SGS-THOMSON MICROELECTRONICS

APPLICATION NOTE

TRISIL™ CROWBAR TYPE PROTECTION DIODE

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I - INTRODUCTION

In the field of parallel protection, the devices used have two main functions in transient operation : **to limit the voltage and to deviate the surge current.**

If the first function is perfectly carried out by an avalanche junction, confirmed by the success of the TRANSIL™ series, the second is limited by voltage permanently present across the diode terminals.

Utilization of increasingly sophisticated but fragile electronic components and publication of new standards do not allow the use of TRANSIL diodes in certain applications.

This problem is solved by the use of a **semiconductor device** with **two conducting states** such as the thyristor (or the triac in the bidirectional version).

SGS-THOMSON Microelectronics has developed this type of component under the trade name of **TRISIL**.

This paper is meant to explain its operation and applications and help to choose the model which is most suitable to each specific requirement.

II - TRISIL CHARACTERISTICS

II.1 - ELECTRICAL CHARACTERISTIC

The electrical characteristic of the TRISIL is similar to that of a TRIAC (figure 1) except that the component has only two terminals. Triggering in this case is not done via a gate but by **an internal mechanism dependent on the current flowing through it.**

II.2 - OPERATION SEEN FROM THE OUTSIDE

At rest, the TRISIL is biased at a voltage lower than or equal to the standby voltage (V_{RM}). At that point of the characteristic, the leakage current is about **ten nanoamperes** and the presence of the TRISIL connected across the equipment to be protected does not disturb its operation (Figure 2).

The characteristic data at this point includes : **the leakage current, the electrical capacity and the reliability of the component in blocking mode.**

As the voltage increases beyond V_{BR}, the TRISIL impedance drops from practically infinite

Figure 1 : I / V Characteristic of a Trisil.

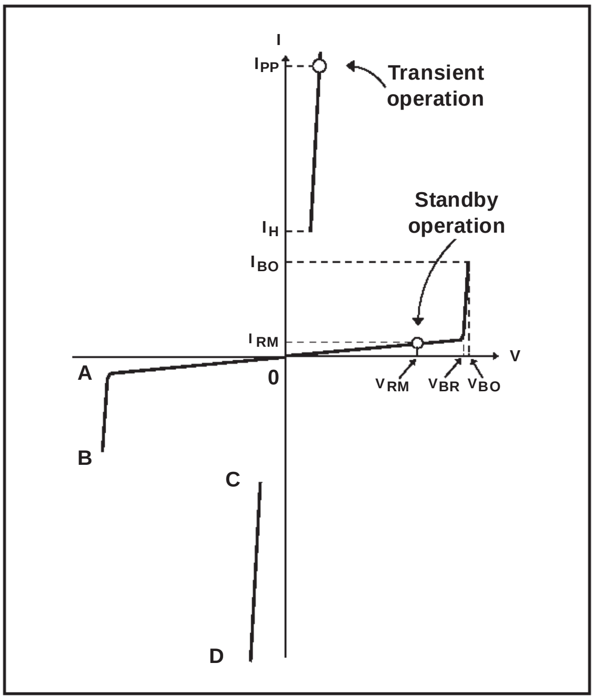
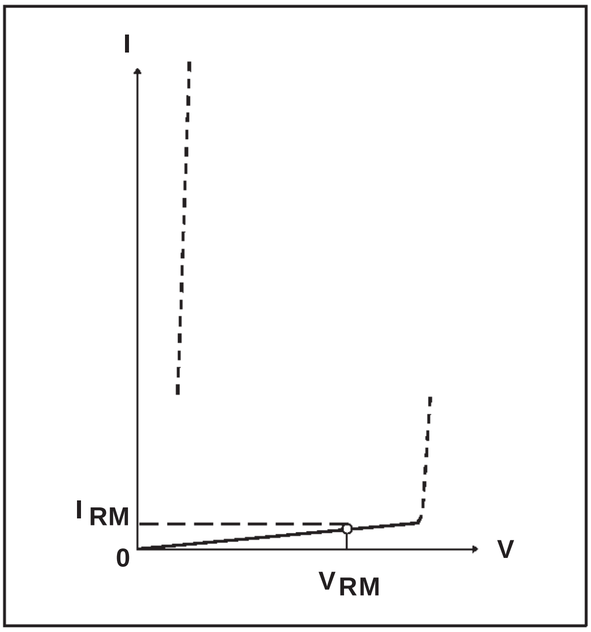


