電力電子元件簡介

Introduction to Power Electronic Devices

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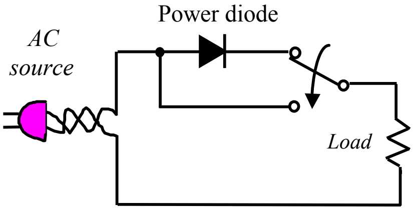
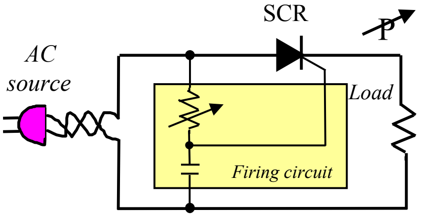
兩段式電熱控制
(應用 Power diode)

無段式電熱控制
(應用 SCR)





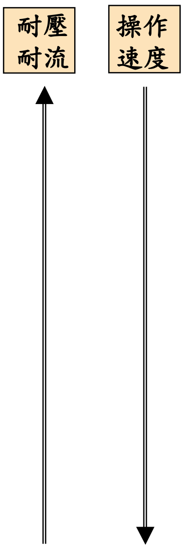
- **Diode: Uncontrolled turn-on and turn-off**
- ***不可控制交流輸出電壓***
  故控制性能較差

- **SCR: Controlled turn-on and uncontrolled turn-off**
- ***可控制交流輸出電壓***
  故控制性能較佳

常用功率半導體元件之額定(表二)

- *Voltage/current ratings*
- *Switching frequency (speed)*
- *Switching time*
- *On-state resistance*
  (or on-state voltage/current)

功率半導體元件



(A) 閘流體 (Thyristor) 或矽控整流器 (Silicon Controlled Rectifier, SCR) : Controlled turn-on, uncontrolled turn-off

(B) 雙向閘流體 (Bidirectional Thyristor 或 TRIAC)

(C) GTO (Gate Turn-off Thysistor)

(D) 基體閘換向閘流體 (Integrated Gate-Commutated Thyristor, IGCT): It is introduced by ABB in 1997. It is a high-voltage, hard-driven, asymmetrical-blocking GTO with unity gain. The gate drive circuit is built-in on the device module.

(E) 功率電晶體 (Power BJT) : Current control device

(F) IGBT (Insulated Gate Bipolar Transistor):
  - *Combines the conduction characteristic of BJT and the control characteristic of the MOSFET*

(G) MOS控制閘流體 (MOS -controlled Thyristor, MCT):
  - *Combines the load characteristic of the thyristor and the control characteristic of the MOSFET*
  - *Low on-state voltage*

(H) 功率金氧半電晶體 (Power MOSFET) : Voltage control device

(I) 其它

功率半導體元件之控制特性

(1) Uncontrolled turn-on and off: **(diode)**

(2) Controlled turn-on and uncontrolled turn-off: **(SCR)**

(3) Controlled turn-on and off ***(Controllable switches):***
(GTO, IGCT, MCT, BJT, IGBT, MOSFET)

(4) Continuous gate signal requirement: **(IGCT, BJT, IGBT, MOSFET)**

(5) Pulse gate signal requirement: **(MCT, SCR, TRIAC, GTO)**

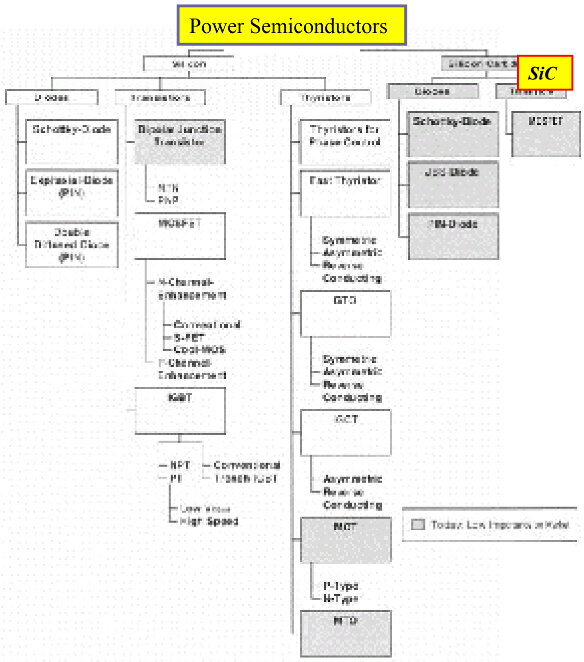
(6) Bipolar voltage-withstanding capability: **(SCR)**

(7) Unipolar voltage-withstanding capability: **(GTO, IGCT, MCT, BJT, IGBT, MOSFET)**

(8) Bidirectional current capability: **(TRIAC)**

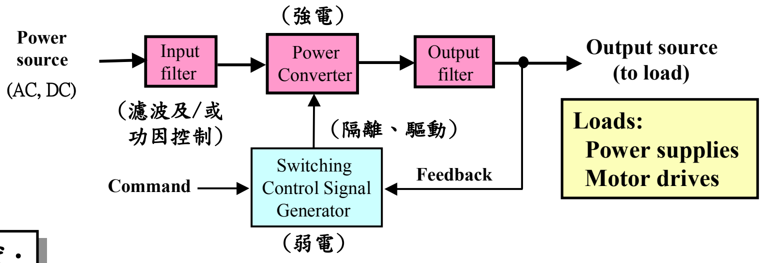
(9) Unidirectional current capability: **(SCR, GTO, IGCT, MCT, BJT, IGBT, MOSFET, diode)**

Classification of state-of-the-art Power Semi-conductors



常用功率半導體元件之符號及操作特性

功率換流器之典型結構



Loads:
Power supplies
Motor drives

型　式:

- 交流至交流交流至交流換流器 (Cycloconverter)
  （含交流至直流至交流換流器）
- 交流至直流換流器 (Converter): Phase control, integral cycle control
- 直流至交流換流器 (Inverter): VVVF, VVFF
- 直流至直流換流器 (Chopper): PWM control, FM control

如何設計一個電力電子設備？

(1) 由機械負載特性選定馬達及換流器之型式。

(2) 設計組裝電力電路：選定功率半導體元件、組裝換流器及其保護電路。

(3) 決定並設計適當之換流器切換控制方式及電路。

(4) 設計邏輯決策電路、隔離電路及觸發驅動電路。

(5) 設計輸入及輸出濾波電路(功因控制電路)。

(6) 感測元件及其信號放大處理電路之組立。

(7) 電力電子系統之動態模式建立：推導或由量測估算得之。

(8) 閉迴路控制系統之設計及實作。

(9) 組裝(注意接地與屏蔽等考量安排設計)。

常用功率半導體簡介

- *Power diodes:*
  - *General purpose (for high-power rectification)*
  - *High speed (for switching application)*
  - *Schottky (for extra-low voltage rectification)*
- *Thyristors*
- *Power transistors*

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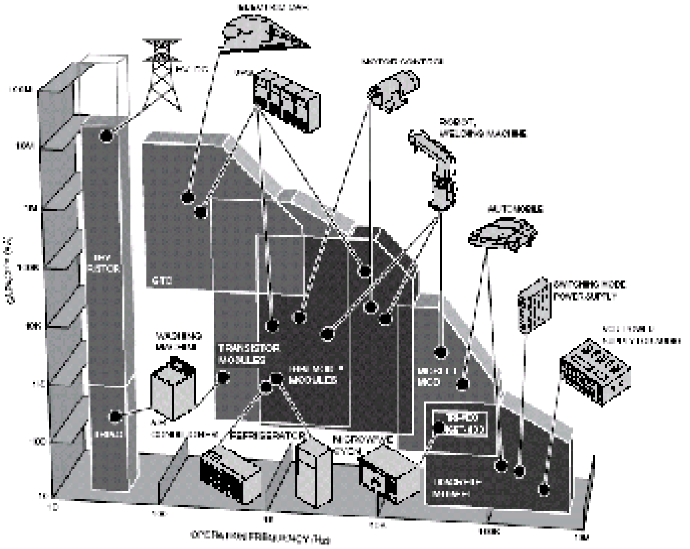
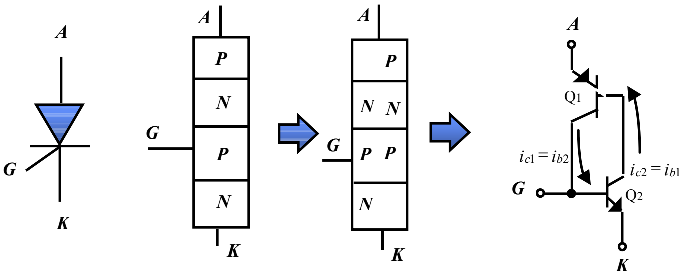
Figure 1.1 Application for Power Devices



SCR (矽控整流器)

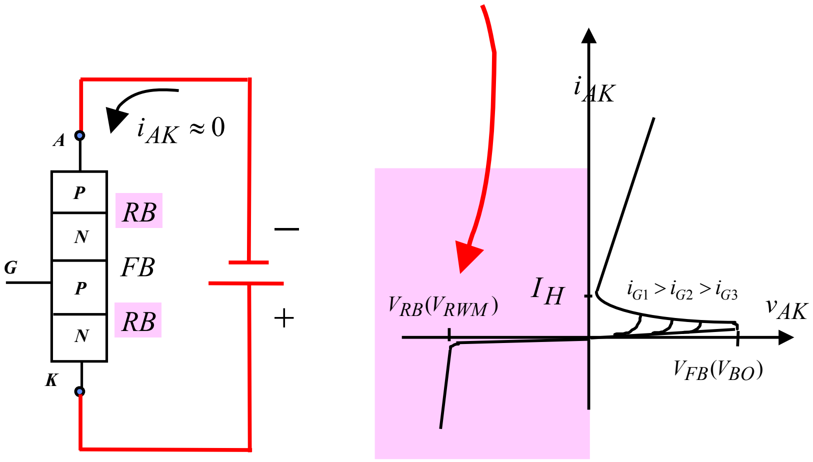
- *閘流體 (Thyristor)- 矽控整流器 (Silicon Controlled Rectifier, SCR) : Controlled turn-on, uncontrolled turn-off*
- *Construction, symbol, equivalent circuit, triggering control, v-i characteristics:*



