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Soft breakdown of Zener diode

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Abstract : Zener diodes are found to show breakdown properties at much lower bias voltages compared to the so called Zener breakdown voltages. The soft breakdown becomes conspicuous from the occurrence of a point of inflexion near the origin of the *i-v* characteristics. The phenomenon has been explained by interband tunneling of carriers taking place under small reverse bias voltages.

Keywords : Zener breakdown, tunneling.

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Highly doped *p-n* junction diodes show sharp breakdown properties under reverse bias voltages. The process was theoretically considered much earlier by Zener (1934) for solid dielectrics where breakdown was assumed to be due to the direct excitation of electrons from valence to conduction band by electric field. The theory was later on extended (McAfee *et al* 1951) to explain the breakdown properties of reversedly biased *p-n* junction diodes. From a study of temperature variations of the junction breakdown Sharma and Peer (1976) observed that for low breakdown voltages (≤ 5V) tunneling mechanism was effective one. Here, we report on the soft breakdown properties of some silicon Zener diodes kept at room temperature (30°C).

The diodes used in this experiment are those available commercially viz, 2.3VZ, 4.3VZ and 6.2VZ having Zener breakdown voltages at -2.3, -4.3 and -6.2 volts respectively. The current-voltage characteristics at low reverse biases have been traced with a highly sensitive pen recorder of a Cambridge Polarograph (C 603282).

Figure 1 shows the breakdown characteristics of the doides at room temperature. Variation of the resistance of the 6.2VZ diodes with reverse bias voltages is shown at the top left portion of the same diagram. Here we observe that effective value of resistance begins to fall much before the so called Zener breakdown voltage.

Figure 2 is the reverse *i-v* characteristics at the low voltage region taken with the high precision pen recorder. Here the *i-v* curve changes its shape from convex to concave one. The reverse current may be supposed to follow a formula of the type i = constant × V^{α}, where α is however a function of voltage. The value of α is less than unity in the region AB and greater than unity in the region BC. To find out the point of inflexion correctly a plot of log i vs log V is made in Figure 3. The two straight lines, which correspond to convex and concave portions of the reverse i-v characteristics (Figure 2) are found to meet at a point where the value of log V_R = – 0.74 i.e. V_R = 0.18 Volt. Thus the soft breakdown of 6.2 VZ Zener diode takes place at about –0.18 volt. Similarly soft breakdown for 4.3 VZ and 2.3 VZ have been observed at about –0.10 volt and zero biases respectively (not shown).

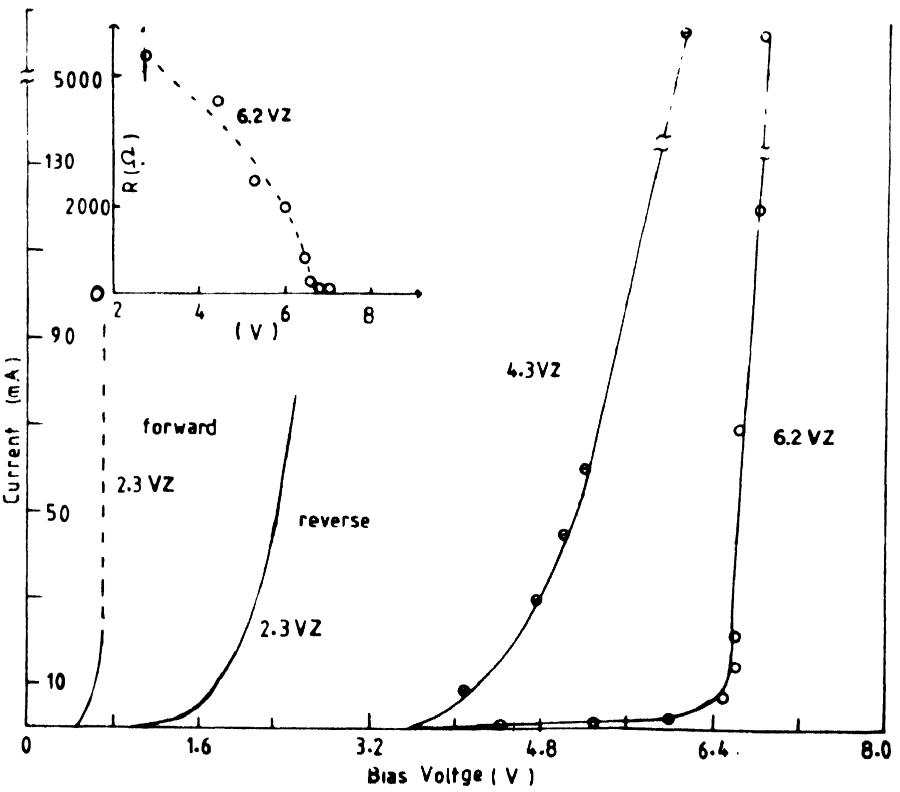

Figure 1. Reverse i-v characteristics of several p-n junction Si-Zener diodes. Resistance - voltage characteristics of the 6.2VZ diode under reverse bias is shown separately at the top left portion

The band diagram and distribution of field at the p-n junction of a Zener diode is depicted in Figure 4. This is the situation under zero or small reverse biases. For highly doped junction the Fermi-levels (F_1 and F_{11}) coincide with upper and lower edges of valence and conduction bands for p and n type of semiconductors respectively. At very small reverse biases electrons in the region F_1F_2 of p side can tunnel to the conduction band of n side. Electrons at position 3 experiences a field greater that $F_{max}/2$ and readily tunnel to identical energy site at 4. F_{max} is the maximum field at the mid-gap of the junction.