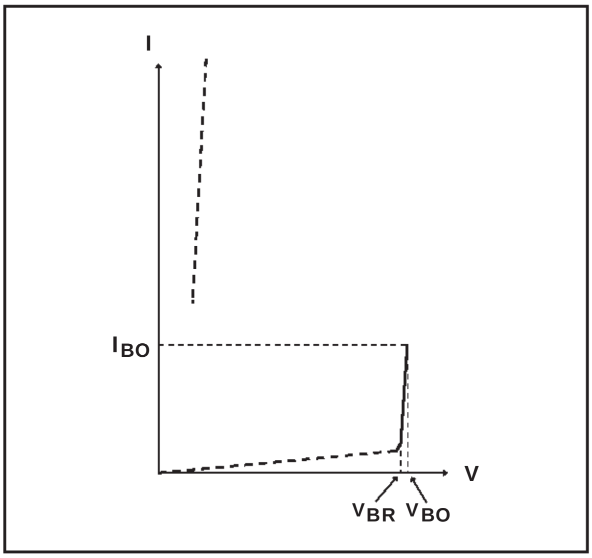
Figure 2 : Stand by Characteristics.



to a few ohms. The TRISIL remains biased at its avalanche voltage and its operation is then identical to that of a TRANSIL diode (Figure 3).

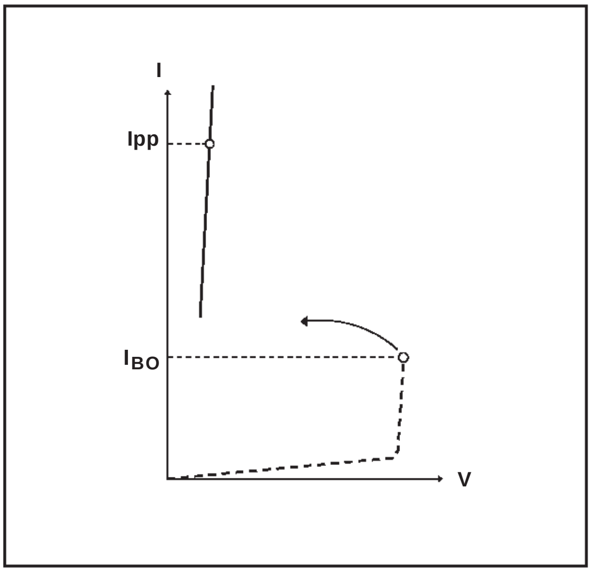
The characteristic parameters at this level are **the limiting voltage** (breakover voltage of the component, V_{BO}) **and the time for switching between the blocked and conducting states.**

Figure 3 : Avalanche Characteristic of the Trisil



For current values higher than I_{BO}, the voltage across the TRISIL drops to a few volts and the high currents permitted without damage are possible due to the low value of this voltage, since the physical limit is dependent on the dissipated power (Figure 4).

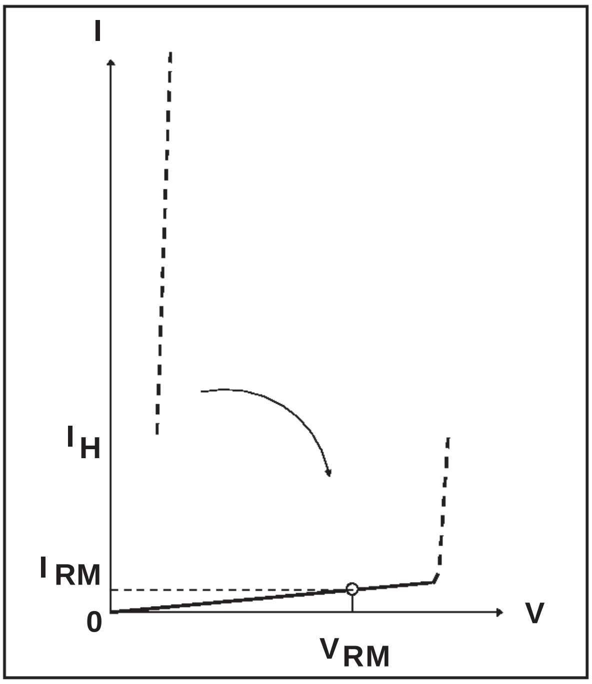
Figure 4 : Triggering, and on-state Characteristics.



