Silicon MOSFETs and IGBTs: evolving for the future

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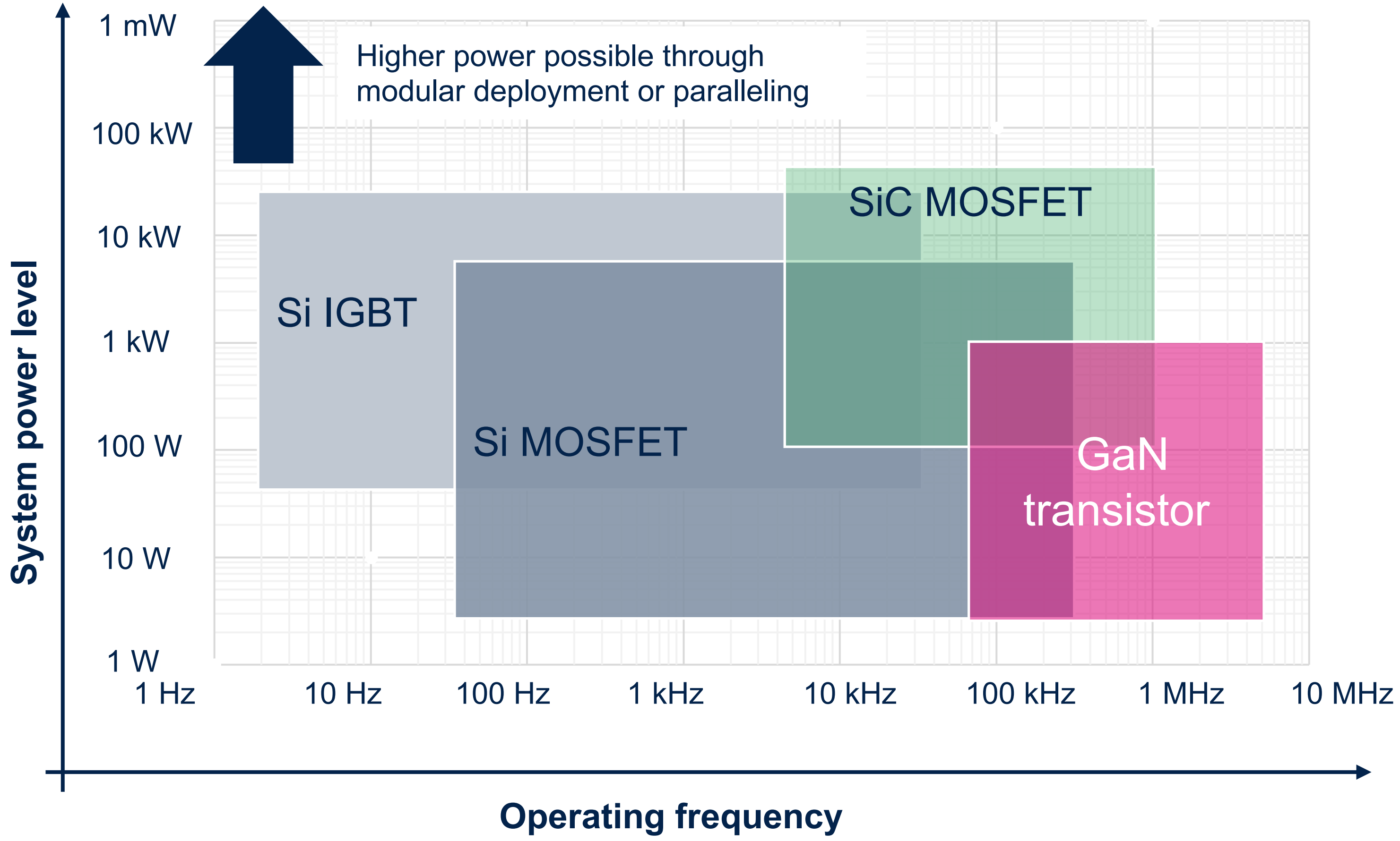
Power transistor technologies



Applications

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Silicon MOSFET: From planar toward new structures

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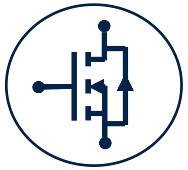
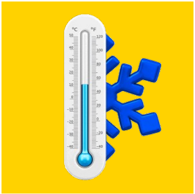
A power MOSFET operates like a switch

Power MOSFET: key player in all applications handling power

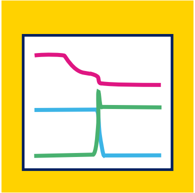


Main parameters impacting performance

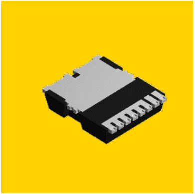
- **$R_{DS(on)}$** (On-state resistance) [Ω]
- **Q_G** (Total gate charge) [nC]
- **Package**
- **Breakdown voltage,** BVDSS
- **Threshold voltage,** Vth
- **dv/dt capability, output capacitance, more…**



$R_{DS(on)}$ impacts conduction losses



Gate charge Qg impacts switching losses



Package impacts power density

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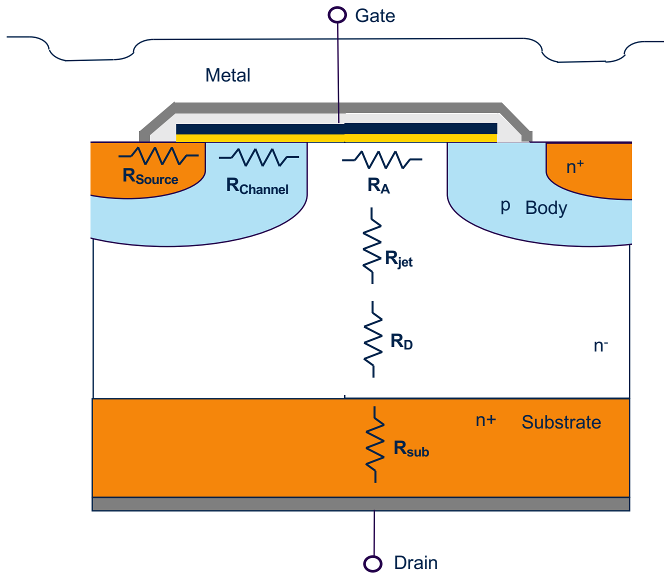
Planar MOSFET

Conventional structure

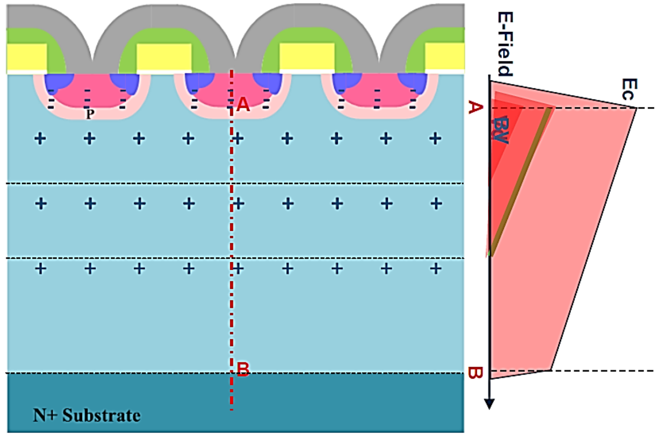


$R_{DSon} = R_{source} + R_{ch} + R_A + R_J + R_D + R_{sub}$

R_{DSon} contribution

BVDss	30V	100V	600V
$R_{channel}$	35%	8%	3%
$R_{epitaxial}$	35%	88%	93%
$R_{substrate}$	30%	3%	2%