Two-transistor model

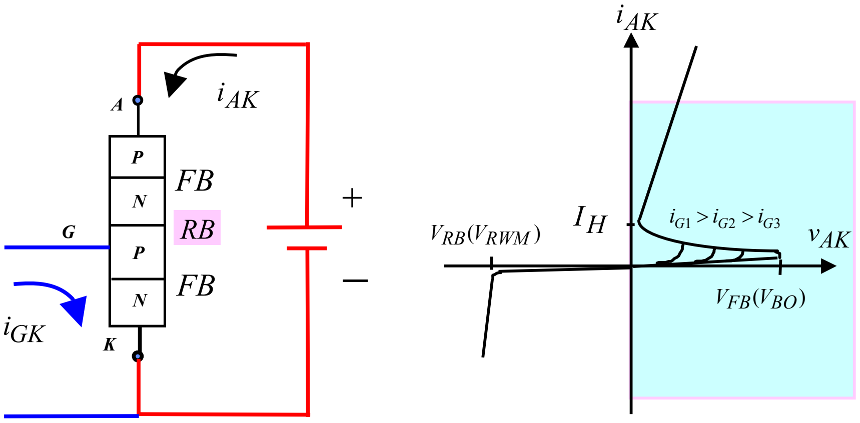
SCR之逆偏

- $v_{AK} > V_{RB}(V_{RWM}) \Rightarrow$ Breakdown



SCR之順偏

- **順偏:**



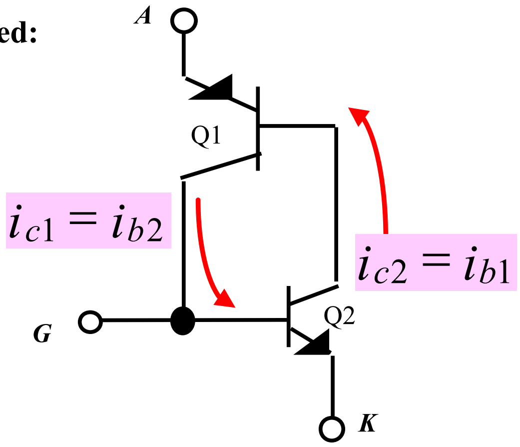
Two-transistor model

- $i_b \Rightarrow i_c \Rightarrow i_b \Rightarrow i_c \Rightarrow$ (Current is cumulatively amplified)
- **Normally triggered:** 當 $v_{AK} > 0$ 時，加以適當之 $i_{GS} > 0$
- **Abnormally triggered:**

  High dv/dt

  High temperature

  $v_{AK} > V_{FB}$

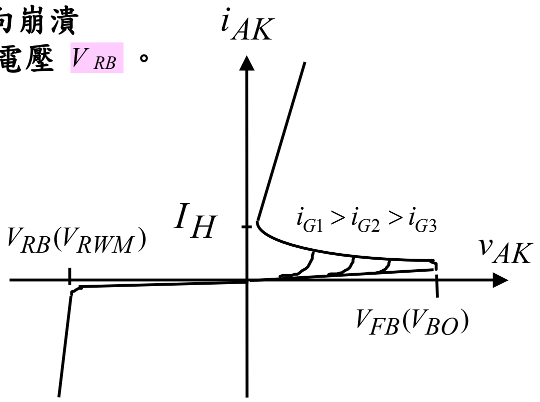


觸發控制

Turn on: 當 $v_{AK} > 0$ 時，加以適當之 $i_{GS} > 0$

Turn off: $i_{AK} < I_H$ *(Holding current)*

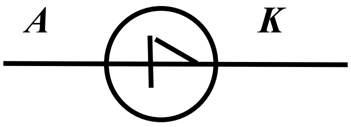
- 在使用時，須注意外加之電壓正負峰值不可大於順向崩潰電壓 V_{FB} 及逆向崩潰電壓 V_{RB} 。



- **沒有 Gate 之SCR ⇒**
  蕭克萊二極體 (Shockley diode)
- *on 及 off:*

$$v_{AK} \geq V_{FB} \Rightarrow ON \ , \quad i_{AK} < I_H \Rightarrow OFF$$

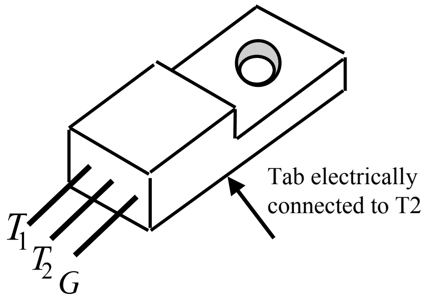
符號：

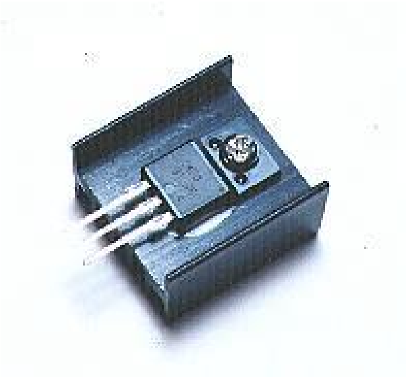


Triac (AC Thyristor)

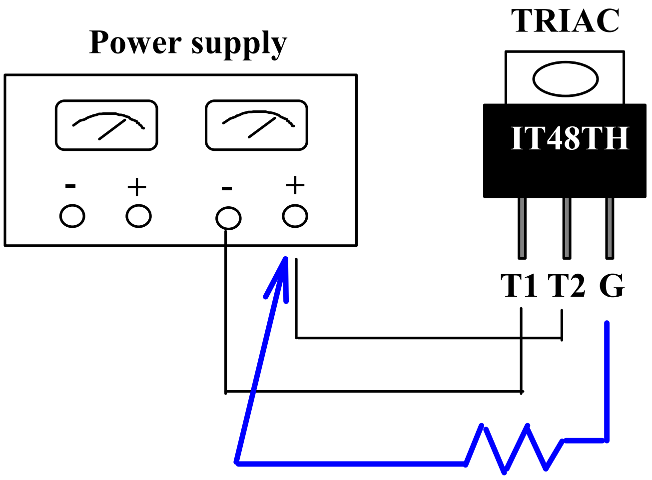
- **A three-terminal, five layer, bilateral semiconductor device.**
- **Bidirectional *TRI*ode *AC* thyristor.**

TRIAC





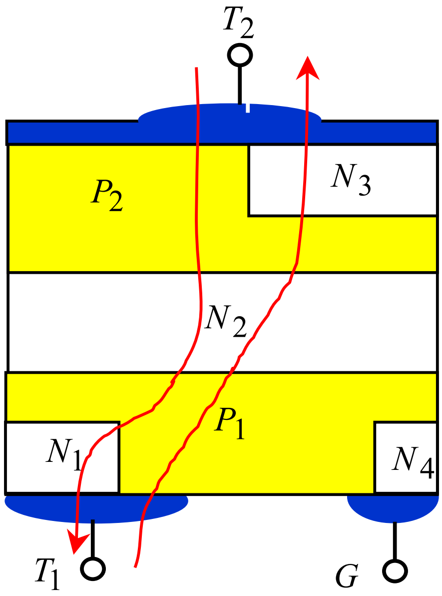
Triac 之簡易測試



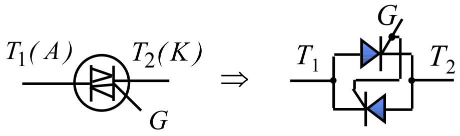
TRIAC

- **A three-terminal, five layer, bilateral semiconductor device.**
- $T_2 \rightarrow T_1:\ P_2 - N_2 - P_1 - N_1$

  $T_1 \rightarrow T_2:\ P_1 - N_2 - P_2 - N_3$



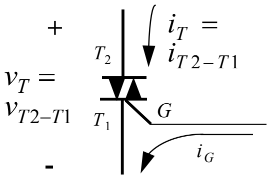
- ***TRIAC***: 為兩個反並接之SCR，可於正負半週觸發導通，為具 bidirectional current capability 之元件。
- 符號：

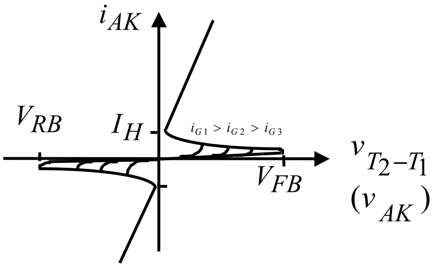


- **觸發控制** ***Turn on:*** 當 $v_{AK} > 0$ 時，加以適當之 $i_{GK} > 0$

  當 $v_{AK} < 0$ 時，加以適當之 $i_{GK} < 0$

  Turn off: $i_{AK} < I_H$ (*Holding current*)



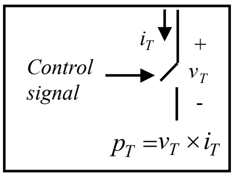


Typical Applications of SCR and TRIAC

- ■ **Converter power control**
  - **(1) Phase control**
  - **(2) Integral cycle control**
- ■ **SSR (Solid State Relay) or AC Switch**

可控開關 (Controllable Switches)

- *元件：(1) Forced-commutated SCR*
  (2) BJT, MOSFET, IGBT, MCT, ...