The characteristic parameter is then the possibility **of withstanding surge currents** (peak-point current, I_{pp}).

Return to standby operation by turning off the TRISIL takes place when the current flowing through it drops below I_H. This is the characteristic parameter for switching from the conducting to the blocked state (Figure 5).

Figure 5 : Return to Standby Operation.



The surge current associated with the disturbance is diverted through the TRISIL as soon as it begins to operate in the avalanche mode (figure 3) and the voltage limitation results from the electrical characteristic at this point. The behaviour of the TRISIL is here identical to that of the TRANSIL. The difference depends on the level of the breakover current, I_{BO}, where the triggering of the thyristor structures take place. This phenomenon results in absolute limitation independently of the current level, and a capacity to deviate currents much higher than those possible for an avalanche diode (TRANSIL). Furthermore, this limitation is independent of the avalanche voltage of the device.

II.3 - LIMITING PROPERTY

Because of its operating mode, the TRISIL results in **absolute voltage limitation, independently of the surge current level** (figure 6) **and of the slope of the applied voltage ramp** (figure 7).

Figure 6 : Correlation Between the Voltage and the Surge Current.

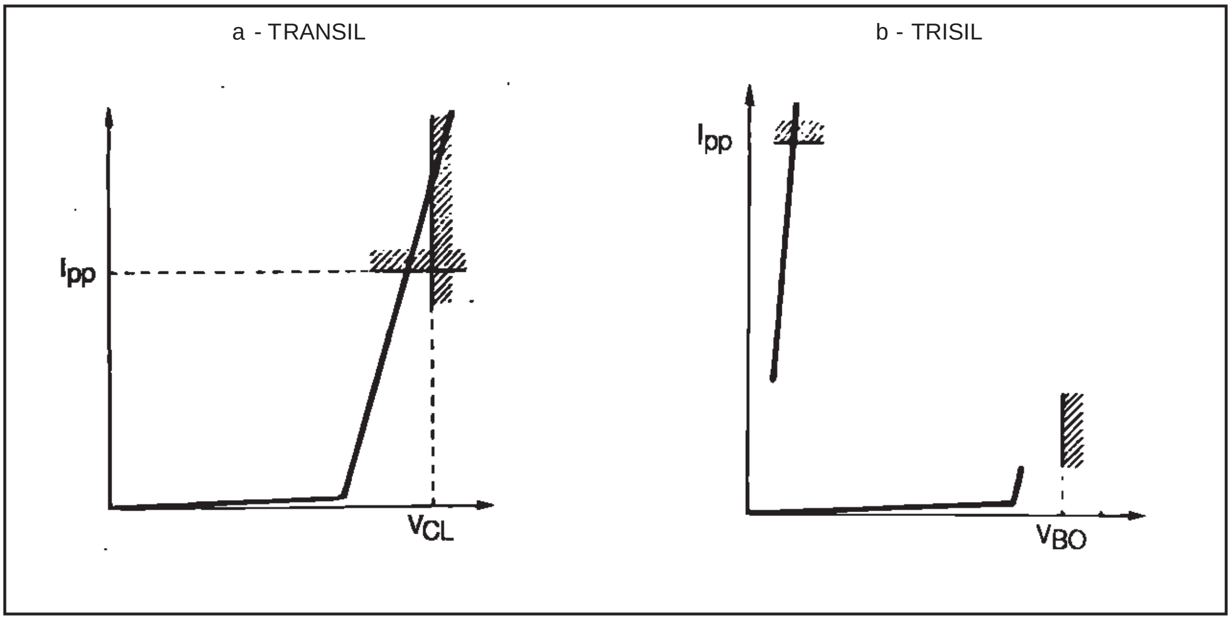
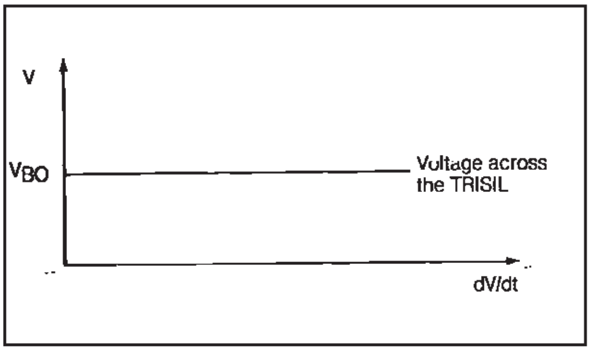


