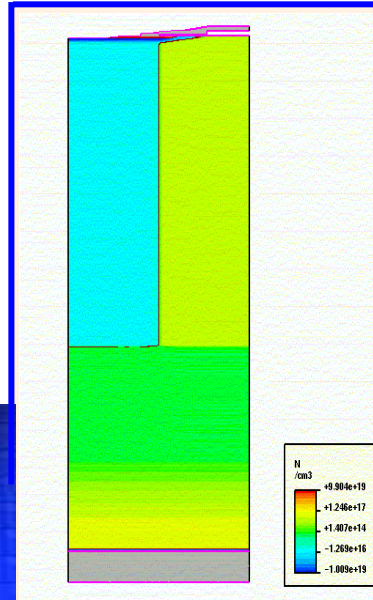


Friedhelm Bauer
ABB Switzerland Ltd.

ROBUSPIC workshop
ISPSD'06 Napoli



Bipolar Super Junction Power Devices: A Case Study for Complex Numerical Modelling

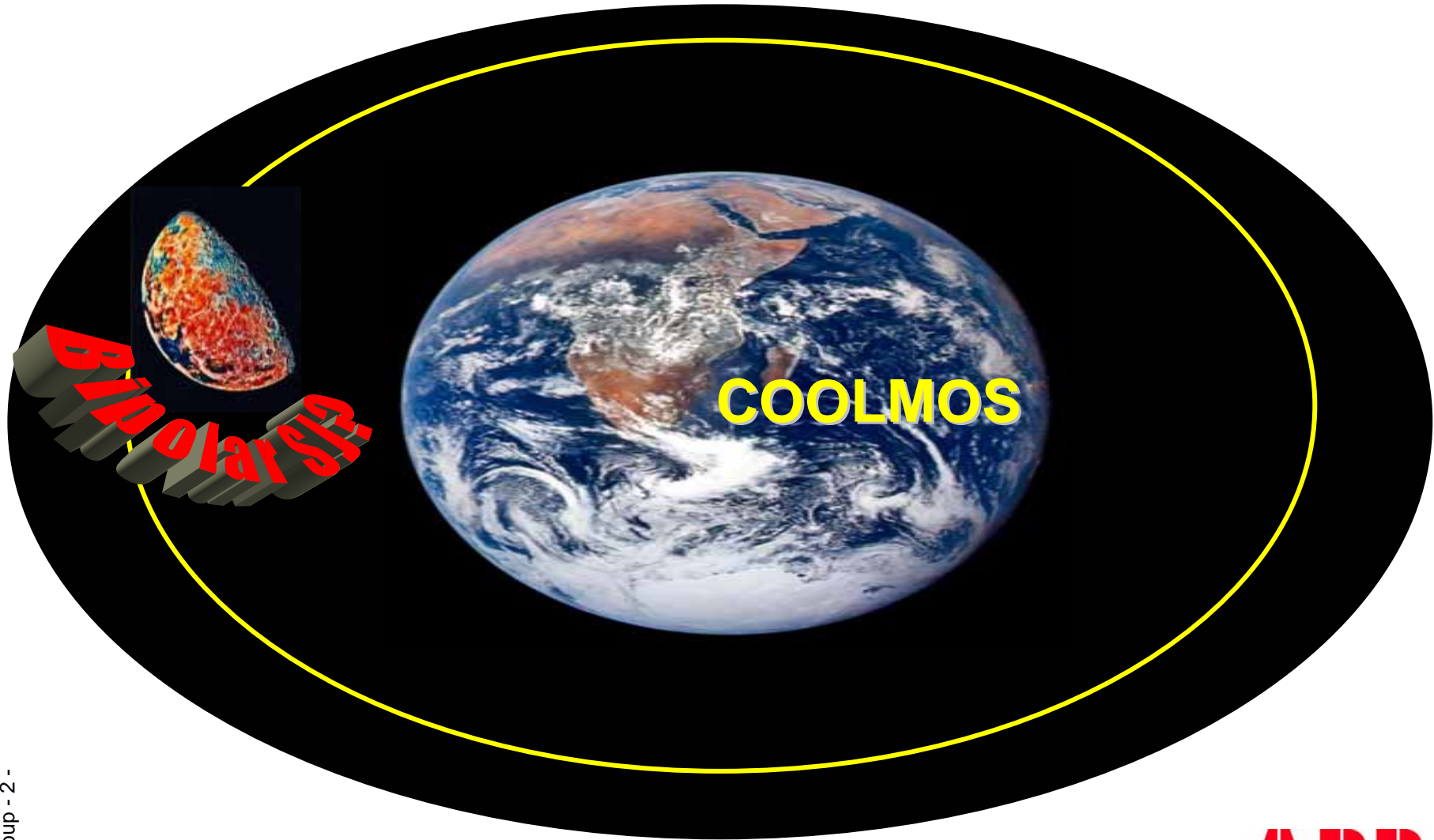
NO EXPONENTIAL IS FOREVER ...

Gordon E. Moore

BUT

WE CAN DELAY "FOREVER"

IS THERE LIFE IN SPACE??

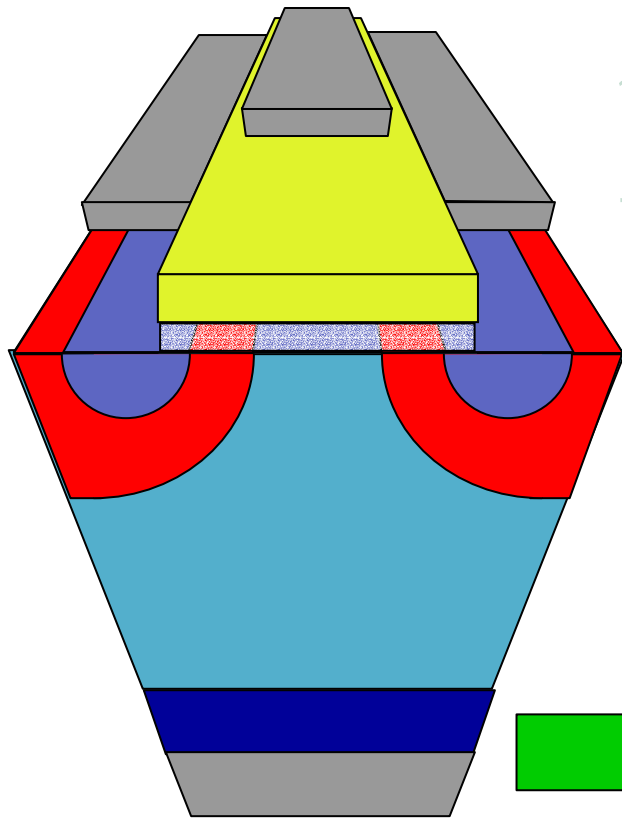


PAST DEVELOPMENT

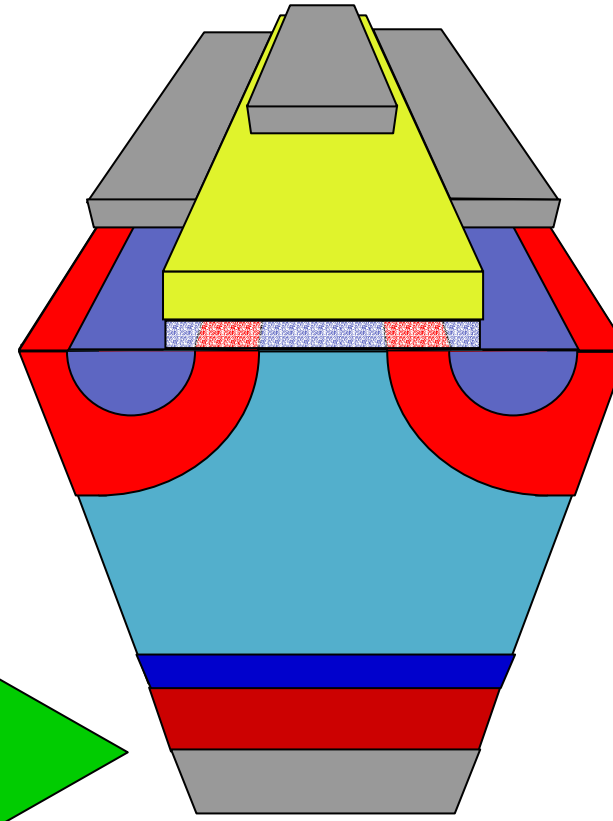
...from **VDMOSFET**

to

IGBT...



1980
1980



n-doped drain

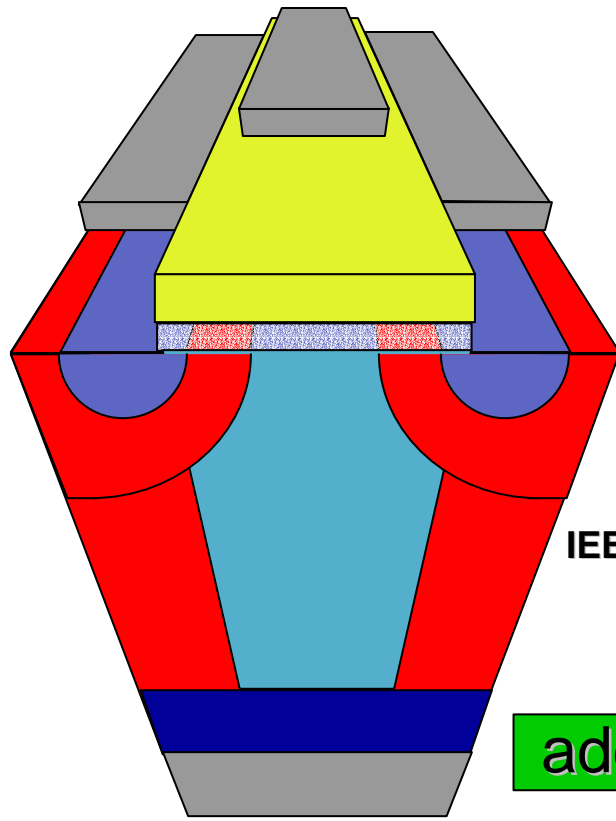
p-doped anode

FUTURE DEVELOPMENT?

...from **SJ MOSFET**

to

SJBT...



n-doped drain

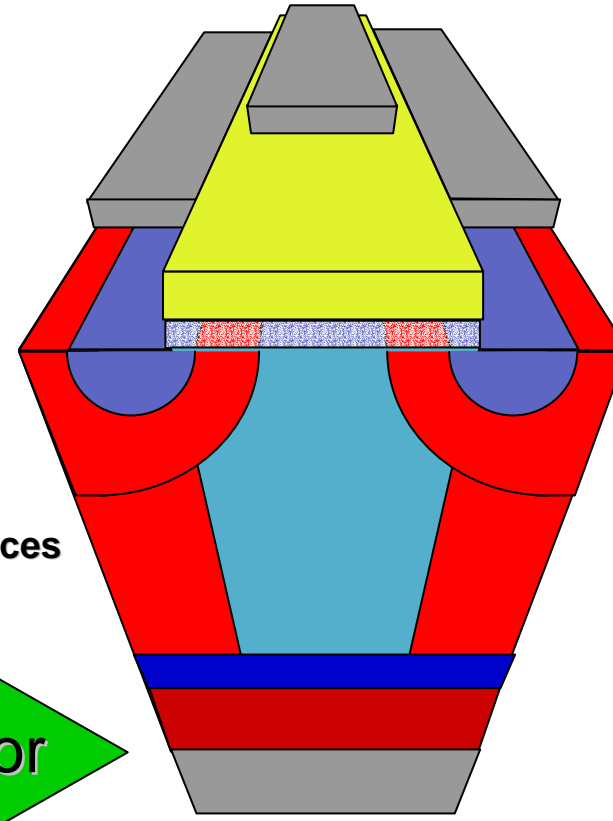
never?
never?

