Lecture Notes

Gate Turn-off Thyristors (GTOS)

OUTLINE

- GTO construction and I-V characteristics.
- Physical operation of GTOs.
- Switching behavior of GTOS

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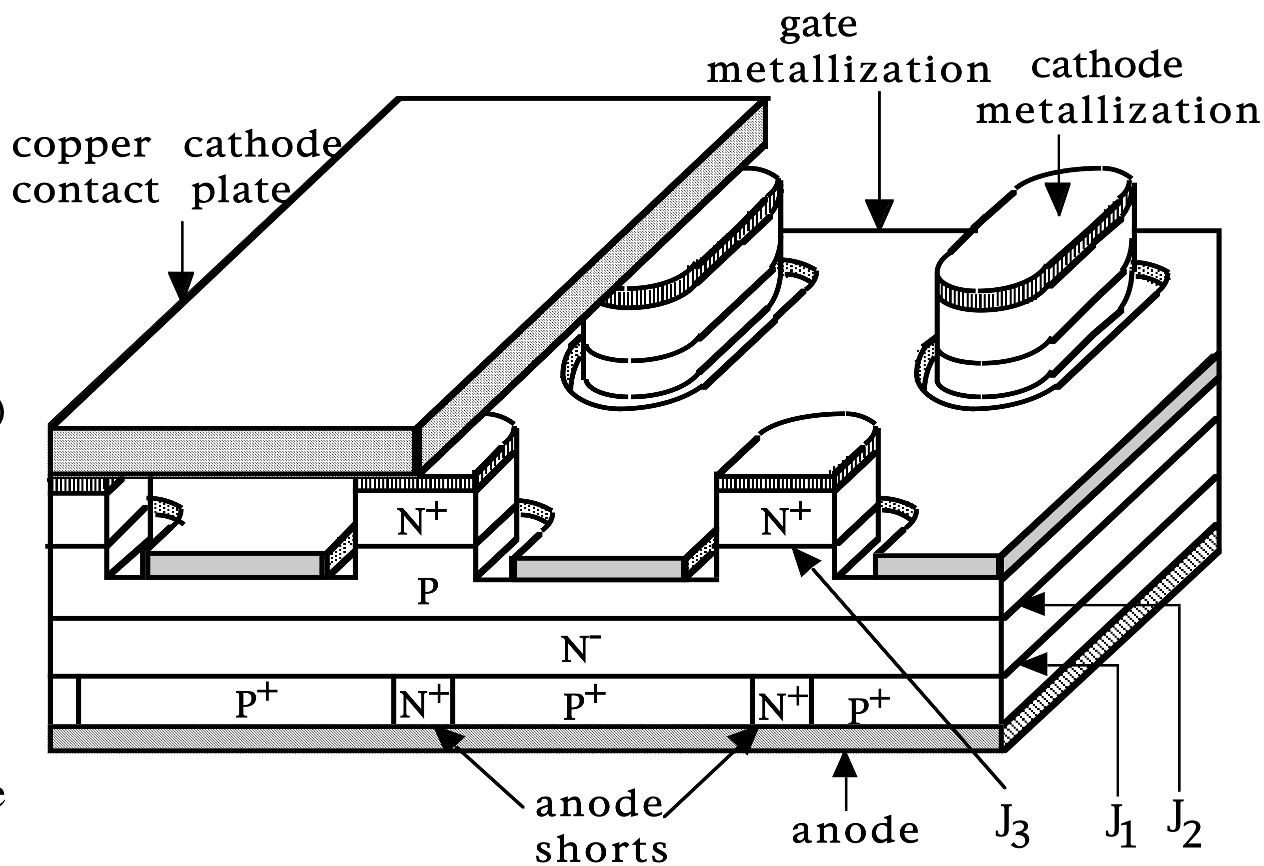
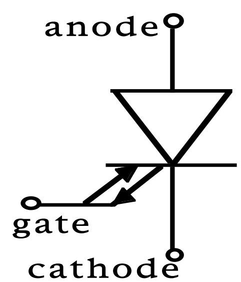
GTO (Gate Turn-off Thyristor) Construction

