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TEST ON RADIATION DAMAGE TO PIN DIODES

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INTRODUCTION

Radiation damage to UNITRODE UM 4010-CR PIN diodes has been studied to find out whether a high power switch for the AC bunch rotator could be placed within the ring shielding. Units have been measured before and after exposure and results compared.

Irradiation has been carried out at CERN (AA and SPS) with doses up to 300 krad.

CHARACTERISTIC VARIATION STUDIED

For the PIN diode application considered, the most important characteristics are:

- the forward bias resistance
- the reverse voltage ratings.

The charge recombination time (τ_L) - also known as carrier lifetime - is the internal parameter that influences the forward bias resistance (see Appendix).

Carrier lifetime and the V-I reverse characteristics have been studied.

CARRIER LIFETIME (τ_L) MEASUREMENT

The measurement is carried out by storing a known amount of charge in the intrinsic region and measuring the time required to extract it using a known reverse bias current (1). The diode (DUT) is mounted in a 50 Ω system and biased by a 10 mA forward current. A pulse generator then supplies a pulse that inverts the current flow.

The current peak at the beginning of the charge extraction cycle is set to be -6 mA. Recombination takes place and the effect is seen as a reverse current reduction. τ_L is assumed to be the time between the current inversion and the instant when it reduces to 10% of the initial value as shown in Fig. 1.

Figure 2 shows the pulse applied and Fig. 3 describes the test set used.

REVERSE V-I CHARACTERISTIC MEASUREMENT

The test is done by measuring the reverse V-I characteristic until the voltage at which a -10 μA current flow is reached. The test set is shown in Fig. 4.

SAMPLE EXPOSURE

Three groups of three diodes were irradiated in a first test at different radiation levels. Group 1 was reexposed later on to reach a missing intermediate dose. Table 1 gives doses received by each group.

TABLE 1

Group	Diode	Received dose (rad)
1	1 2 3	$3 \cdot 10^2$
1	1 2 3	$5.3 \cdot 10^3$
2	4 5 6	$1.4 \cdot 10^4$
3	7 8 9	$2.9 \cdot 10^5$

MEASUREMENT RESULTS

Table 2 gives the results of carrier lifetime measurement before (τ_{L_0}) and after (τ_L) exposure.

The parameter

$$\left\langle \frac{\tau_L - \tau_{L_0}}{\tau_{L_0}} \right\rangle$$

is the relative variation averaged over the group samples.

TABLE 2

Diode	Dose (rad)	τ_{L_0} (μs)	τ_L (μs)	$\frac{\tau_L - \tau_{L_0}}{\tau_{L_0}}$ (%)	$\left\langle \frac{\tau_L - \tau_{L_0}}{\tau_{L_0}} \right\rangle$ (%)
1 2 3	$3 \; 10^2$	21.5 20.6 20.4	18.0 17.4 17.2	- 16.3 - 15.5 - 15.7	- 15.8
1 2 3	$5.3 \; 10^3$	21.5 20.6 20.4	8.5 8.3 9.5	- 60.5 - 59.7 - 53.4	- 57.9
4 5 6	$1.4 \; 10^4$	13.3 22.2 15.3	2.0 1.8 1.8	- 85.0 - 92.0 - 88.0	- 86.3
7 8 9	$2.9 \; 10^5$	14.9 16.6 22.1	.7 .6 .6	- 95.0 - 96.0 - 97.0	- 96.0

In the diagram shown on Fig. 5,

$$\left\langle \frac{\tau_L - \tau_{L_0}}{\tau_{L_0}} \right\rangle \quad \text{vs. received dose has been plotted.}$$

Measurement of V-I reverse characteristic did not show any variation even for the highest doses.

CONCLUSIONS

Carrier lifetime characteristic of these PIN diodes is very sensitive to radiations; it reduces to 50 % of the original value after exposure to doses in the order of krad.

Since inside the AC ring shielding, at the bunch rotator location, 1.2 m off the beam axis, estimated radiation is about 5 rad/h, the diode life will be reduced to an excessively short period.

Therefore, the high power PIN switch must be located outside the radiation shielding.

REFERENCES

1. Ma-Com Pin Diodes Designers' Guide, catalog N. 4013 8/83, p. 51-52.

2. Pin Diode Designers' Handbook, PD 500-B, Unitrode Corp., p. 75-83.

3. G. Hochschild, Phasensynchronisierung supraleitender Beschleunigungsresonatoren, Institut für experimentelle Kernphysik, Karlsruhe, 1975, p. 26-27.

