INTERNATIONAL RECTIFIER IOR

SILICON CONTROLLED RECTIFIERS

AN-309

APPLICATION NOTE

SCRs — Their Parameters, Specifications, Ratings, and Characteristics

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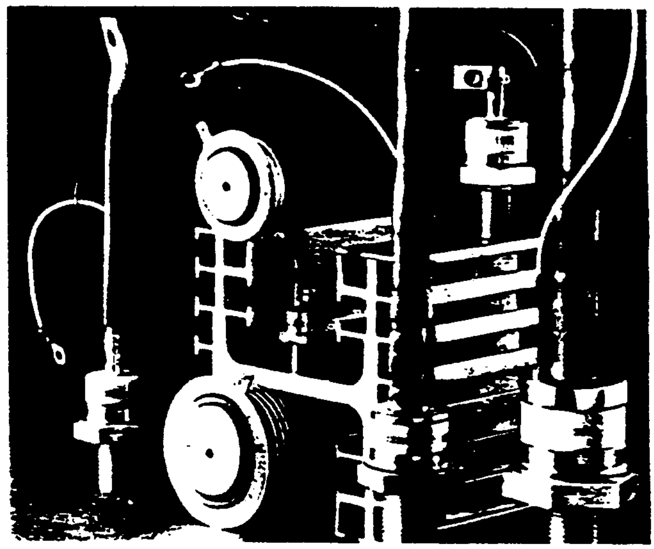

The silicon controlled rectifier is a *rectifying* device inasmuch as it has a **forward direction** in which it may have a very low resistance and a **reverse direction** in which it has a very high resistance. It is *controlled* since it can be switched from a high forward resistance **(off-state)** to a low forward resistance condition **(on-state)**. Although the change in resistance is great (high voltages can be blocked, high currents can be conducted), it can be achieved with very small values of gate voltage, current, and power.

International Rectifier offers its SCRs in the most practical and efficient package outlines available. Some of these packages are shown in Photo 1.

IR provides all flex lead outline packages with an auxiliary cathode lead. This lead is designed to be twisted with the gate lead to prevent stray signal pickup and resultant false firing, and to provide a cathode connection to the firing circuit.

The circuit symbol and block diagram of the silicon controlled rectifier are illustrated in Figure 1. Figure 2 shows the cross-section of a typical silicon wafer used in such a device.

As a circuit element, the silicon controlled rectifier can be used to block the normal flow of current for any length of time desired. To initiate conduction, a signal should be

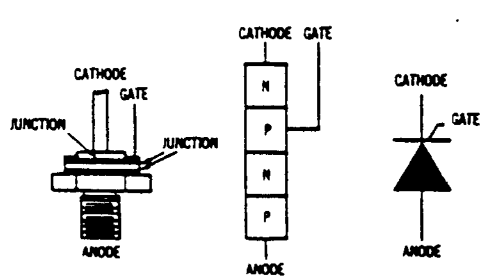

Fig. 1 — Cross Section, Block Diagram, and Electrical Symbol of Silicon Controlled Rectifier

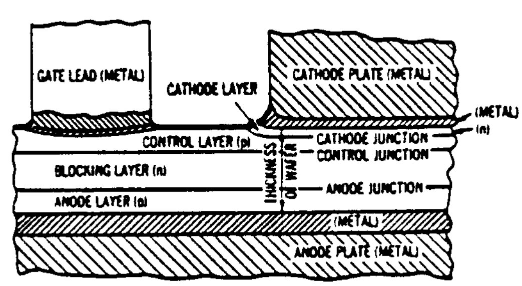

Fig. 2 — Cross Section of Idealized Controlled Rectifier Structure in the Region Close to the Gate

applied to the gate to fire or trigger the device on. When used in an ac circuit, conduction may be initiated at the beginning of any given positive half cycle, thus providing a simple on-off control, or at some later time in the positive half cycle, thus varying the voltage impressed upon the load.

When conduction is initiated only at the beginning of the positive half cycle, it is called zero cross-over firing. It virtually eliminates system electrical noise, radio frequency interference and line voltage disturbance. When conduction is initiated at some time during the positive half cycle it is called phase control and the interval of delaying the initiation of current is the firing angle or angle of phase retard, α (in electrical degrees). The interval of current conduction (in a simple, half-wave resistive circuit) is known as the conduction angle.

