was supported by the DARPA THETA program under HR0011-09-C-006.

A portion of this work was done in the UCSB nanofabrication facility, part of NSF funded NNIN network and MRL Central Facilities supported by the MRSEC Program of the NSF under award No. MR05-20415