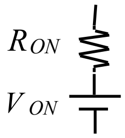


- *所欲之特性：*

穩態:

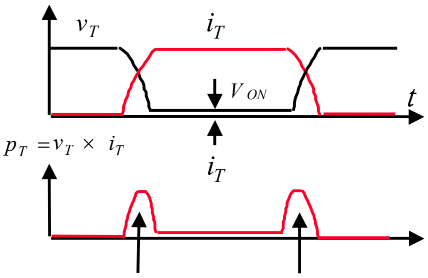
(1) Off : Leakage current ↓↓

(2) On : R_{ON}↓↓, V_{ON}↓↓



Conduction loss ↓↓

暫態: ***Switching speed*** ↑↑ ⇨ ***Switching losses*** ↓↓

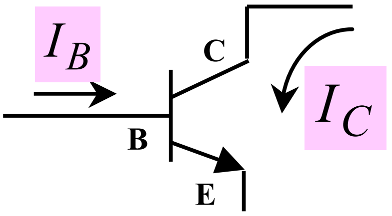


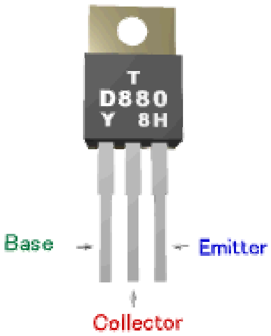
turn-on ***turn-off***

(Switching losses)

Power BJT

- **Current-controlled device**

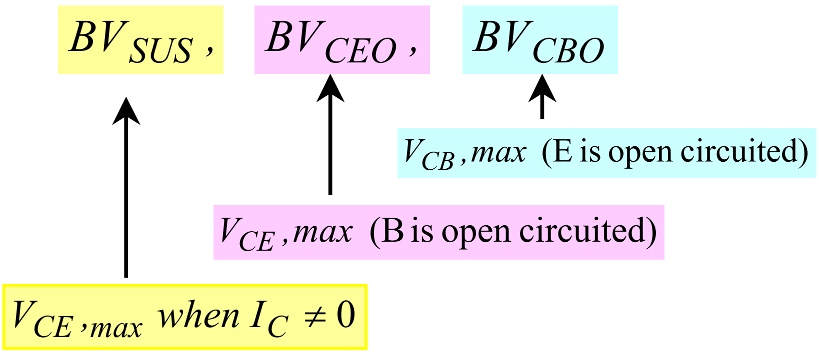




Turn on: $I_B \geq I_{C,sat} / \beta_{min}$

Power BJT

- ***Voltage ratings: (primary breakdown)***



BV_{SUS}, BV_{CEO}, BV_{CBO}

$V_{CB,max}$ (E is open circuited)

$V_{CE,max}$ (B is open circuited)

$V_{CE,max}$ when $I_C \neq 0$

- ***Secondary breakdown:***

  Caused by large di/dt at turn-on instant.

Power BJT

- β ***is smaller compared with small-signal BJTs.***
- ***Hard saturation and quasi-saturation:***

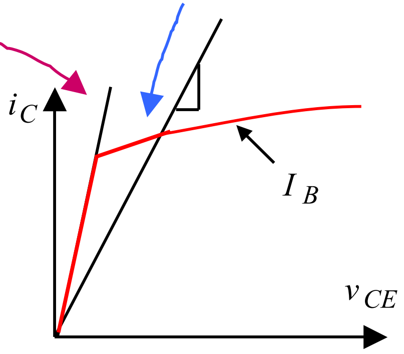
Quasi-saturation:

$I_B = I_{C,sat} / \beta_{min}$

Hard-saturation:

Conduction loss ↓
Switching speed ↓

$I_B > I_{C,sat} / \beta_{min}$

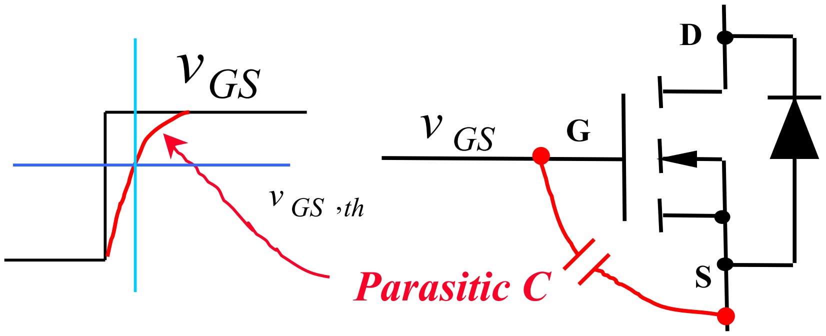


Power MOSFET

- **Voltage-controlled device**

Turn on: $v_{GS} > v_{GS,th}$

$i_{G,steady-state} \approx 0$ (very small)



Power MOSFET

- $v_{GS,max} > v_{GS} > v_{GS,th}$
- $v_{GS} \uparrow \Rightarrow i_{D,sat} \uparrow,\ R_{on} \downarrow,\ P_{switching} \uparrow$
- $R_{DS,on} = k\ BV_{DS}^{2.5\sim 2.7}$

■ ***Light load:***

Switching loss dominant :

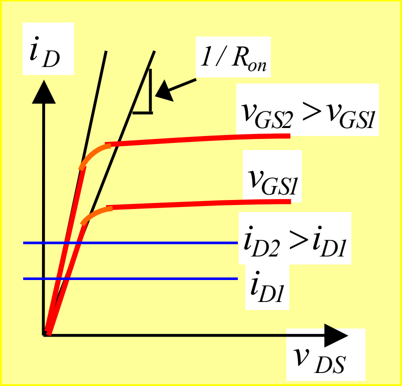
$v_{GS} \downarrow \Rightarrow P_g = Q_g v_{GS} f_{sw} \downarrow$

Q_g *= total gate charge*

■ ***Heavy load:***

Conduction loss dominant :

$v_{GS} \uparrow \Rightarrow R_{DS,on} \downarrow$



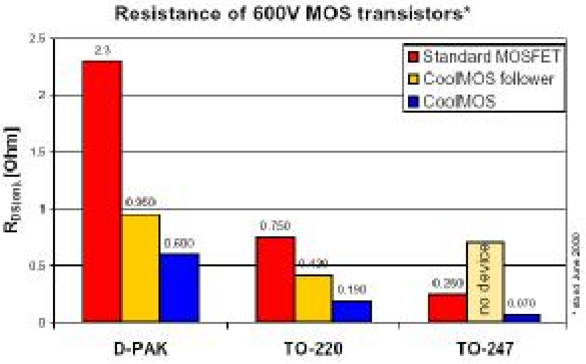
Cool MOSFET

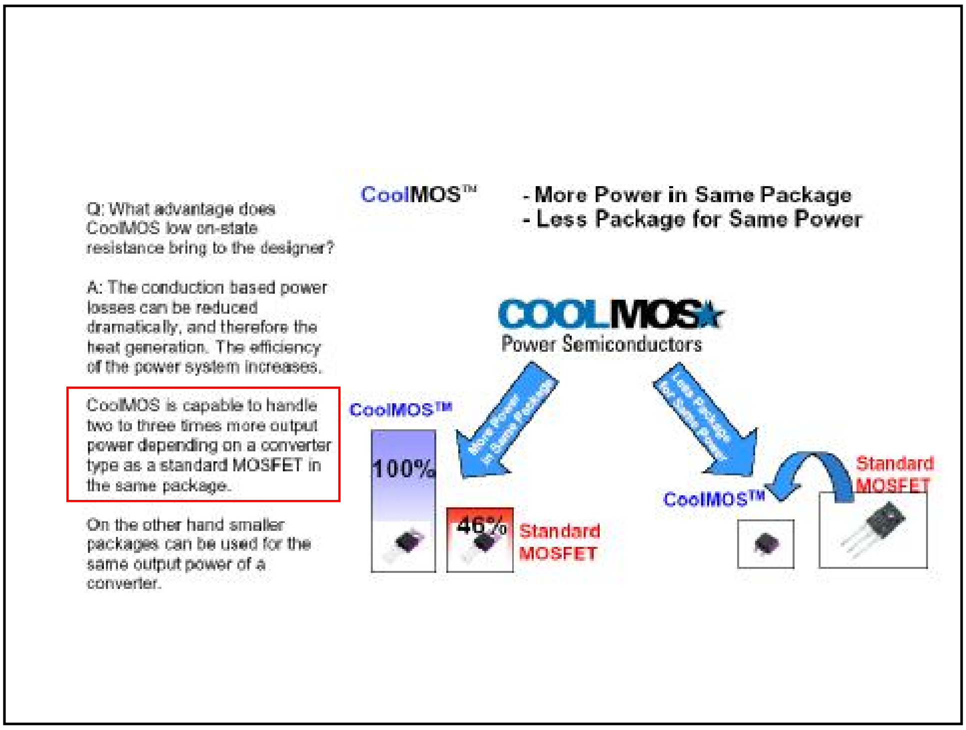
- It is a new revolutionary technology for high voltage power MOSFETs. It implements a compensation structure in the vertical drift region of a MOSFET in order to improve the *on-state resistance*.
- $R_{DS,on} \downarrow, \ Q_g \downarrow, \ \theta_{JA}$ *slightly higher (~ 10%)*

  Pulse current rating is lower.

Q: Does CoolMOS have lower on-state resistance for the same package compared to other MOSFETs?

A: Yes, CoolMOS has a much lower on-state resistance in the same package.





Q: What advantage does CoolMOS low on-state resistance bring to the designer?

