Essentials of MOSFETs

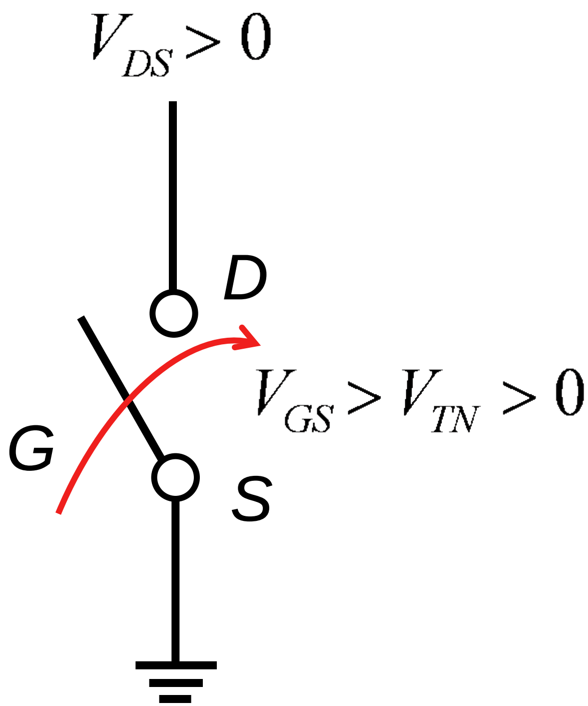
Unit 5: Additional Topics

Lecture 5.2: Power MOSFETs

Mark Lundstrom

lundstro@purdue.edu
Electrical and Computer Engineering
Purdue University
West Lafayette, Indiana USA

Power MOSFETs are used as switches



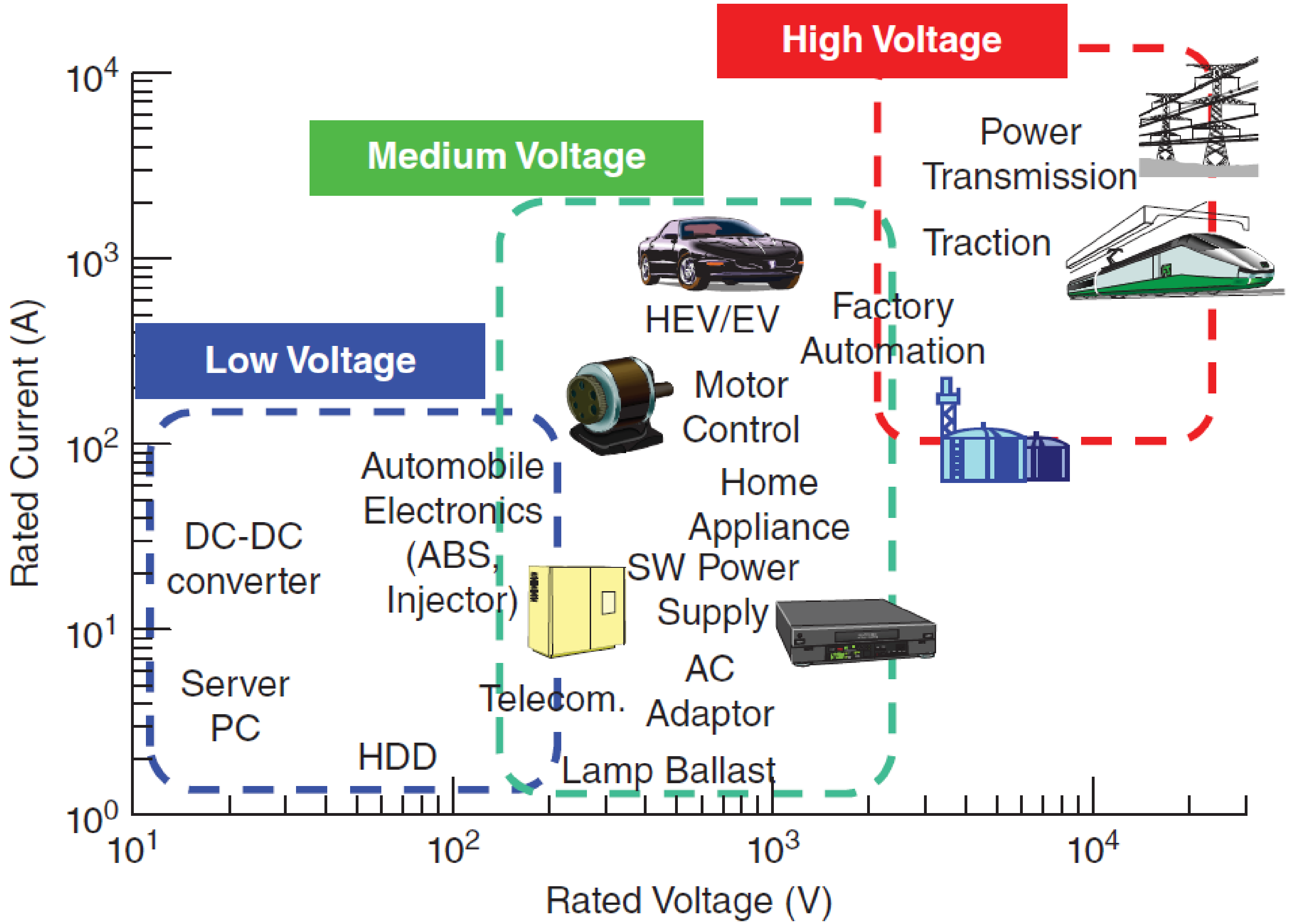
When **on**, the resistance of the switch should be as low as possible.

When **off**, the device should block current to as high a voltage as possible.