Electric field



- R_{DSon} is due mainly to the epi-region for high voltage MOSFETs
- The breakdown voltage is determined by the epitaxial layer (drift layer) doping concentration and its thickness

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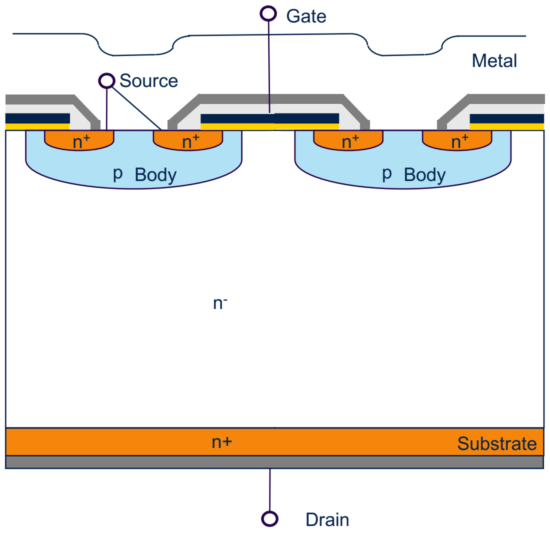
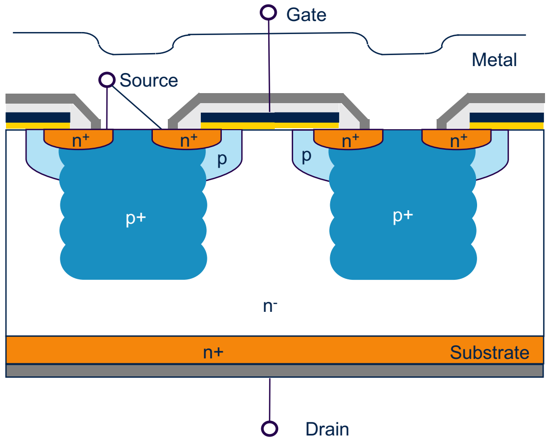
MOSFET evolution

Planar



- **Thermal performance** (Rth)
- **Low electromagnetic** effects
- **Extended SOA**

Super-junction



- **Better control** of the dynamic behavior
- **Improved performance** like lower conduction and switching loss
- Significant **Rth reduction** due to very thin die

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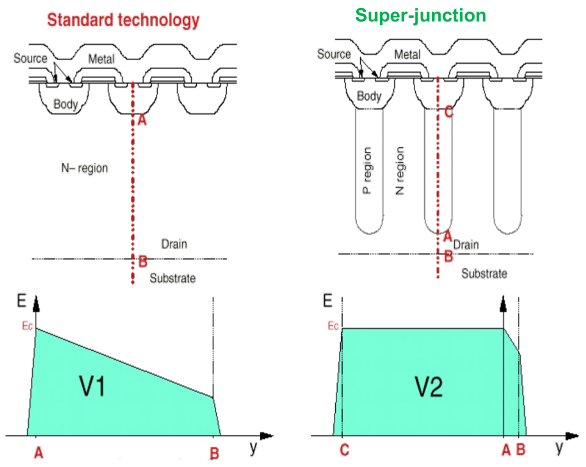
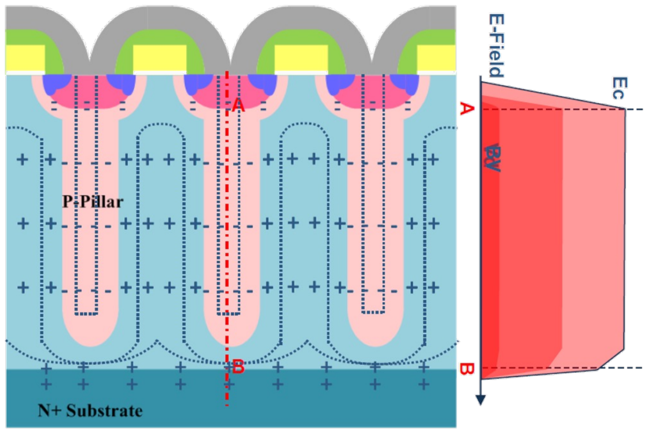
From planar to superjunction structure





Comparison @ same BVdss

Parameter	Planar	Multidrain
Drift doping layer		**Higher** Increasing dopant concentration
R_{DSon}	**Related to Epi layer**	**Lower** Epi layer reduced
Electrical Field	**Variable** During the n region	**Higher** Increased by column structure

$$V(x) = \int E(x)dx$$

Poisson's Law

$$\frac{d^2V}{dx^2} = -\frac{dE}{dx} = -\frac{Q(x)}{\varepsilon_S} = \frac{qN_A}{\varepsilon_S}$$

N_A= Charge density

ε_S=permittivity

Benefits

- Higher current density
- Lower Zth
- Suitable for low thickness packages

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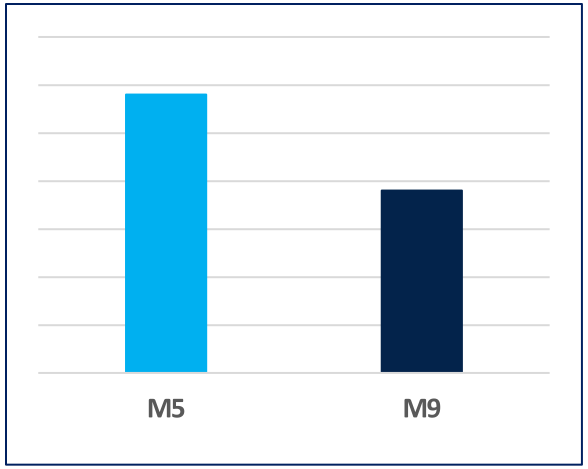
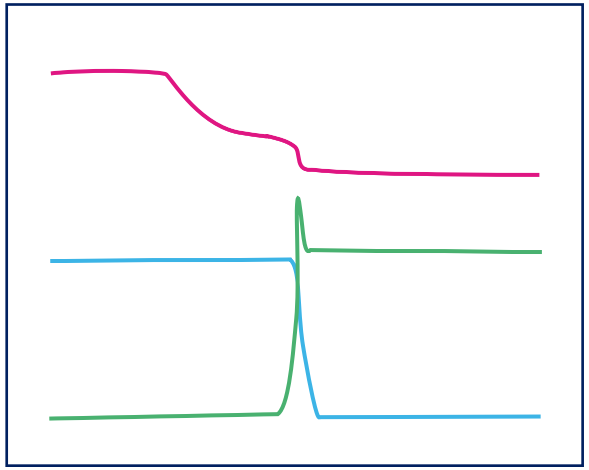
Main features

$R_{DS(on)}$ * Area



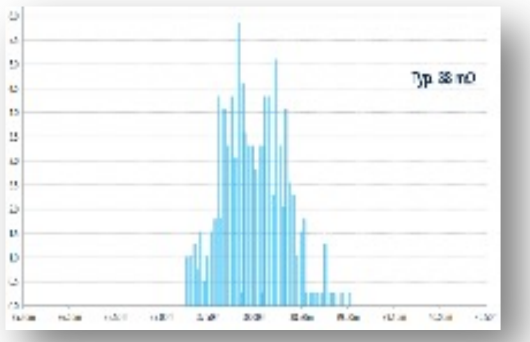
- Very low $R_{DS(on)}$ per area
- Suitable for hard-switching topologies
- Best choice for resonant high power density systems