2002

2006

IEEE Trans. El. Devices
Vol. 53, No. 4
pp. 884 -890

add p - injector



**p-doped anode
& n - buffer**

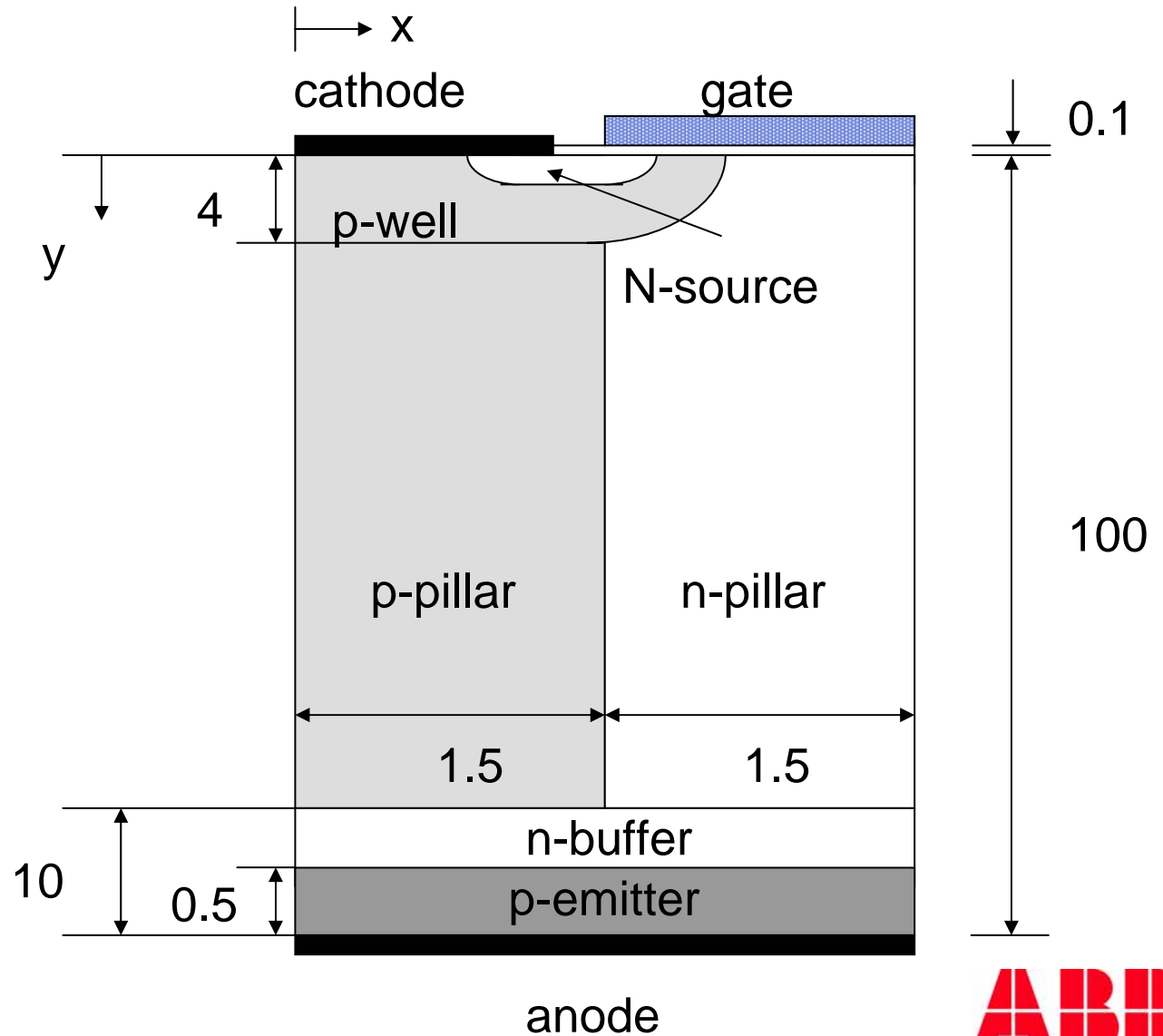


BIPOLAR SUPER JUNCTION CONCEPTS

**SJBT
implementation
for 1.2 kV**

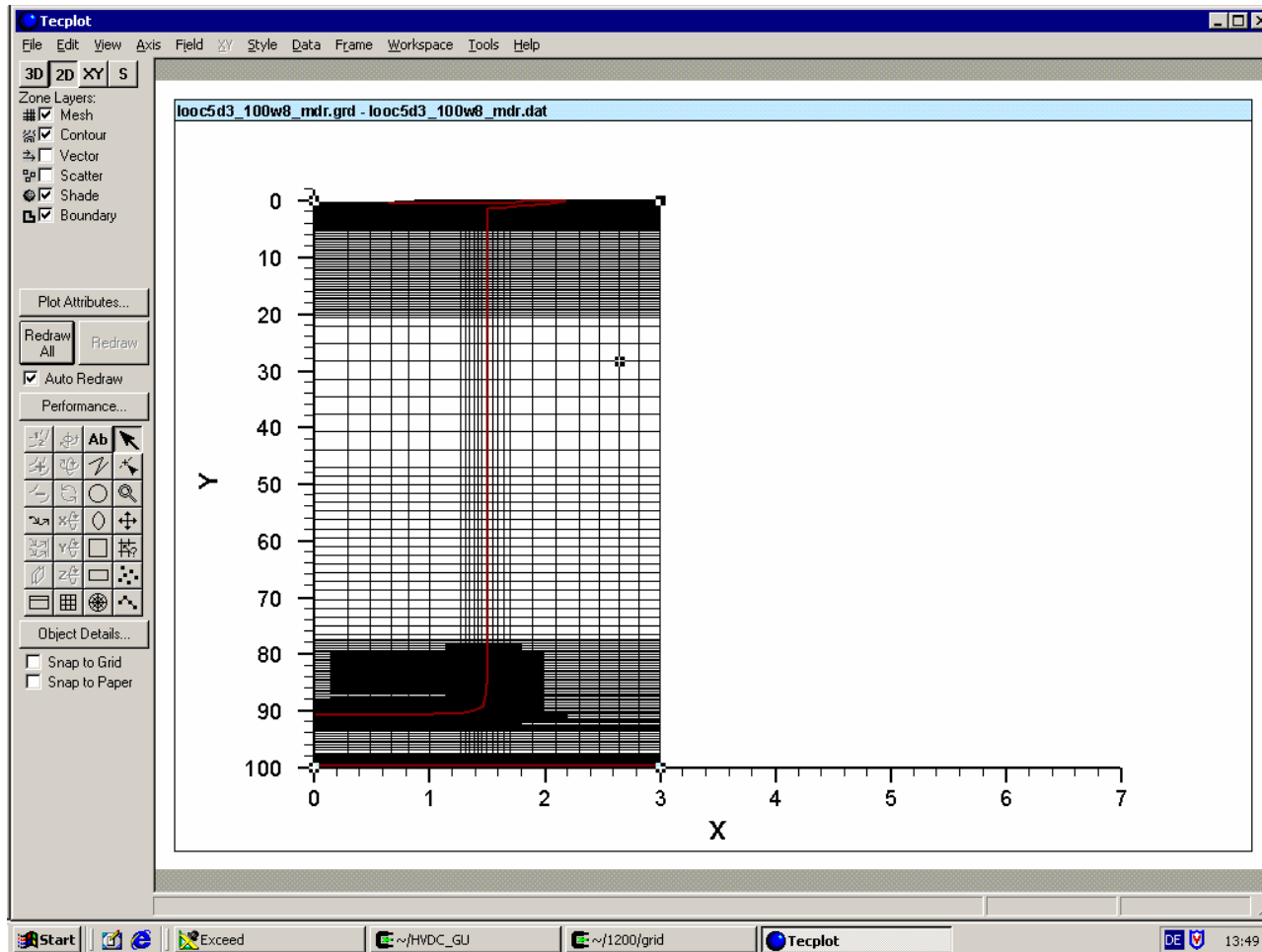
**pillar doping:
1E16 cm⁻³**

**investigation
variable:
n – buffer
doping**

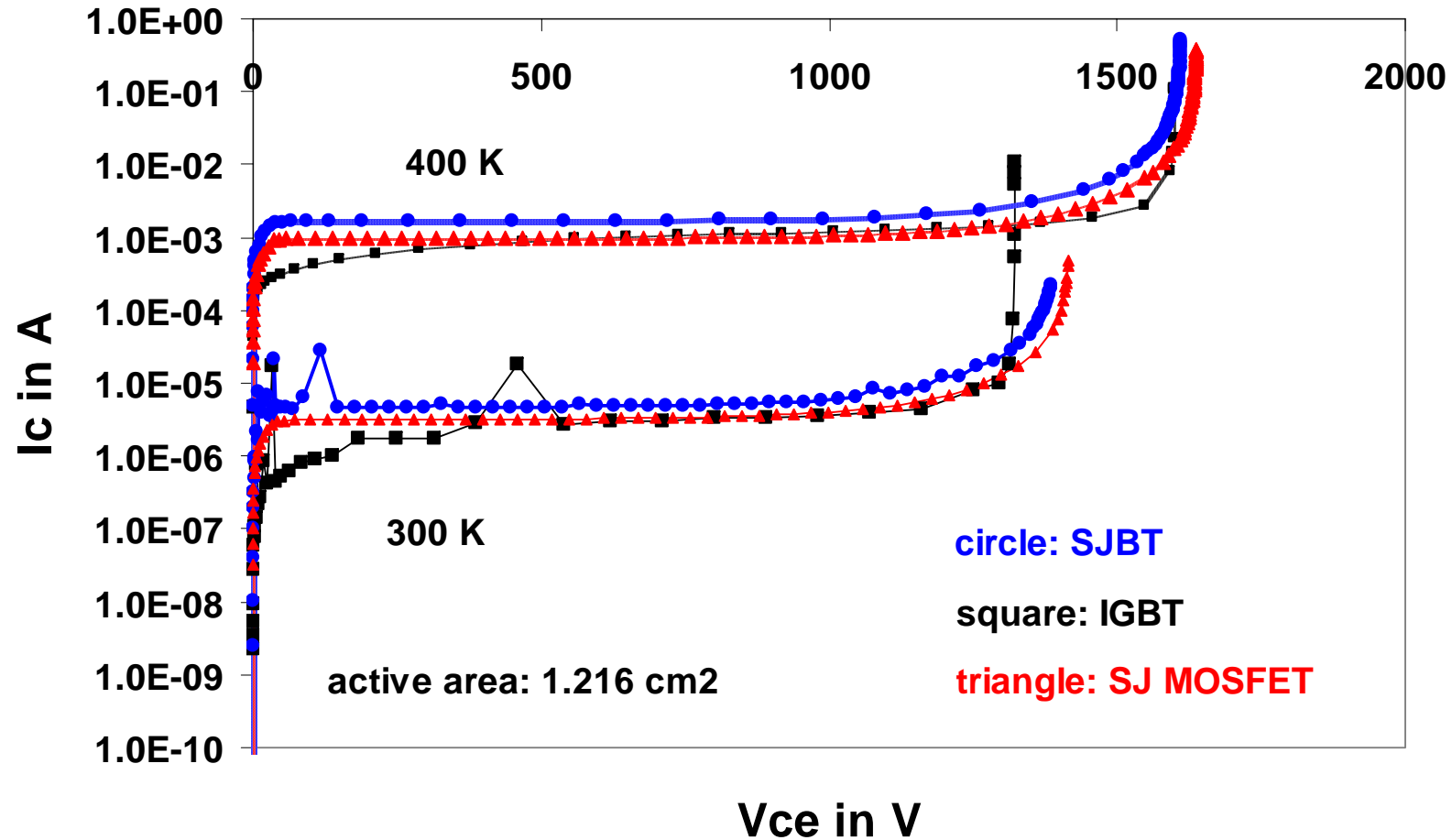


BIPOLAR SUPER JUNCTION CONCEPTS

Example for SJBT numerical grid

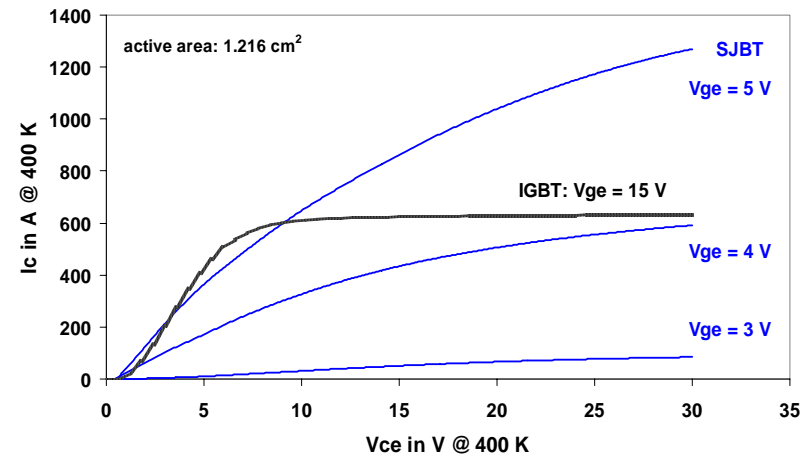
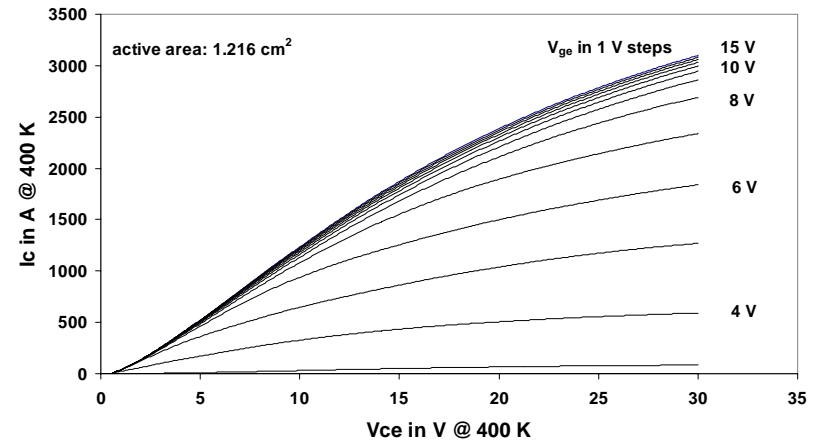
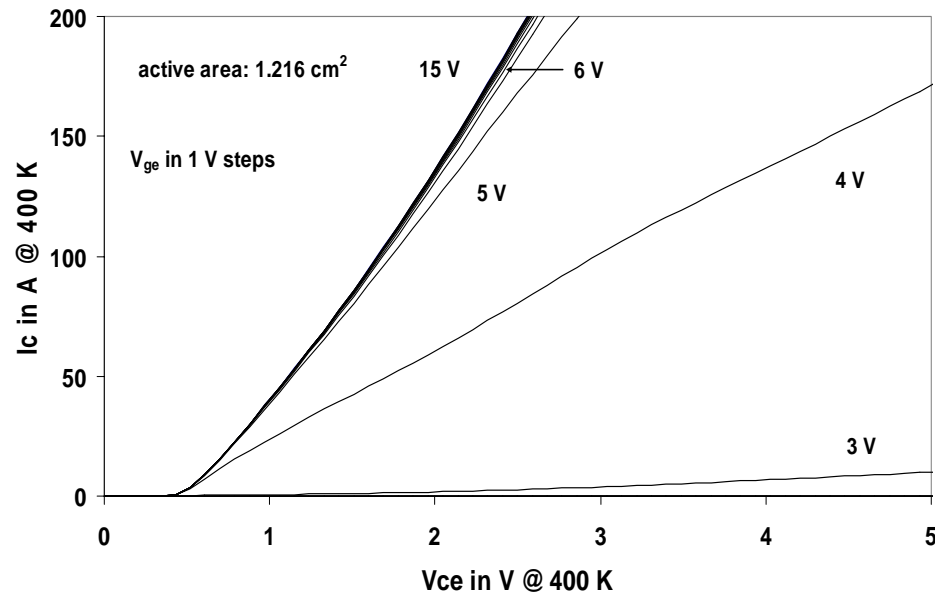


