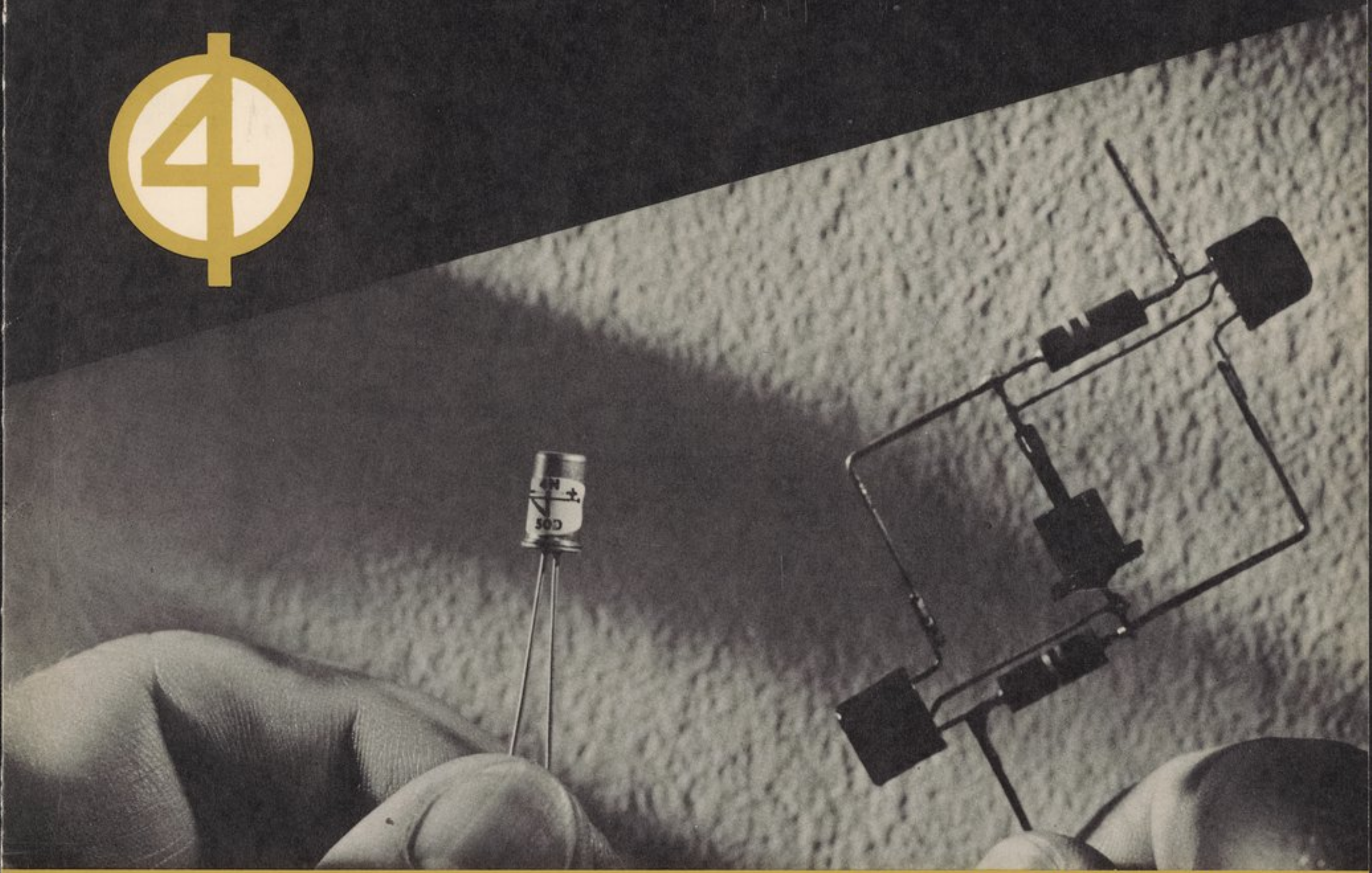


Equivalent to a combination of five separate elements

the shockley

4-LAYER BISTABLE TRANSISTOR DIODE

for: computers
telephony
control
pulse circuitry

Shockley / Transistor Corporation

SHOCKLEY 4-LAYER TRANSISTOR DIODE

DATA FOR CIRCUIT DESIGNERS

Introduction

Transistor diodes of the four-layer bistable type, invented at Bell Telephone Laboratories, are semiconductor switches with functions based on the principles of transistor action. Because the switching properties so closely approach many of those demanded from an ideal switch, the four-layer diode finds many applications in the otherwise diverse fields of high-power switching, pulse generation, and pulse counting.