Power losses



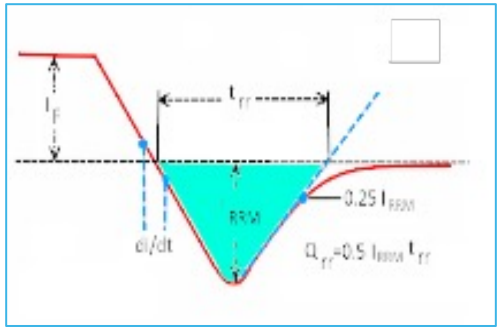
- Reducing switching energy losses
- Reducing switching time
- Increasing switching frequency

Process



- Reduced BVdss spread <70V
- Reduced Vth spread <1V
- Higher reliability

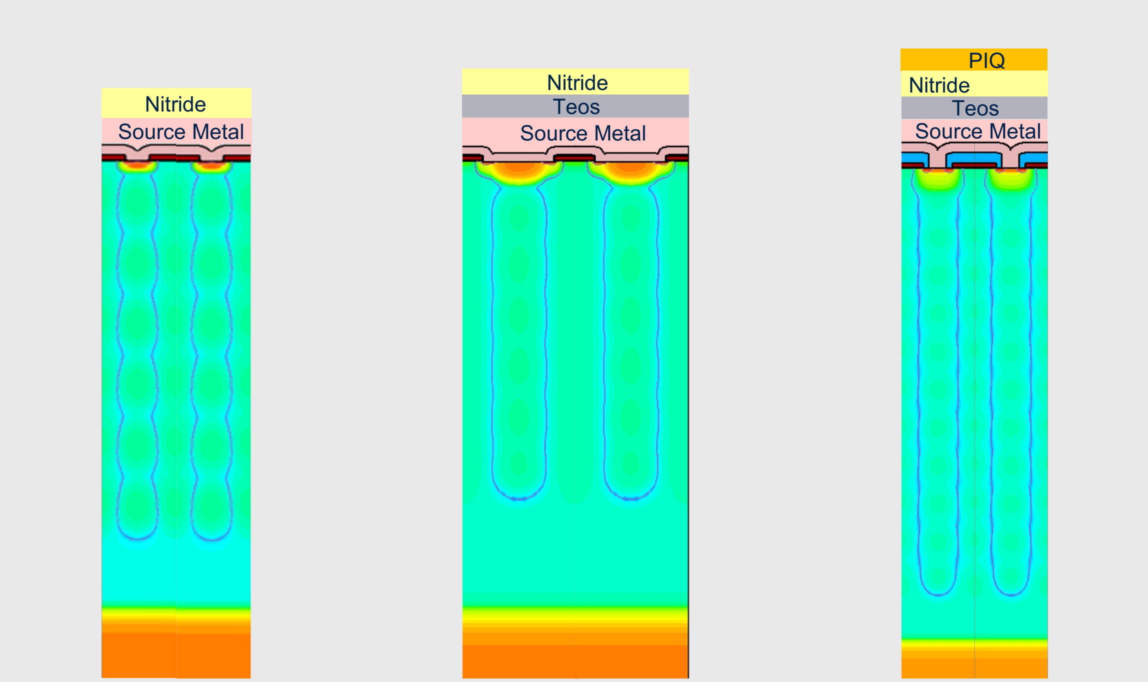
Robustness



- Static dv/dt up to 120V/ns
- Dynamic dv/dt up to 50V/ns
- Dynamic dv/dt up to 120V/ns

MOSFET evolution

Active area: cell structure comparison



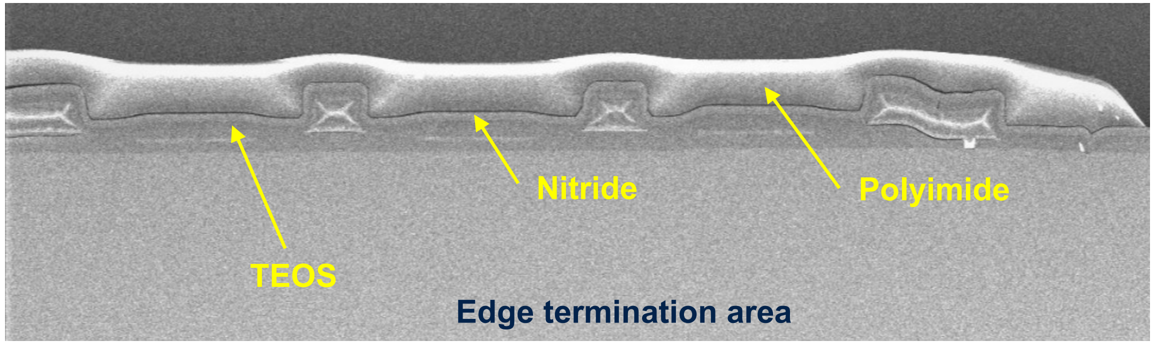
Single passivation — M5

Double passivation — M6

Triple passivation — M9

Passivation layers optimization

- **Nitride** is an excellent and common passivation layer
- **Teos** layer to reduce Nitride stress
- Extra **polymide** layer (organic polymer that exhibits excellent mechanical properties and electrical insulation) to reduce the mechanical stress coming from BE processes



Note: **MDmesh™ Mx** are the proprietary technologies of STMicroelectronics

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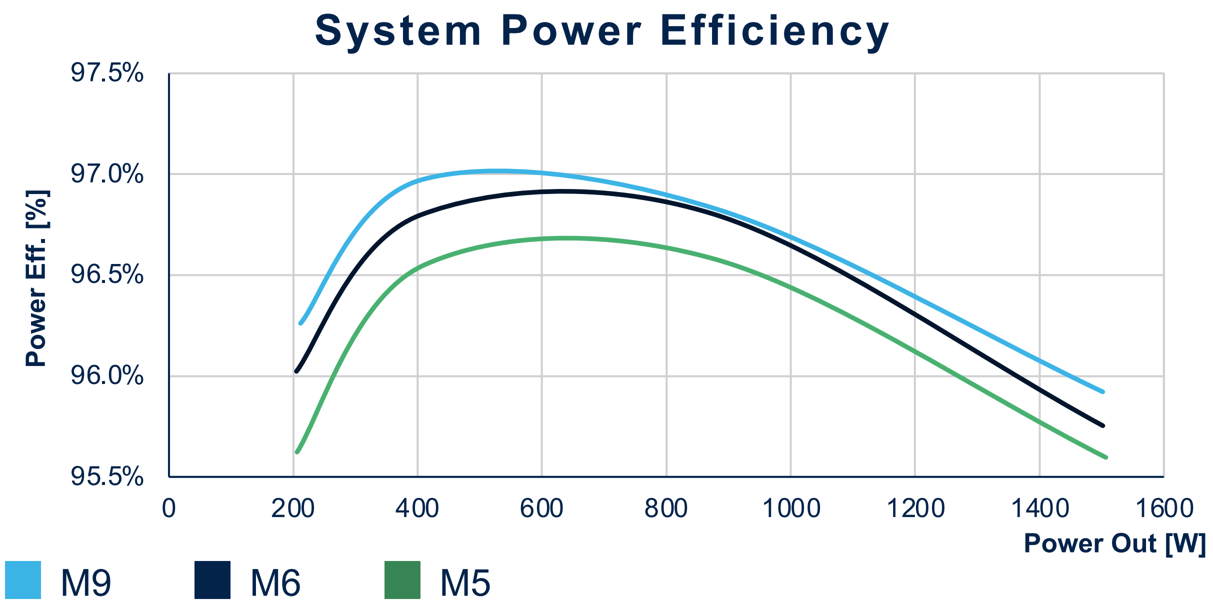
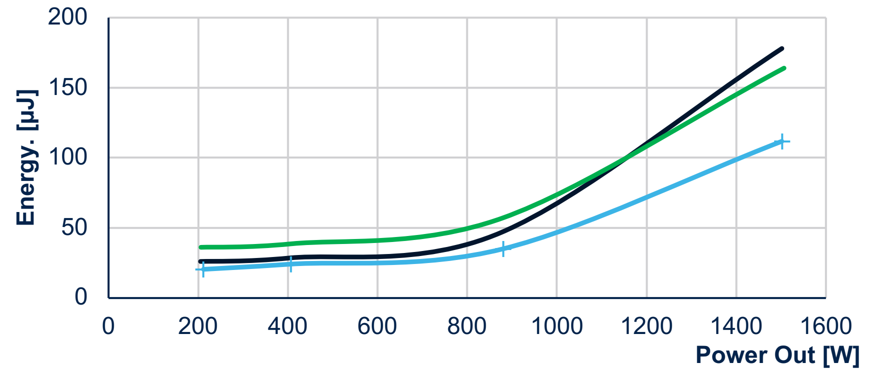
Application test and analysis

