2. Theory and Characteristics of Tunnel Diode.

A common P-N junction diode has an impurity concentration of about 1 part in 10^8. With this amount of doping the width of the depletion layer, which constitutes a potential - barrier at the junction, is of the order of 5 microns (5×10^{-4} cm.). This potential barrier restrains the flow of carriers from the side of the junction where they constitute majority carriers to the side where they constitute minority carriers. If the concentration of impurity atoms is greatly increased, say to 1 part in 10^3, then the device characteristics are completely changed. This new diode was announced in 1958 by Esaki, who also gave the correct theoretical explanation for its volt-ampere characteristic, which is depicted in Fig. 2.1. The width of the junction barrier varies inversely as the square root of impurity concentration and therefore is reduced from 5 microns to about 100^0 A (10^{-6} cm). This thickness is only about one - fiftieth the wave length of a visible light. Classically, a particle must have an energy at least equal to the height of a potential barrier if it is to move from one side of the barrier to the other. However, for barriers as thin as those estimated above in the Esakidiode, quantum-mechanics dictates that there is a large probability that an electron will penetrate through the barrier. The quantum mechanical behavior is referred to as "Tunnelling", and hence this high impurity density P-N junction devices are called "Tunnel diodes".

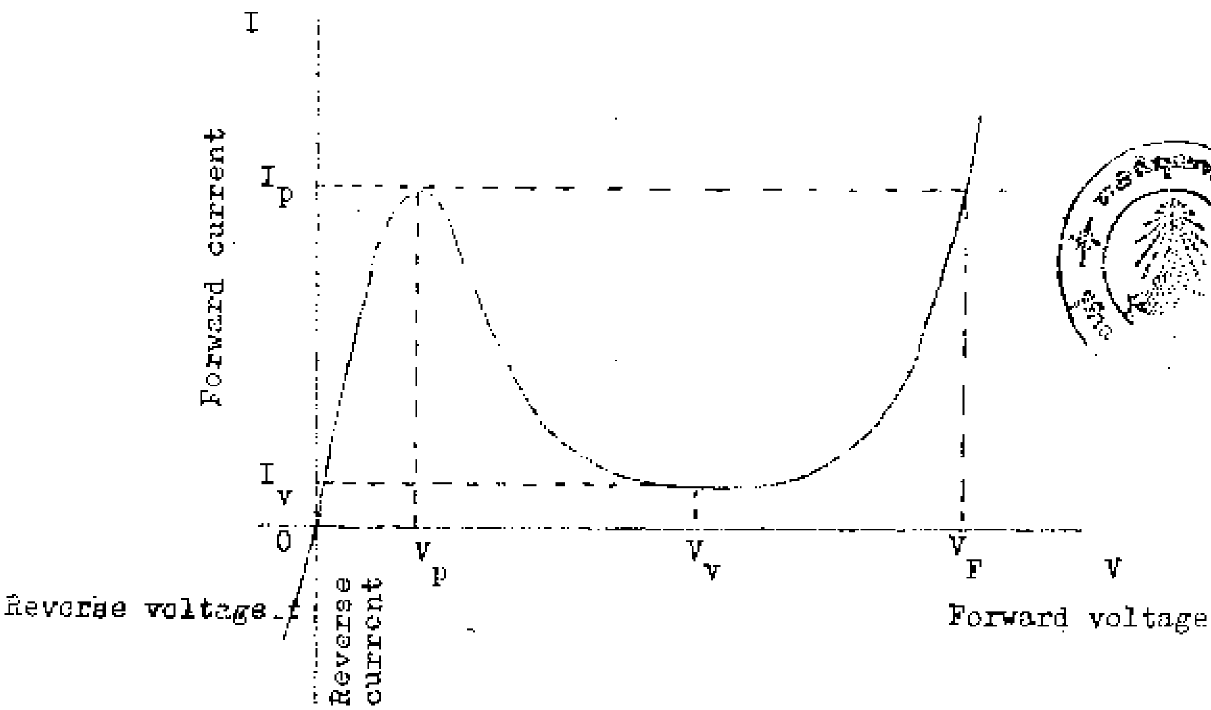


Fig. 2.1 V - I Characteristic of tunnel diode.