In more complicated rectifier circuits having two or more rectifying devices, varying the firing angle α reduces the average output voltage but does not necessarily change the conduction angle, since this is determined primarily by the particular circuit used.

Controlled rectifiers may be used to control ac power by connecting them in an anti-parallel (inverse parallel) manner so that one conducts load current in one direction while the other conducts in the opposite direction (IR's Logic-Triac controls ac as well as dc, depending on gate signal characteristics). The gate firing signal may be used to switch the flow of current on and, by using phase control, the average voltage applied to the load may be varied.

In dc circuits where the voltage across the controlled rectifier does not reverse, the gate may be used to initiate current flow, but some specific means must be provided to turn the flow off. (In operation in ac circuits, current flow ceases when the supply voltage reverses at the end of each positive half cycle.) In a dc circuit, a mechanical switch may be used to interrupt the current, or a more complex circuit can be used in which firing a second controlled rectifier causes a momentary flow of reverse current through the first controlled rectifier, causing it to turn off. This process is known as commutation, and is the basis of operation of the controlled rectifier inverter. Devices having fast turn-off times are used for such applications.

Gate triggering circuits should provide a well defined pulse of current which is several times greater than the maximum required gate current to trigger (I_{GT}) (at the minimum anticipated operating temperature) given for the particular device to be used. Curves are presented in each IR Product Data Sheet which show the range of gate voltage and current within which satisfactory operation can readily be achieved without exceeding the voltage, current, and power dissipation ratings of the gate. For applications where the initial anode current rises very steeply (high di/dt), gate pulses approaching the maximum permitted by the gate characteristic curve are most desirable to minimize device heating while it is first turning on. Triggering by varying a dc bias, commonly used with thyratron tubes, is not recommended for controlled rectifiers since gate sensitivity varies markedly with changes in junction temperature as well as from one device to another.

SCR PARAMETERS

Forward and Reverse Characteristics

The graph of the on-state, off-state, and reverse characteristics of a typical controlled rectifier is shown in Figure 3.

Turn-On Time

Turn-On Time consists of two distinct periods, the Delay Time (t_d) and the Rise Time (t_r). See Figure 4 for a display of the graphs of current and voltage during turn-on.

The Delay Time of a controlled rectifier is dependent on the internal geometry of the device and the bulk properties of the silicon. It takes a finite time for the injected carriers to move in the thin gate layer.

Delay time (t_d) is defined as the time taken from the moment at which the gate pulse reaches 10% of its peak to the time when the anode-to-cathode voltage has fallen to 90% of its initial value.

Rise time (t_r) is defined as the time taken for the anode-to-cathode voltage to drop from 90% to 10% of its initial value. It should be noted that 10% of the initial anode-to-cathode voltage is generally many times the on-state voltage which the controlled rectifier will exhibit at the same current when it is fully turned on.

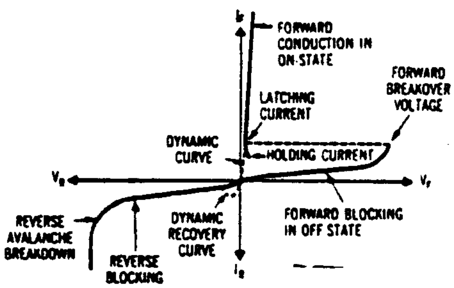

Fig. 3 — Controlled Rectifier Instantaneous Forward and Reverse Characteristics

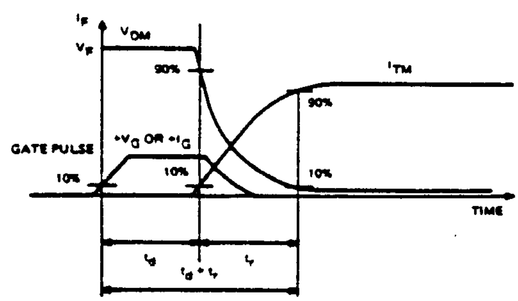

Fig. 4 — Anode Voltage and Current Waveforms During Test for Turn-on Time

Controlled rectifiers turn on first in the region near the gate and then the action spreads until the entire junction is turned on. This action is illustrated in Figure 5. The propagation rate of turn-on is approximately 0.1 mm/μsec, but it may vary during the turn-on interval and is affected by the magnitude of the load current.

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IR's ACE SCRs incorporate an advanced internal geometry, thereby, offering improved turn-on characteristics, including greater area turned on initially and a reduction in the time required for device to completely turn on.