Basically, the unit is a two-terminal device which operates electrically in either of two states:

1) an 'open' or low-conductance state of 10 to 1,000 megohms, in parallel with about 50 $\mu\mu$f, and

2) a 'closed' or high-conductance state of 1 to 10 ohms. The resistance in this state depends on current and decreases in some units to values as low as 0.2 ohm at currents of 2 to 3 amperes.

The diode is switched from one state to the other through control of the voltage and current. When the voltage exceeds the breakdown level, the diode changes from 'open' to 'closed'—provided sufficient current is available to hold it in the 'closed' state. (Switching occurs very rapidly and is discussed in section on Switching Times.) When the current drops below a threshold value, the diode will switch back to 'open'.

Circuit Properties

As shown in Fig. 1 (below) the four-layer diode passes back and forth between its 'open' and 'closed' state through a negative-resistance transition region II located between region I ('open' or 'off') and region III ('closed' or 'conductive').

Action of the Four-Layer Diode

Visualize the voltage across the device being increased from zero with polarity shown in Fig. 2a. Junctions 1 and 3 are forward biased, and junction 2 reverse biased. Therefore junction 2 has a much higher impedance than junctions 1 and 3. Nearly the entire applied voltage will be developed across junction 2, and the current that flows will be largely that characteristic of a reverse-biased silicon junction.

Hence, the device will have a low-frequency impedance in this range of operation of possibly several hundred megohms. Since pn junctions also possess capacitance, the high-frequency impedance will be considerably lower.

As the voltage continues to be increased, the electric field produced within the silicon at junction 2 increases. The so-called avalanche current together with the increasing alphas of the emitter junctions then lead to the shape of the characteristic in region II.

Transistor Equivalent

The four-layer diode Fig. 2a can be regarded as two interconnected silicon-junction transistors. Current passing junction 2 (which is also the total device current) arises from three components: (a) that which is thermally generated in and near junction 2 and multiplied there, (b) that injected by the p emitter and collected and multiplied at junction 2, and (c) that injected by the n emitter and collected and multiplied at junction 2.

Negative resistance arises in the transition region II as follows: For small current through the device, the alphas of the transistors of Fig. 2b are low, and a large avalanche multiplication M is necessary to account for device current at junction 2. As the current increases beyond I_b (Figure 1) the alphas of the transistors begin to increase rapidly and a decreasing value of M is required to keep charge from piling up at the center junction. Since M is dependent on the voltage drop across junction 2, a decreasing value of M implies a decreasing value of V. Hence beyond I_b, device current increases and device voltage decreases.

This finally results in a condition of zero voltage drop across the center junction, at which point it acts as an emitter as well as a collector. The device is then 'closed', the base layers are flooded with charge, and the device has low impedance. (In region II, proper design will permit the control of certain features of the negative-resistance characteristic, such as a widened flat portion or a modified slope and width of the transition region on the current axis.) At this point on the curve, the voltage drop is about 1 volt plus the voltage drop associated with the ohmic contacts. The 'closed' resistance is defined as the slope R_h of the characteristic in region III.

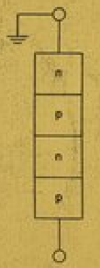
R_h is approximately constant for pulse currents in the neighborhood of 2 - 3 amps and equal to the ohmic contact resistance of one ohm or less. This characteristic permits high-power applications; i.e., switching 6 watts or, with proper heat sinking, 12 watts, at a power efficiency of nearly 100 per cent.

Switching Times

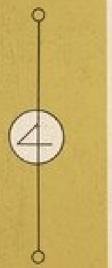
In many applications, it is desirable to calculate and predict switching times under a variety of boundary conditions. In one of these, the voltage is slowly increased to slightly higher than the switching voltage. A resistance in series with the voltage source makes intersections with the characteristic as shown in Fig. 3. When the upper load line is reached an exponential build-up with a time constant of the order of 0.1 μsec occurs until I increases from I_1 to I_2.