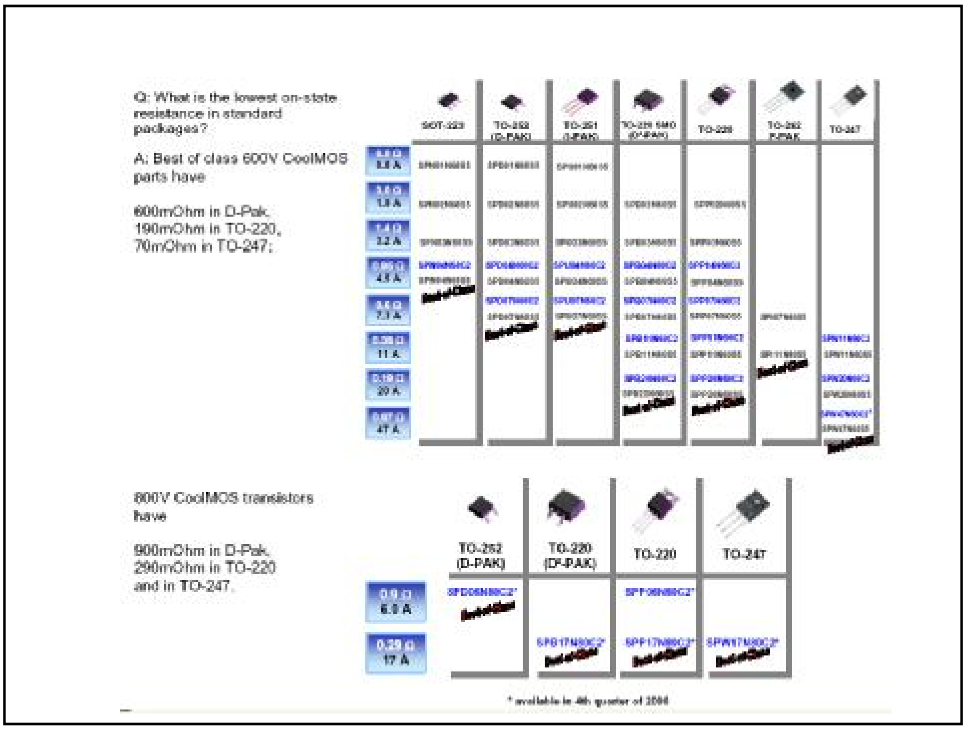
A: The conduction based power losses can be reduced dramatically, and therefore the heat generation. The efficiency of the power system increases.

CoolMOS is capable to handle two to three times more output power depending on a converter type as a standard MOSFET in the same package.

On the other hand smaller packages can be used for the same output power of a converter.

CoolMOS™

- More Power in Same Package
- Less Package for Same Power



Q: What is the lowest on-state resistance in standard packages?

A: Best of class 600V CoolMOS parts have

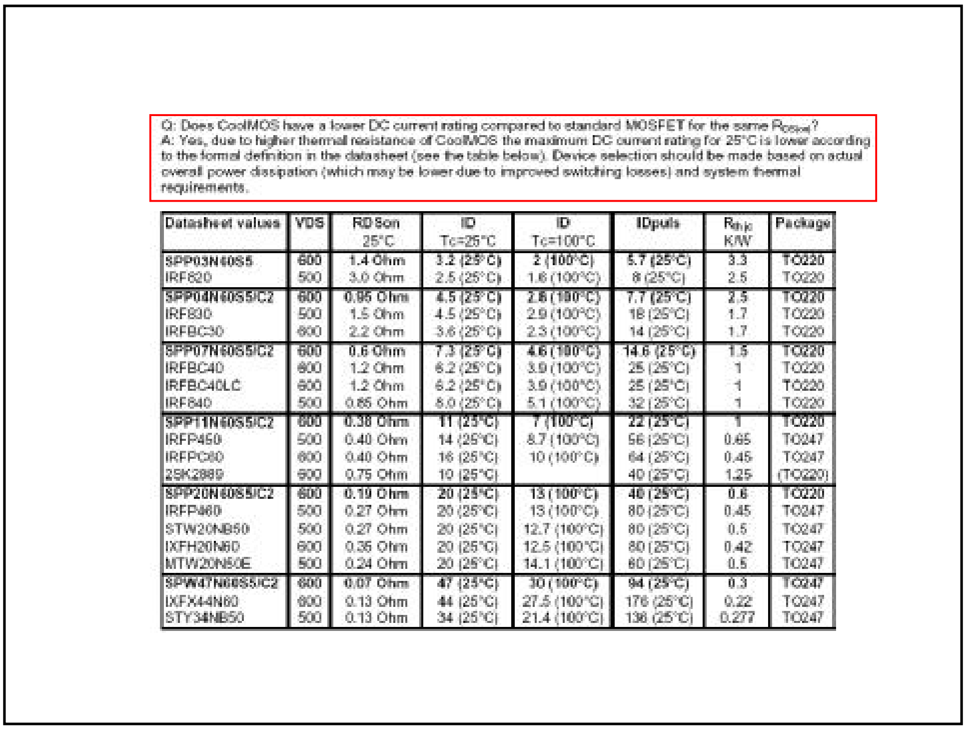
600mOhm in D-Pak,
190mOhm in TO-220,
70mOhm in TO-247;

800V CoolMOS transistors have

900mOhm in D-Pak,
290mOhm in TO-220
and in TO-247.

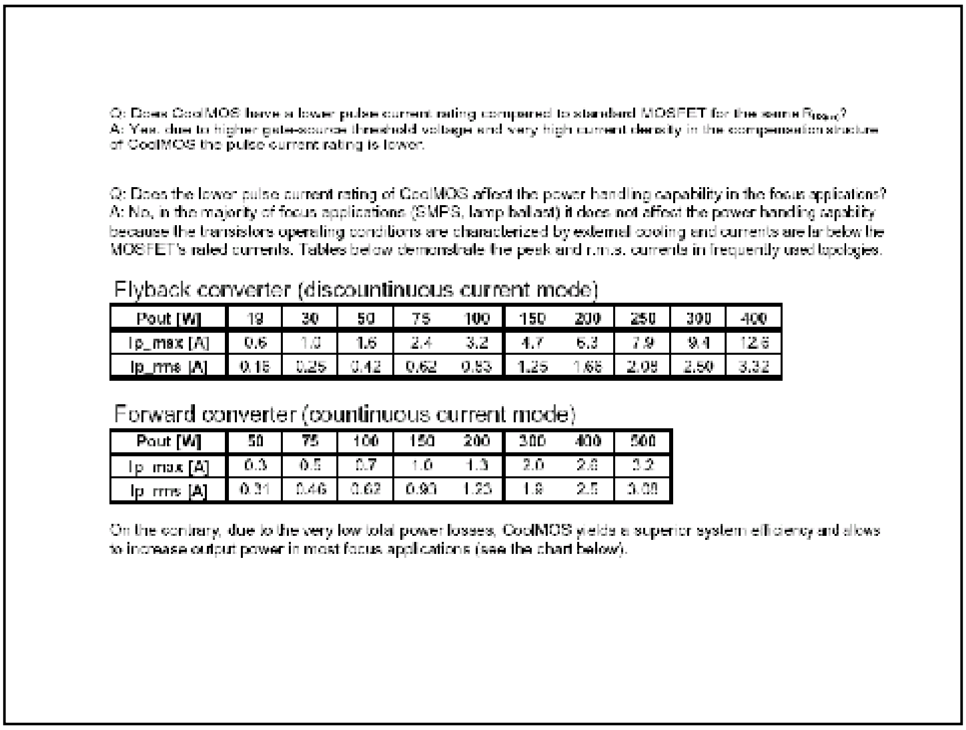
	TO-252 (D-PAK)	TO-220 (D²-PAK)	TO-220	TO-247
0.9 Ω 6.0 A	SPD06N80C2*		SPP06N80C2*	
0.29 Ω 17 A		SPB17N80C2*	SPP17N80C2*	SPW17N80C2*

* available in 4th quarter of 2004



Q: Does CoolMOS have a lower DC current rating compared to standard MOSFET for the same $R_{DS(on)}$?
A: Yes, due to higher thermal resistance of CoolMOS the maximum DC current rating for 25°C is lower according to the formal definition in the datasheet (see the table below). Device selection should be made based on actual overall power dissipation (which may be lower due to improved switching losses) and system thermal requirements.

Datasheet values	**VDS**	**RDSon 25°C**	**ID Tc=25°C**	**ID Tc=100°C**	**IDpuls**	R_{thjc} K/W	**Package**
SPP03N60S5	**600**	**1.4 Ohm**	**3.2 (25°C)**	**2 (100°C)**	**5.7 (25°C)**	3.3	**TO220**
IRF820	500	3.0 Ohm	2.5 (25°C)	1.6 (100°C)	8 (25°C)	2.5	TO220
SPP04N60S5/C2	**600**	**0.95 Ohm**	**4.5 (25°C)**	**2.8 (100°C)**	**7.7 (25°C)**	**2.5**	**TO220**
IRF830	500	1.5 Ohm	4.5 (25°C)	2.9 (100°C)	18 (25°C)	1.7	TO220
IRFBC30	600	2.2 Ohm	3.6 (25°C)	2.3 (100°C)	14 (25°C)	1.7	TO220
SPP07N60S5/C2	**600**	**0.6 Ohm**	**7.3 (25°C)**	**4.6 (100°C)**	**14.6 (25°C)**	**1.5**	**TO220**
IRFBC40	600	1.2 Ohm	6.2 (25°C)	3.9 (100°C)	25 (25°C)	1	TO220
IRFBC40LC	600	1.2 Ohm	6.2 (25°C)	3.9 (100°C)	25 (25°C)	1	TO220
IRF840	500	0.85 Ohm	8.0 (25°C)	5.1 (100°C)	32 (25°C)	1	TO220
SPP11N60S5/C2	**600**	**0.38 Ohm**	**11 (25°C)**	**7 (100°C)**	**22 (25°C)**	**1**	**TO220**
IRFP450	500	0.40 Ohm	14 (25°C)	8.7 (100°C)	56 (25°C)	0.65	TO247
IRFPC60	600	0.40 Ohm	16 (25°C)	10 (100°C)	64 (25°C)	0.45	TO247
2SK2889	600	0.75 Ohm	10 (25°C)		40 (25°C)	1.25	(TO220)
SPP20N60S5/C2	**600**	**0.19 Ohm**	**20 (25°C)**	**13 (100°C)**	**40 (25°C)**	**0.6**	**TO220**
IRFP460	500	0.27 Ohm	20 (25°C)	13 (100°C)	80 (25°C)	0.45	TO247
STW20NB50	500	0.27 Ohm	20 (25°C)	12.7 (100°C)	80 (25°C)	0.5	TO247
IXFH20N60	600	0.35 Ohm	20 (25°C)	12.5 (100°C)	80 (25°C)	0.42	TO247
MTW20N50E	500	0.24 Ohm	20 (25°C)	14.1 (100°C)	60 (25°C)	0.5	TO247
SPW47N60S5/C2	**600**	**0.07 Ohm**	**47 (25°C)**	**30 (100°C)**	**94 (25°C)**	**0.3**	**TO247**
IXFX44N60	600	0.13 Ohm	44 (25°C)	27.5 (100°C)	176 (25°C)	0.22	TO247
STY34NB50	500	0.13 Ohm	34 (25°C)	21.4 (100°C)	136 (25°C)	0.277	TO247