The device is an excellent conductor in the reverse direction (P side of junction negative with respect to the N side). At the peak current I_p corresponding to the voltage V_p the slope dV/dI of the characteristic is zero. If V is increased beyond V_p, then the current decreases. As a consequence the dynamic conductance $g = dI/dV$ is negative. The tunnel diode exhibits a negative resistance characteristic between the peak current I_p and the minimum value I_v, called the **valley current**. At the **valley voltage** V_v at which I = Iv the conductance is again zero, and beyond this point the resistance becomes and remains positive. At the so called peak forward voltage V_F the current again reaches the value I_p. For larger voltages the current increases beyond this value. This portion of the characteristic beyond V_v is caused by the injection current in an ordinary P-N junction diode. The remainder of the characteristic is a result of the tunnelling phenomenon in the highly doped diode.

For currents whose values are between I_V and I_P the curve is triple - valued, because each current can be obtained at three different applied voltages. It is this multivalued feature which makes the tunnel diode useful in pulse and digital circuitry.

Note that while the characteristic is a multivalued function of current, it is a single valued function of voltage. Each value of V corresponds to one and only one current. Hence, the tunnel diode is said to be voltage controlled.

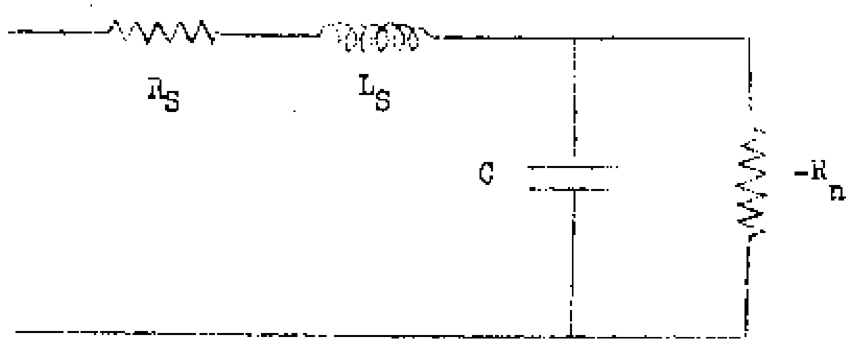


Fig. 2.2 Model of tunnel diode for small signal operation

The standard model for small signal operation in the negative resistance region is shown in Fig. 2.2, the negative resistance (- Rn) has a minimum at the point of inflection between I_p and I_v. The series resistance R_s is the ohmic resistance. The series inductance L_s depends upon the lead and the geometry of the diode package. The junction capacitance (depends upon the bias and is usually measured at the valley point.)

The principal interest in the tunnel diode is its application as a very high speed switch. Since tunnelling takes place at the speed of light, the transient response is limited only by total shunt capacitance (junction plus stray wiring capacitance) and peak driving current. Switching times of the order of a nanosecond are reasonable, and times as low as 50 pico-second have been obtained.