In another case, the voltage across the device is held constant as the switching proceeds, as in Fig. 4. The capacitor charges up to V_b. The device now switches 'closed' with essentially constant voltage across it to a current limited by its resistance and with initial time constants of the order of 30 or 40 millimicroseconds. By using only a portion of the current buildup, circuits can be made to generate rapidly rising pulses.

Consideration of the breakdown voltage point as a rigid threshold value should be modified somewhat with respect to the rate of the voltage rise. The capacitance of junction 2 permits passage of a displacement current proportional to the rate of change of the voltage across the device. Appearing at the two emitter junctions, this current, when large enough, acts to reduce the breakdown-voltage level. This effect, with rising drive frequency, approaches a limit as the device becomes a pure bilateral capacitor.



Schematic diagram of the four-layer transistor diode construction. Produced from single-crystal silicon, the four layers in the silicon unit are obtained by controlled diffusion of suitable impurities. Thickness is approximately 0.002 in.



Schematic symbol for the four-layer bistable transistor diode is a modified 4, identifying the diode type. At the same time, the slant line of the 4 indicates the forward direction of the device when in 'on' condition.

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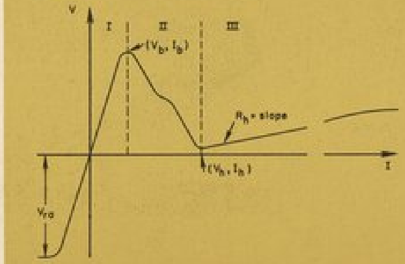

Fig. 1. Voltage-current characteristic for the four-layer diode shows the three essential operating regions: I 'open', II transition or negative resistance, and III 'closed'. Voltage and current conventions are shown in Fig. 2a (For illustration purposes, the current is not shown to scale.)

2a
2b

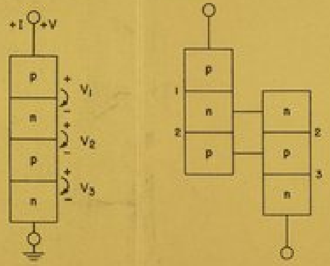

Fig. 2. One way of viewing four-layer diode operation is to regard the device as though it were two interconnected silicon-junction transistors, as shown here. This is related particularly to the characteristic curve in the transition region between the 'open' and 'closed' conditions.

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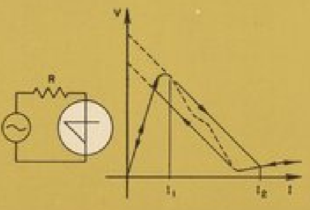

Fig. 3. Switching transient of the four-layer diode when a voltage is slowly increased to slightly greater than breakdown and held there. The arrows indicate the "hysteresis loop" traced by applying a-c voltage. (The current is not shown to scale.)

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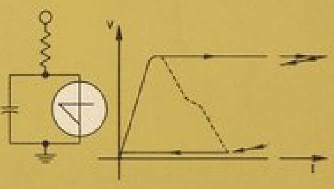

Fig. 4. Switching transient of the four-layer diode when voltage across the device is held constant as switching proceeds. The arrows show the path followed in discharging the capacitor. (The current is not shown to scale.)

SHOCKLEY 4-LAYER TRANSISTOR DIODE

CHARACTERISTICS & TESTS

For application convenience, the following parameters of the four-layer diode are available within the ranges listed below:

No.	V_b Volts	I_b μa	V_h Volts	I_h ma	R_h ohms
4N20D	20±5	<500	<2	<50	<10
4N30D	30±5	<500	<2	<50	<10
4N40D	40±5	<500	<2	<50	<10
4N50D	50±5	<500	<2	<50	<10
4N20-50DL	As above, and <4v drop for 3-amp pulse				

For applications requiring more specific limits, please request information.

Since the values I_b and I_h are, to some extent, dependent on the test circuit used, two suggested circuits are shown. See Figs. 5 and 6 (below).