Figure 7 : Correlation Between the Limiting Voltage and the Surge Voltage Ramp.



In particular, if the surge current is higher than the guaranteed value in the catalogue, without however exceeding the physical limits of the component, the voltage across a TRANSIL could reach the critical value destroying the equipment to be protected. For a TRISIL, this risk is excluded.

Finally, for a surge current much higher than the guaranteed value, destruction of the TRISIL always results in a short-circuit thus providing absolute protection for the equipment located downstream.

II.4 - BEHAVIOUR IN CASE OF CURRENT SURGES

The ability of semiconductor components to withstand high currents in transient operation is limited for pulses longer than 10 nano-seconds by a second breakdown due to heat. This phenomenon, although not destructive, is considered as the normal utilization limit in so far as the behaviour of the component depends on the external circuit.

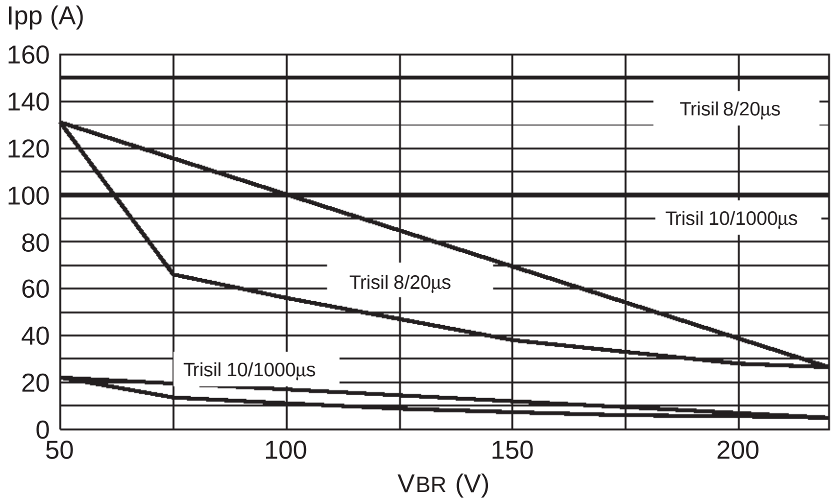
The temperature rise within the semiconductor is thus the parameter which defines the behaviour of the component and its capacity to withstand current surges. It is given by equation (1) :

$$T_j = T_a + Z_{th} V_{on} \times I_{RS} \quad (1)$$

With T_j : instant temperature at the junction level
T_a : ambient temperature
Z_{th} : transient thermal impedance (as a function of the duration of the pulse)
V_{on} : voltage across the terminals of the component in the conducting state
I_{RS} : transient current flowing through the component.

This equation clearly shows the advantage of the TRISIL : decrease in the voltage across its terminals enables it to conduct a **much higher current** than the avalanche diode, for example, for the same junction temperature. Since the voltage to be taken into consideration for the calculation is that in the conducting state, the permitted current levels in transient operation are independent of the avalanche voltage and the **guaranteed values are identical for all the types of a given series** (figure 8).

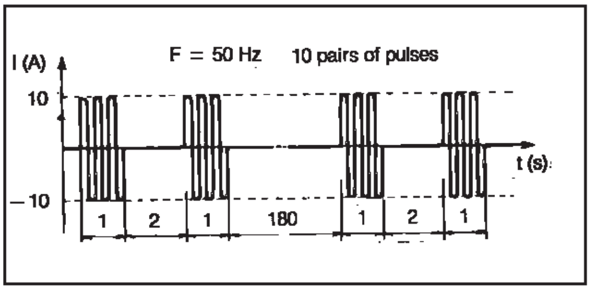
Figure 8 : Comparison of the Limit Transient Currents for a Transil and a Trisil in the Same Case (SMB).