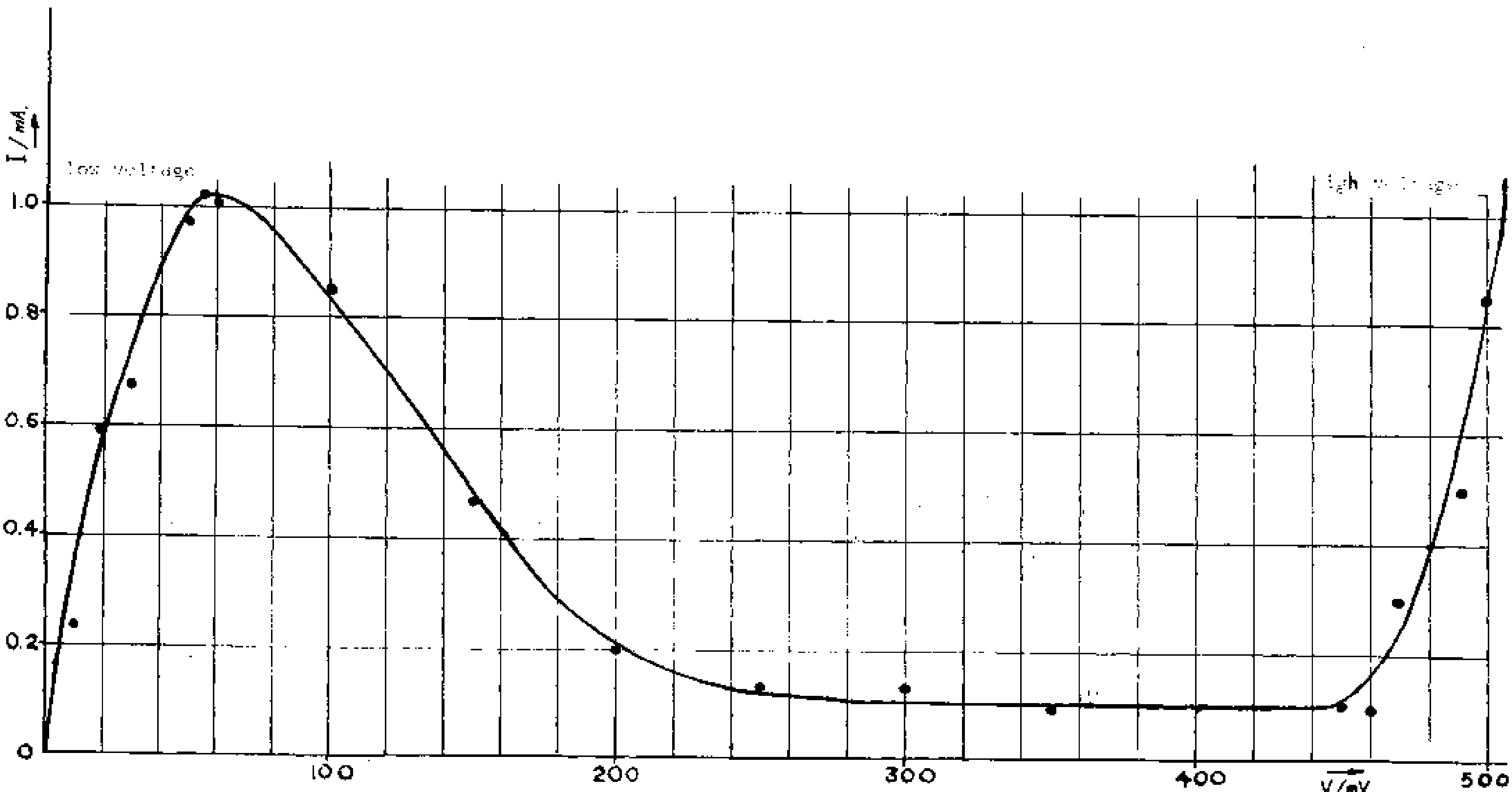
2.2 <u>The determination of tunnel diode characteristic.</u>

The most common commercially available tunnel diode are made from germanium, gallium arsenide and silicon. The later is difficult to manufacture with a high ratio of peak to valley current I_P/I_V. The typical tunnel diode parameters are shown in Fig. 2.3

	Ge	GaAs	Si
I_P/I_V	6	15	3.50
V_P V.	0.055	0.15	0.065
V_V V.	0.35	0.50	0.42
V_F V.	0.50	1.10	0.70

Fig. 2.3 Typical tunnel diode parameters

The static characteristic of these devices is shown in Fig. 2.4 and Fig. 2.5



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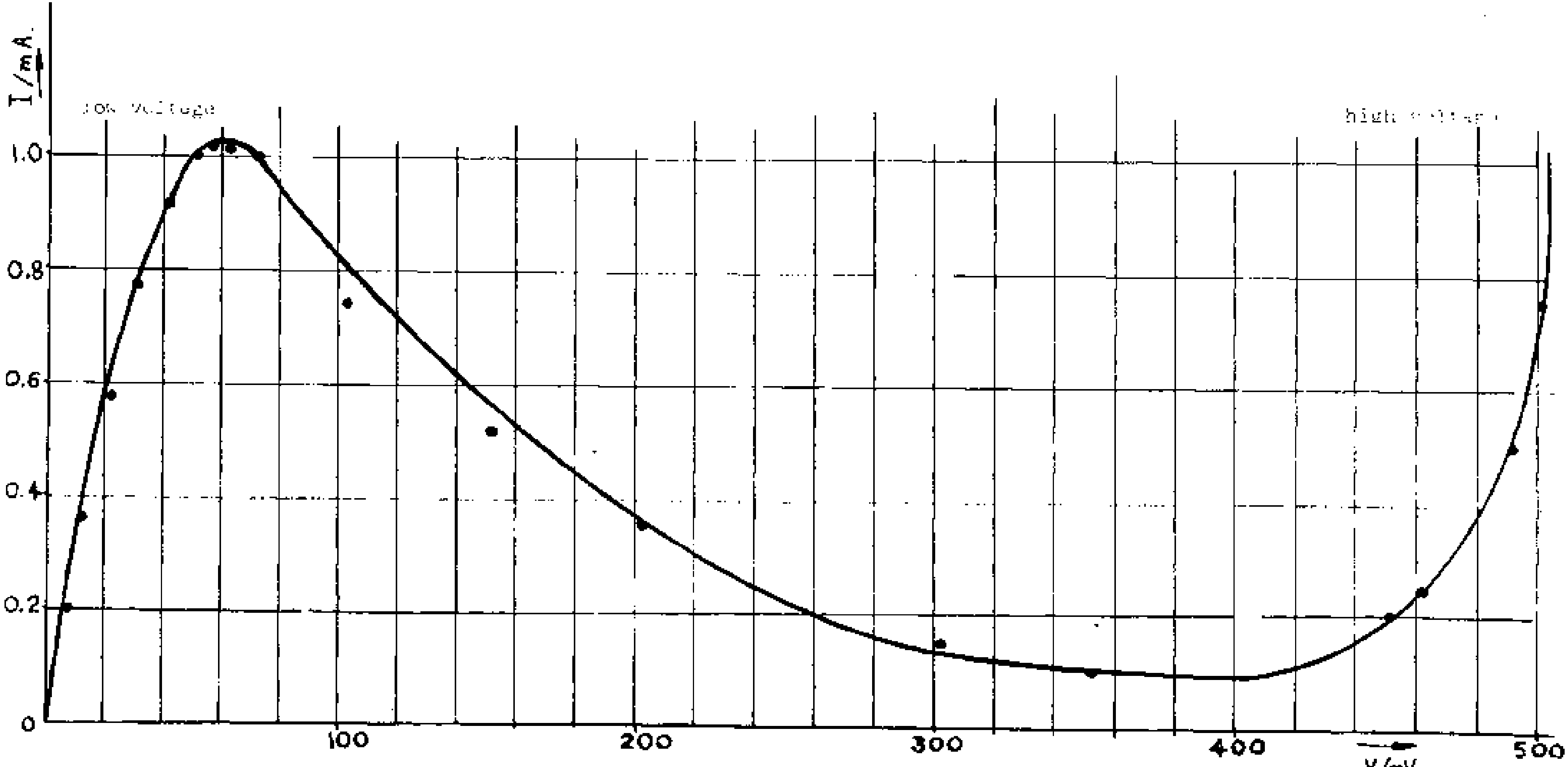