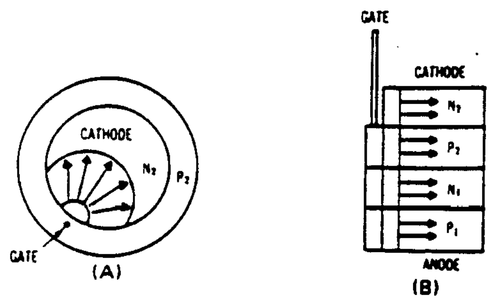


Fig. 5 — Initiation of Gated Turn-on Action

Turn-On Voltage Drop

Turn-on voltage drop (V_{TO}) is measured by applying a short, sinusoidal current pulse and measuring the voltage drop at the peak of this pulse. Two test conditions have been commonly used by controlled rectifier manufacturers:

1. 10 microsecond pulse width, 150 Amperes peak. (Fig. 6A)
2. 4 microsecond pulse width, 300 Amperes peak. (Fig. 6B)

A third method has been devised which permits V_{TO} to be read at both current levels and at almost the same time intervals. (Fig. 6C)

Waveforms under all three test conditions are shown in Figure 6. IR employs conditions (B) and (C).

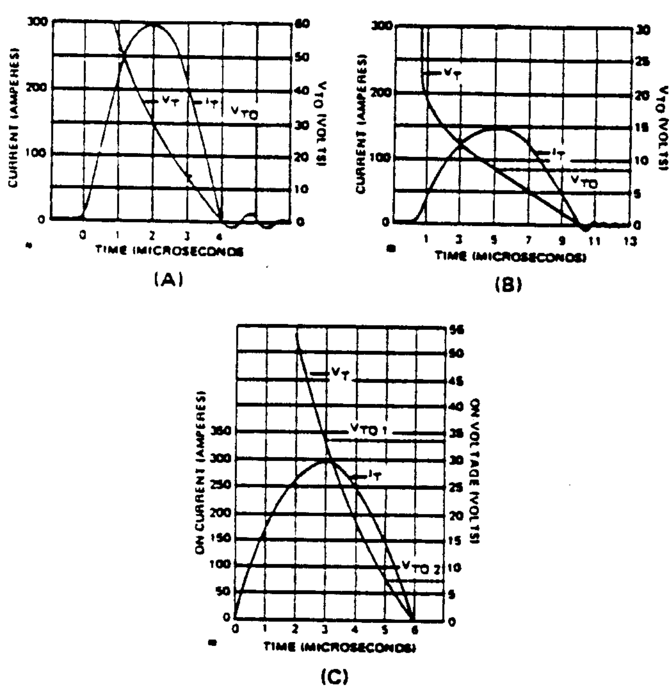
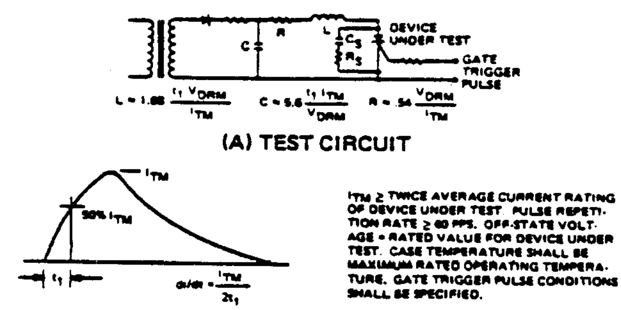


Fig. 6 — Voltage and Current During Test for V_{TO}

Di/dt Rating

The test circuit and on-state current waveform adopted by the industry for testing for di/dt are given in Figure 7. The anode current pulse is such that the 50 per cent point is reached in 1 microsecond or a little longer. The pulse reaches its peak about 2 microseconds later and then drops quickly to zero. Thus, this test is truly a test only of the ability of the device to handle a steeply rising current during initial turn-on.



(B) ON-CURRENT WAVEFORM

Fig. 7 — Circuit and Waveform for Testing di/dt

Critical Dv/dt

If the forward voltage across a controlled rectifier in the off-state increases at a very high rate, it can cause the device to turn on as if the device has been triggered by a gate pulse. If this takes place under normal operation the controlled rectifier may be damaged. To avoid this, the device should be tested to be sure it has a minimum dv/dt greater than the maximum value it will be subjected to in normal operation. Figure 8 shows the waveform and measurement points during the test.