SIMULATED SJBT CHARACTERISTICS (1)



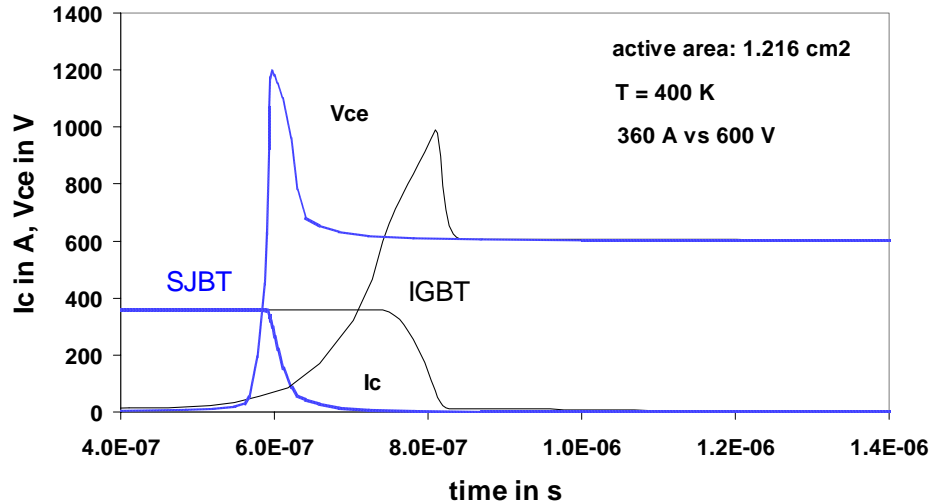
SIMULATED SJBT CHARACTERISTICS (2)

SJBT on-state:
in the neighbourhood of IGBT



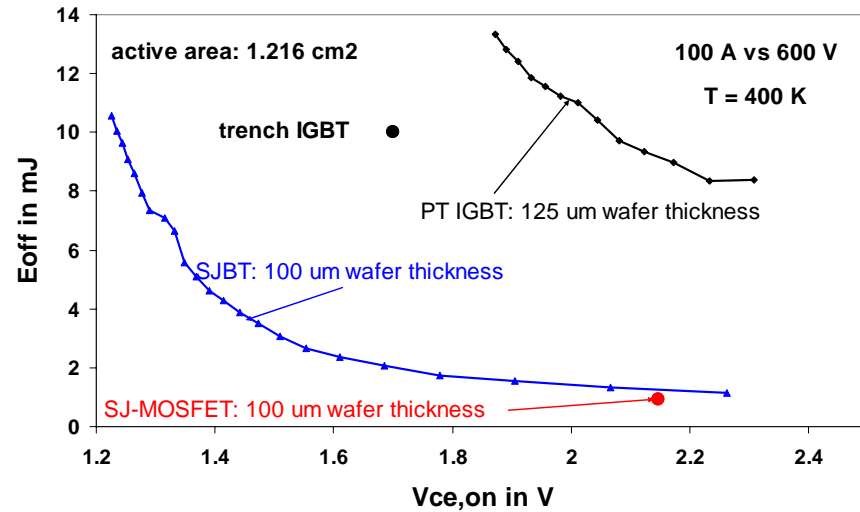
SIMULATED SJBT CHARACTERISTICS (3)

SJBT turn-off losses as low as 10 – 20% of IGBT losses



transients

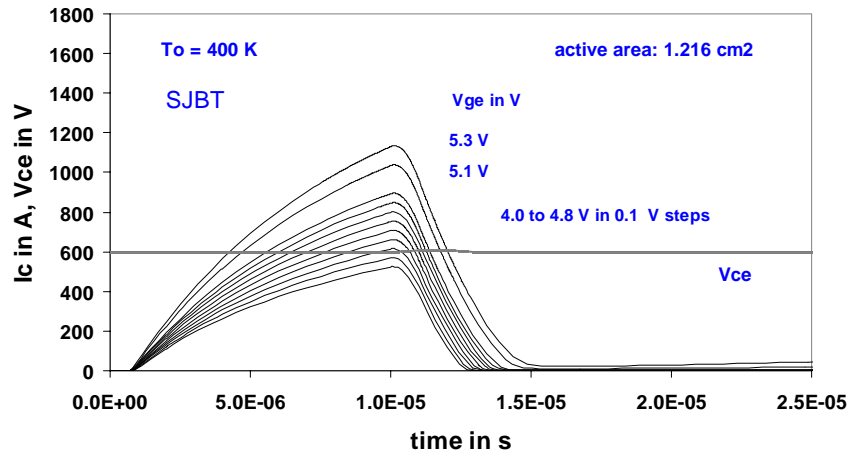
trade-off



SIMULATED SJBT CHARACTERISTICS (4)

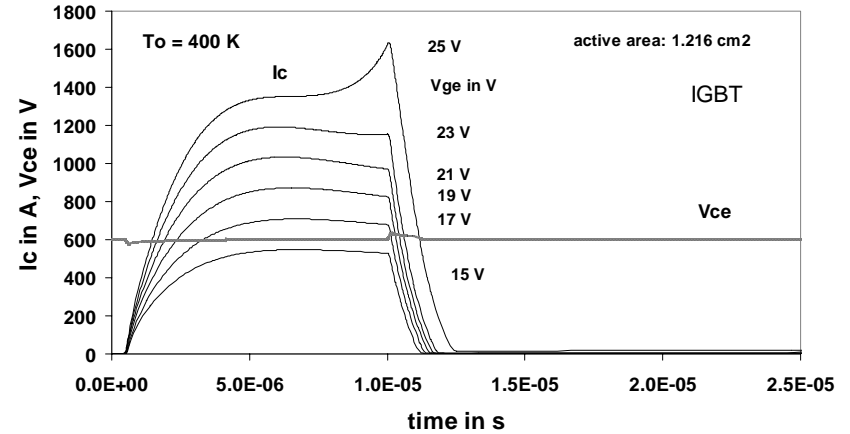
SJBT short circuit capability similar to IGBT

SJBT

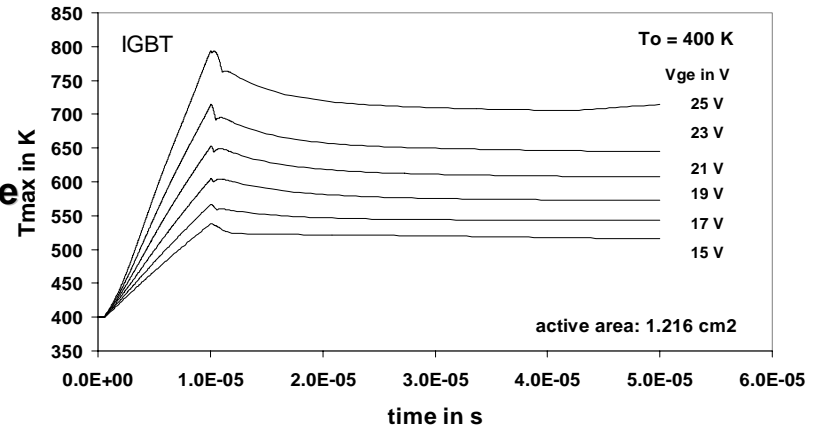
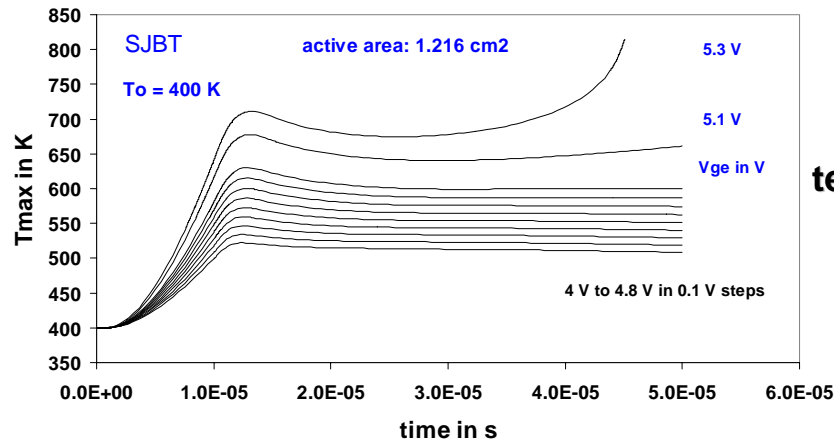