Q: Does CoolMOS have a lower pulse current rating compared to standard MOSFET for the same $R_{DS(on)}$?
A: Yes, due to higher gate-source threshold voltage and very high current density in the compensation structure of CoolMOS the pulse current rating is lower.

Q: Does the lower pulse current rating of CoolMOS affect the power handling capability in the focus applications?
A: No, in the majority of focus applications (SMPS, lamp ballast) it does not affect the power handling capability because the transistors operating conditions are characterized by external cooling and currents are far below the MOSFET's rated currents. Tables below demonstrate the peak and r.m.s. currents in frequently used topologies.

Flyback converter (discountinuous current mode)

Pout [W]	19	30	50	75	100	150	200	250	300	400
Ip_max [A]	0.6	1.0	1.6	2.4	3.2	4.7	6.3	7.9	9.4	12.6
Ip_rms [A]	0.16	0.25	0.42	0.62	0.83	1.25	1.66	2.09	2.50	3.32

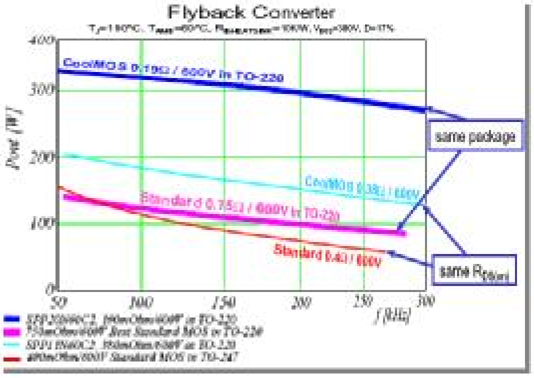
Forward converter (countinuous current mode)

Pout [W]	50	75	100	150	200	300	400	500
Ip_max [A]	0.3	0.5	0.7	1.0	1.3	2.0	2.6	3.2
Ip_rms [A]	0.31	0.46	0.62	0.90	1.25	1.8	2.5	3.08

On the contrary, due to the very low total power losses, CoolMOS yields a superior system efficiency and allows to increase output power in most focus applications (see the chart below).

CoolMOS™ C2:
Superior Power Handling Capability

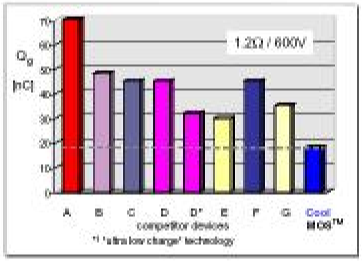
Due to its superior switching characteristic second generation of CoolMOS can handle up to 30% more output power of a converter as the standard MOSFET with same $R_{DS(on)}$. Just compare the 0.4Ω/600V standard MOSFET curve with 0.38Ω/600V CoolMOS C2 curve in the chart.
In the same package (e.g. TO-220) CoolMOS C2 makes it possible to triple the output power of a converter compared to conventional MOSFET under the same operating conditions.



CoolMOS™
Low Gate Charge Technology is a Benchmark

Q: Does CoolMOS have a lower gate charge compared to standard MOSFET for the same $R_{DS(on)}$?

A: Yes, the CoolMOS has almost 2 times lower gate charge as the standard MOSFET for the same $R_{DS(on)}$.



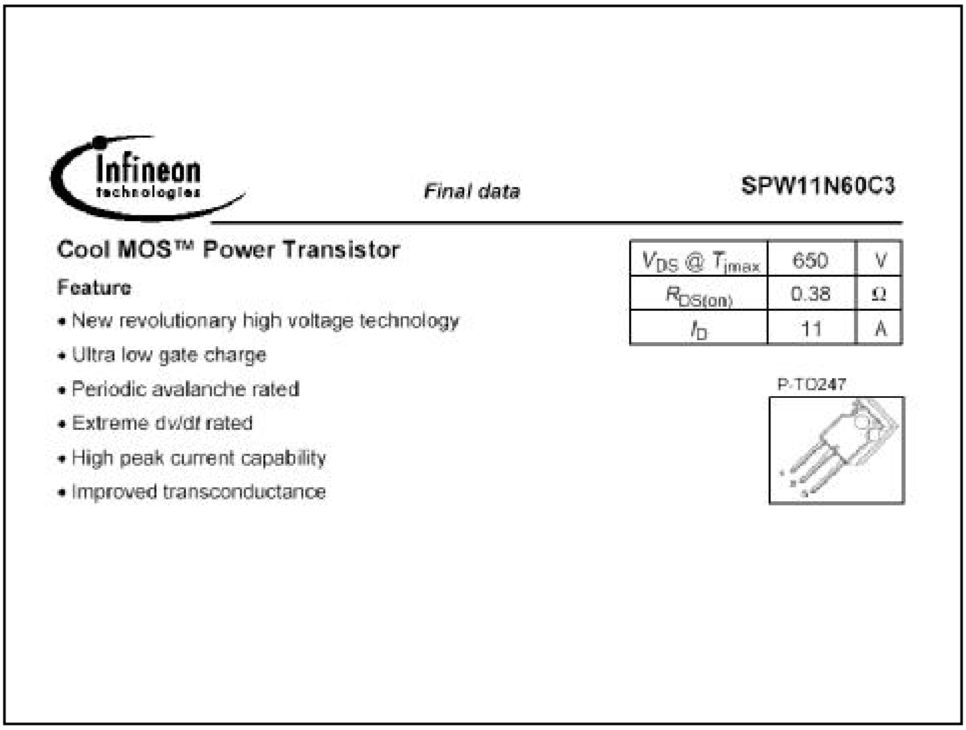
Gate Drive Power

$$P_G = Q_g \cdot V_{GS} \cdot f_{sw}$$

CoolMOS™

- ☑ Low-cost gate driver
- ☑ Lower switching losses
- ☑ Higher switching frequencies

Q: How can designer use this advantage of CoolMOS lower gate charge?
A: The gate drive power rating as well as the switching power losses can be significantly reduced.



Infineon technologies

Final data

SPW11N60C3

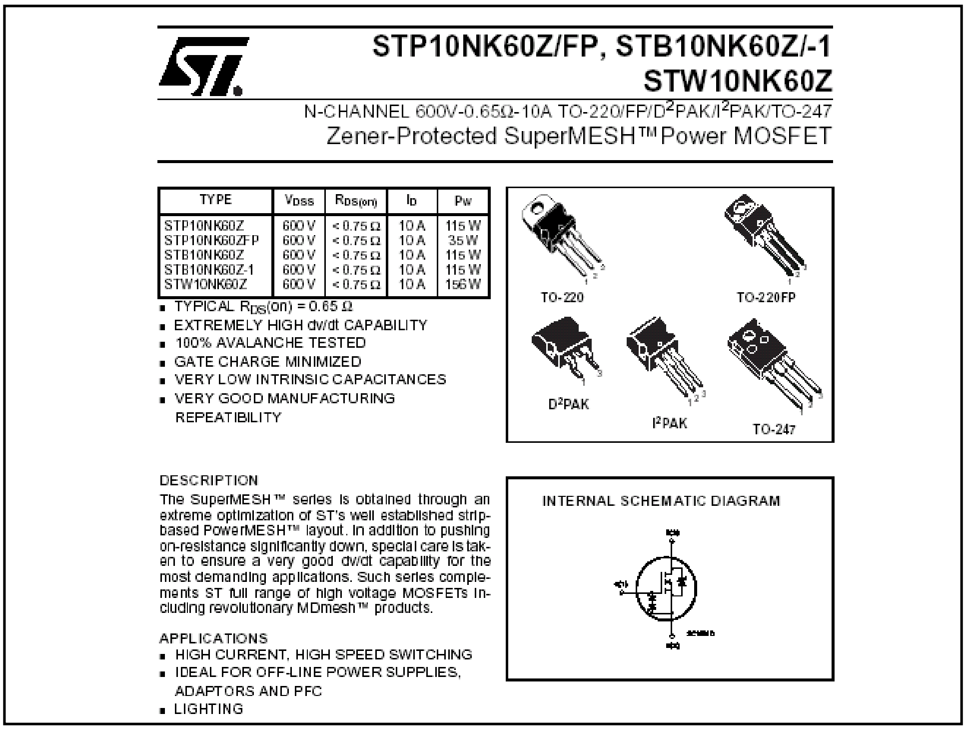
Cool MOS™ Power Transistor

Feature

- New revolutionary high voltage technology
- Ultra low gate charge
- Periodic avalanche rated
- Extreme dv/dt rated
- High peak current capability
- Improved transconductance