Power factor corrector (PFC) 1500W

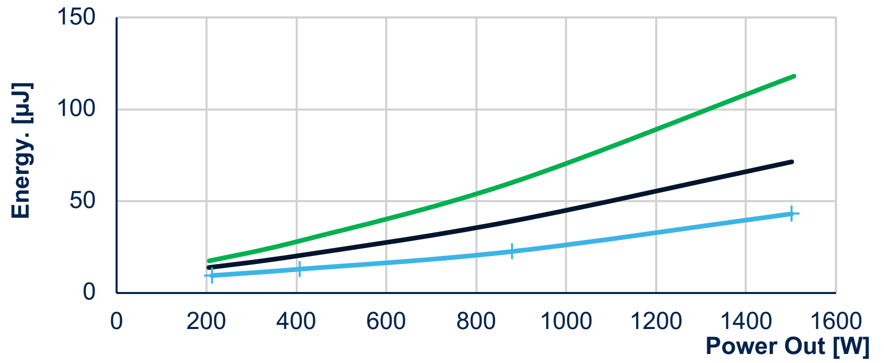


Device	BVdss [V] @ 1mA	Vth [V] @ 250uA	$R_{DS(on)Max}$ [mΩ]*	Qg [nC]
MDmesh M9	650	3.7	45	80
MDmesh M6	600	4	41	106
MDmesh M5	650	4	45	143

Eoff



Eon



New technology maximizes system efficiency and thermal performances

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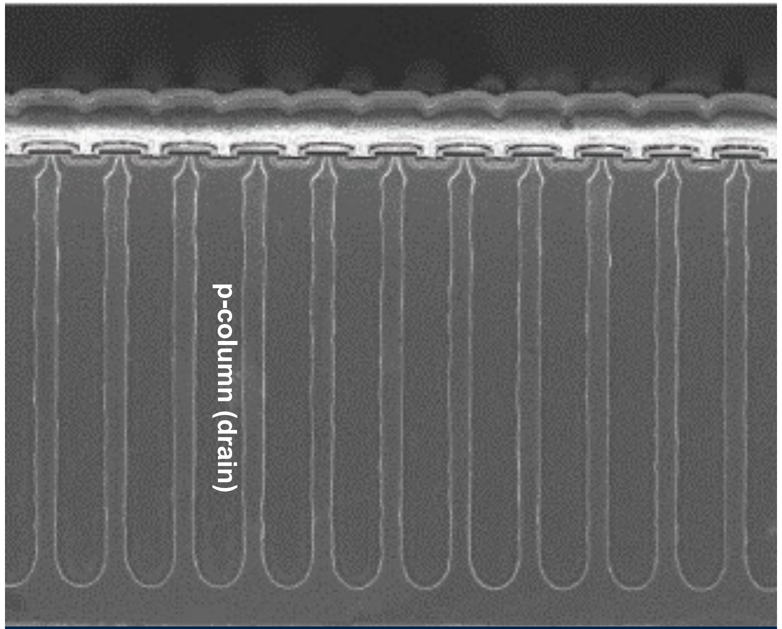
What is next for superjunction?

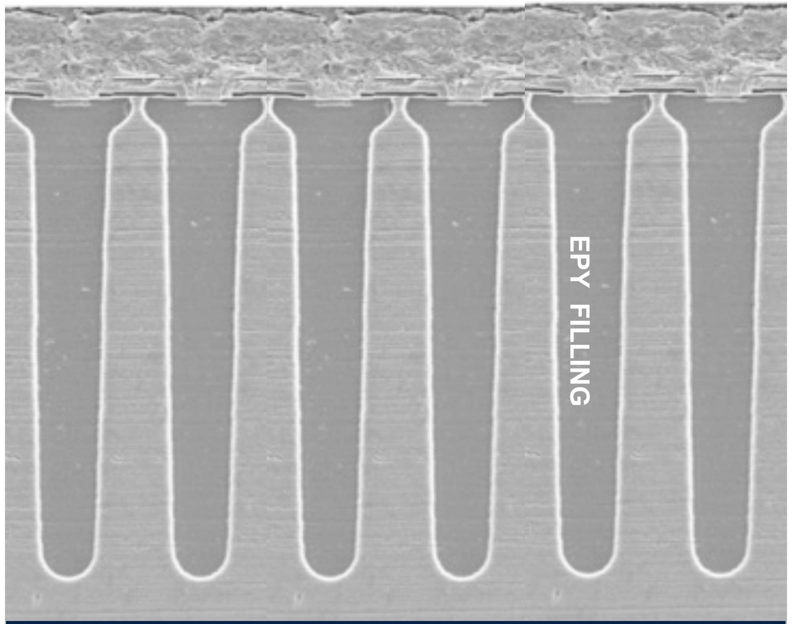
Multidrain approach



Colum by multi epy/implantation and diffusion

From multi-epitaxy to *"dig & fill"* approach

Trench approach



Column by single epy etch and trench filling

- Reduced mask levels
- Single epitaxy
- No thermal process for column formation

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IGBT:
Evolution of a technology

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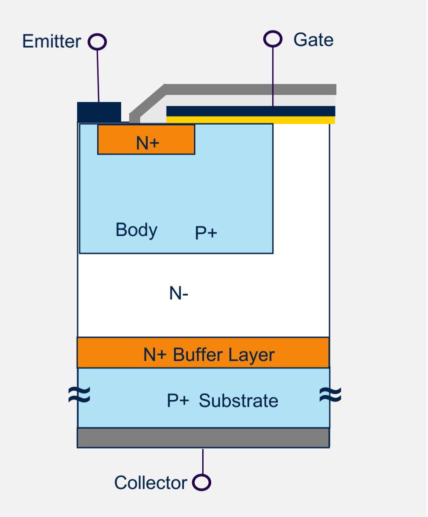
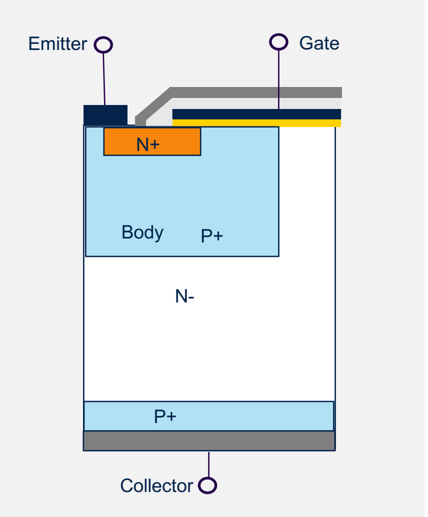
IGBT technology