1) **Low on resistance**

2) **High breakdown voltage**

Applications



T. Kimoto and J. A. Cooper, *Fundamentals of Silicon Carbide Technology*, Wiley (2014).

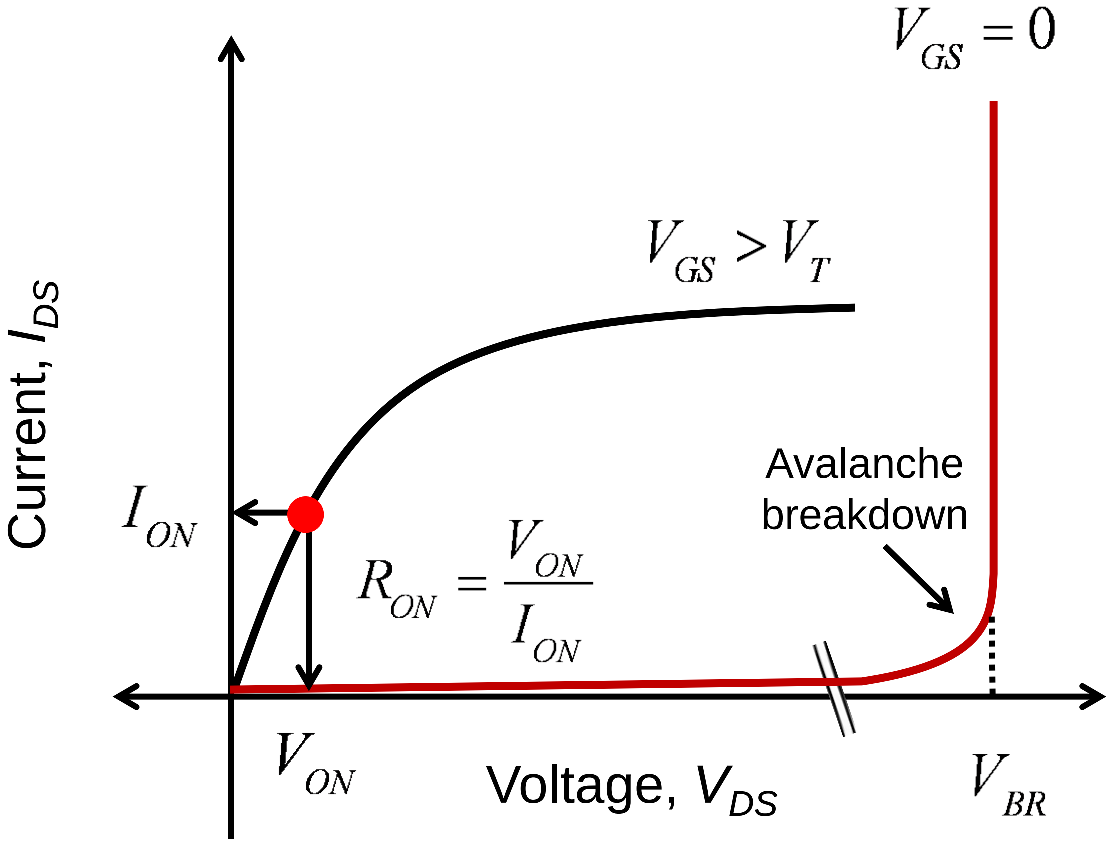
Power semiconductor devices

There are several different types of three-terminal, power semiconductor switching devices – e.g.

- Vertical Diffused MOS transistors (DMOSFET)
- V-groove trench MOSFETs
- Trench MOSFETs
- Insulated Gate Bipolar Transistors (IGBT)
- Superjunction devices

To illustrate some of the considerations, we will only discuss the DMOSFET transistor.

On and off-states



Device design goals

On-state: Maximize I_{ON} (minimize R_{ON})

Off-state: Maximize V_{BR}

Minimize area

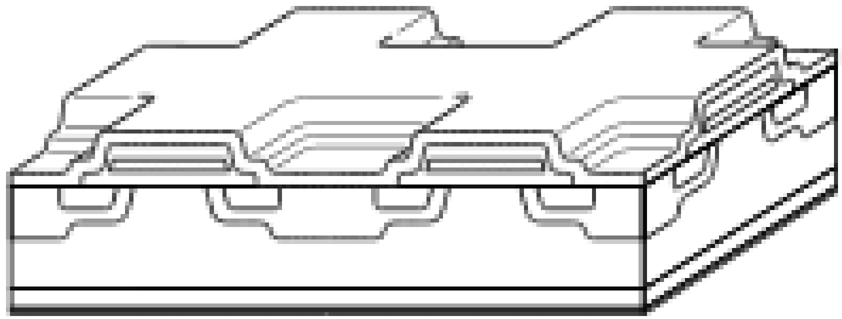
Specific on-resistance: $R_{ON,SP} = R_{ON} \times A$

Device design goals

High currents require large *W* (MOSFET width)

High breakdown voltage requires that we spread the voltage drop out (long channels) to minimize the electric field.

To achieve these goals, power MOSFETs use vertical current flow and cellular structures.



https://en.wikipedia.org/wiki/Power_MOSFET

Area must be minimized

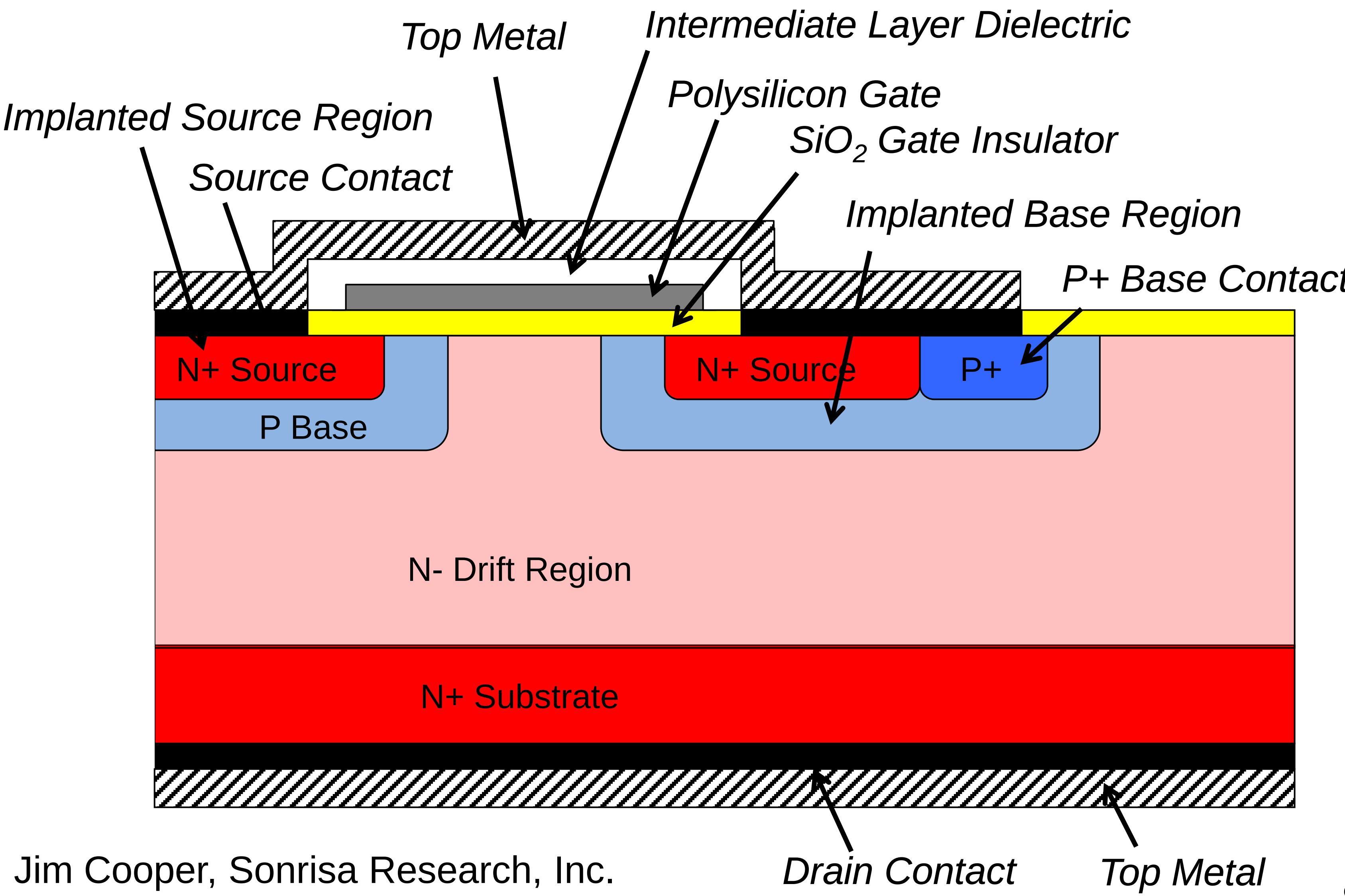
$$R = \rho \frac{L}{A} \qquad R \times A = R_{SP} = \rho L \; \Omega\text{-cm}^2$$

specific resistance

$$A_{DIE}\left(\text{cm}^2\right) = \frac{R_{ON,SP}\left(\Omega - \text{cm}^2\right)}{R_{ON}\left(\Omega\right)}$$