The maximum junction temperature taken into account in transient operation is not that given in the catalogues (junction temperature in operation or in storage) but corresponds, with a certain safety margin, to the second breakdown due to thermal causes, i.e. about 350 - 400 °C.

This high current capacity can be applied in AC operation at the 50 Hz industrial frequency (figure 9), which is particularly interesting in telephony where equipment should be protected against overvoltages resulting from accidental coupling of the telephone line with the power distribution network. This type of protection is required by certain standards used in telecommunications.

Figure 9 : Long Duration Overload Test



II.5 - RESPONSE TIME

The response time of the component is the time **it requires to limit the voltage.** From this point of view the TRISIL has exactly the same behaviour as a TRANSIL. The time is that required to switch from the standby operating point to the avalanche voltage. This is **quasi instantaneous.**

This time should not be confused with that required to pass from the breakover point (V_{BO}) to the conducting characteristic. This time is longer but does not influence the limiting capability of the device.

II.6 - OPERATION WITHIN THE AVALANCHE AREA

This paragraph concerns the segment V_{BR} - V_{BO} (Figure 3) of the TRISIL characteristic between the blocked state and the conducting state at low V_{on}.

This portion of the characteristic is identical to that of an avalanche diode. Thus within this area, DC, AC or pulse-type operations are permitted. The currents are limited depending on the possibilities of junction-ambient air heat dissipation. The maximum current is defined by the following inequality (2) :

$$T_j = T_a + R_{th} V_{BO} I_{max} \leq T_{jmax} = 150\ °C \quad (2)$$

and inequality (3) defining when the TRISIL is not triggered :

$$I_{max} < I_{BO} \quad (3)$$

The main differences from equation (1) are the maximum junction temperature which is now that given by the catalogue, i.e. 150 °C, the voltage which is that of the avalanche mechanism and the continuous thermal resistance replacing the transient thermal impedance.

In AC operation, although equation (2) still holds good, the voltage-current diagram as a function of the time (figure 10) is more clear.

The value of the breakover current (I_{BO}) plays an important part in the capacity of the device in avalanche operation.

Figure 10 : AC Operation in the Avalanche Mode.

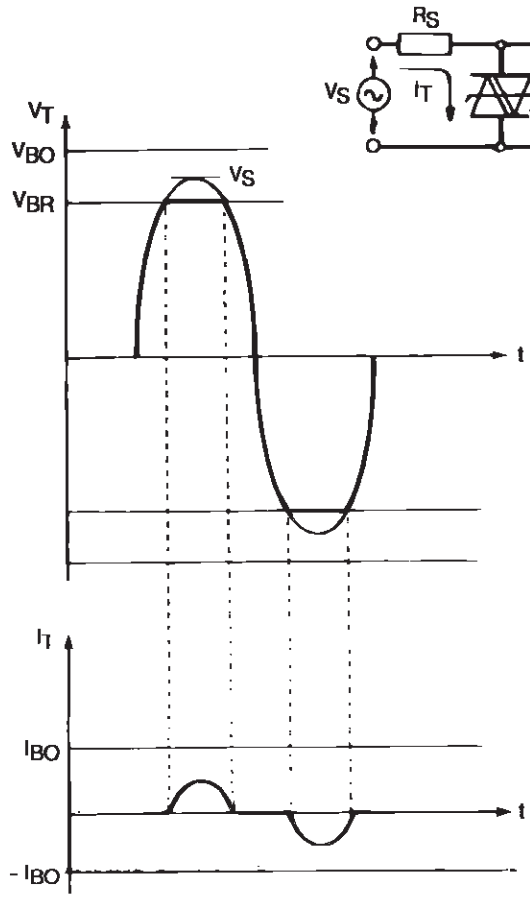
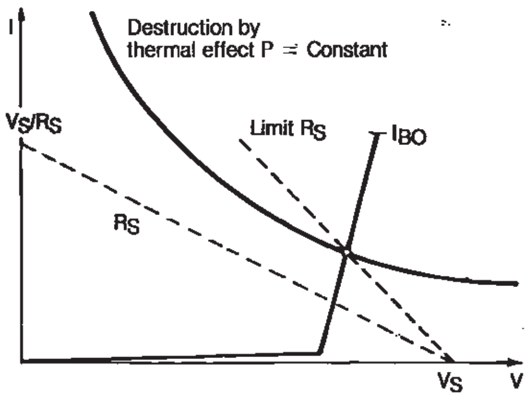
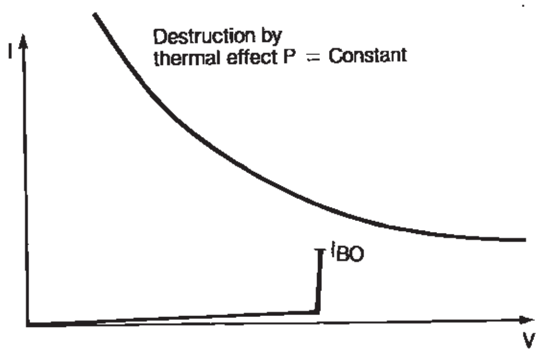