Punch through



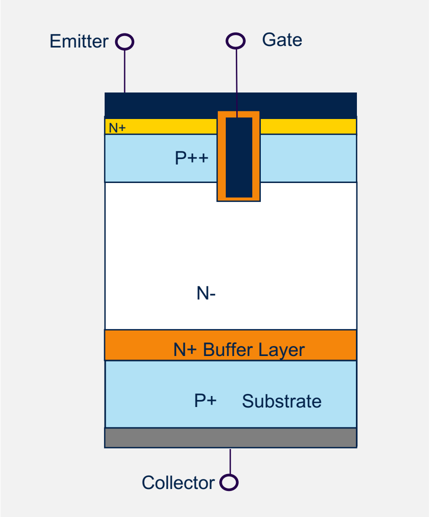
- First IGBT structure
- Faster, but higher V_{CEsat}
- Large E_{off}

Non-Punch through



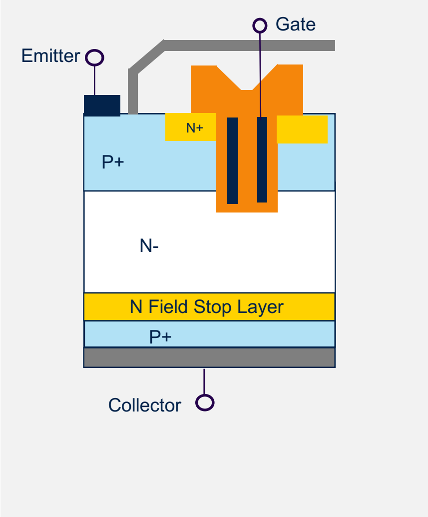
- Thinner substrate
- Lower thermal resistance,
- Lower E_{off}

Trench PT



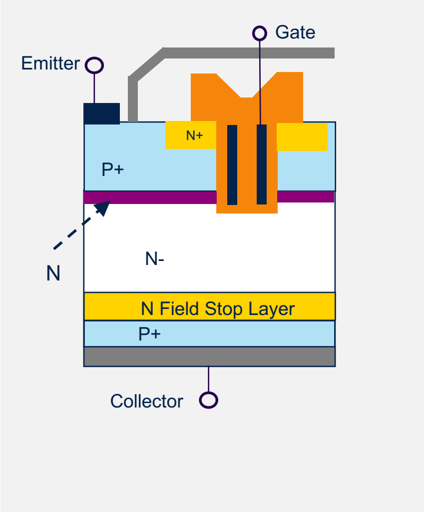
- Vertical Gate
- Optimized channel design
- Lower V_{CEsat}
- Higher current density

Field-stop



- no tail current
- Reduced switching losses
- Decreased V_{CEsat}
- Thinner n-drift region

Hole barrier



- Lower V_{CEsat}
- N+ layer removes JFET resistance
- Carried stored layer fastens turn-on switching ability

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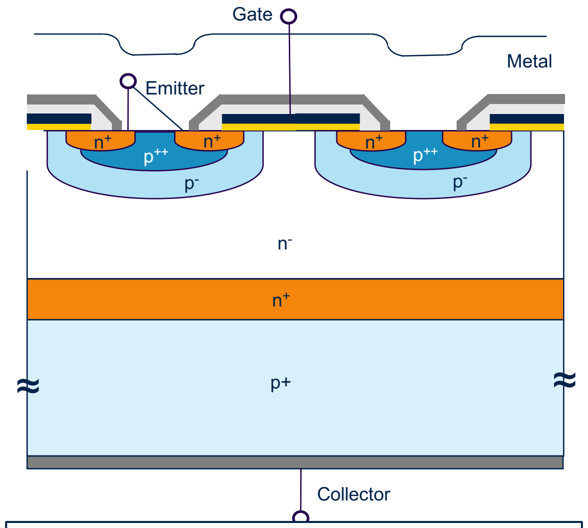
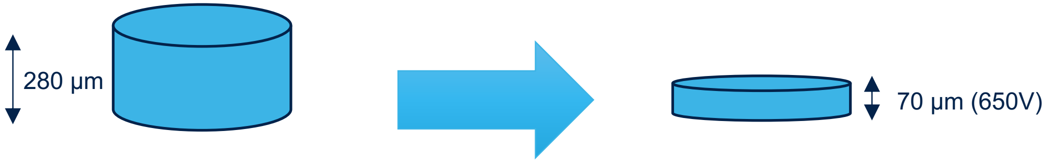
IGBT evolution

Punch through (PT)



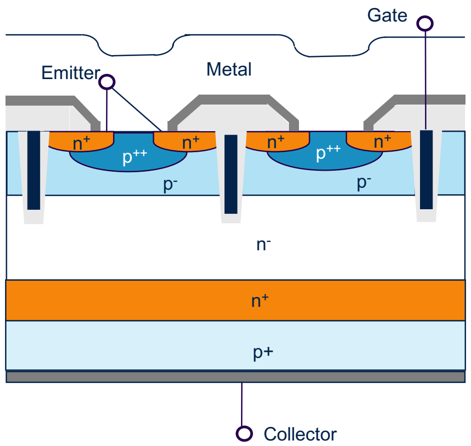
- Asymmetrical configuration
- Low conduction loss
- Less thermal stability

- Not preferred for parallel
- Low switching losses
- Mostly used in DC circuits



Parameter	Planar PT	Trench field stop
Switching losses	**Low**	**Low**
Conduction losses	**High** Slightly decrease with T	**Low** increase with T
Paralleling	**Difficult** Small positive T coefficient	**Easy** Positive T coefficient
Short circuit rated	**Limited** High gain	**Yes**
i.e. Vcesat @10A	**2.8V**	**1.6V**

Trench field stop (TFS)



- Absence of JFET region
- Higher current density
- Lower V_{CEsat}

- Implantation of FS and emitter
- Better V_{CEsat}/E_{off} control
- No need β- irradiation