APPENDIX

In a forward biased PIN diode, the RF resistance "R" depends on the charge "Q" stored in the intrinsic region.

For a given forward current "I_f", the stored charge "Q" is

$$Q = \tau_L \cdot I_f$$

and the resistance "R" is (2)

$$R = \frac{W}{(\mu_p + \mu_n) \quad Q}$$

where

μ_p = hole mobility

μ_n = electron mobility

W = intrinsic region width.

If a sinusoidal current $i = I_0 \sin \omega t$ is added to the bias current, the stored charge becomes a function of time. The charge related to the sinusoidal current of period "T"

$$T = \frac{2 \pi}{\omega} = \frac{1}{f}$$

is

$$q_0 = \int_{\frac{T}{2}}^{T} I_0 \sin \omega t \, dt = - \frac{2 I_0}{\omega}$$

over half a period. Between 0 and $\frac{T}{2}$, q_0 is positive and between $\frac{T}{2}$ and T, q_0 is negative.

The stored charge varies between two limits

$$q_{min} = Q - |q_0|$$

$$q_{max} = Q + |q_0|$$

and the resistance "R" varies with it. To avoid driving the diode into a reverse bias condition, we must have

$$M = \left|\frac{Q}{q_0}\right| > 1$$

and to keep the resistance "R" nearly constant

$$M >> 1$$

A suggested value for "M" is (3)

$$M_{min} = 30$$

then

$$\left|\frac{Q}{q_0}\right| > M_{min}$$

$$\frac{\frac{\tau_L I_f}{2 I_0}}{\omega} > M_{min}$$

$$\frac{I_f}{I_0} > \frac{M_{min}}{\pi f \tau_L}$$

The last equation shows that a certain ratio between the bias current I_f and the sinusoidal current I_0 must be ensured and that the internal parameter of the diode which affects it is the carrier lifetime.