Figure 11 : Conditions for non Destructive Operation in the Avalanche Mode.

a - Case in which the current should be limited by the external circuit R_S > limit R_S.



b - Correct operation whatever the external circuit.

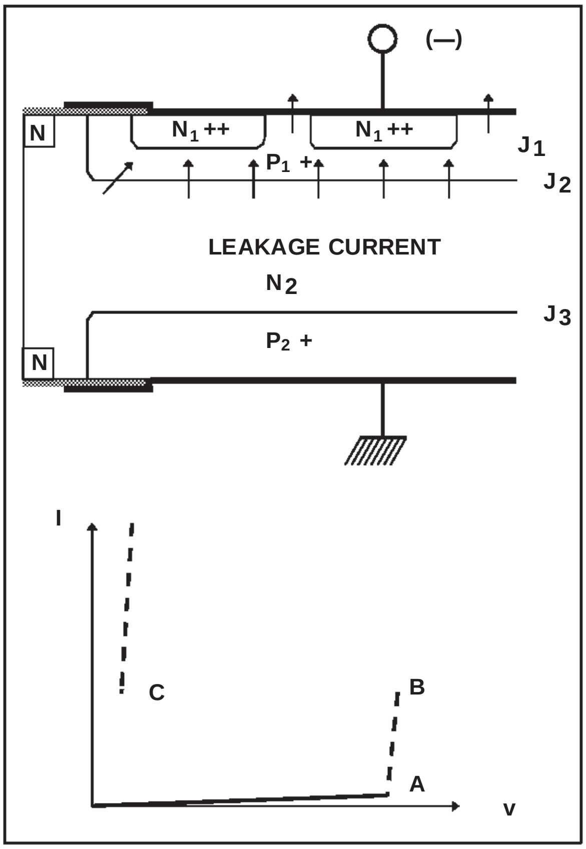


If this value is high (figure 11.a), the current in the component must be limited by a suitable series resistor. For lower values, avalanche operation takes place without destruction whatever the external circuit.

III - PHYSICAL OPERATION

The TRISIL in fact consists of two thyristors connected back to back. It will suffice to explain the operation of one thyristor. The other operates in the same way if the voltage across the component is reversed.