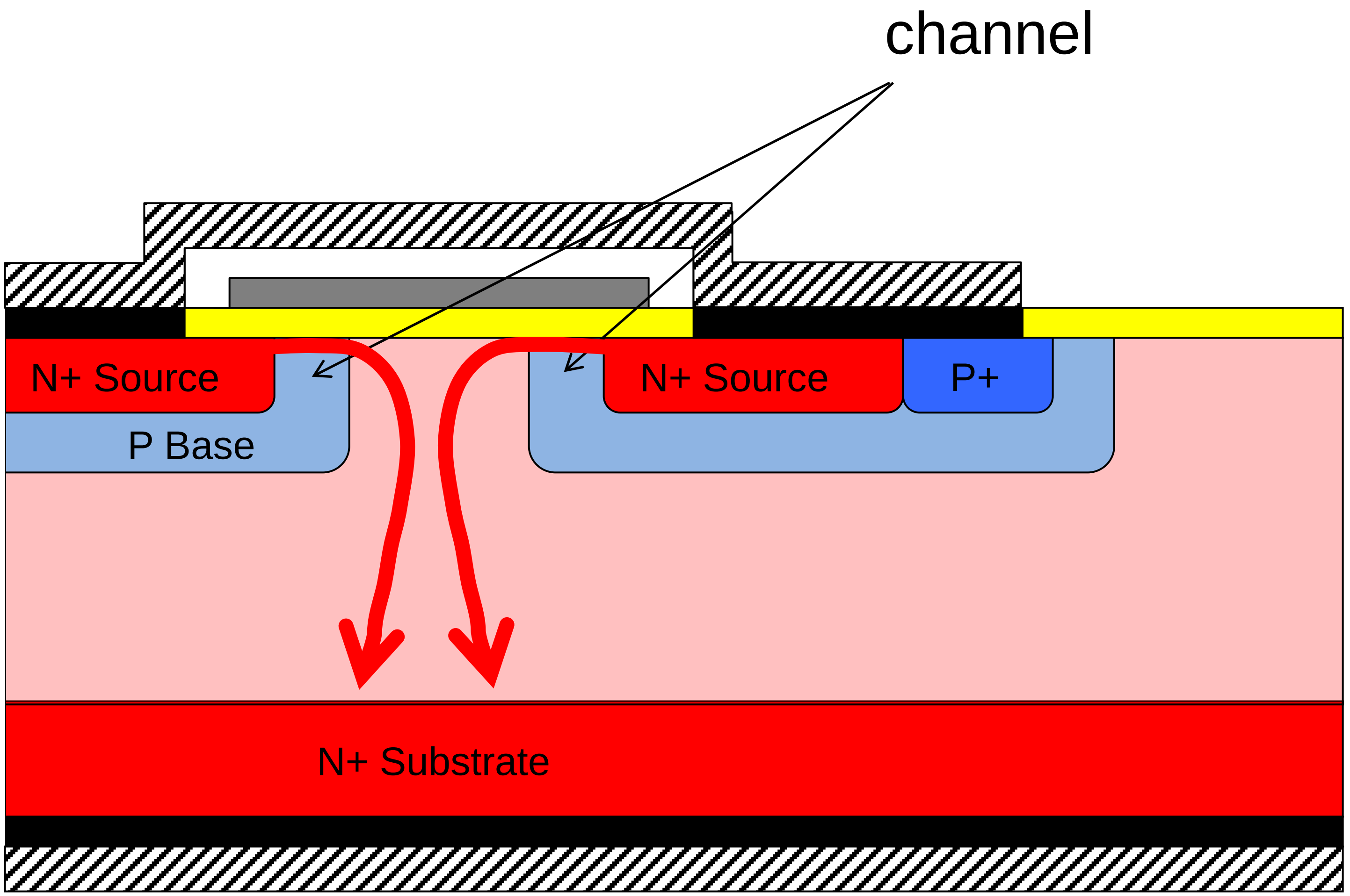
$\Longrightarrow$ Die cost

DMOSFET

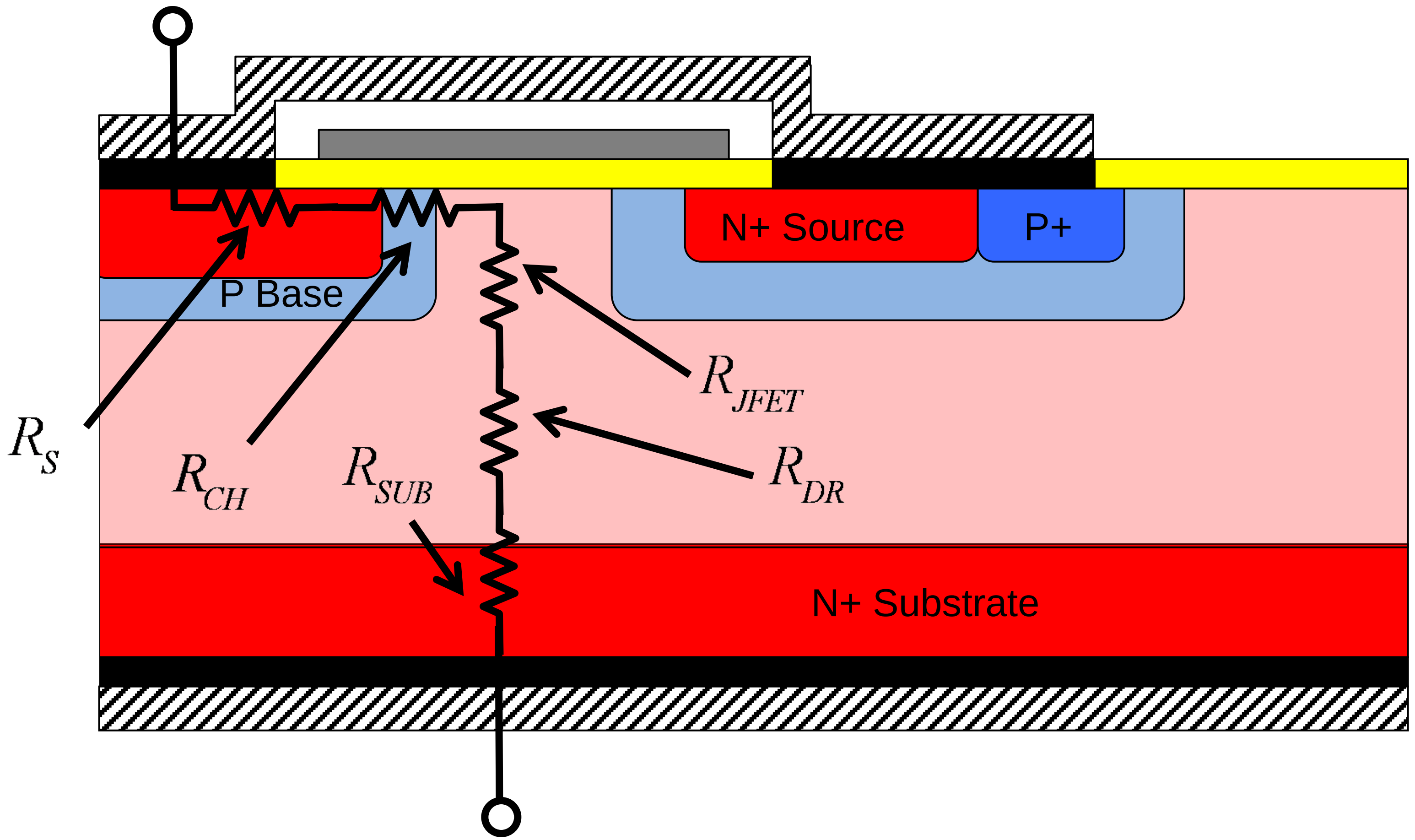


Top Metal
Intermediate Layer Dielectric
Polysilicon Gate
SiO_2 Gate Insulator
Implanted Source Region
Source Contact
Implanted Base Region
P+ Base Contact
N+ Source
N+ Source
P+
P Base
N- Drift Region
N+ Substrate
Drain Contact
Top Metal

