Semiconductor Technology from A to Z

Devices

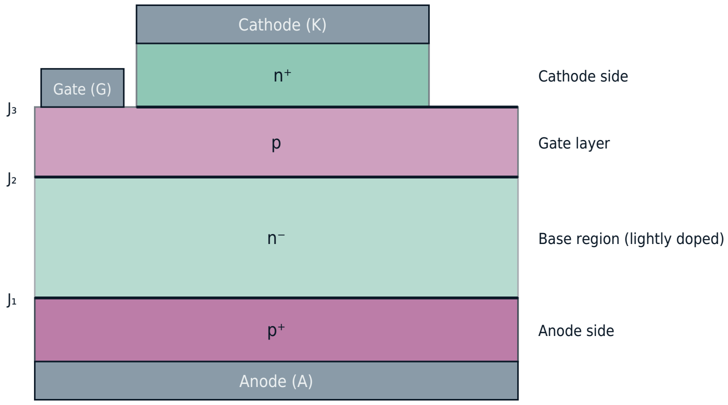
Thyristors and Triacs

The Four-Layer p-n-p-n Structure

A thyristor consists of a sequence of four alternately doped semiconductor layers (p-n-p-n) with a total of three p-n junctions, and can be electrically represented as two cross-coupled bipolar transistors – a pnp transistor and an npn transistor, whose base and collector regions are each connected to one another. This two-transistor equivalent circuit is exactly the same structure already encountered in the chapter on ESD protection structures as a parasitic effect in snapback devices, where it can cause unwanted latchup; in the thyristor, however, this behavior is not tolerated as a parasitic side effect but is deliberately engineered and dimensioned as a standalone power device.

Layer Structure of a Thyristor

Four alternately doped layers with three p-n junctions



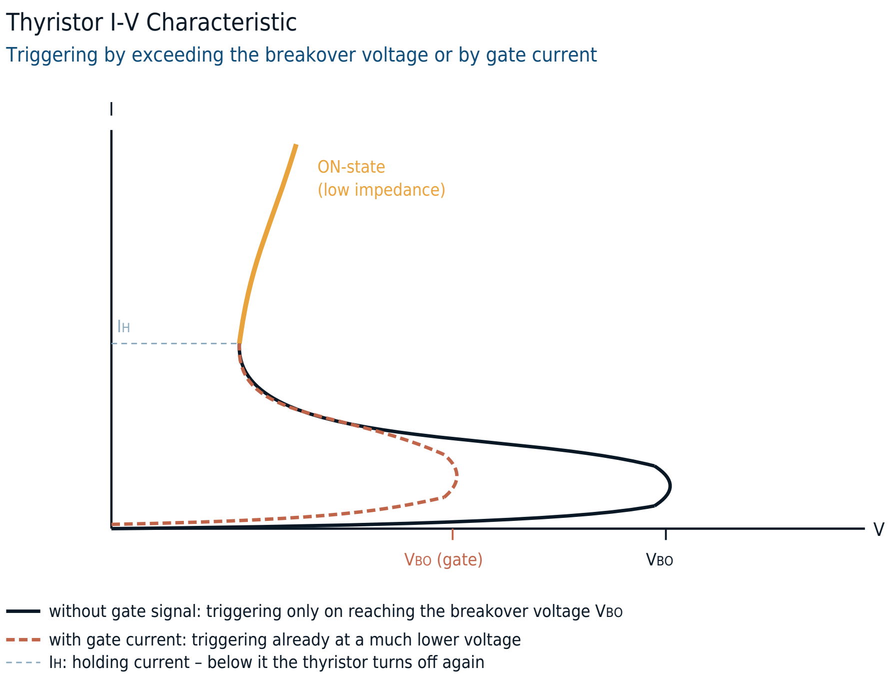
Equivalent circuit: p^+-n^--p forms the pnp, n^--p-n^+ the npn transistor – both share the middle layers and are thereby cross-coupled.

J_1, J_2, J_3: the three p-n junctions – in the blocking state J_2 blocks, after triggering all three junctions conduct.

The three external terminals of a thyristor are the anode (at the outer p-region), the cathode (at the outer n-region), and a control terminal, the gate, attached to one of the two inner layers, which triggers the structure into conduction via a comparatively small control current. Thyristors are manufactured for blocking voltages from a few hundred volts up to several kilovolts and for currents from a few amperes up to several thousand amperes, making them among the most powerful semiconductor switches available today.

Triggering Behavior and Holding Current

In the blocking state, a thyristor does not conduct even with forward voltage applied between anode and cathode, until it is triggered either by a brief gate current pulse, typically lasting a few microseconds, or by exceeding the voltage-dependent breakover voltage even without any gate signal. Once one of the two internal transistors begins to conduct, its collector current supplies the base current for the other transistor, whose collector current in turn further amplifies the original base current – this positive feedback leads to a complete, low-impedance turn-on of both transistors within a few microseconds.



Once triggered, the thyristor latches into this conducting state regardless of the further course of the gate signal and remains there as long as the anode current stays above a device-specific holding current I_H, usually a few milliamperes to a few tens of milliamperes. The gate therefore completely loses control over turning the device off once triggered – a fundamental difference from, for example, a MOSFET, where the gate can actively end the conducting state at any time. In AC applications this is unproblematic, since the current falls below the holding current at every zero crossing of the mains voltage anyway and the thyristor extinguishes on its own before needing to be triggered again for the next half-cycle; in DC applications, by contrast, additional commutation circuits are needed to actively force the anode current below the holding current.

The Triac as a Bidirectional Thyristor

A triac (Triode for Alternating Current) essentially corresponds to two antiparallel thyristors integrated into a single semiconductor crystal and package, sharing a common gate. This allows a triac, unlike a single thyristor that conducts in only one direction, to both conduct and control current in both directions – a property that makes it particularly well suited for direct AC voltage control, since each half-cycle involves the opposite current direction.

This bidirectional operation makes the triac the standard device for numerous direct AC control applications: phase-control dimmers in lighting technology, speed controls for simple AC motors in household appliances, and solid-state relays all take advantage of the comparatively simple control via a single gate signal and the low circuit complexity of triacs. Compared to two discretely wired antiparallel thyristors, the monolithic triac integration offers a considerably more compact design, though at somewhat lower voltage rating and with a more complex triggering behavior possible across four different quadrants that must be accounted for in circuit design.