V_{DS} @ T_{jmax}	650	V
$R_{DS(on)}$	0.38	Ω
I_D	11	A

P-TO247



STP10NK60Z/FP, STB10NK60Z/-1
STW10NK60Z

N-CHANNEL 600V-0.65Ω-10A TO-220/FP/D^2PAK/I^2PAK/TO-247

Zener-Protected SuperMESH™Power MOSFET

TYPE	V_{DSS}	$R_{DS(on)}$	I_D	P_W
STP10NK60Z	600 V	< 0.75 Ω	10 A	115 W
STP10NK60ZFP	600 V	< 0.75 Ω	10 A	35 W
STB10NK60Z	600 V	< 0.75 Ω	10 A	115 W
STB10NK60Z-1	600 V	< 0.75 Ω	10 A	115 W
STW10NK60Z	600 V	< 0.75 Ω	10 A	156 W

- TYPICAL R_{DS}(on) = 0.65 Ω
- EXTREMELY HIGH dv/dt CAPABILITY
- 100% AVALANCHE TESTED
- GATE CHARGE MINIMIZED
- VERY LOW INTRINSIC CAPACITANCES
- VERY GOOD MANUFACTURING REPEATIBILITY

TO-220

TO-220FP

D^2PAK

I^2PAK

TO-247

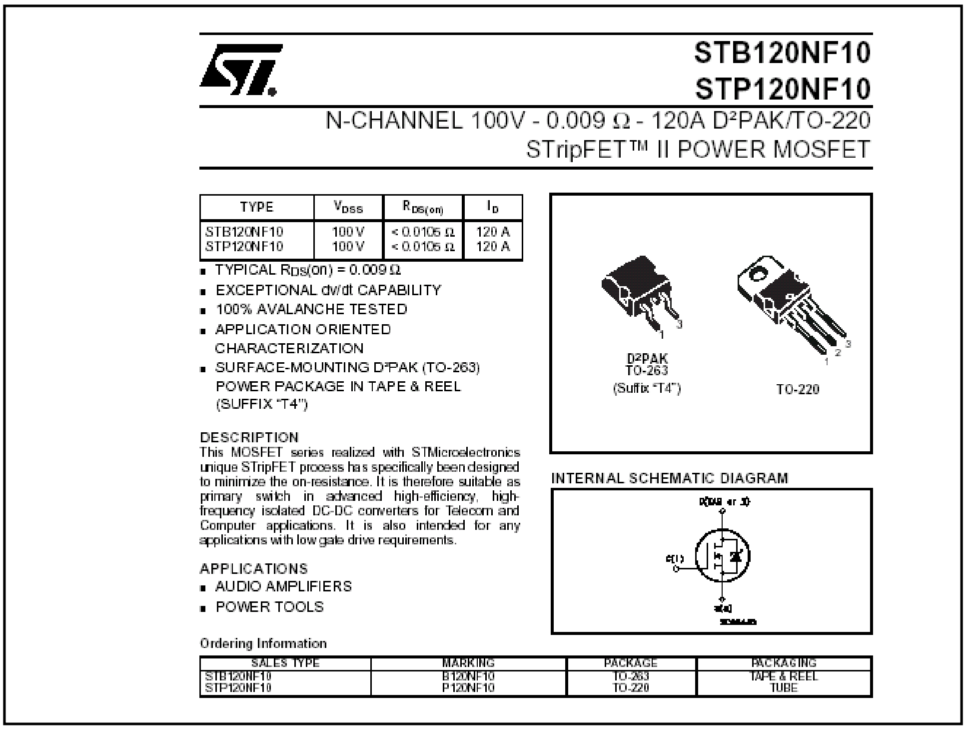
DESCRIPTION

The SuperMESH™ series is obtained through an extreme optimization of ST's well established strip-based PowerMESH™ layout. In addition to pushing on-resistance significantly down, special care is taken to ensure a very good dv/dt capability for the most demanding applications. Such series complements ST full range of high voltage MOSFETs including revolutionary MDmesh™ products.

APPLICATIONS

- HIGH CURRENT, HIGH SPEED SWITCHING
- IDEAL FOR OFF-LINE POWER SUPPLIES, ADAPTORS AND PFC
- LIGHTING

INTERNAL SCHEMATIC DIAGRAM



STB120NF10
STP120NF10

N-CHANNEL 100V - 0.009 Ω - 120A D²PAK/TO-220
STripFET™ II POWER MOSFET

TYPE	V_{DSS}	$R_{DS(on)}$	I_D
STB120NF10	100 V	< 0.0105 Ω	120 A
STP120NF10	100 V	< 0.0105 Ω	120 A

- TYPICAL R_{DS}(on) = 0.009 Ω
- EXCEPTIONAL dv/dt CAPABILITY
- 100% AVALANCHE TESTED
- APPLICATION ORIENTED CHARACTERIZATION
- SURFACE-MOUNTING D²PAK (TO-263) POWER PACKAGE IN TAPE & REEL (SUFFIX "T4")

DESCRIPTION
This MOSFET series realized with STMicroelectronics unique STripFET process has specifically been designed to minimize the on-resistance. It is therefore suitable as primary switch in advanced high-efficiency, high-frequency isolated DC-DC converters for Telecom and Computer applications. It is also intended for any applications with low gate drive requirements.

APPLICATIONS
- AUDIO AMPLIFIERS
- POWER TOOLS

D²PAK
TO-263
(Suffix "T4")

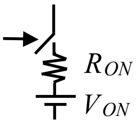
TO-220

INTERNAL SCHEMATIC DIAGRAM

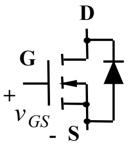
Ordering Information

SALES TYPE	MARKING	PACKAGE	PACKAGING
STB120NF10	B120NF10	TO-263	TAPE & REEL
STP120NF10	P120NF10	TO-220	TUBE

Power MOSFET 與 Power BJT 之比較



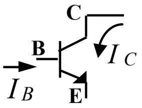
Power MOSFET (Enhancement mode)



觸發控制 Turn on:
- $v_{GS} > v_{GS,th}$，$i_{G,steady-state} \approx 0(very\ small)$
- **為電壓控制元件**
- **需有特殊驅動電路以加速 switching speed**

導通特性:
- $V_{ON} = 0, R_{ON}$ **較大，但綜合導通損較大。**
- **電阻之溫度係數為正，無 Thermal run away 問題，並聯分流特性佳。**

Power BJT



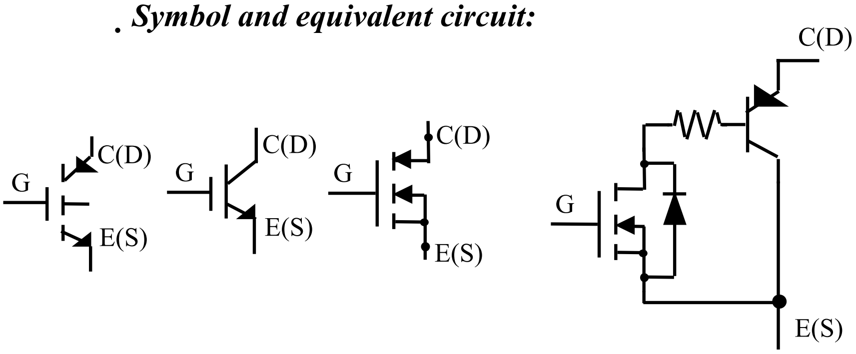
觸發控制 Turn on:
- $I_B > I_{C,sat}/\beta_{\min}$ **，為電流控制元件**
- **需有電流放大之驅動電路，switching speed 比MOSFET慢**

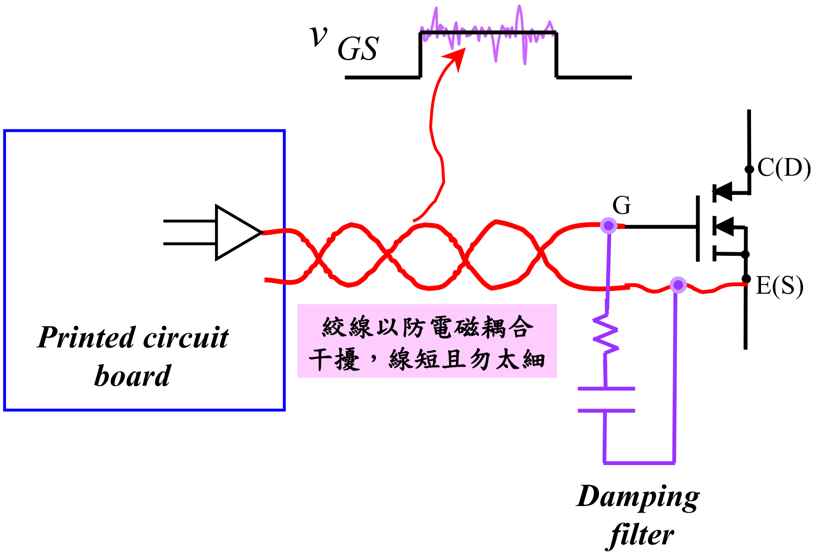
導通特性:
- $V_{ON} = V_{CE,sat}, R_{ON}$ **較小，但綜合導通損較MOSFET小。**
- **電阻之溫度係數為負，有 Thermal run away 問題，不易並聯分流。**

IGBT (Insulated-Gate Bipolar Transistor)

- **MOSTFET + BJT**

  - *IGBT (Insulated Gate Bipolar Transistor):*
    - *Combines the conduction characteristic of BJT and the control characteristic of the MOSFET*
  - *Symbol and equivalent circuit:*