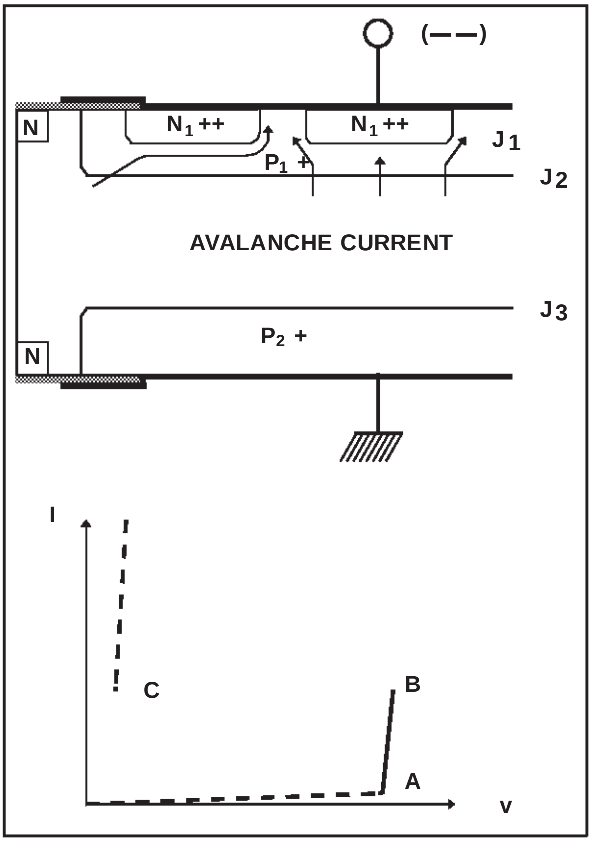
Figure 12 : Operation in the blocked mode.



Application of a negative voltage on cathode N++ results in forward biasing of junctions J_1 and J_3 and reverse biasing of J_2.

The current observed is thus the leakage current of junction J_2.

Figure 13 : Operation in the avalanche mode.



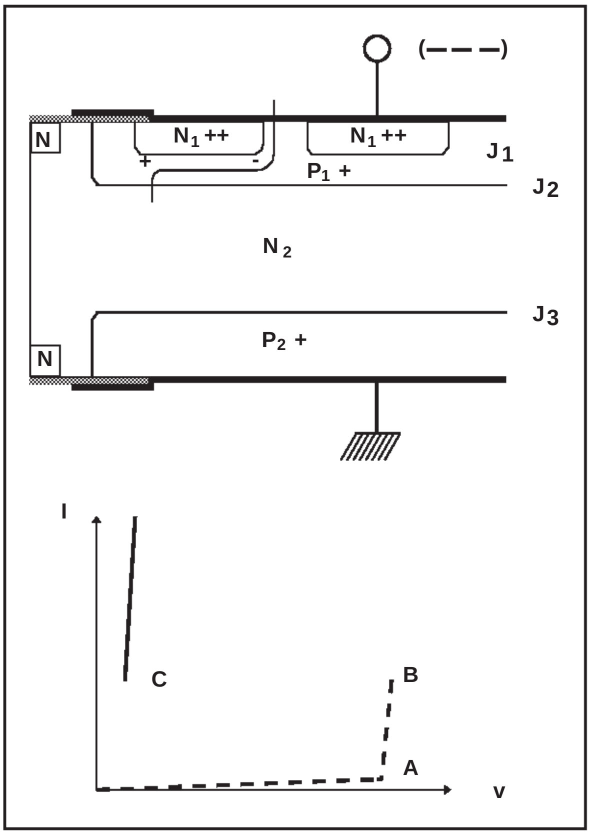
When the voltage exceeds a certain value, junction J_2, which is reverse biased, begins to operate in the avalanche mode.

The structure up to this current level operates like a diode (junction J_2).

The side current biases the P_1 layer next to the N_1 part of the emitter. The highly dopped N_1 layer has the same potential.

The P_1 area at the surface is forced to the same potential as the N1 region by metallization.

Figure 14 : Thyristor Effect of the Trisil.



As the avalanche current increases this difference of potential can reach the threshold of 0.6 V, a value which is sufficient to create injection of electrons from the cathode towards the P_1 area and thus trigger thyristor N_1 P_1 N_2 P_2.

The electrons thus injected into P_1 in fact will reach J_2 by diffusion, and cross it under the effect of the electrical field operating in the space charge of the reverse biased J_2 junction.

In N_2, the electrons help to reduce the potential of this area compared with P_2 and as a result inject holes from P_2 towards N_2. These holes travel in the reverse direction because of their polarity. When they arrive at P_2 they help to increase the potential of P_1 with respect to N_1, this time resulting in the injection of electrons from N_1 to P_1.

The procedure is cumulative. The excess electrons in N_2 and the holes in P_1 will compensate the fixed charges of the space charge and will thus suppress it. Junction J_2 will act as a forward biased junction and the voltage across the component will drop.

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