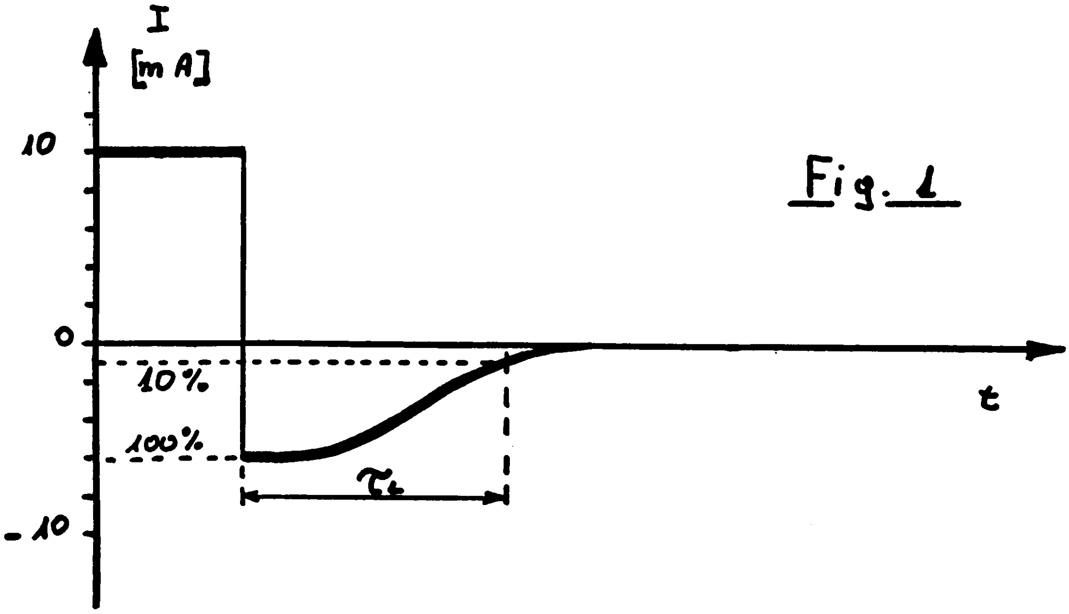

Fig. 1

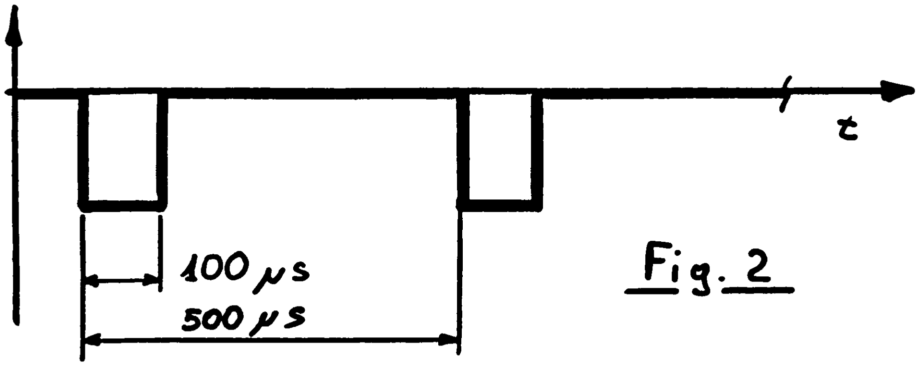

Fig. 2

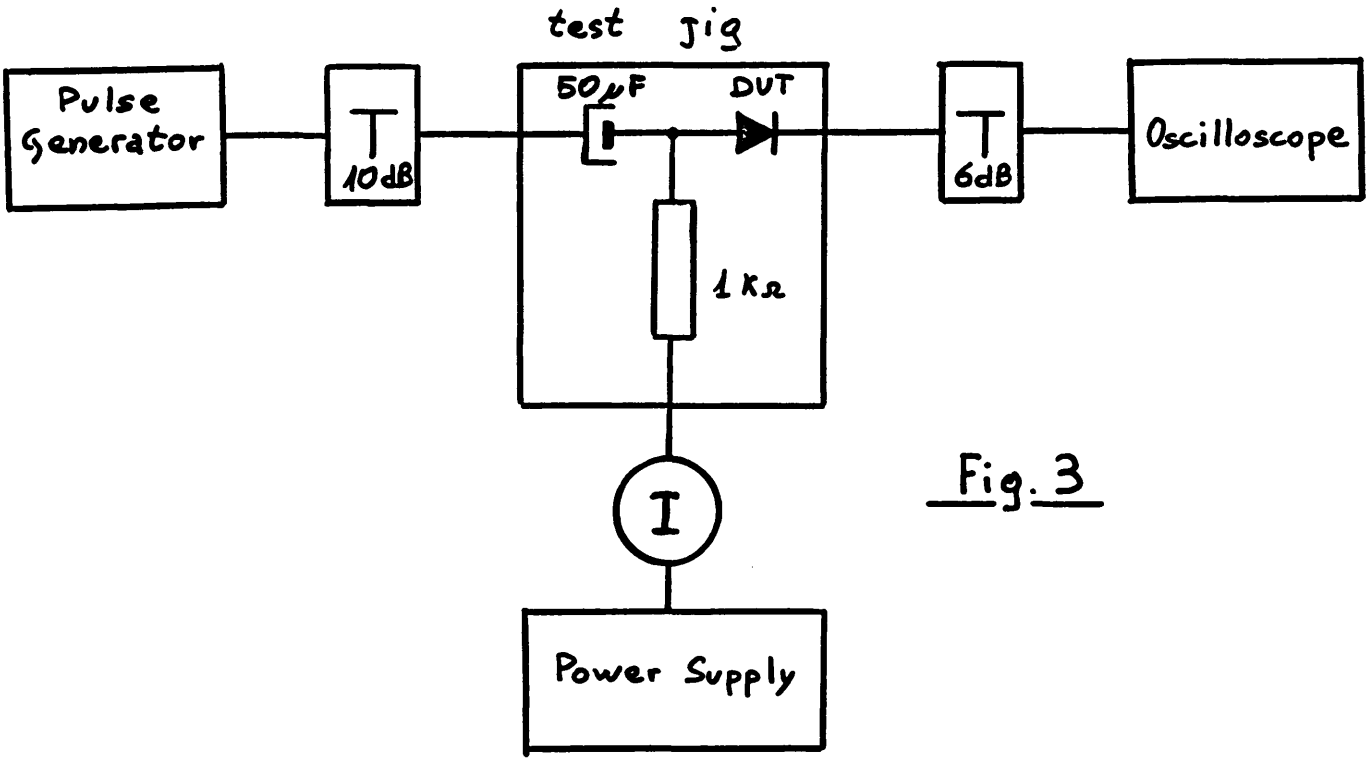
test jig
Pulse Generator
10dB
50µF
DUT
1KΩ
6dB
Oscilloscope
I
Power Supply