- Unique features of the GTO.
  - Highly interdigitated gate-cathode structure (faster switching)
  - Etched cathode islands (simplify electrical contacts)
  - Anode shorts (speed up turn-off)
- GTO has no reverse blocking capability because of anode shorts
- Otherwise i-v characteristic the same as for standard SCR



GTO circuit symbol



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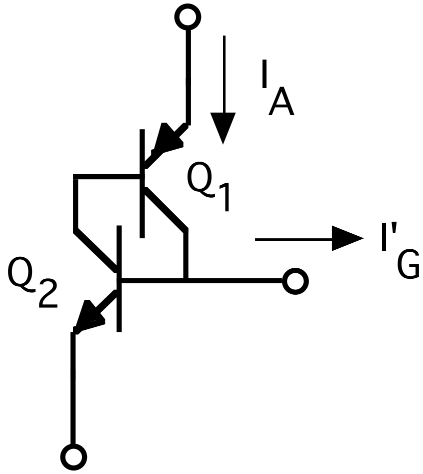
GTO Turn-off Gain



- Turn off GTO by pulling one or both of the BJTs out of saturation and into active region.
- Force Q_2 active by using negative base current I_G' to make $I_{B2} < \frac{I_{C2}}{\beta_2}$
- $I_{B2} = \alpha_1 I_A - I'_G$; $I_{C2} = (1 - \alpha_1) I_A$
- $\alpha_1 I_A - I'_G < \frac{(1-\alpha_1) I_A}{\beta_2} = \frac{(1-\alpha_1)(1-\alpha_2) I_A}{\alpha_2}$
- $I'_G < \frac{I_A}{\beta_{off}}$; $\beta_{off} = \frac{\alpha_2}{(1 - \alpha_1 - \alpha_2)}$ = turn-off gain

- Large turn-off gain requires $\alpha_2 \approx 1$, $\alpha_1 << 1$
- Make α_1 small by
  1. Wide n_1 region (base of Q_1) - also needed for large blocking voltage
  2. Short lifetime in n_1 region to remove excess carriers rapidly so Q_1 can turn off
- Short lifetime causes higher on-state losses
- Anode shorts helps resolve lifetime delimma
  1. Reduce lifetime only moderately to keep on-state losses reasonable
  2. N^+ anode regions provide a sink for excess holes - reduces turn-off time
- Make $\alpha_2 \approx$ unity by making p_2 layer relatively thin and doping in n_2 region heavily (same basic steps used in making beta large in BJTs).
- Use highly interdigitated gate-cathode geometry to minimize cathode current crowding and di/dt limitations.