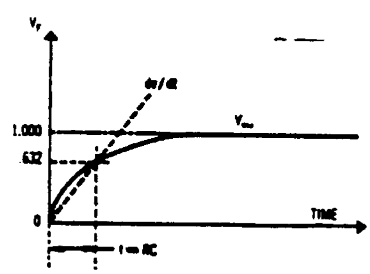


Fig. 8 — Anode Voltage Waveform During Test for Critical dv/dt

Turn-Off Time

Circuit commutated turn-off of a controlled rectifier may be achieved by the application of a reverse voltage to the anode to cathode circuit, causing a substantial reverse current to flow for a short period of time. The Turn-off Time (t_q) of a controlled rectifier is defined as the shortest time interval between the instant at which the anode current reverses from positive to negative and the instant at which the anode-to-cathode voltage becomes positive which can exist with the device being able to sustain the forward voltage without switching to the on-state. The waveforms during turn-off time testing are shown in Figure 9.

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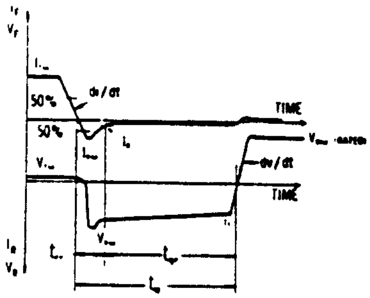

Fig. 9 – Anode Voltage and Current Waveforms During Test for Turn-off Time

Parameter Trade-Off

The development of devices with standard or special characteristics is a result of compromises among the various parameters a device may exhibit. Table 1 lists the parameters most often discussed for a specific application of a controlled rectifier and the effects various process changes and operating conditions have on them.

These trade-offs may not apply to IR's ACE SCRs. Other IR application notes are devoted to applying and selecting inverter type SCRs.

DEVICE DATA

Data for the individual devices are listed in IR's individual Product Data Sheets under the headings described below.

Voltage Ratings

These values are listed by part number for each device.

This listing includes parameters which are peculiar to specific voltage ratings rather than to specific series as listed under the heading Electrical Specifications. These ratings include specific repetitive and non-repetitive peak reverse or avalanche voltage ratings, and breakover voltage for each individual device.

Electrical Specifications

The values covered in this section give the major characteristics of the devices covered. The values are listed by series rather than by part number.

Mechanical Specifications

Under this heading are outlined the mechanical characteristics needed to enable the user to properly install the device in a given piece of equipment and a physical description of the device.

Rating Curves

Each Product Data Sheet includes curves for rating the device at conditions other than those listed in the specification table.

SPECIAL ORDER DEVICES

IR has a broad background of producing enhanced characteristic devices and a long history of developing SCRs for special applications. IR can help you solve a specific SCR application problem by selecting standard devices which exhibit the characteristics you require; by developing specially produced devices; by evaluating the circuit parameters, operating conditions, and device requirements; or by offering special SCR and SCR-rectifier assemblies, firing circuits, or pressure-assembled devices.

To discuss special requirements or to secure other technical assistance, or to obtain delivery and price quotations, feel free to contact your local IR Distributor, your local IR Field Office, or IR's El Segundo offices.

TABLE 1 – CONTROLLED RECTIFIER PARAMETER TRADE-OFFS

SCR Parameter (1)	Voltage Rating	Current Rating (3)	I_{GT}	Critical dv/dt	t_q	V_{TO}	di/dt Rating	S
Edge Contouring	↑							↑
Emitter Shorting		↓	↑	↑				↑
Gold Doping (2)	↓	↓	↑	↑	↓	↑	↓	↑
Thinner n-Base	↓	↑			↓	↓	↑	
Multiple Gates			↑			↓	↑	↑
Better Cooling (4)		↑		↑	↓			↑
Reduced Voltage Operation (4)				↑				↑

(1) In each case it is assumed that silicon wafers having identical anode and cathode areas are being compared, with and without the parameter change shown.

(2) In addition to gold doping, other means of reducing minority carrier lifetime will have the same effect on the listed parameters except voltage rating may not be adversely affected by other methods.

(3) This refers to current within the basic device rating which can be carried at a given case temperature. Changes in current rating are brought about by changes in the opposite direction of on-state voltage and power dissipation. Surge current rating will be affected in the same manner as current rating.

(4) The user as well as the manufacturer can influence the cooling of the semiconductor junction and also the maximum voltage which will be applied to it.

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