In case of uniform field of value $E + E^1$ where E is the built-in field and E^1 is the external field due to applied reverse bias voltage, the emission current density is given by

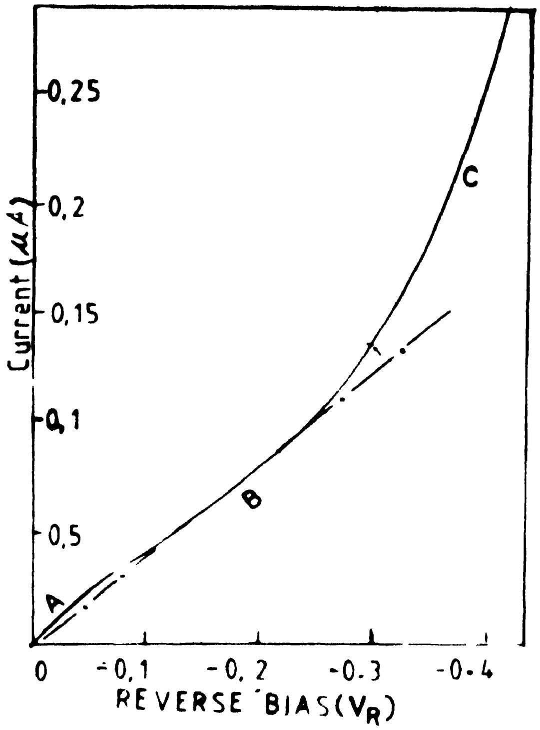

Figure 2. Reverse i-v characteristics (near the origin) for 6.2VZ Zener diode showing point of inflexion.

$$J \alpha \operatorname{Exp}\left[-\frac{\pi\sqrt{2m^*}}{4\hbar q} \quad \frac{E_g^{3/2}}{|E + E^1|}\right]$$

where m^* = effective mass of an electron

q = electronic charge

E_g = energy gap.

The above equation which is applicable for uniform field viz when

$$|E + E^1| = F_{\max}/2$$

For non-uniform field (vide Figure 4) where at least few electrons experience field greater that $F_{\max}/2$ the reverse characteristics is likely to appear softer.

In a diffused *p-n* junction local fluctuations of impurity concentration is most probably another cause leading to the onset of soft breakdown which is observed much before the so called Zener breakdown. Thus we conclude that the soft breakdown of a Zener diode at room temperature is most probably due to a tunneling mechanism and actually this is what is expected from the theoretical model of a highly doped *p-n* junction diode. Further work are now in progress.

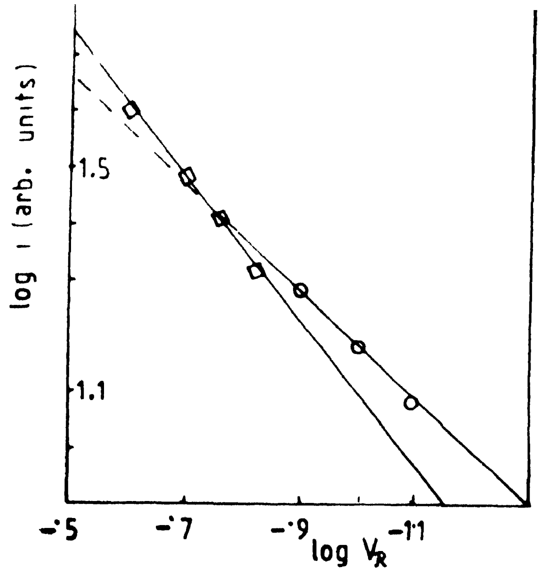

Figure 3. Log i (i in arbitrary unit) vs log V_R characteristics (V_R is the reverse bias voltage).

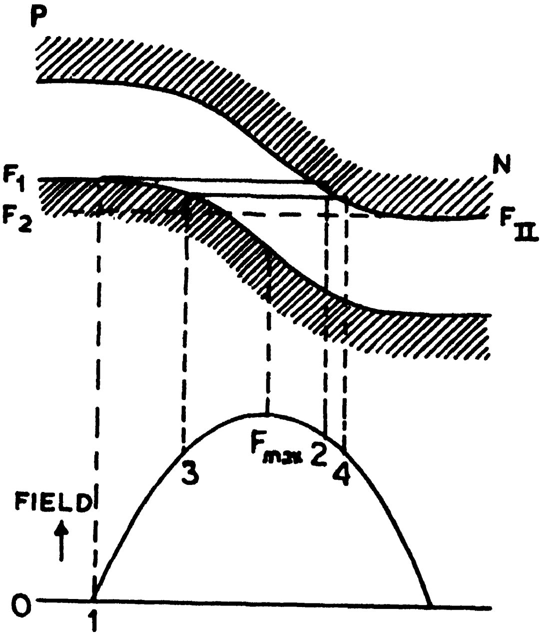

Figure 4. Band diagram and field distribution in a highly doped p-n junction put under small reverse bias voltages.

References

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