current

IGBT

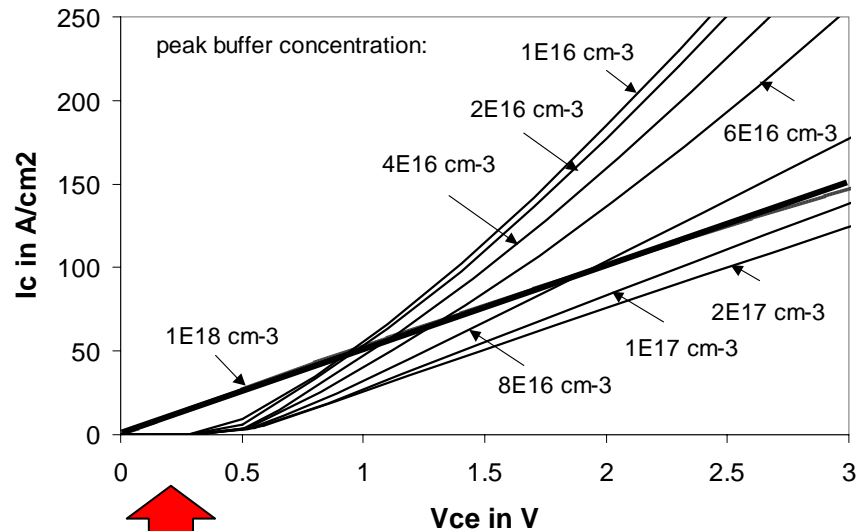


temperature

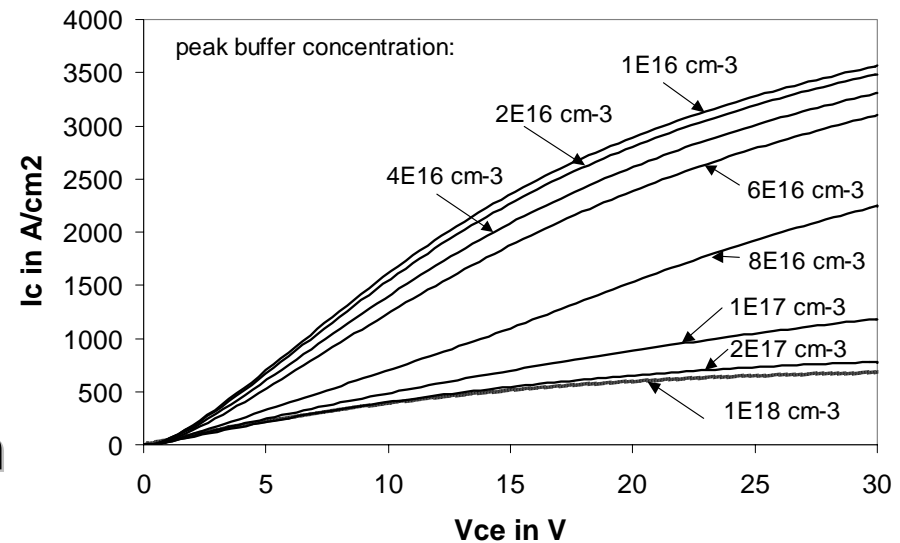


UNDERSTANDING THE SJBT (1)

buffer doping variation – effect on on-state



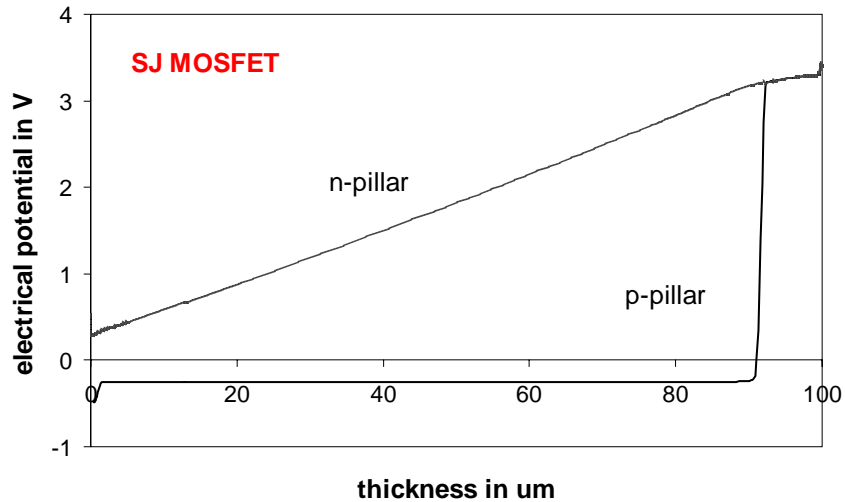
$V_{ce} = 3$ V, $T = 400$ K



unipolar – to - bipolar transition

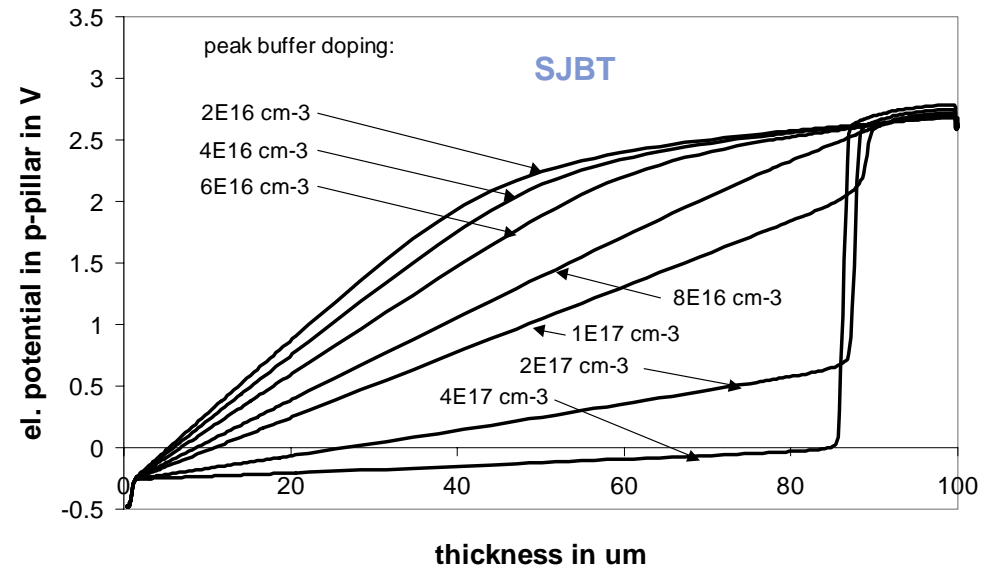
UNDERSTANDING THE SJBT (2)

el. potential along pillars @ $V_{ce} = 3\text{ V}$, $T = 400\text{ K}$



no current in p – pillar
drift transport in n-pillar

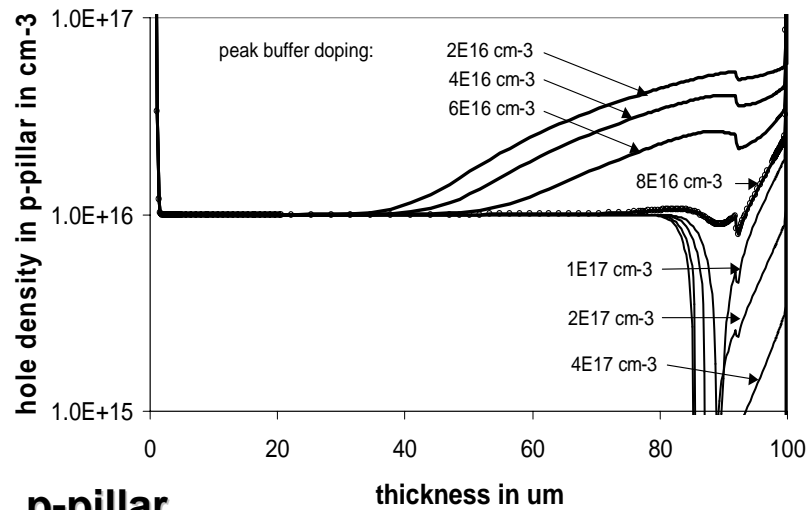
current in n & p – pillars
drift & diffusion in n & p-pillars



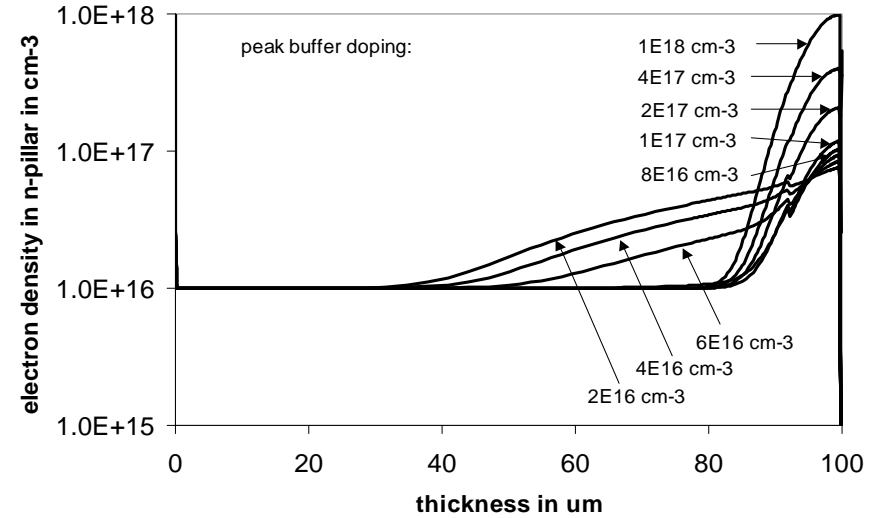
UNDERSTANDING THE SJBT (3)