Referring to Fig. 5, the 100 k limiting resistor (R_3) is used to measure the value of I_b, which is arbitrarily defined as the point where the trace disappears on the scope display (see Fig. 7a). The values of V_b, V_h, I_h, and R_h are measured with the 1 k resistor (R_1) as the limiting resistor, in which case the V-I plot appears as in Fig. 7b.

In this circuit, the diode switch S_3 in the 'In' position prevents the reverse avalanche current from heating the device and thus changing the values of the parameters being measured.

Holding current I_h and holding voltage V_h are read at the point on the plot where the trace disappears. This is marked B on Fig. 7b. For low current values, the 'closed' resistance is the slope of the line R_h.

This V-I plotter does not display the shape of the negative-resistance part of the four-layer diode characteristic, but the circuit shown in Fig. 6 will display the entire curve, as shown in Fig. 7c.

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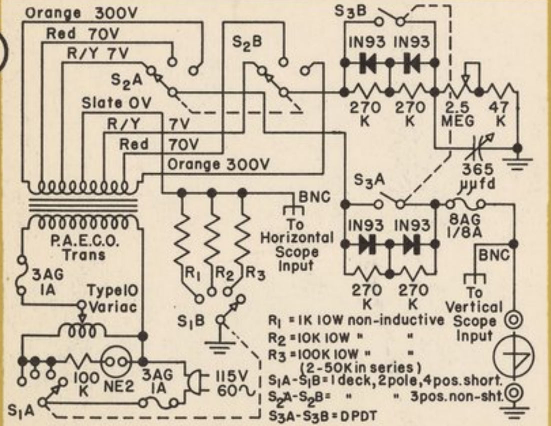

Fig. 5. Circuit of the V-I plotter used to measure four-layer-diode parameters.

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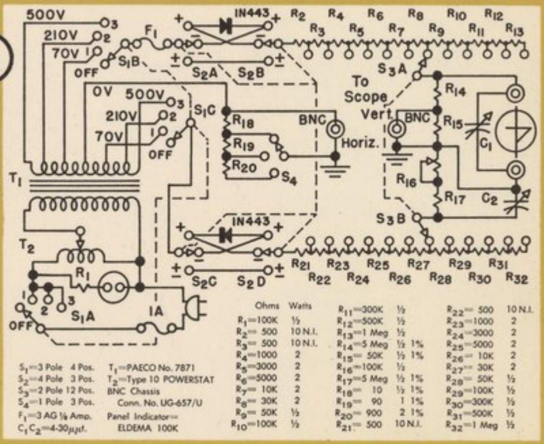

Fig. 6. Circuit of high-impedance curve tracer used to display the entire characteristic curve of the four-layer diode.

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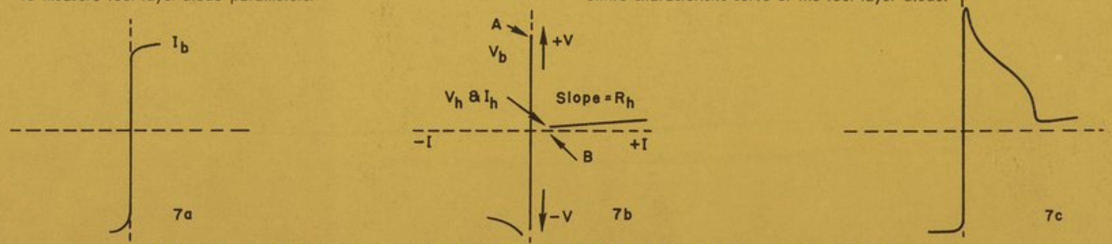

Fig. 7a. The V-I plot of the four-layer diode in the test circuit of Fig. 5 with a limiting resistor of 100 k ohms; 7b, same as (a) but with 1 k ohm limiting resistor; 7c, V-I plot of the four-layer diode in the test circuit of Fig. 6.

Data Sheets

Separate engineering sheets are produced and regularly kept up to date on numerical values and limits of four-layer-diode parameters including information on temperature effects.

Similarly, information sheets on circuit application and design are made available.

For additional copies of any of this material, write to the address shown.

Shockley / **Transistor Corporation**
Stanford Industrial Park
Palo Alto, California

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