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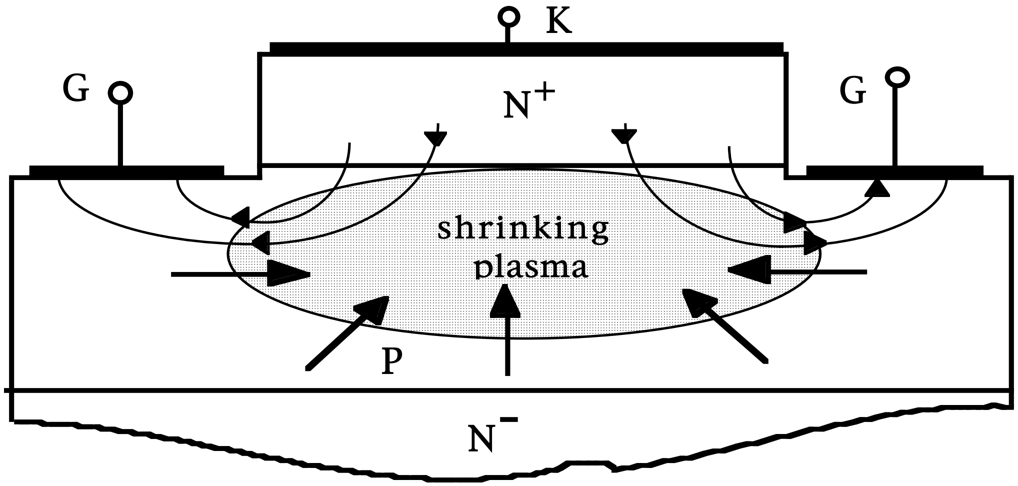
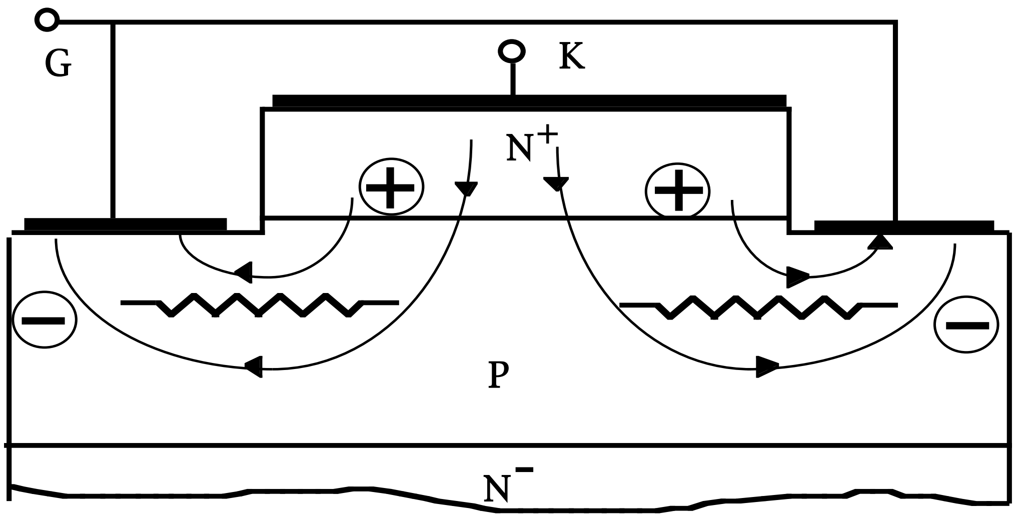
Maximum Controllable Anode Current





- Large negative gate current creates lateral voltage drops which must be kept smaller than breakdown voltage of J_3.
- If J_3 breaks down, it will happen at gate-cathode periphery and all gate current will flow there and not sweep out any excess carriers as required to turn-off GTO.
- Thus keep gate current less than $I_{G,max}$ and so anode current restricted by $I_A < \frac{I_{G,max}}{\beta_{off}}$

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GTO Step-down Converter

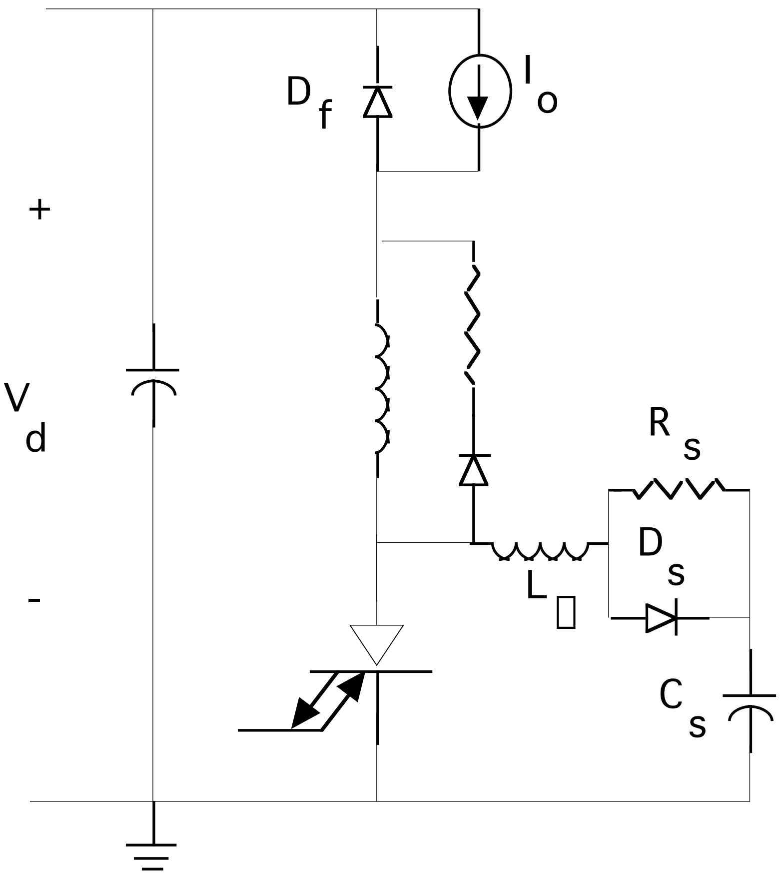
- GTO used in medium-to-high power applications where electrical stresses are large and where other solid state devices used with GTOs are slow e.g. free-wheeling diode D_F.