SJBT on-state: carrier distributions

$V_{ce} = 3 \text{ V}$, $T = 400 \text{ K}$

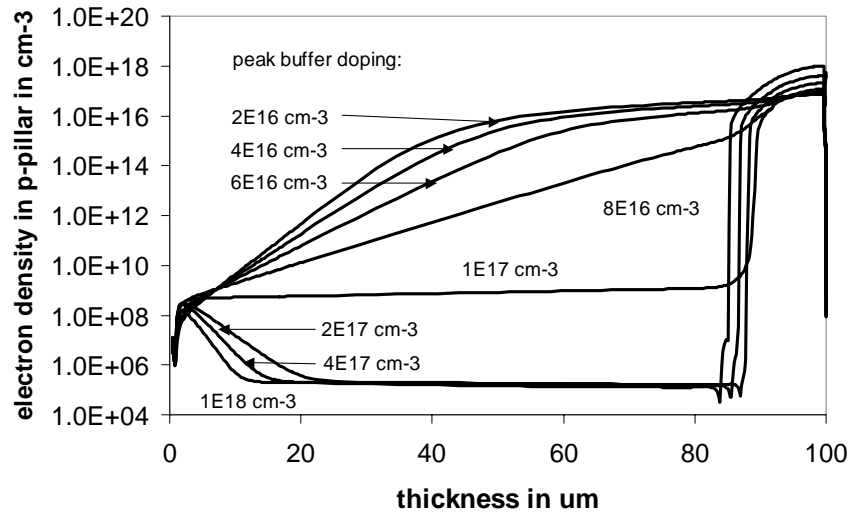


maj

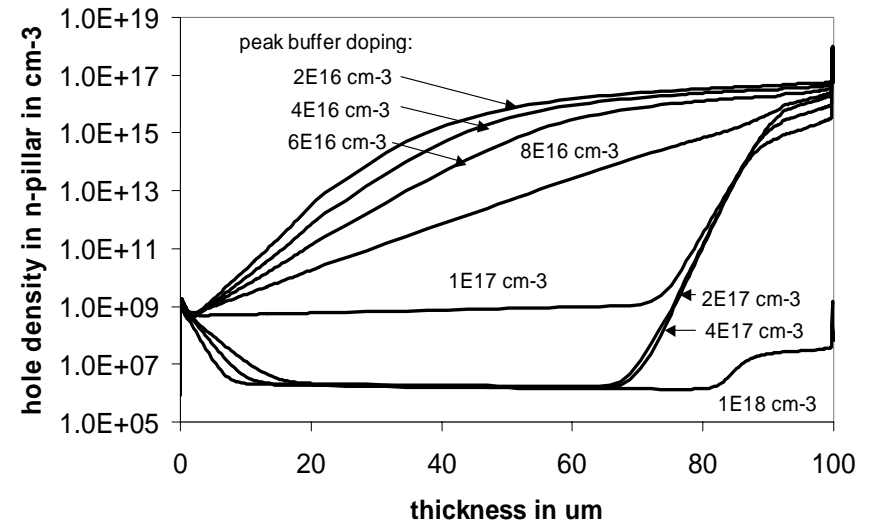


n-pillar

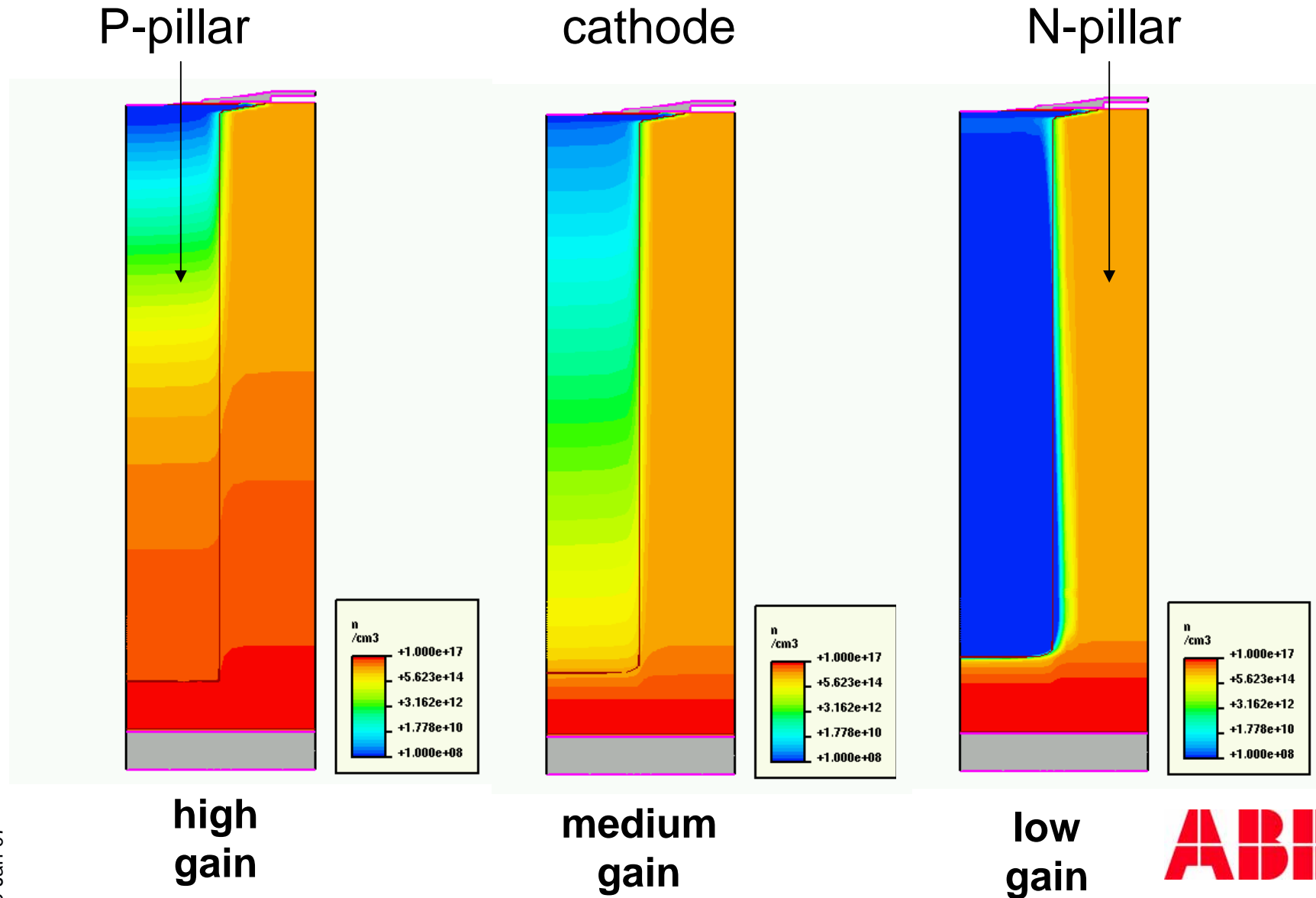
p-pillar



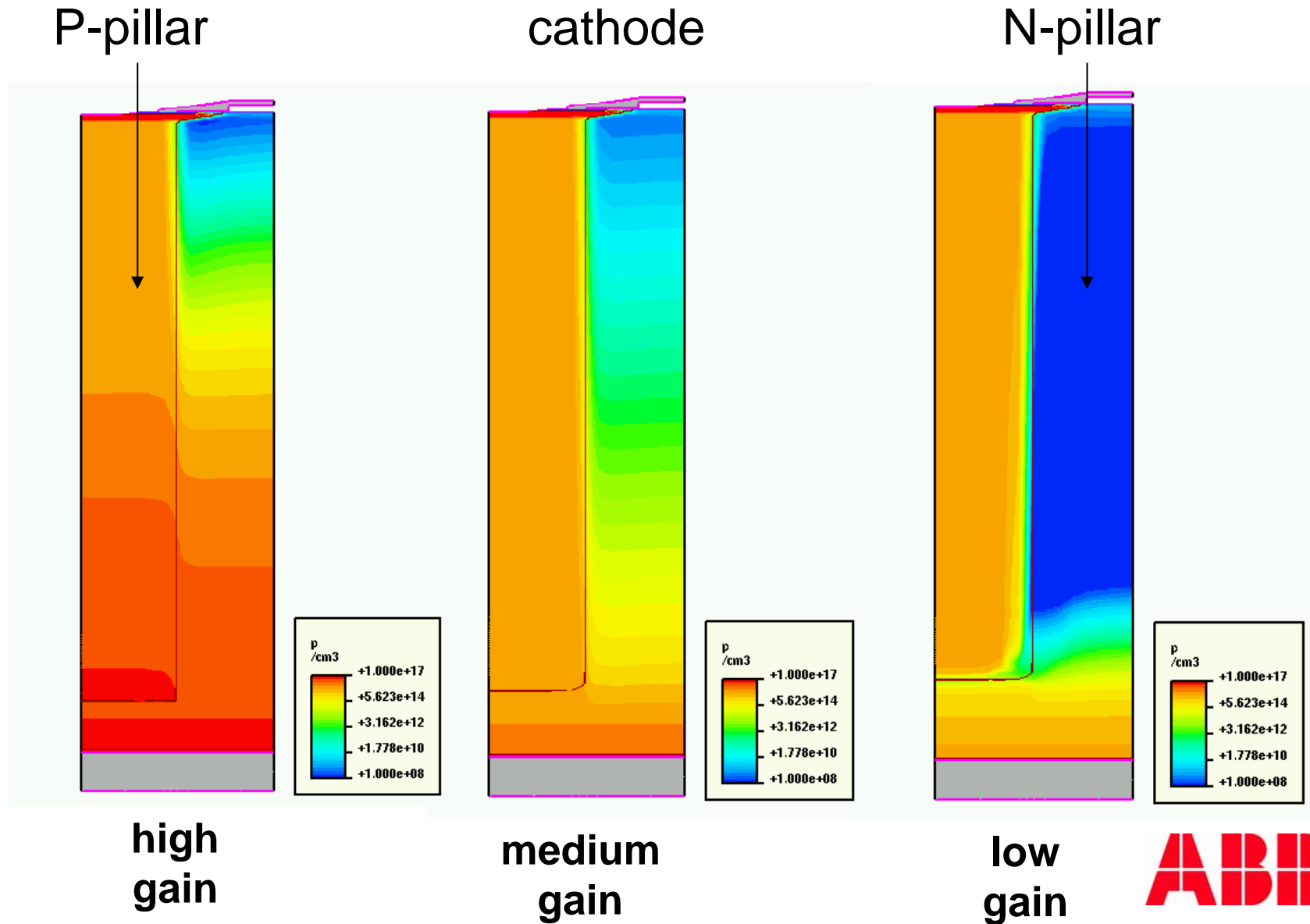
min



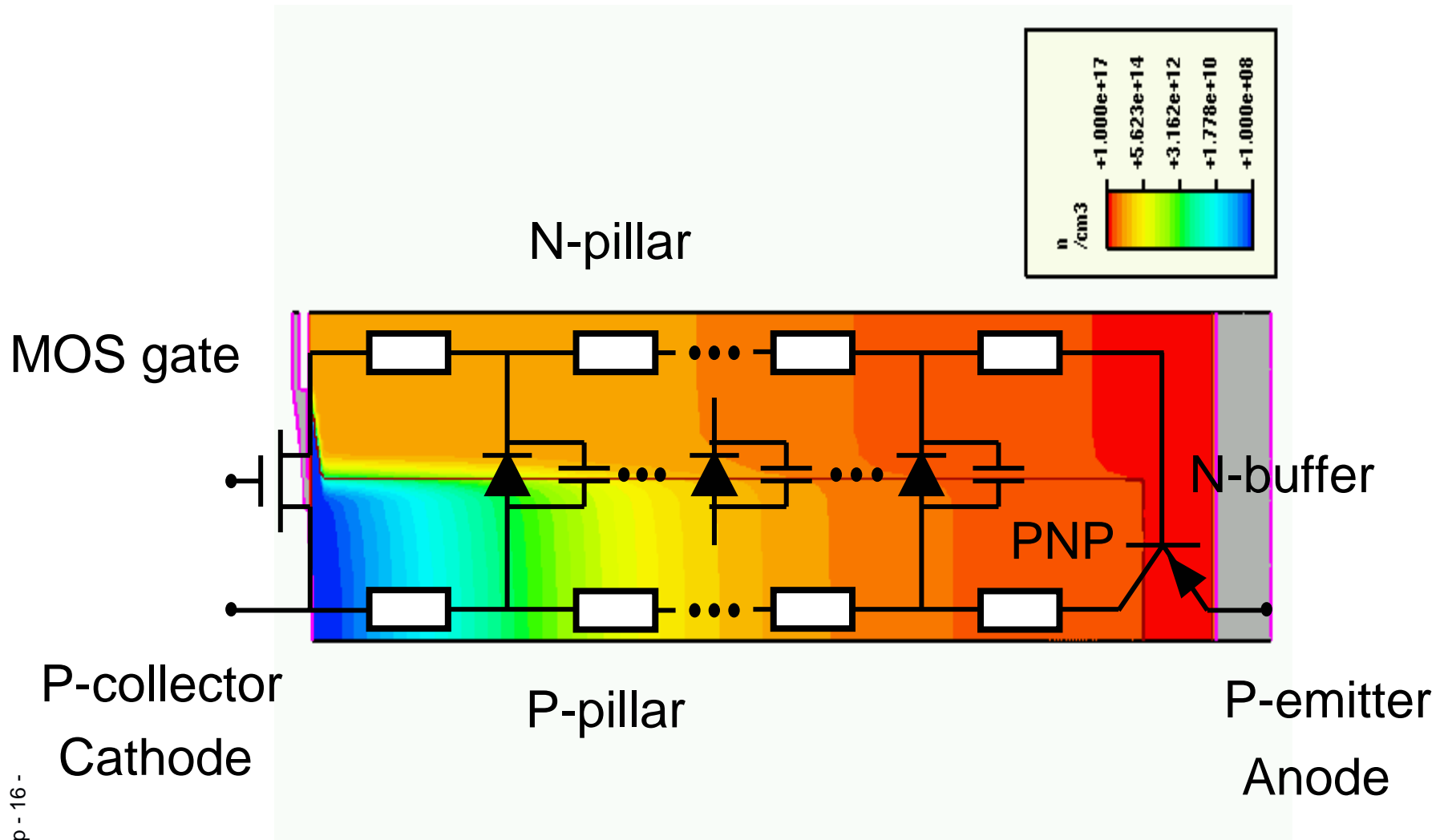
ELECTRONS IN THE SJBT: $V_{ce} = 3 \text{ V}$, 400 K