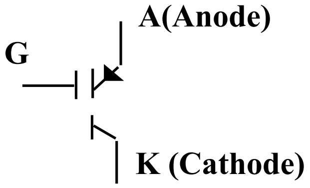
Printed circuit board

絞線以防電磁耦合
干擾，線短且勿太細

Damping filter

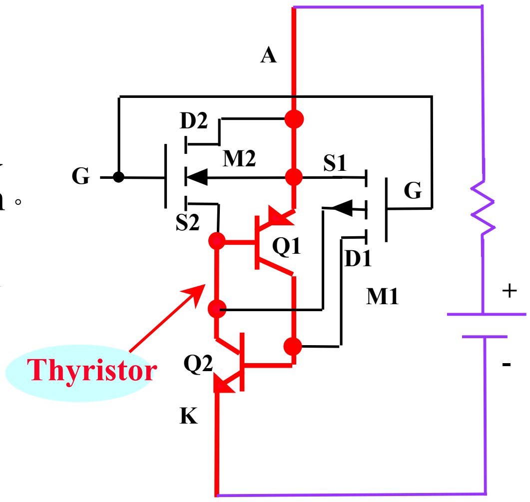
MCT (MOS-controlled Thyristor)

- **MOSTFET + Thyristor**
  - *Combines the load characteristic of thyristor and the control characteristic of MOSFET*
  - *Low on-state voltage*
  - *Symbol*



Turn on: 加負脈衝 V_{GA}
使 p-ch MOSFET M1
導通，提供BJT Q2 之
基極電流，使MCT on。

Turn off: 加正脈衝 V_{GA}
使 n-ch MOSFET M2
導通，將BJT Q1 之
基極與射極短接，
使MCT off.



Triggering Devices (觸發元件)

- 產生觸發控制脈波，以觸發功率半導體開關

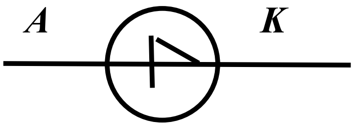
- 蕭克萊二極體 (Shockley diode), Four-layer diode
- DIAC
- UJT (Uni-junction Transistor)
- PUT (Programmable Uni-junction Transistor)
- SUS (Silicon Unilateral Switch)
- SBS (Silicon Unilateral Switch)
- 其他

蕭克萊二極體 (Shockley diode)

- 沒有 Gate 之SCR ⇒
- *on 及 off:*

$$v_{AK} \geq V_{FB} \Rightarrow ON \ , \quad i_{AK} < I_H \Rightarrow OFF$$

符號：



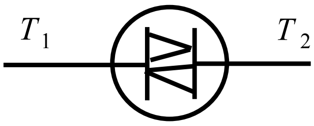
DIAC (沒有 Gate 之 TRIAC)

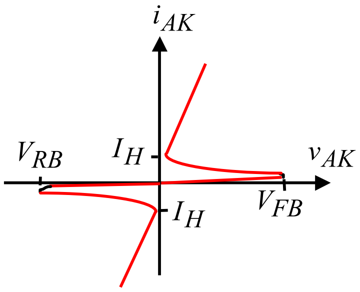
- ***on 及 off:***

$$v_{AK} > 0: \quad v_{AK} \geq V_{FB} \Rightarrow ON, \quad i_{AK} < I_H \Rightarrow OFF$$

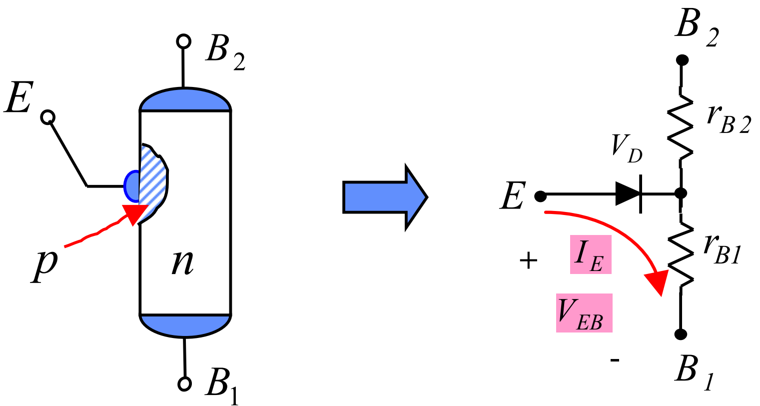
$$v_{AK} < 0: \quad |v_{AK}| \geq V_{RB} \Rightarrow ON, \quad |i_{AK}| < I_H \Rightarrow OFF$$

符號：

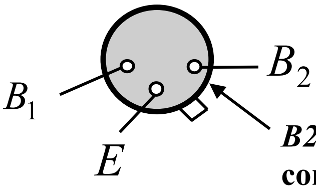




單接面電晶體(Uni-Junction Transistor, UJT)

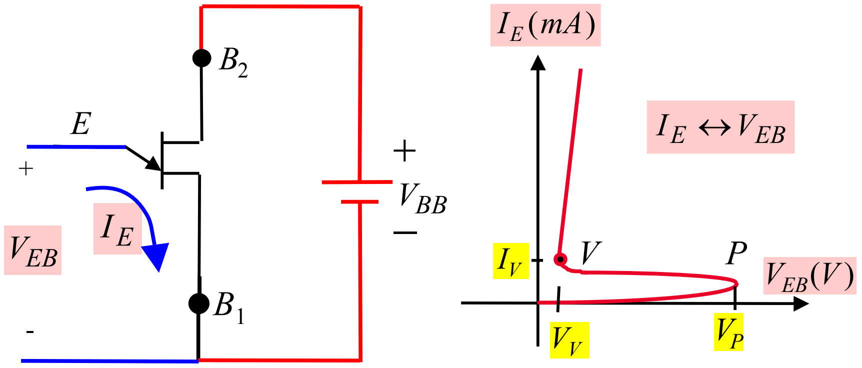


TO-18 package



***B2* electrically connected to case**

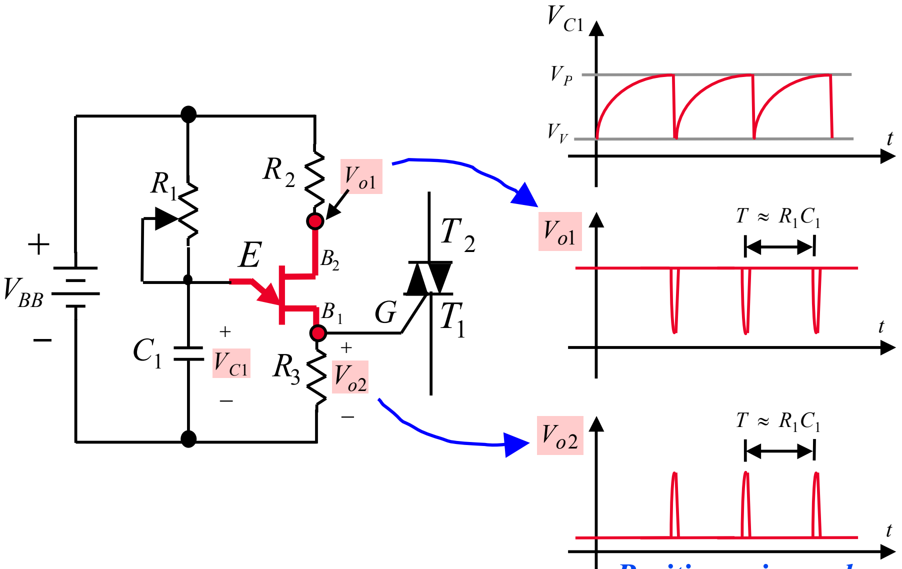
Emitter Characteristic Curve



Peak voltage $V_p = V_D + \frac{r_{B1}}{r_{B1}+r_{B2}} V_{B2,B1} \overset{\Delta}{=} V_D + \eta V_{B2,B1}$

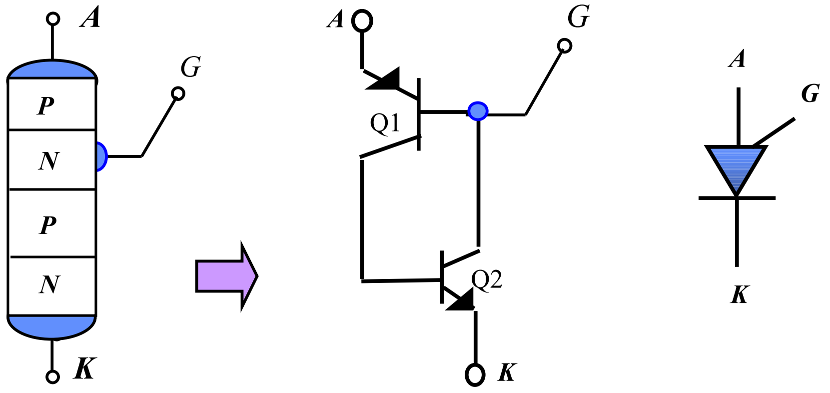
$\eta \overset{\Delta}{=} \frac{r_{B1}}{r_{B1}+r_{B2}}$: (Intrinsic standoff ratio，本質分立比)