- GTO almost always used with turn-on and turn-off snubbers.

  1. Turn-on snubber to limit overcurrent from D_F reverse recovery.

  2. Turn-off snubber to limit rate-of-rise of voltage to avoid retriggering the GTO into the on-state.

- Hence should describe transient behavior of GTO in circuit with snubbers.



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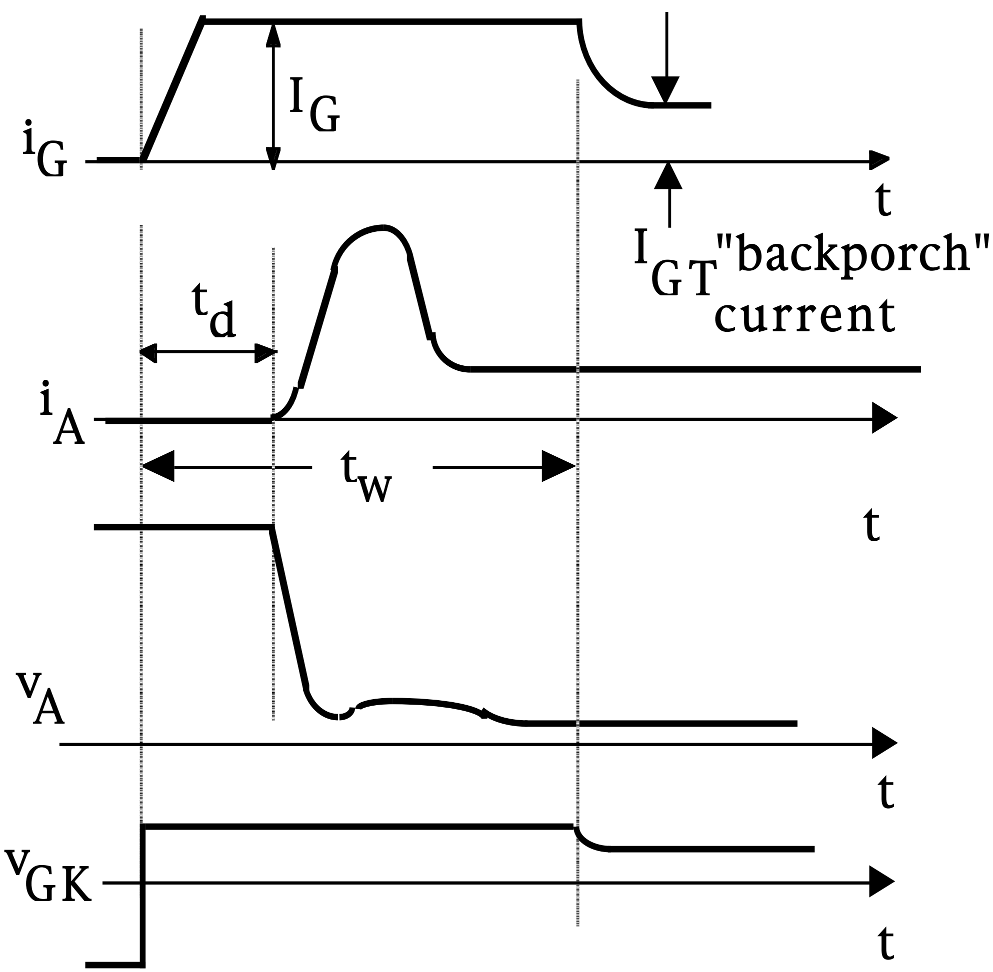
GTO Turn-on Waveforms