HOLES IN THE SJBT: $V_{ce} = 3 V$, 400 K



SJBT EQUIVALENT CIRCUIT

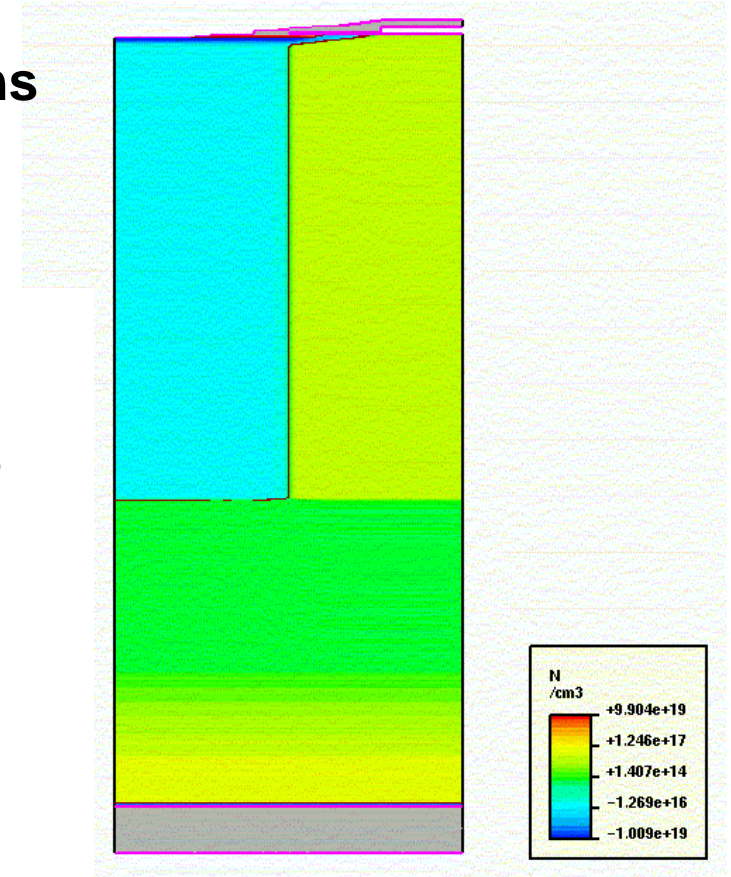
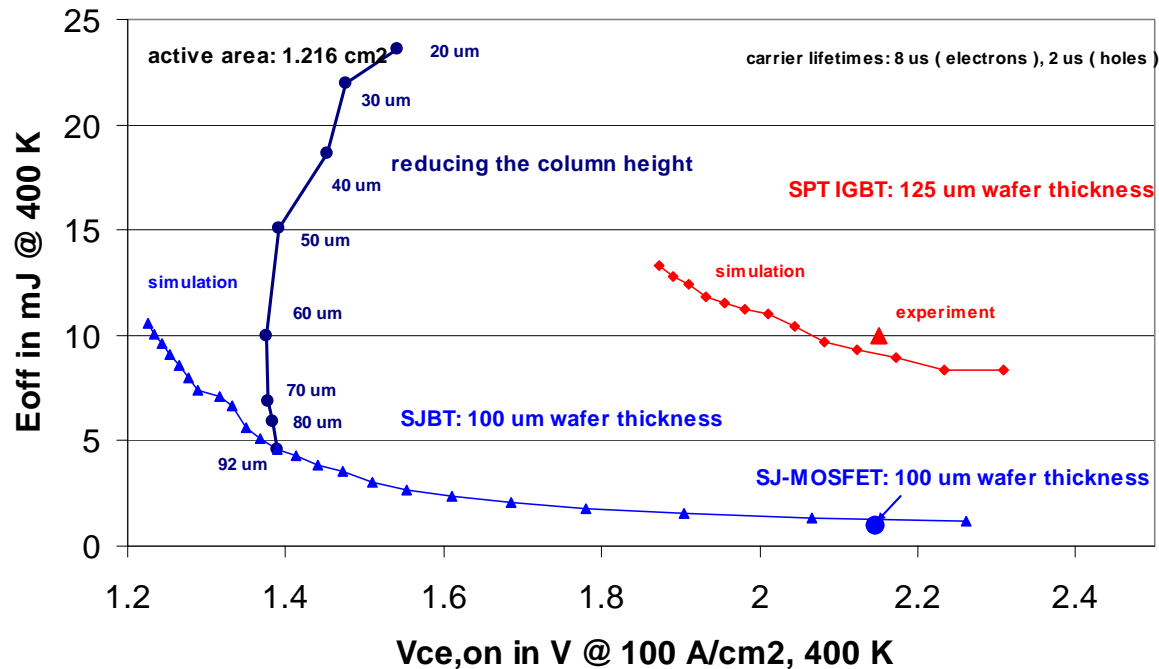


ECONOMICALLY VIABLE SJBT

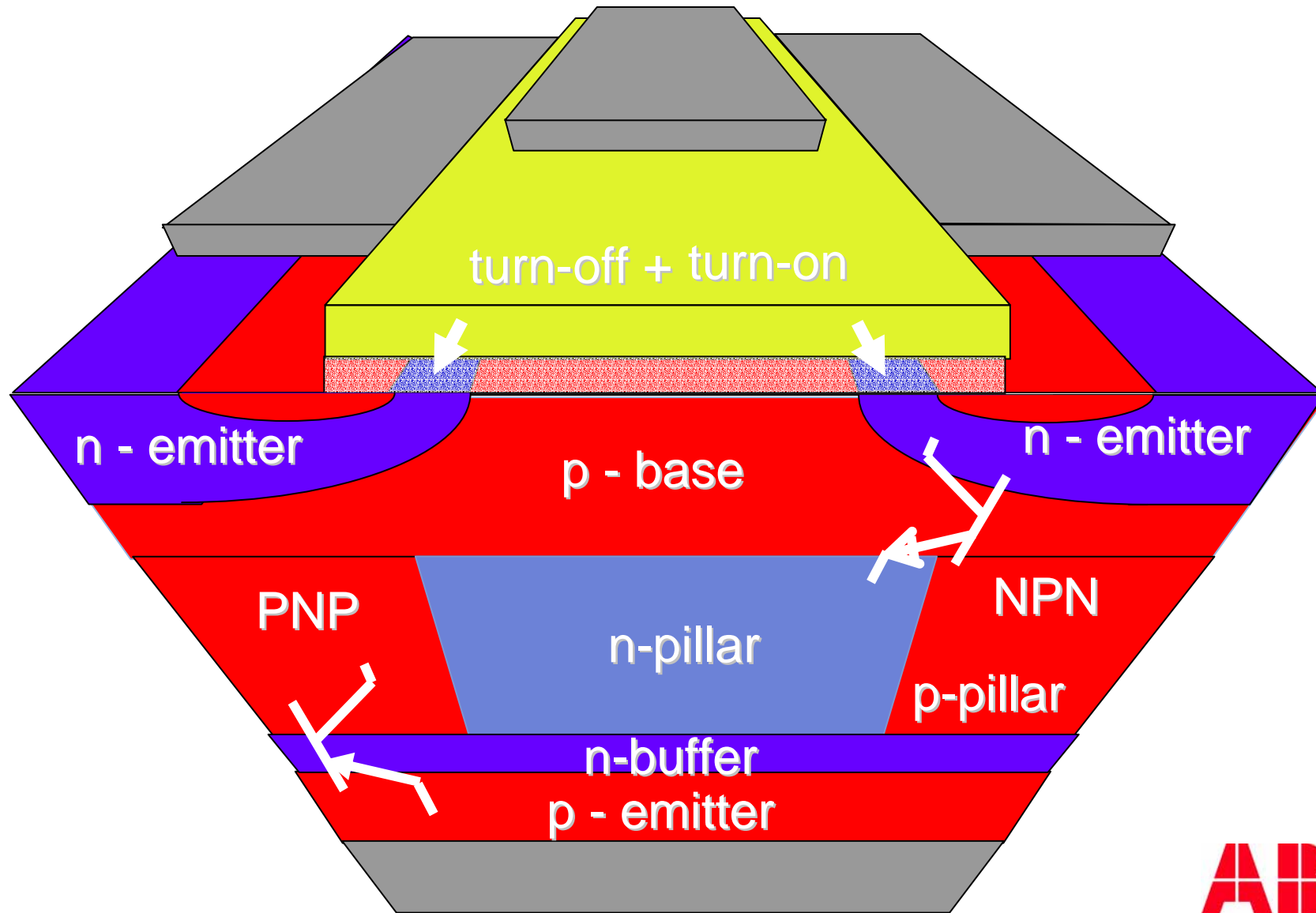
1.2 kV hybrid – structure consisting of

- partial SJ zone with moderately high columns
- partial PIN zone with n⁻ -doped base region
- > *spin-off: latch-free IGBT*

400 K 1.2 kV trade-off curves: SJBT versus SPT IGBT
 100 A vs 600 V, 400 K hard inductive switching; variable column height



SUPER JUNCTION MCT

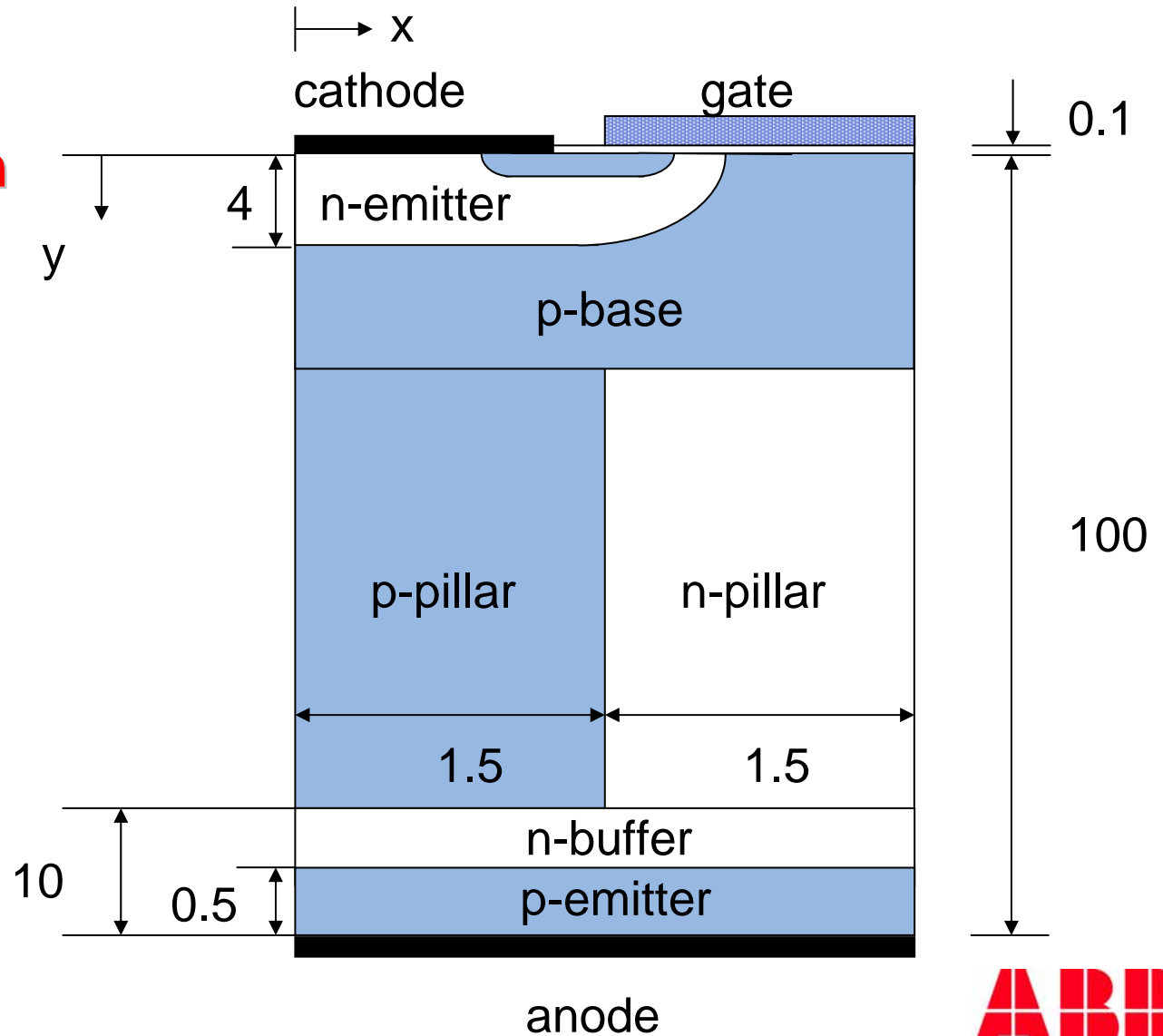


BIPOLAR SUPER JUNCTION CONCEPTS

**SJMCT
implementation
for 1.2 kV**

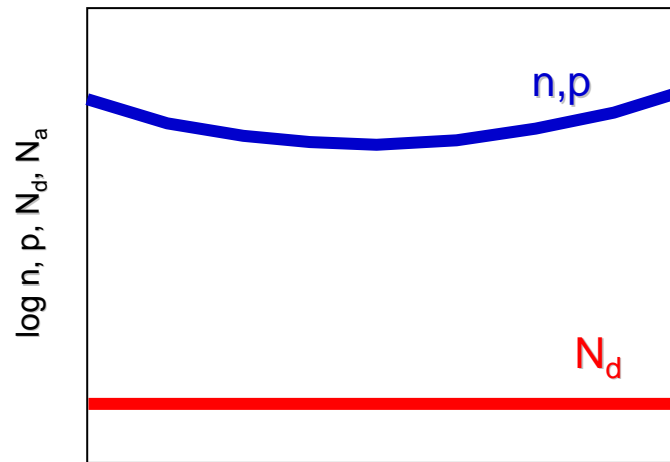
**pillar doping:
 $1E16 \text{ cm}^{-3}$**