DMOSFET: On-state



DMOSFET: On-state resistances



On resistance

$$R_{ON} = R_S + R_{CH} + R_{JFET} + R_{DR} + R_{SUB}$$

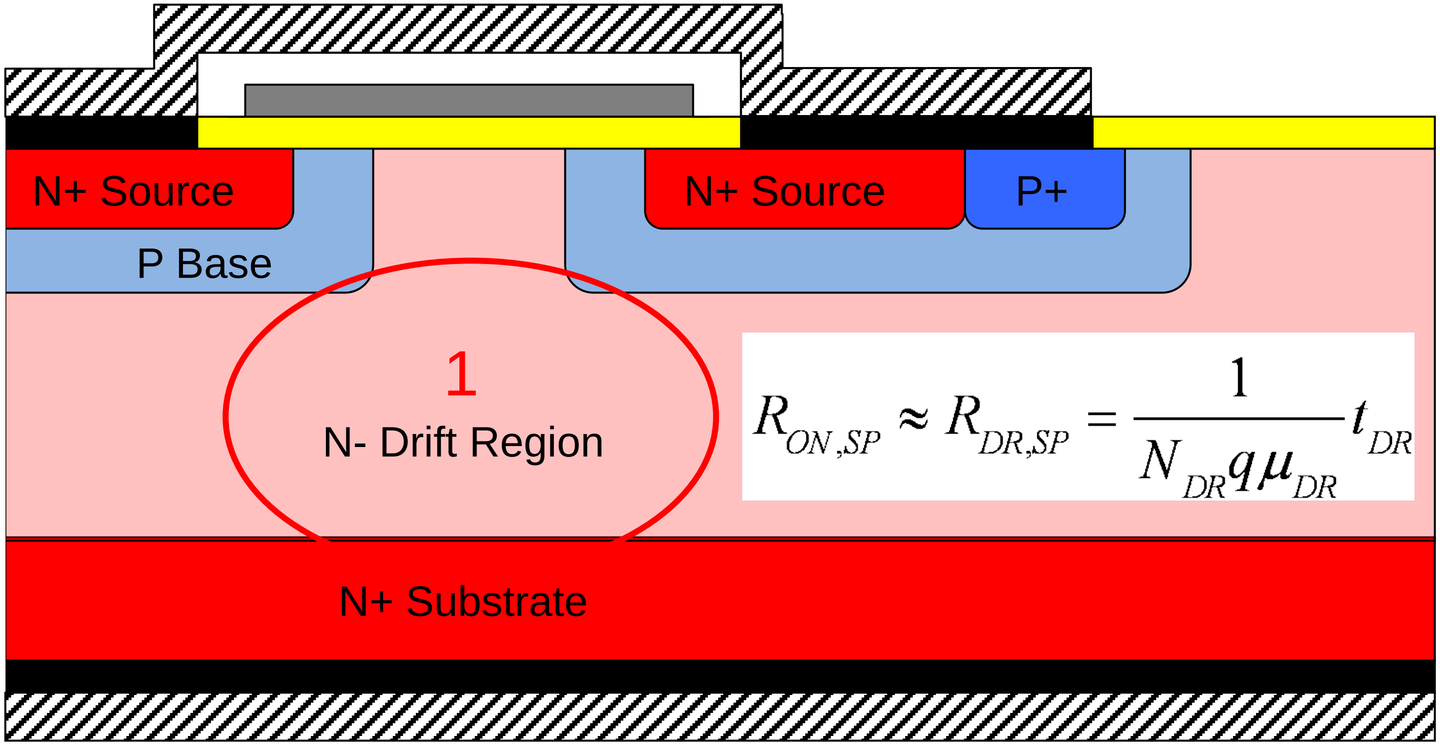
For high voltage MOSFETs, the N^{--} region is thick, so R_{DR} dominates.

$$R = \rho \frac{t_{DR}}{A}$$

$$R_{DR,SP} = \frac{1}{N_{DR} q \mu_{DR}} t_{DR} \left(\Omega \text{ - cm}^2 \right)$$

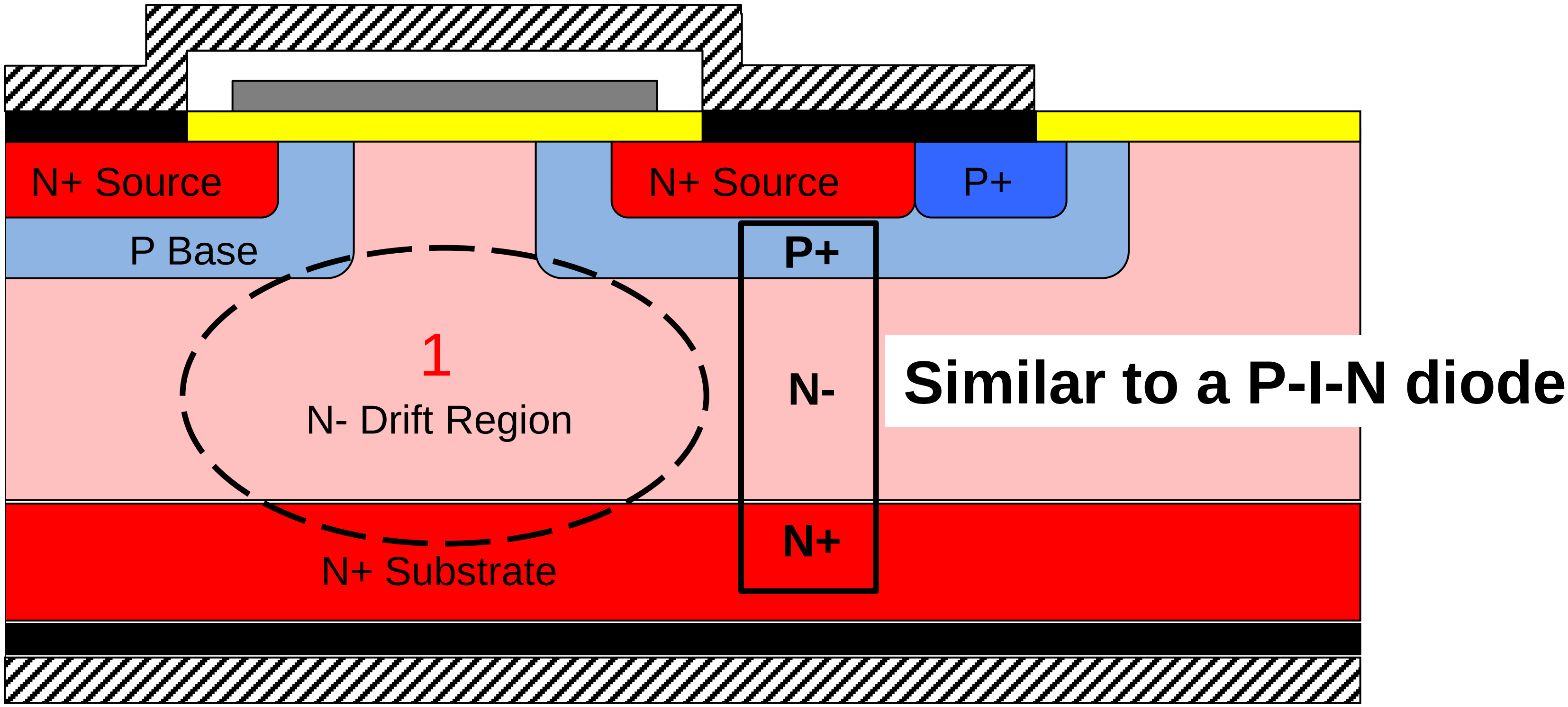
$$R \times A = R_{SP} = \rho t_{DR} \ \Omega \text{ - cm}^2$$