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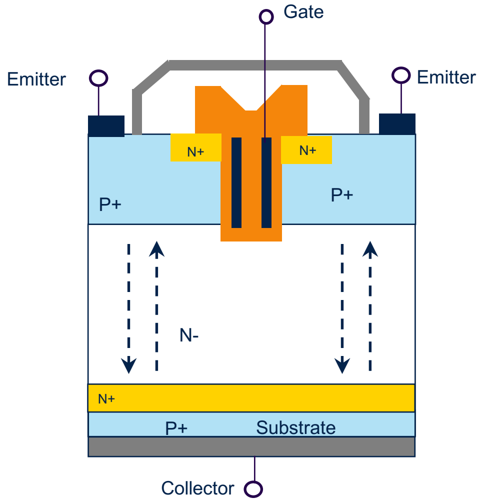
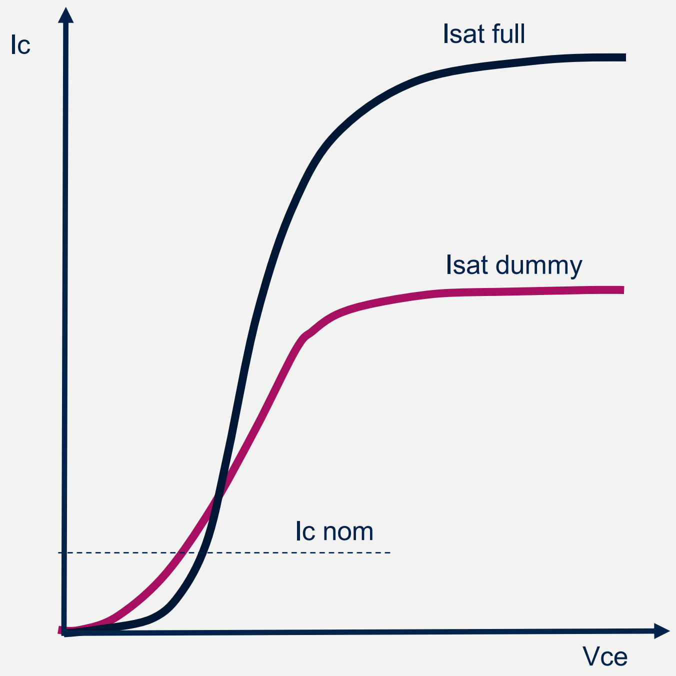
Trench layout strategy

Full active

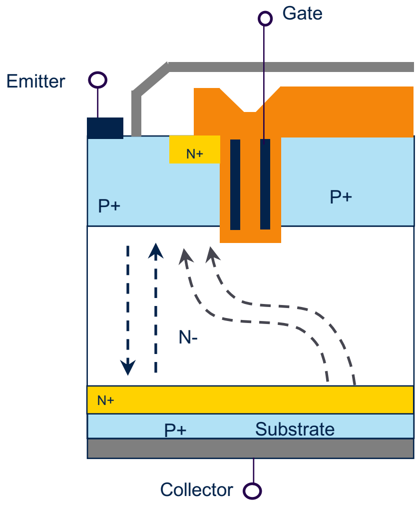


Output curves



Trench pitch	Full Active	Dummy Cell	Extra Dummy
4µm	4 (low, fast)	4 + 4 (medium, fast)	--
8µm	8 (medium, fast)	8 + 8 (medium, fast, SC rated)	8 + 16 (medium, fast, strong SC rated)

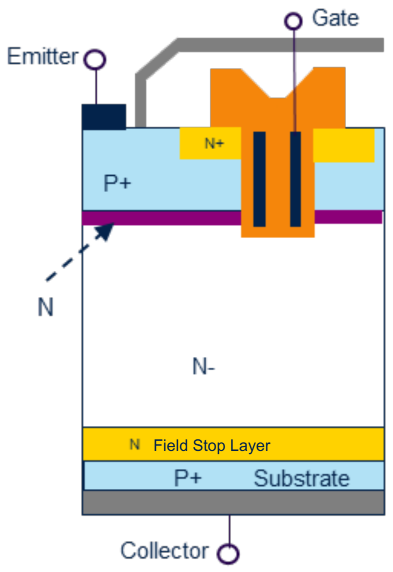
Half dummy

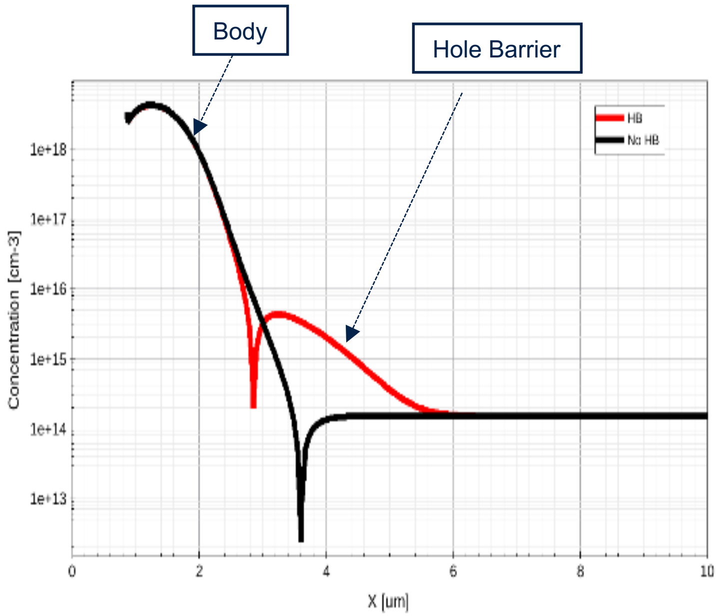


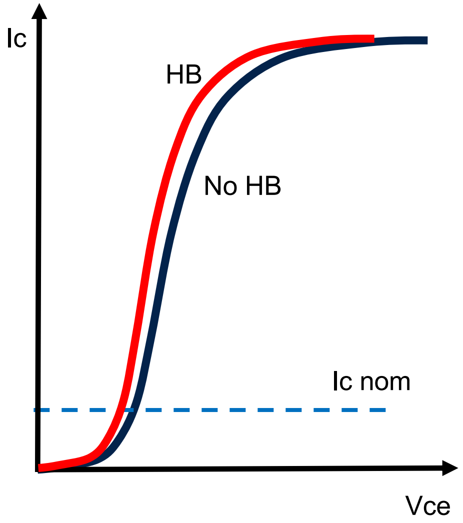
- Lower active cell density
- Low Ciss, Coss, Crss
- Lower saturation current
- Improved Tsc

What’s next in Trench Field Stop?

Hole Barrier Structure







- Process Option
- Additional Mask
- Additional Implant Phosphorus
- New vertical profile with additional N-type layer that enhances the majority carriers and so improving the ON state losses