Application: *Relaxation OSC. (鬆弛振盪器)*



Positive going pulse

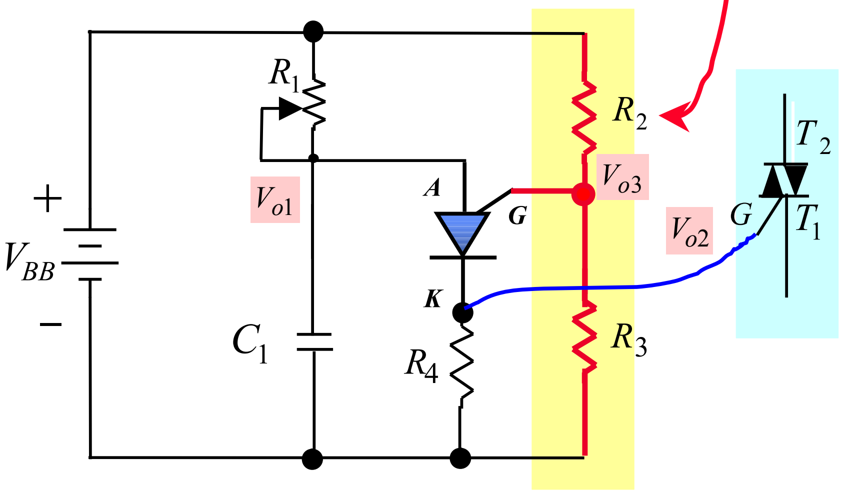
Programmable Unijunction Transistor, **PJT**)

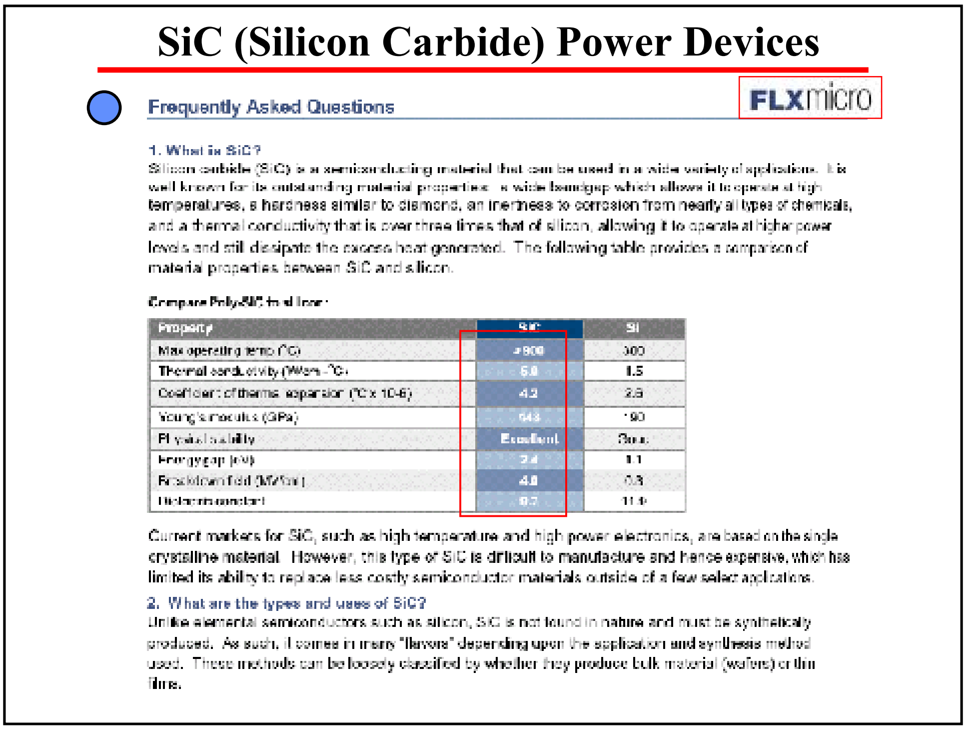


$$V_p = V_D + \frac{R_3}{R_2 + R_3} V_{BB} \overset{\Delta}{=} V_D + \eta V_{BB}$$

η 可由外加之電阻定之

$$V_p = V_D + \frac{R_3}{R_2 + R_3} V_{BB} \overset{\Delta}{=} V_D + \eta V_{BB}$$





SiC (Silicon Carbide) Power Devices

Frequently Asked Questions

1. What is SiC?

Silicon carbide (SiC) is a semiconducting material that can be used in a wide variety of applications. It is well known for its outstanding material properties: a wide bandgap which allows it to operate at high temperatures, a hardness similar to diamond, an inertness to corrosion from nearly all types of chemicals, and a thermal conductivity that is over three times that of silicon, allowing it to operate at higher power levels and still dissipate the excess heat generated. The following table provides a comparison of material properties between SiC and silicon.

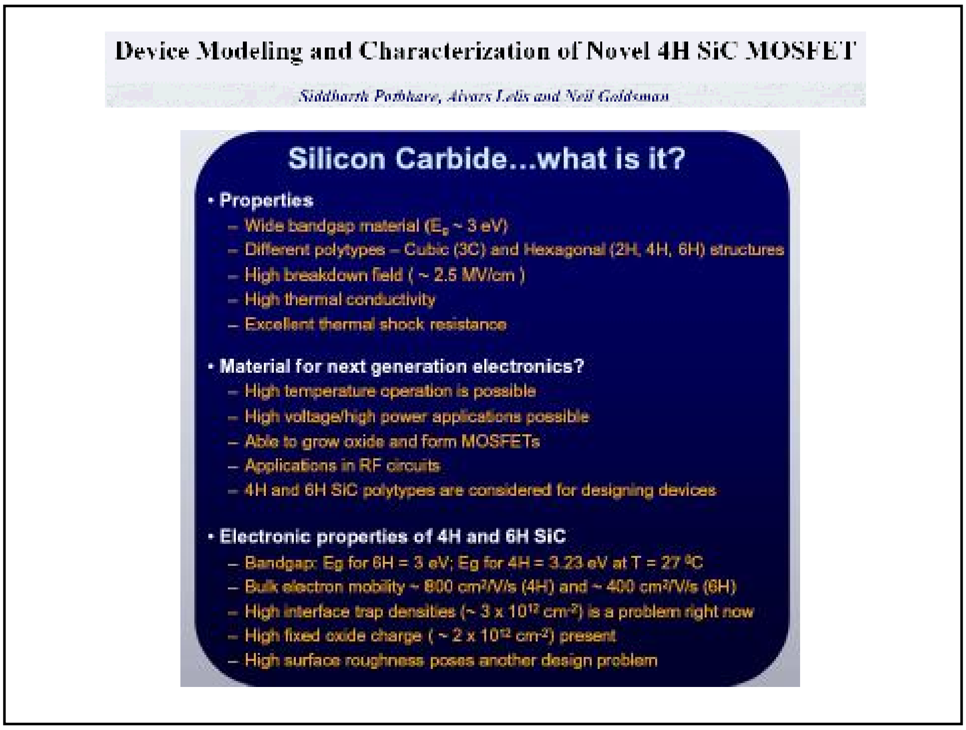
Compare Poly-SiC to silicon:

Property	SiC	Si
Max operating temp (°C)	>800	300
Thermal conductivity (W/cm-°C)	5.0	1.5
Coefficient of thermal expansion (°C x 10-6)	4.2	2.6
Young's modulus (GPa)	448	190
Physical stability	Excellent	Good
Energy gap (eV)	2.4	1.1
Breakdown field (MV/cm)	4.0	0.3
Dielectric constant	9.7	11.9

Current markets for SiC, such as high temperature and high power electronics, are based on the single crystalline material. However, this type of SiC is difficult to manufacture and hence expensive, which has limited its ability to replace less costly semiconductor materials outside of a few select applications.

2. What are the types and uses of SiC?

Unlike elemental semiconductors such as silicon, SiC is not found in nature and must be synthetically produced. As such, it comes in many "flavors" depending upon the application and synthesis method used. These methods can be loosely classified by whether they produce bulk material (wafers) or thin films.



Device Modeling and Characterization of Novel 4H SiC MOSFET

Siddharth Potbhare, Aivars Lelis and Neil Goldsman

Silicon Carbide…what is it?

- Properties
  - Wide bandgap material (E_g ~ 3 eV)
  - Different polytypes – Cubic (3C) and Hexagonal (2H, 4H, 6H) structures
  - High breakdown field (~ 2.5 MV/cm)
  - High thermal conductivity
  - Excellent thermal shock resistance
- Material for next generation electronics?
  - High temperature operation is possible
  - High voltage/high power applications possible
  - Able to grow oxide and form MOSFETs
  - Applications in RF circuits
  - 4H and 6H SiC polytypes are considered for designing devices
- Electronic properties of 4H and 6H SiC
  - Bandgap: Eg for 6H = 3 eV; Eg for 4H = 3.23 eV at T = 27 °C
  - Bulk electron mobility ~ 800 cm^2/V/s (4H) and ~ 400 cm^2/V/s (6H)
  - High interface trap densities (~ 3 x 10^{12} cm^{-2}) is a problem right now
  - High fixed oxide charge (~ 2 x 10^{12} cm^{-2}) present
  - High surface roughness poses another design problem

Introduction to SiC

Silicon Carbide (SiC) is a wide-bandgap semiconductor, which has been intensively studied in the recent years, due to its physical properties **, such as high breakdown field, high saturated drift velocity and high thermal conductivity. This characteristics make SiC a very good candidate for the applications in which *high temperature, high radiation intensity, high voltage or high power dissipation are involved, such as temperature sensors, nuclear radiation detectors, UV detectors, microwave devices and power devices.***

Although of the high potential of this material for the use in the electronic industry, the SiC technology shows some limitations and requires further study in order to obtain electronic devices of the same quality standards as Si technology:

- the bulk growth of SiC is still very expensive and material quality is still lower than device production requirements;
- the epitaxial growth **is necessary to obtain device-quality material, but it requires high temperature processes;**
- selective doping of SiC layers requires the use of ion implantation, since the diffusion coefficients for the doping species are too small for practical applications;
- the realization of ohmic contacts on SiC is difficult and requires high temperature processes;
- the thermal oxidation of SiC is difficult due to the high temperature needed and the quality of the material obtained is still lower respect to Si oxidation.

These limitations underline the need of further study in the SiC field. In particular, the growth of epitaxial layers is a first-step process for the realization of a wide variety of electronic devices.