DMOSFET: On resistance

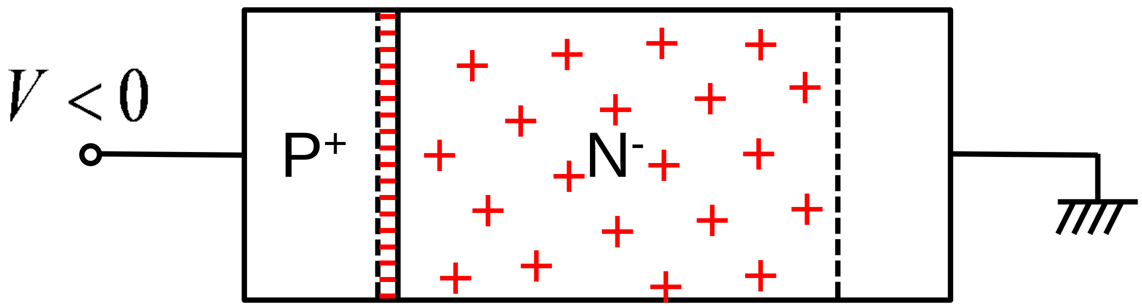


$$R_{ON,SP} \approx R_{DR,SP} = \frac{1}{N_{DR} q \mu_{DR}} t_{DR}$$

DMOSFET: Breakdown voltage

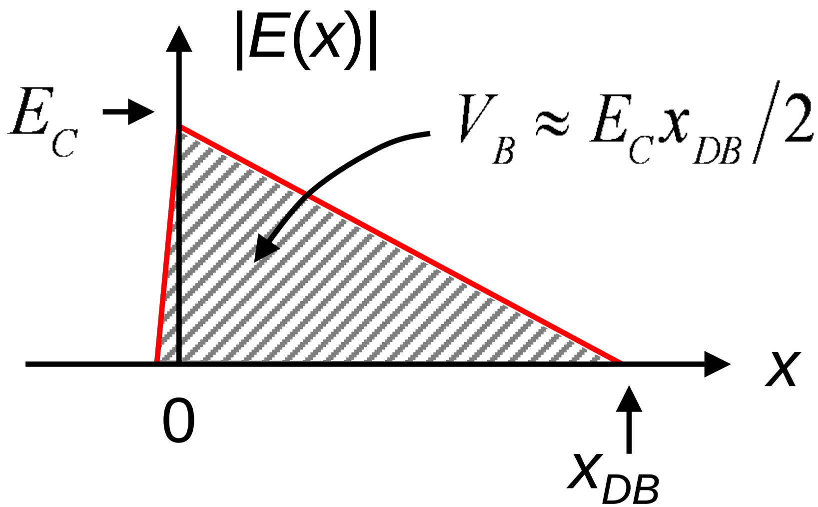


P+/N- diode at reverse breakdown



For a one-sided step junction,

$$x_{DB} \approx \sqrt{2\varepsilon_S V_B / (qN_D)}$$



$$V_B \approx E_C x_{DB}/2 \longrightarrow x_{DB} \approx 2V_B/E_C$$

$$\boxed{V_B \approx \left(\varepsilon_S E_C^2\right) / \left(2qN_D\right)}$$

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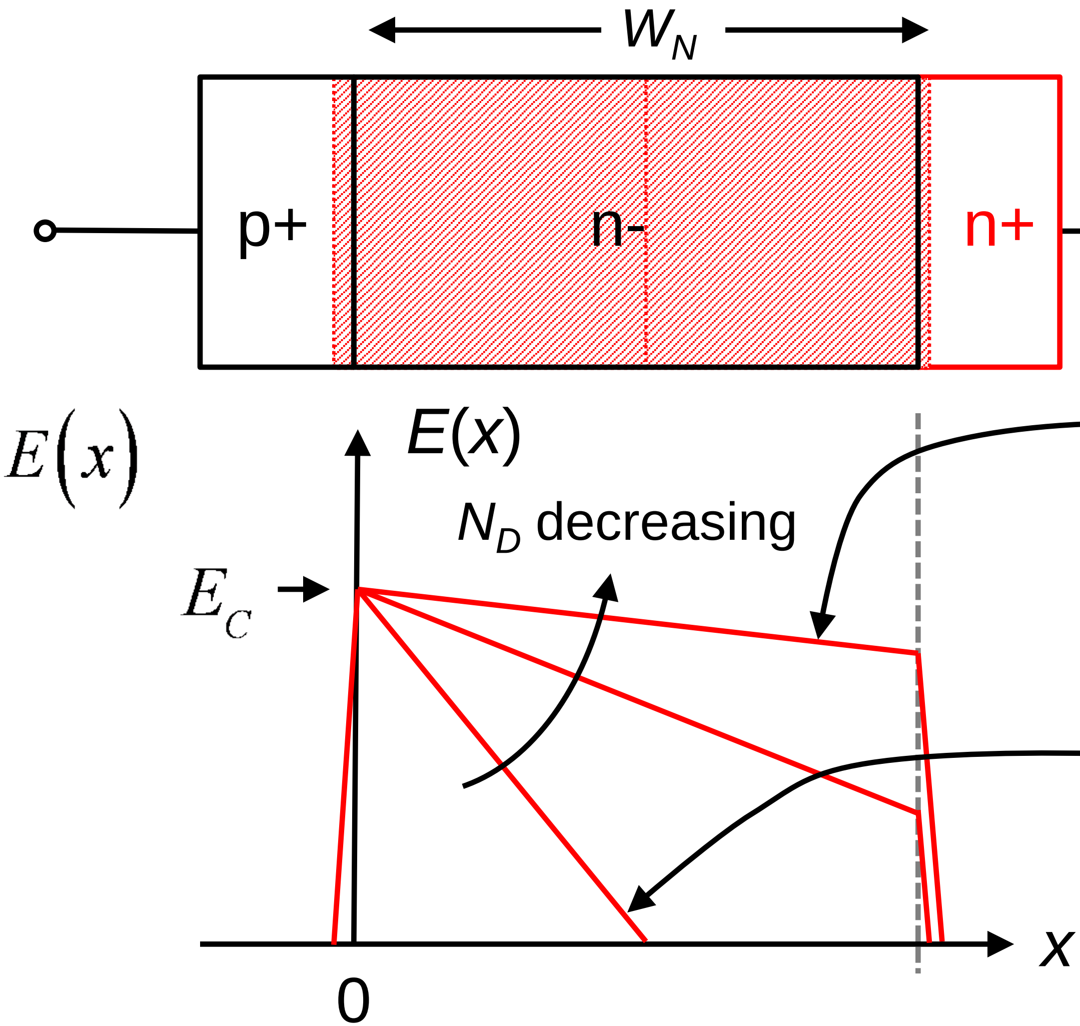
P+/N- diode at reverse breakdown