Benefit
- lower Vcesat ~ 180mV

Warning
- Vth lowering to be retuned
- BVces lowering

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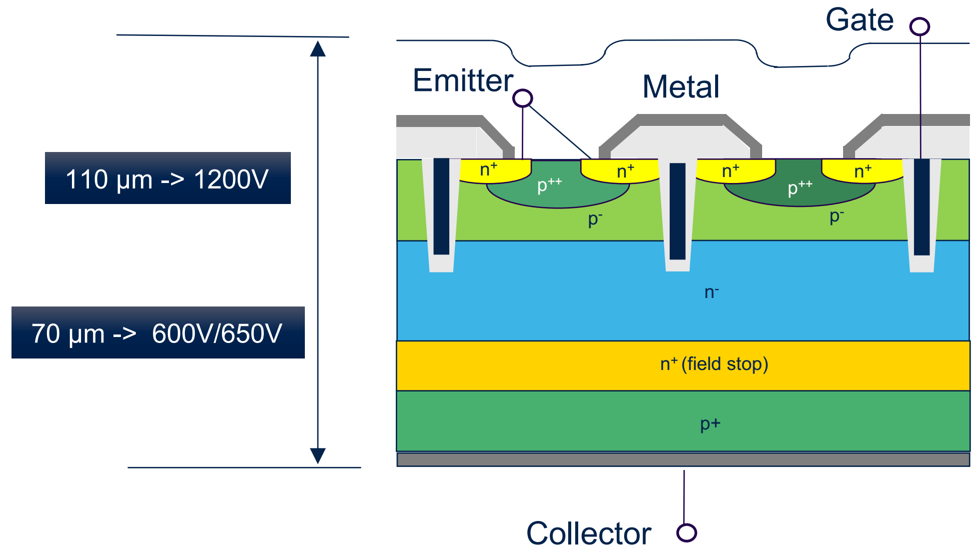
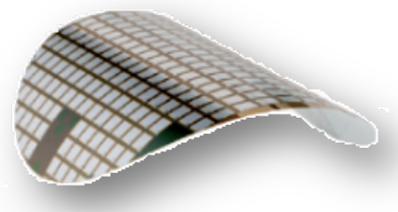
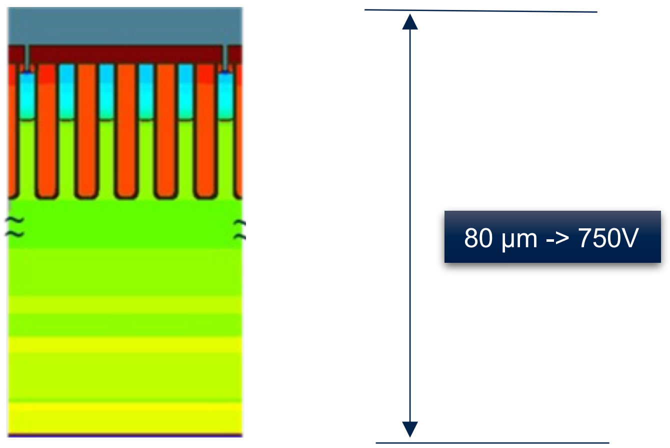
Narrow Mesa II

Trench field-stop





Narrow Mesa II



Technology features	Benefits
• Very fine cell pitch • Trench potential engineered • Multiple deep field stop	• Lower V_{CEsat} • Higher current density: • Better V_{CEsat}/ E_{off} trade-off • Smoother turn-off

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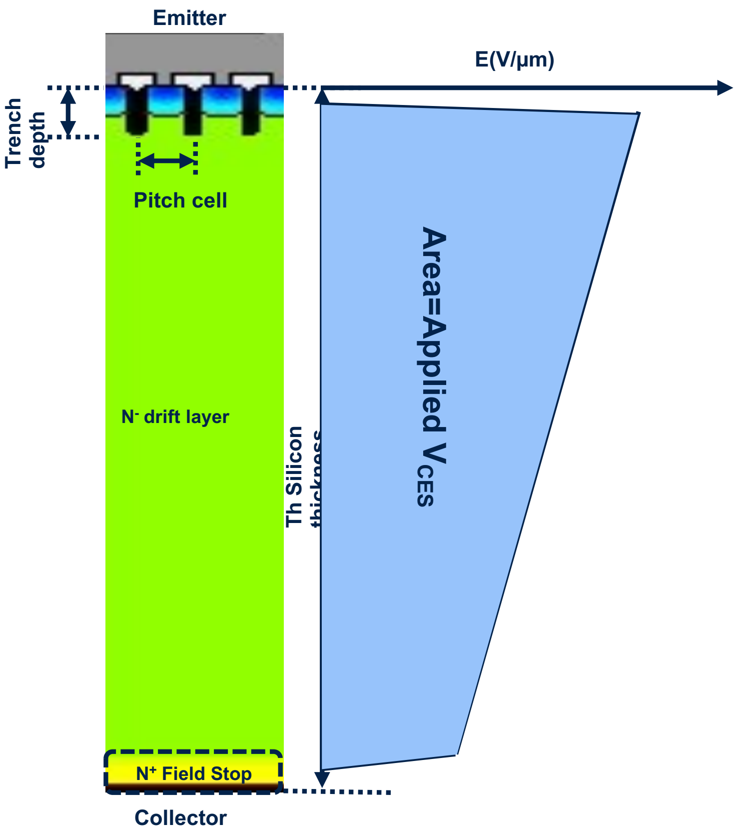
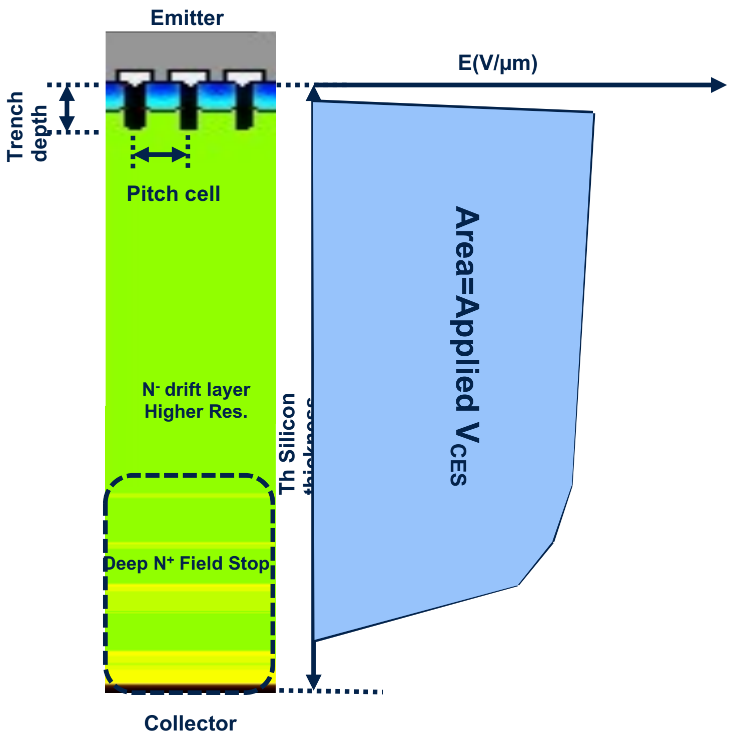
Main features to improve V_{CEsat} and Turn off

Trench field-stop



Narrow Mesa II



N-Drift Lower Thickness, Higher Resistivity:

- to guarantee the same BV_{CES};
- to improve V_{CEsat};

Field Stop Design:

- to improve turn-off in thinner wafer;

Main other upgrades:

- Nitride + Polyimide Passivation
- Backside Emitter Activation by Laser Annealing
- Tune-up of the Emitter Efficiency on Collector
  Backside for the right the trade-off;

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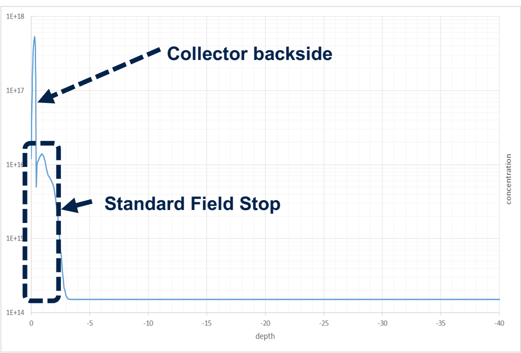
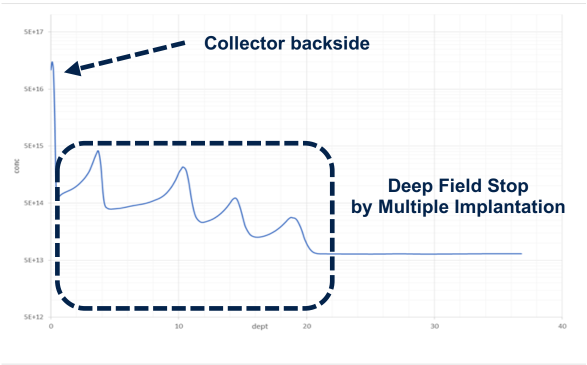
Static electrical improvements