**investigation
variable:
p – emitter
doping**



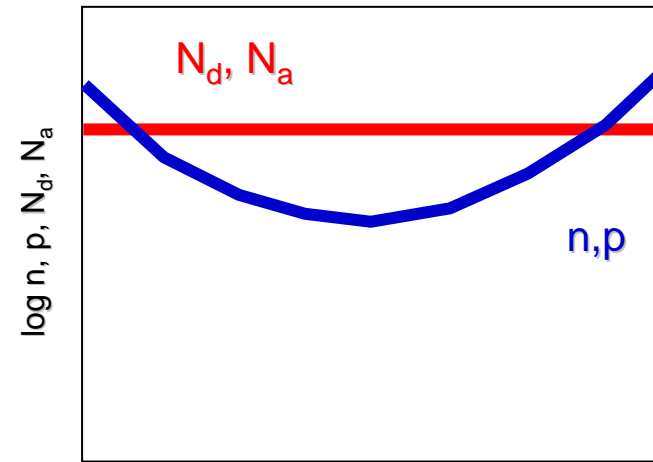
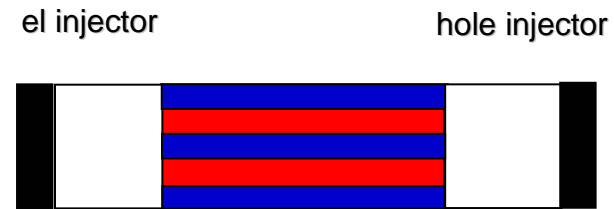
WHY SJMCT (1)?

conventional pnpn



width of middle region

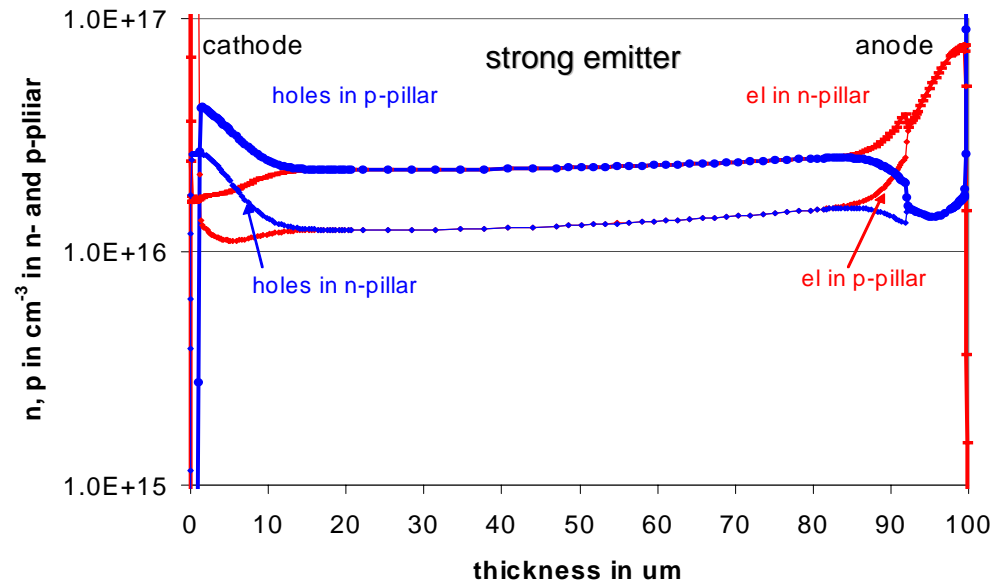
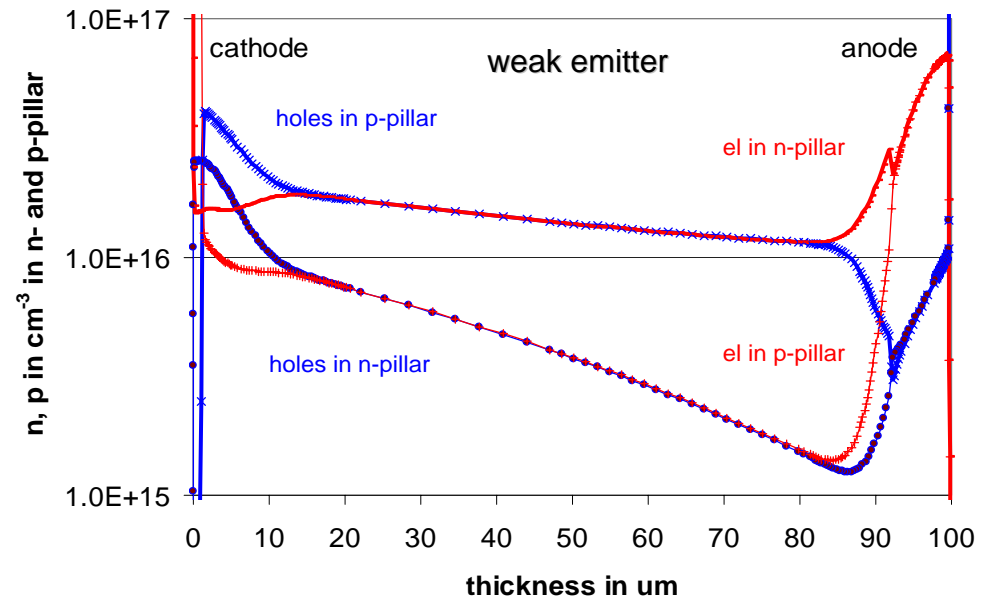
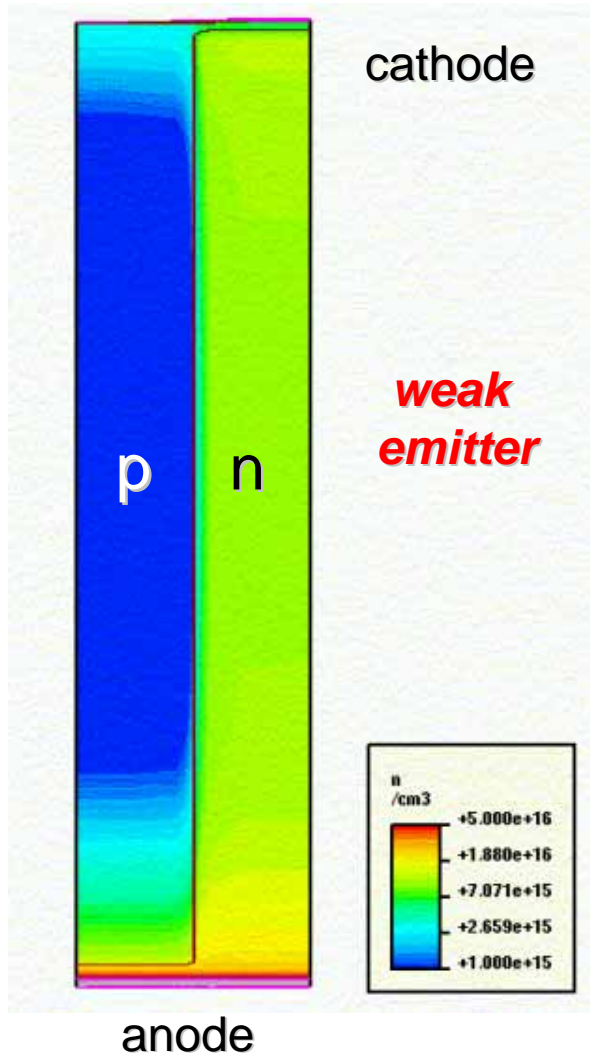
super junction pnpn



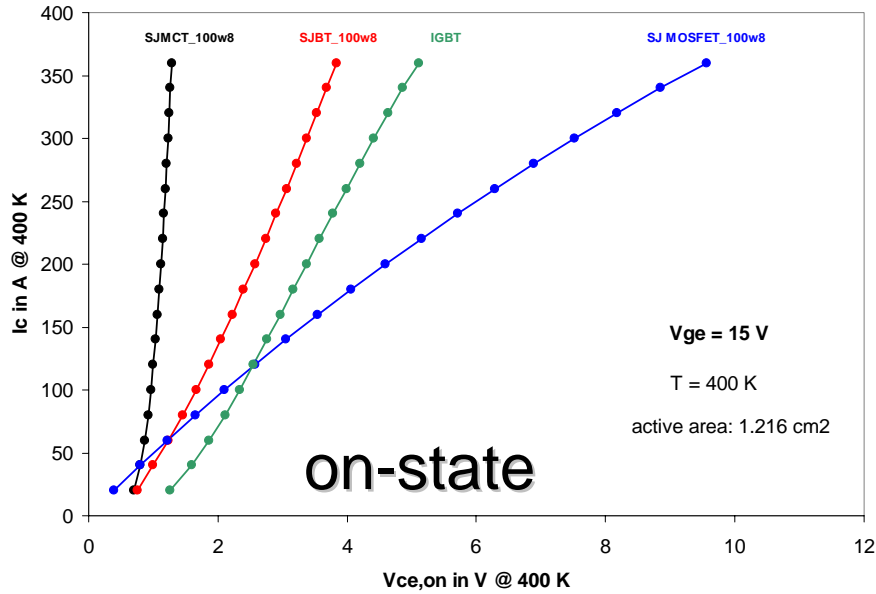
width of middle region

WHY SJMCT (2)?

carrier distributions
at 100 A on-state

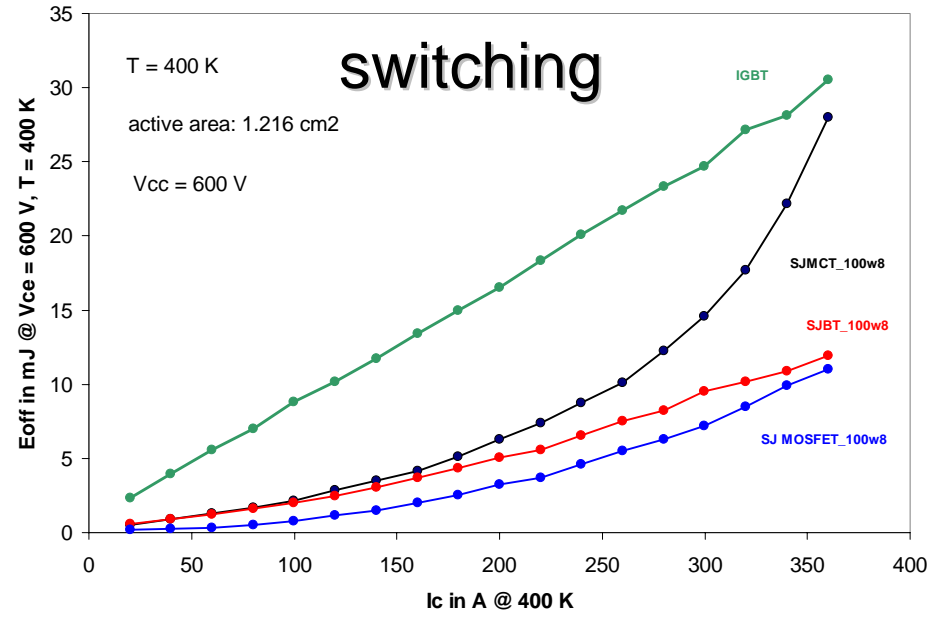


PERFORMANCE COMPARISON (1)