- GTO turn on essentially the same as for a standard thyristor
- Large I_{GM} and large rate-of-rise insure all cathode islands turn on together and have good current sharing.
- Backporch current I_{GT} needed to insure all cathode islands stay in conduction during entire on-time interval.
- Anode current overshoot caused by free-wheeling diode reverse recovery current.
- Anode-cathode voltage drops precipitiously because of turn-on snubber

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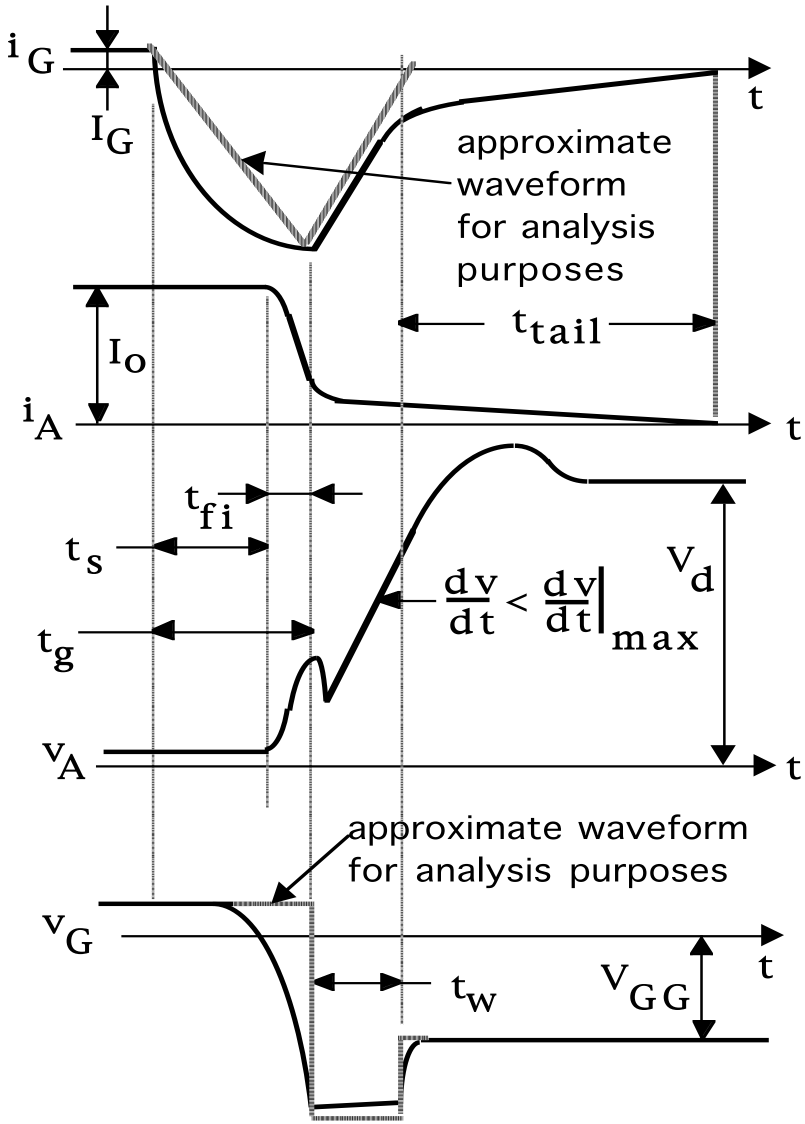
GTO Turn-off Waveforms



- t_s interval

  Time required to remove sufficient stored charge to bring BJTs into active region and break latch condition

- t_{fi} interval

  1. Anode current falls rapidly as load current commutates to turn-off snubber capacitor
  2. Rapid rise in anode-cathode voltage due to stray inductance in turn-off snubber circuit

- t_{w2} interval

  1. Junction J_3 goes into avalanche breakdown because of inductance in trigger circuit. Permits negative gate current to continuing flowing and sweeping out charge from p_2 layer.
  2. Reduction in gate current with time means rate of anode current commutation to snubber capacitor slows. Start of anode current tail.

- t_{tail} interval

  1. Junction J_3 blocking, so anode current = negative gate current. Long tailing time required to remove remaining stored charge.
  2. Anode-cathode voltage growth governed by turn-off snubber.
  3. Most power dissipation occurs during tailing time.

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