Electrical field: Vertical profile

Standard N+ Field STOP

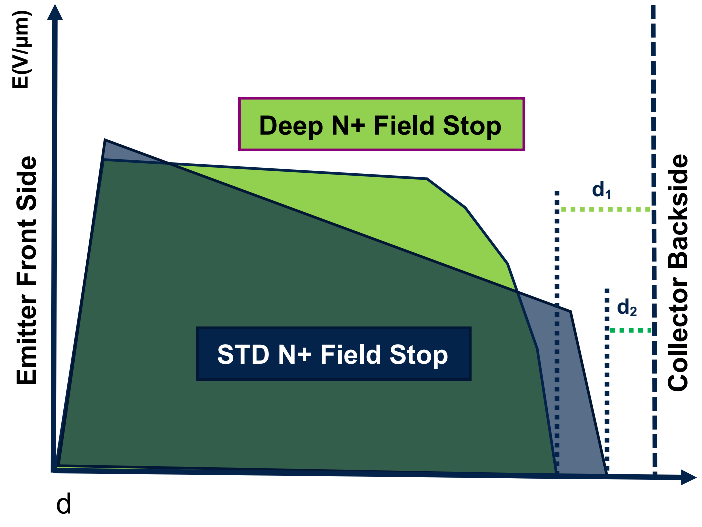


Deep N+ Field STOP



Deep Field Stop Layer;
- To gradually block the electric field near the collector side;
- To reduce V_{CE} peak at turn-off when "reducing the wafer thickness";

Narrow Mesa II



Electric field in high voltage withstanding

- Multiple field-stop profile shows better resolution of field slope-down to have more robust devices
- Higher efficiency voltage withstanding

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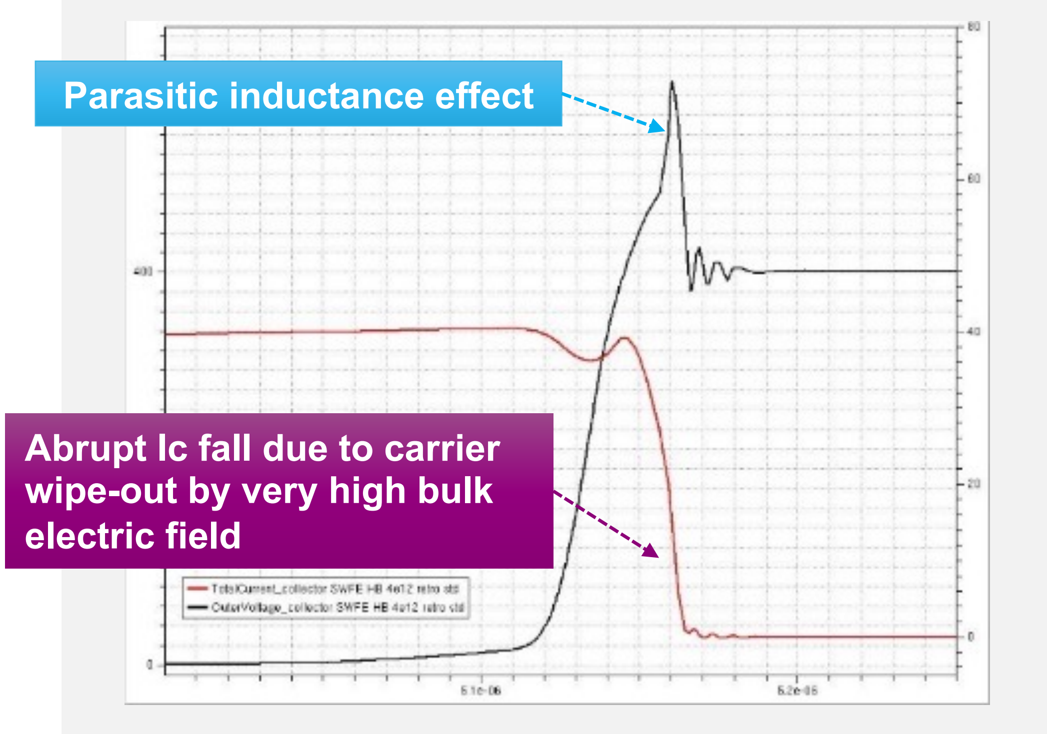
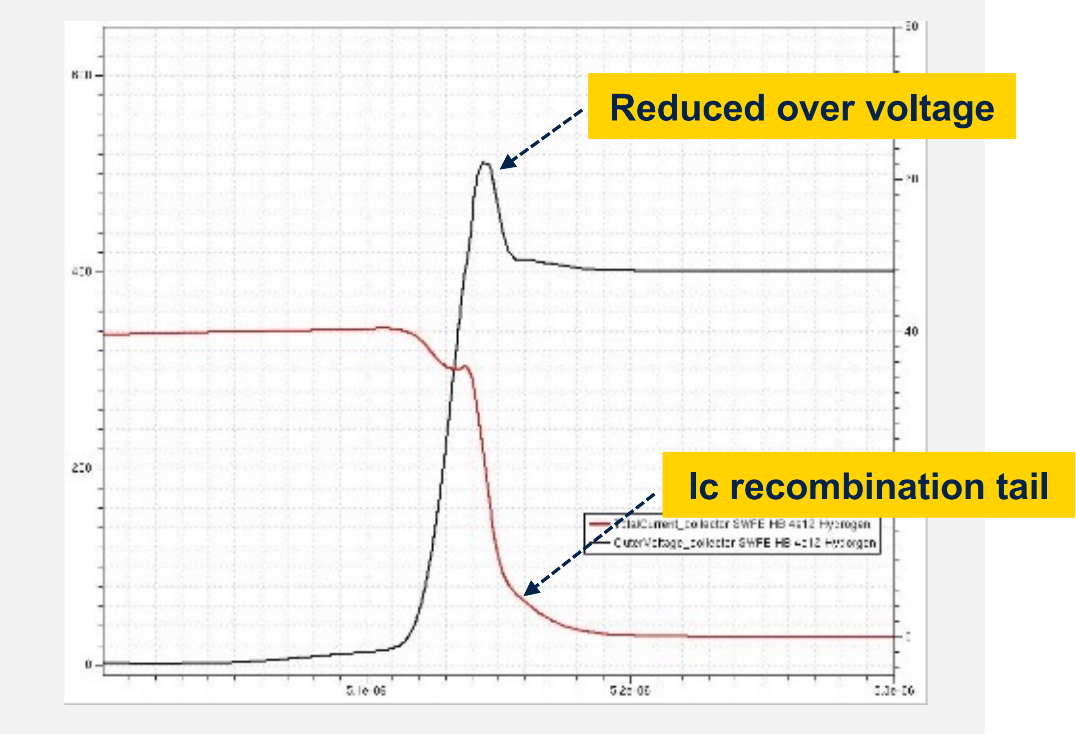
Dynamic electrical improvements
Turn OFF simulation

Standard field stop profile



Multiple field stop profile



Multiple field stop design profile technique is used to control the carrier's lifetime improving performance by reducing overvoltage during switching events

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Takeaways

- **Silicon technologies** span an extensive market, from industrial to automotive sectors
- The **wide product portfolio** targets from low to high power range and from low to high frequency operation
- **New structures** and concepts allow to take up new challenges
- New technologies are one of the key contributors for the **green economy**

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Our technology starts with You

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