layout example: 1.2 kV

- **SJ MOSFET**
- **IGBT**
- **SJBT**
- **SJMCT**



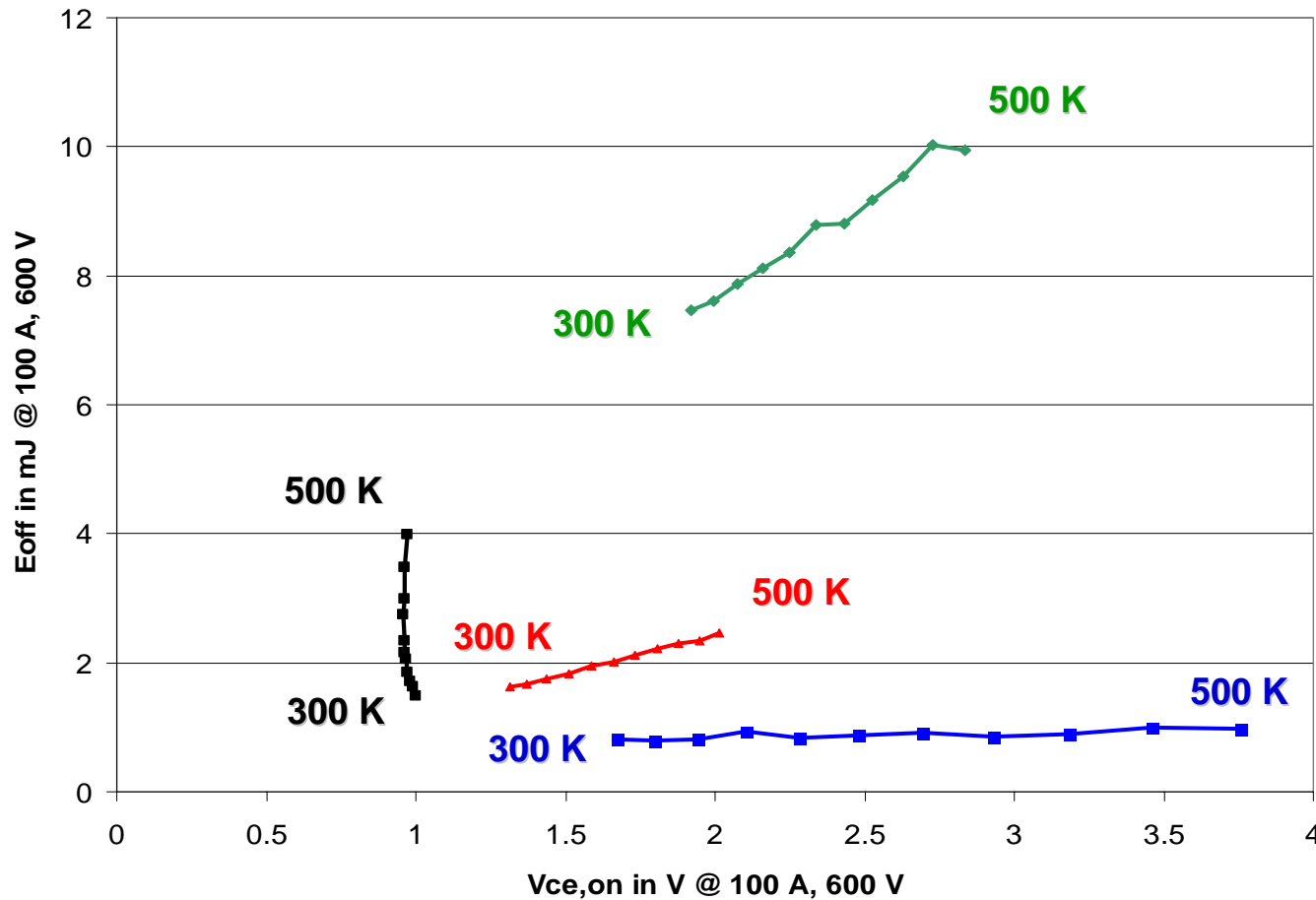
PERFORMANCE COMPARISON (2)

layout example: 1.2 kV

hard inductive switching

100 A vs 600 V

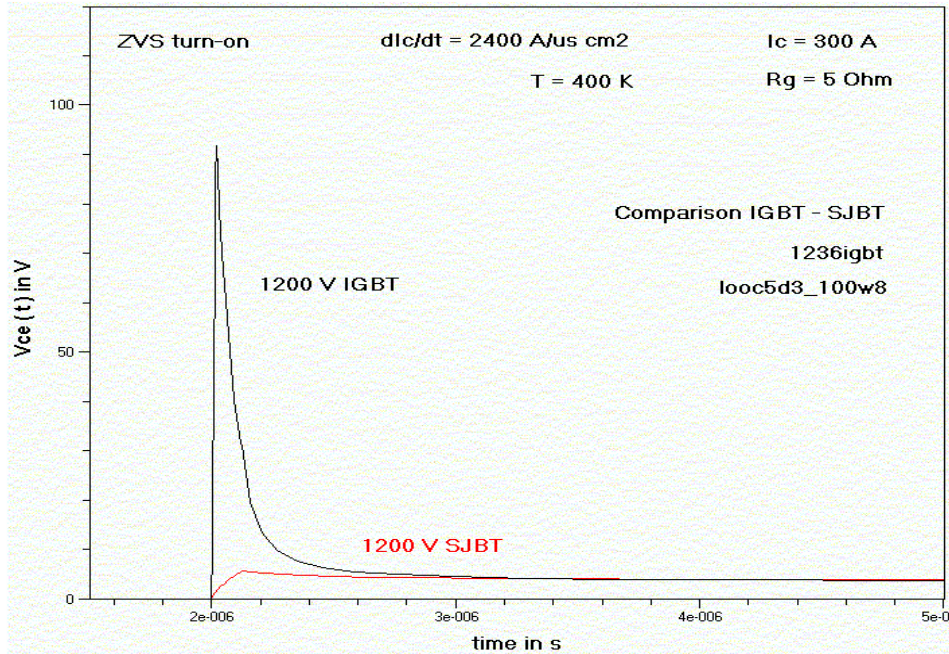
T from 300 to 500 K



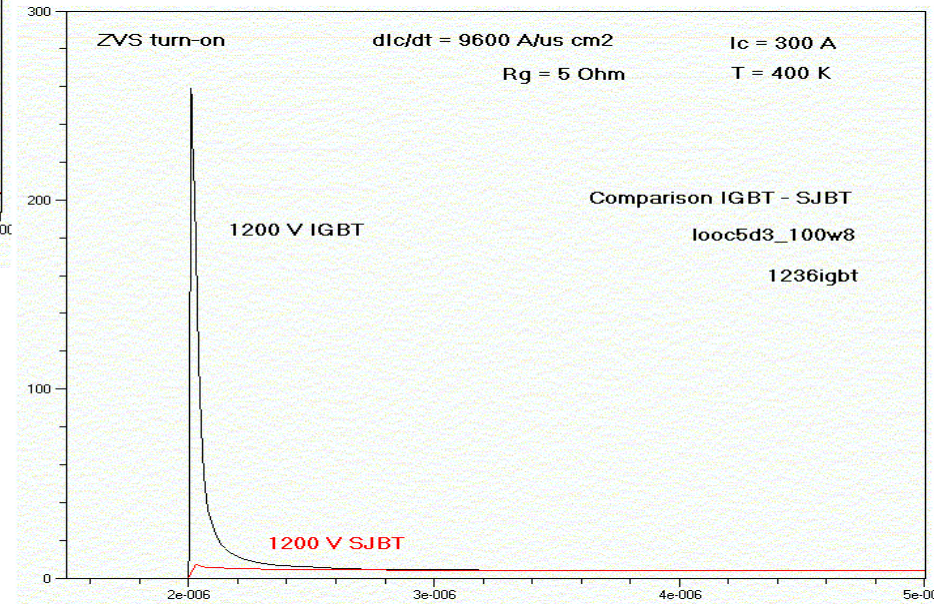
- SJ MOSFET
- IGBT
- SJBT
- SJMCT



SJBT APPLICATION



zero voltage switching
turn-on at high dI_c/dt



layout example: 1.2 kV

CONCLUSIONS

Bipolar super junction power device concepts

- feasibility proof (numerical simulation)

diode (early published work)

SJBT

SJMCT

- realization not interesting to date

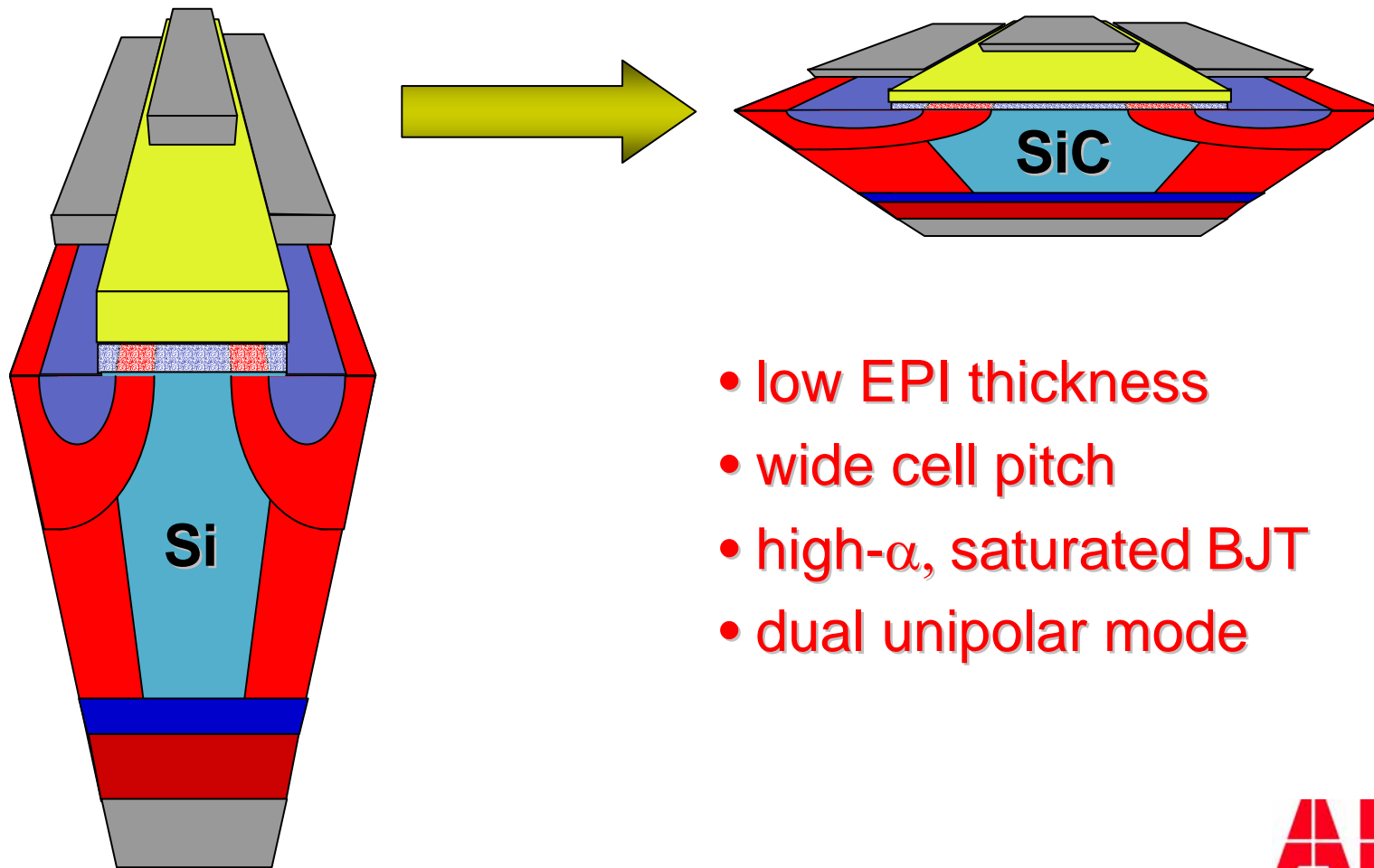
technology complexity

limited blocking capability

competition for CoolMOS and IGBT

OUTLOOK

Wide bandgap (WBG) bipolar super junction power device



- low EPI thickness
- wide cell pitch
- high- α , saturated BJT
- dual unipolar mode



ABB



ABB