Fig. 3

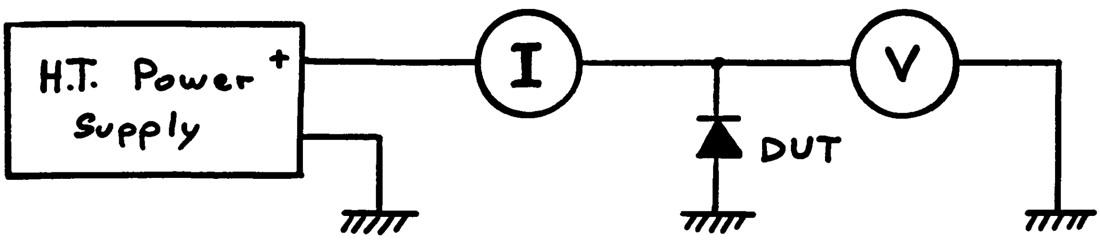
H.T. Power Supply
+
I
DUT
V

Fig. 4

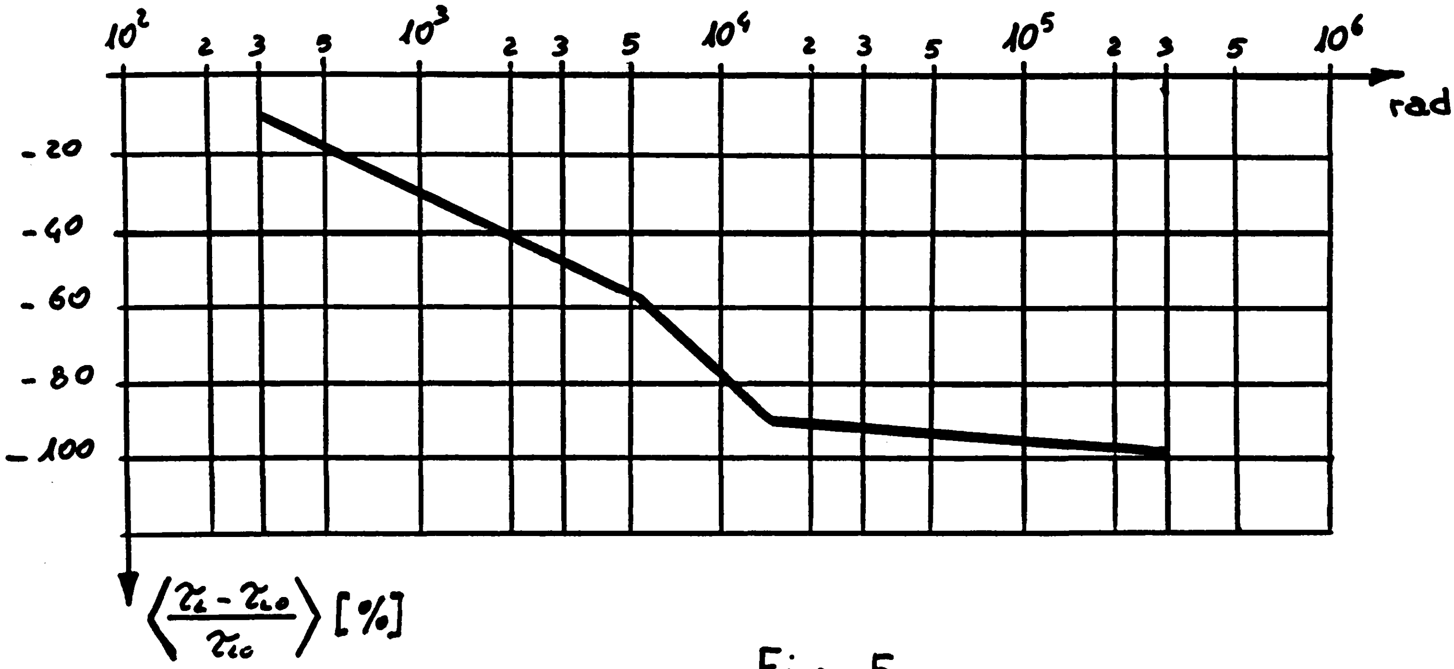

Fig. 5