$$V_B \to E_C W_N$$

If N_D is <u>low</u> (punchthrough), V_B is independent of N_D and proportional to W_N

$$V_B \approx \left(\varepsilon_S E_C^2\right) / \left(2qN_D\right)$$

If N_D is <u>high</u> (non-PT), V_B is proportional to $1/N_D$

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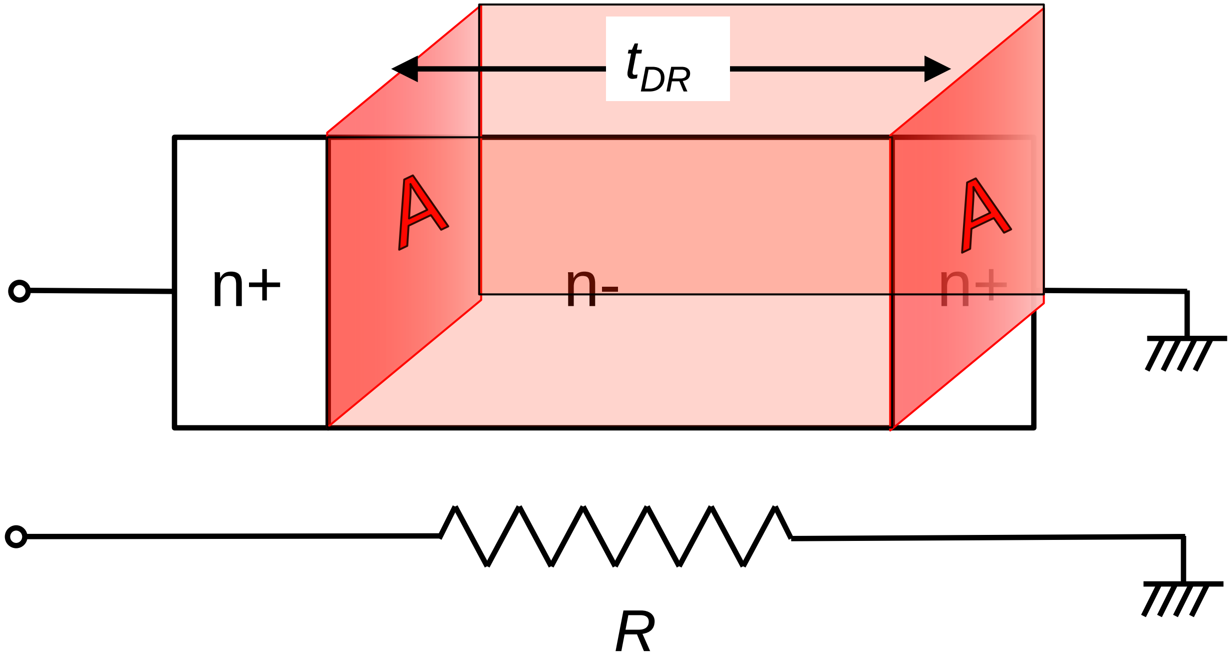
Specific on-resistance



$$R_{ON,SP} = R \times A = \left(\rho \frac{t_{DR}}{A} \right) A = \frac{t_{DR}}{q \mu_n N_D}$$

Resistance – breakdown voltage trade-off

$$V_B \approx \left(\varepsilon_S E_C^2\right) \Big/ \left(2qN_D\right) \qquad \Rightarrow \qquad N_D = \left(\varepsilon_S E_C^2\right) \Big/ \left(2qV_B\right)$$

$$V_B = E_C x_{DB} / 2 \qquad \Rightarrow \qquad x_{DB} = 2V_B / E_C = t_{DR}$$

$$R_{ON,SP} = \frac{t_{DR}}{q\mu_n N_D} \qquad \Rightarrow \qquad \boxed{R_{ON,SP} = \frac{4V_B^2}{\mu_n \varepsilon_S E_C^3}}$$

