

**Tiristore (Thyristor)**

- SCR – Silicon Controlled Rectifier – 1957 GE

![Thyristor Diagram](attachment:thyristor_diagram.png)

- Drift region

**Ideal thyristor**

- $V_{AK} > 0$ Forward blocking
  - $J_2$ supports $V_{AK}$
- $V_{AK} < 0$ Reverse blocking
  - $J_3$ supports $V_{AK}$

- Two states:
  - OFF: BJTs in cutoff
  - ON: BJTs in sat.

**Ebers-Moll model**

- $I_{ED} = I_{CS}$
- $I_E = -I_{ED} - \alpha_R I_{CS}$
- $I_C = \alpha_F I_{ED} + I_{CS} = -\alpha_F I_{ED} + I_{CO}$

\[ I_{CO} = I_{CS}(1-\alpha_F) \]

**Equivalent circuit**

\[ i_A = i_L + i_C2 \]

\[ i_A = \frac{\alpha_{pnp} i_G - I_{CO1} + I_{CO2}}{1 - \alpha_{pnp} - \alpha_{pnp}} \]

\[ \alpha_{pnp} + \alpha_{pnp} < 1 : \text{OFF} \]

\[ \alpha_{pnp} + \alpha_{pnp} = 1 : \text{ON} \]

**Turn on**

- If $V_{AK}$ increases, the voltage drop in $n-$ shrinks the base of the PNP transistor $\Rightarrow \alpha_{pnp}$ increases (an partly on the NPN transistor) $\Rightarrow \alpha_{pnp}$ increases

- Injection of electrons in the drift region causes more hole injection from the anode, to compensate excess charge $\Rightarrow$ positive feedback.

**On state operation**

- $V_{ON} = V_G + R_{ON} I$

- $N_{SD}^+$

- N-drift

- N⁺-doping

- Conductivity modulation
### Turn off

- Gate current cannot turn the SCR off
- Cathode area >> gate area
- Current crowding keeps pn+ junction forward bias
- SCR is turn off with $V_{AK} < 0$

### DC characteristics

- $V_{WUM} = V_{ON} + V_{BO}$
- $V_{WUM}$ and $V_{BO}$ depend on drift region

### Turn on transient

- $i_A$ vs. $t$
- $i_{GR}$
- $i_{tp}$ = plasma spreading time
- $i_f$ = limit $di/dt$
- $V_{AK}$ vs. $t$

### Turn off transient

- $i_A$ vs. $t$
- $t_f$ = recovery time
- $i_{rr}$
- $V_{AK}$ vs. $t$

### Cathode short

- $n^+$ and $p^+$ drift region
- $J_e$, $J_i$, $J_3$

### Interdigitated gate-cathode

- Interdigitated gate-cathode structure
- $V_{AK}$
- CATHODE
- GATE
**Gate Turn Off (GTO) thyristor**

GTOs are turned off with negative $i_g$ pulse
1. Highly interdigitated structure (1K cells)
2. Cathode islands
3. Anode short

![GTO structure diagram]

**Turn off**

- To reduce turn off $i_G$ we must suppress $\alpha_{pnp}$
- In order to suppress $\alpha_{pnp}$ we can
  - Use anode short / barrier thyristor does not block $V_{AK} < 0$
  - Increase thickness and recombination in drift region $\Rightarrow V_{ON}$ increases
- Typically
  $$i'_G \approx \frac{1}{3} \div \frac{1}{5} i_A$$

**GTO switching characteristics**

- GTO is fast $\Rightarrow$ requires snubber circuits

![GTO switching characteristics diagram]

**Turn on transient**

- $V_d$ sets $I_0$
- $RL$ limits $di/dt$ at turn on
- [GTO turns on before diode turns off]
- $V_{AK}$ di/dt limited by snubber
- $V_{ON}$
- [back porch]
GTO switching characteristics

- GTO is fast → requires snubber circuits

Turn off transient

\[ \frac{dv}{dt} < \frac{I_o}{C} \]

\[ \text{AC turn off} \]

\[ \text{Snubber limits } \frac{dv}{dt} \]

\[ v_{AK}, v_{ON}, v_{off} \]