1N3713

This curve is obtained by varying voltage supply V and resistance R in the circuit (See Fig. 2.6). The series resistance R + Rs is cho-sen to limit the current. The shunt resistance R_L is cho-sen to limit the voltage across the tunnel diode with respect to the maximum current I_P. In order to obtain the portion of negative resistance, the absolute value of R_L must be less than the absolute value of $- R_n$ (i.e. $R_L < |- Rn|$). The value of (- Rn) for the IN 3712 and IN 3713 tunnel diodes under investigation are 125 ohms and 118 ohms respectively. The entire characteristic (Static) is obtained by measuring the voltage V_D across the tunnel diode and the current Id through the tunnel diode. One gets the current Id easily by subtracting I_1 from I_2 See Fig. 2.6

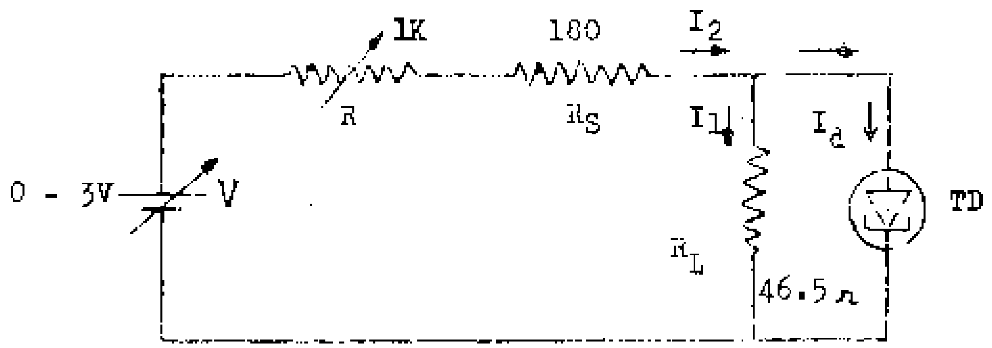

Fig. 2.6 Circuit used to determine the static characteristic of a tunnel diode.

The advantages of the tunnel diode are low cost, low noise, simplicity, high speed, environmental immunity, and low power. The disadvantages of the diode are its low out-put voltage swing and the fact that it is a two terminal device. Because of the later **feature**, there is no isolation between in-put and output and this leads to ser-ious circuit design difficulties. Hence, a transistor (an essentially unilateral device) is usually preferred for frequencies below about 1 GHz or for switching time longer than several nanosecond. The tunnel diode can be combined with the transistor to generate signal pulse with sufficient amplitude to operate other electronic circuits in the counting system.

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