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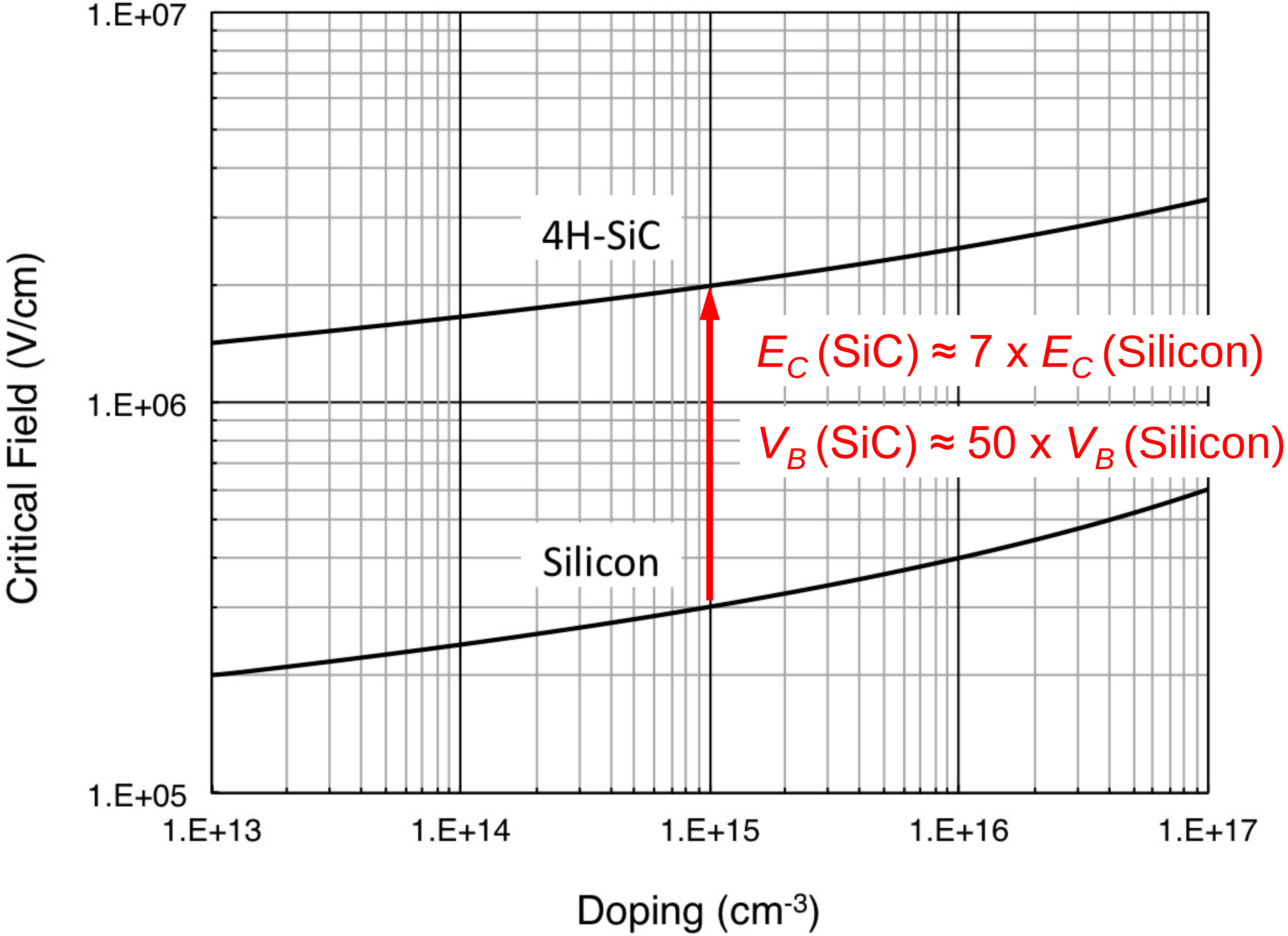
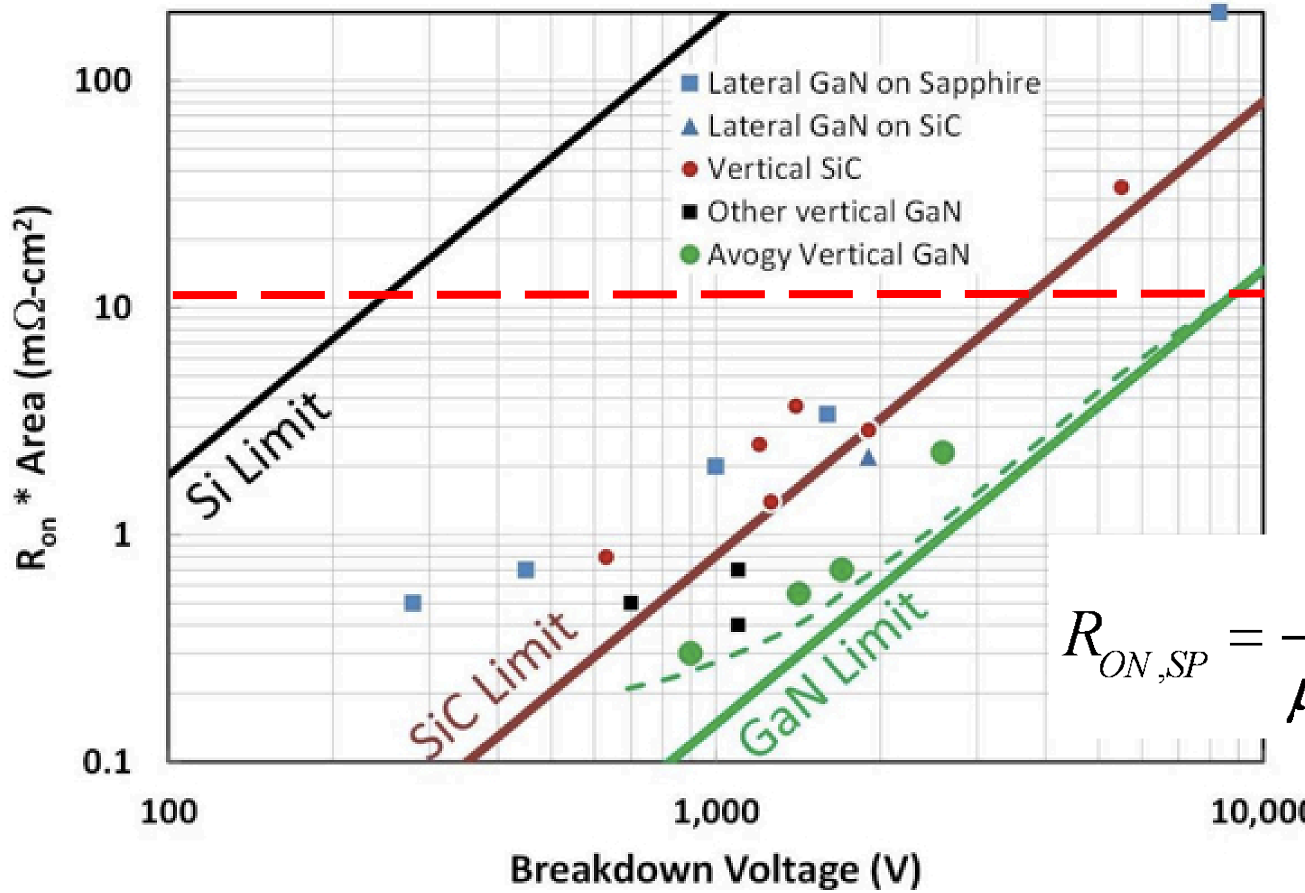
Critical field for breakdown

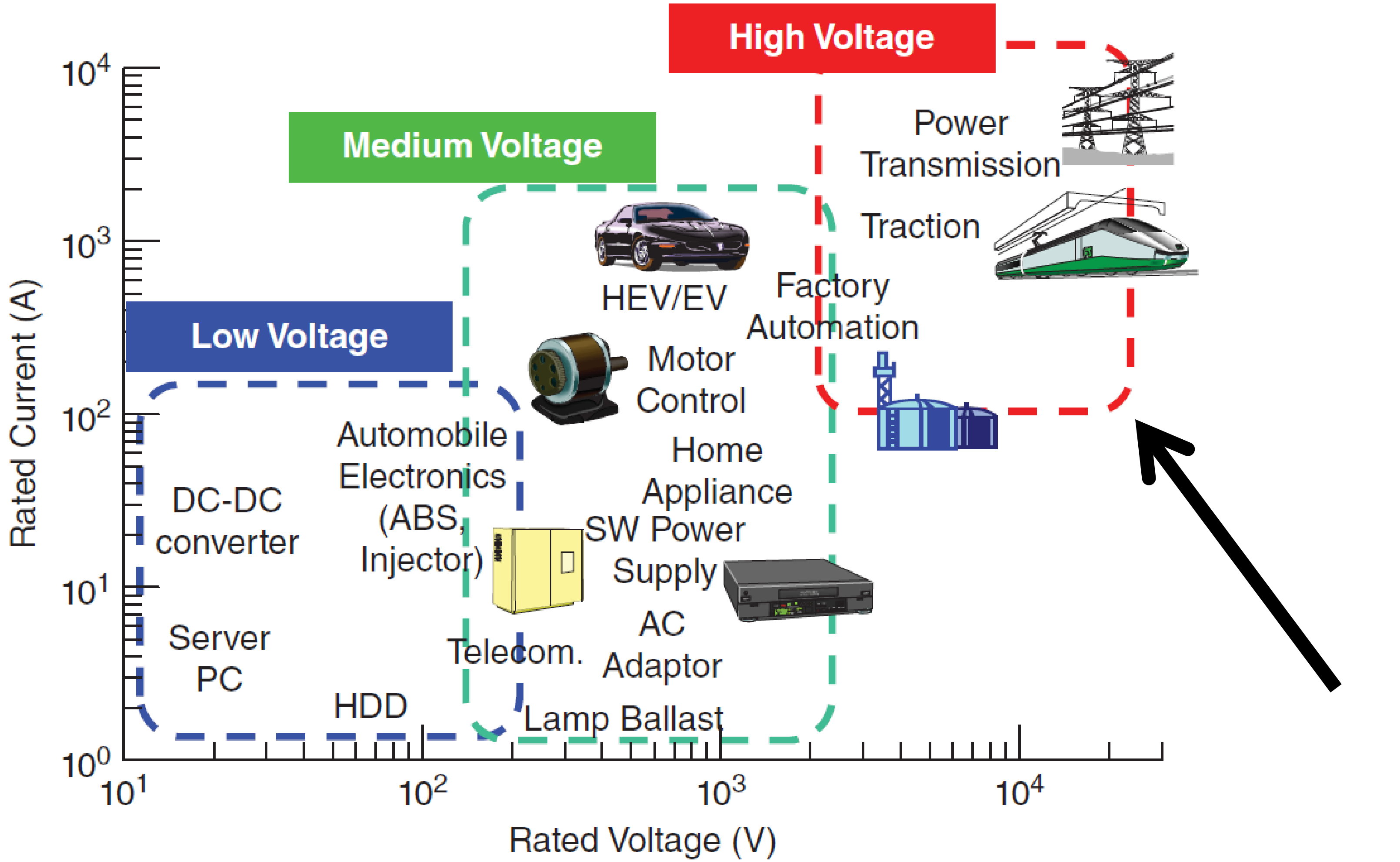


On resistance vs. blocking voltage



$$R_{ON,SP} = \frac{4V_B^2}{\mu_n \varepsilon_S E_C^3}$$

Applications



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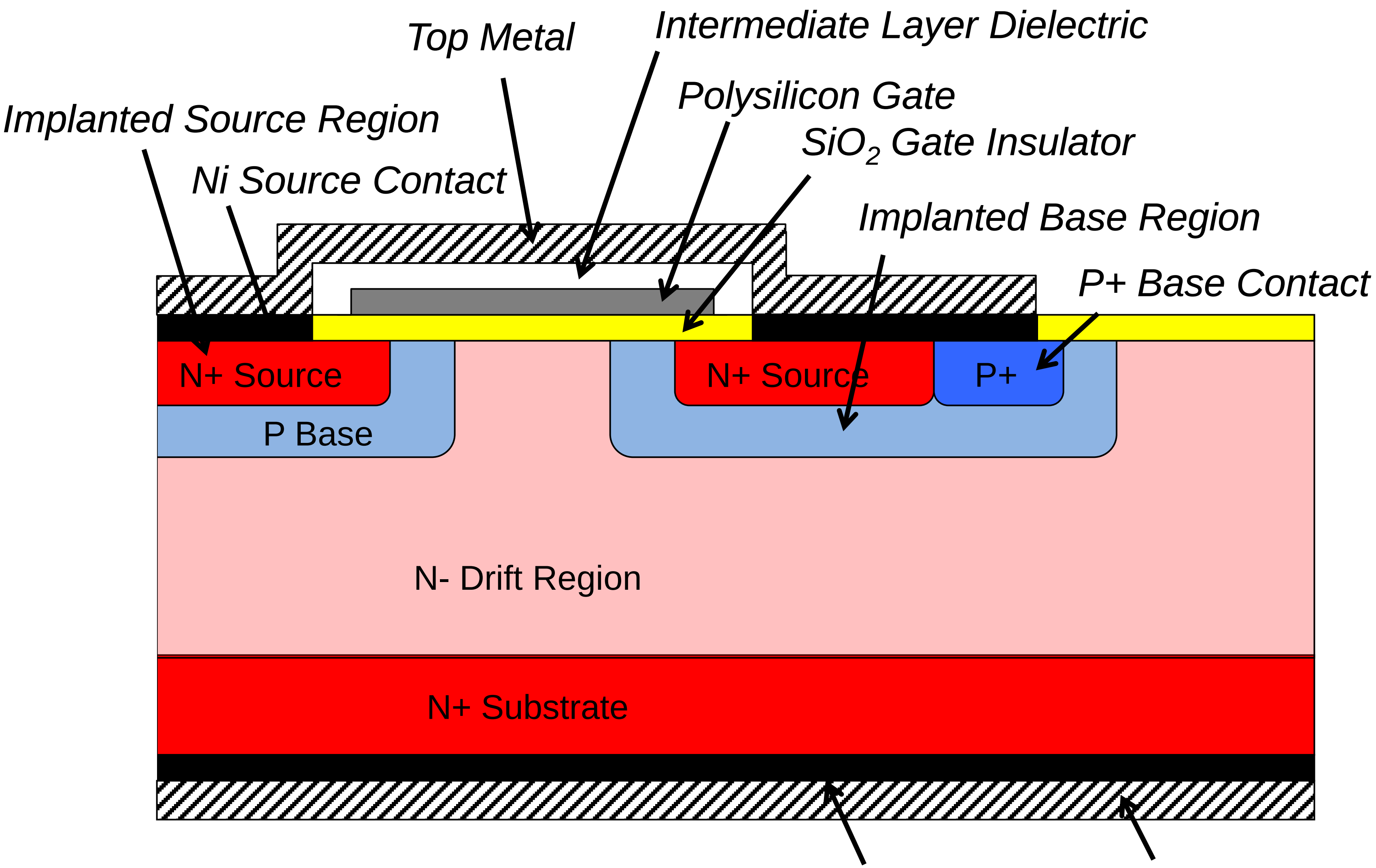
DMOSFET



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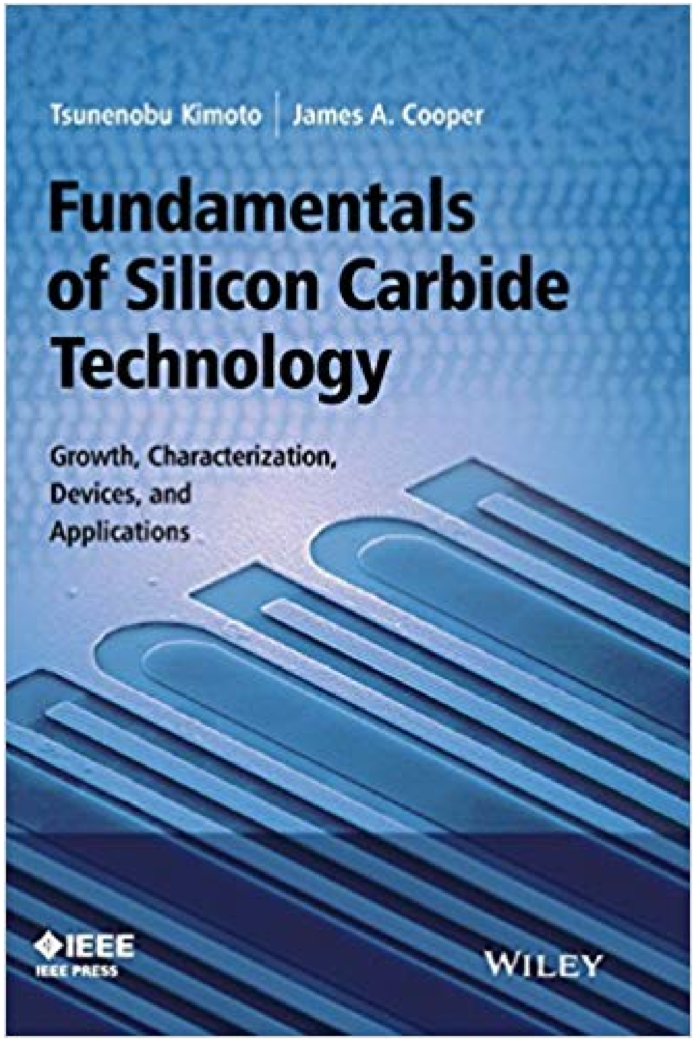
For more information



Tsunenobu Kimoto and James A. Cooper, *Fundamentals of Silicon Carbide Technology*, Wiley (2014).

Summary

1) MOSFETs have important appications beyond digital and RF/analog electronics.

2) Power MOSFET device geometries and design considerations are much different.

3) Power electronics is an important and rapidly advancing field.

Next topic

MOSFETs are not the only type of transistor. In the next lecture, we'll discuss the HEMT – an important RF device.