Using of GaAs Diode as Gamma Rays Sensor for Dose Rate Measurements

M. Ashry
National Center for Radiation Research and Technology (NCRRT), AEA,
P.O. 29 Nasr City Egypt, Fax.: +202 – 2749298
E mails: M_Ashry@hotmail.com

ABSTRACT
The effect of Gamma-irradiation on the electrical characteristics of GaAs diodes have been investigated using current-voltage (I-V) in the forward and reverse bias as a transient and permanent effects. The samples GaAs diodes were applied till 50 V in the reverse bias. The measured current was 1 nA before irradiation and was about 21 uA steady state photocurrent and 0.0065 Gy/sec dose rate after 2.8 sec which is the arrival time of Cesium-137 source to the samples. The C-V has been measured against the reverse bias and the measured values were from 0.18 nF to 41 pF at the range from 0 t0 50 volts respectively. I selected the GaAs diodes according the condition of previous results [1] (the diffusion length (L) is larger than the base width (W)) which gives the highest degree of sensitivity for the steady state photocurrent by pre-irradiation and the width of depletion layer . these reasons I chose the GaAs diode as a sensor for low dose rate. Very small permanent effects of γ -irradiation until about 25 M Gy.

Keyword: transient, permanent effect of γ-irradiation , electrical properties ,I-V and C-V Circuit .

1- Introduction

Thirty years ago, in May of 1959, JackLowen and I gave a talk at the Electrochemical Society meeting, reporting the first gallium-arsenide diffused diodes ever fabricated [1]. Measurements of the diode's switching time clearly showed the usefulness of p-n junction GaAs diodes for high-speed semiconductor components. Prior diodes in GaAs had been point contacts [3,4] The rectification ratios for the diffused diodes were orders of magnitude larger than those for point-contact diodes or for an alloy junction diode described in another presentation at the same meeting [4].Thus we at Lincoln Laboratory were at the forefront in taking GaAs forward from the point-contact age. It all started With my decision, supported by management, that my small semiconductor device group could make a larger contribution to semiconductor-device development if we did not follow the mainstream of research, which was switching from germanium to silicon. We decided, instead, to study gallium arsenide, which promised higher speed because of its higher mobility, and lower leakage currents because of its higher bandgap. In 1958, I visited Professor Welker at Siemens, Erlangen, West Germany, who was the expiration GaAs, and he affirmed our view on the future applicability of this semiconductor. Meter obtaining our first GaAs material from RCA Laboratories With the help of the Wright Air Development Center, we developed a technique to make p-n junction diodes by diffusing zinc into n-type wafers 1 .always remember my surprise at seeing the metallic droplets that miraculously appeared after our first diffusion in a vacuum ampoule. Of course, be cause we had not used an arsenic atmosphere, the arsenic had evaporated, and the droplets were gallium. We solved this problem by including crushed GaAs, which produced an arsenic atmosphere in the ampoule. Figure 1,

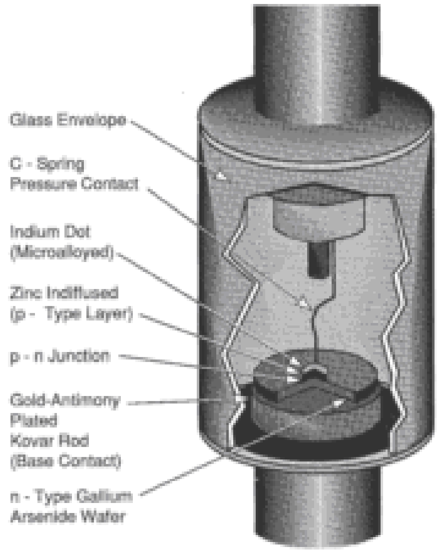

Fig. 1- Artist's representation of a packaged diode

which is an artist 'representation of a packaged diode, includes various details of the fabrication process. The indium dot, which was micro alloyed into the p-type skin, served as a mask for the etch that defined the p-n junction area, and then as a contactor the p-type region. The package was one that was Widely used for point-contact diodes of that era. In our diode, the contact was an ohmic one to the soft top of the indium dot. The reverse-recovery transient, which limited the speed of the diodes of the time, is plotted in Fig. 2.

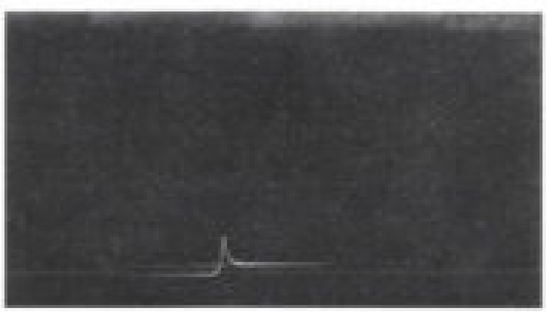

Fig.2-Traveling-wave-oscilloscope image of there verse recovery transient. Also shown is the zero diode-current line, on which two markers 6 ns apart have been superimposed

To obtain the data that showed the 3-ns diode switching time was another challenge [1], and I spent more than two days synchronizing the sweep of a state-of-the-art traveling-wave oscilloscope. Further results[5]were reported in the fall of 1959 and the written publication appeared the following year [6]. In the fall of 1960, we published data on diodes With reverse-leakage current sat room temperature of about 10-12 A, using GaAs that was now being grown for us by Alan Strauss's group at Lincoln [7]. These results showed that the high-speed GaAs diffused diodes could replace vacuum diodes in applications requiring extremely low leakage. Jack Lowen and then John Halpern collaborated in the early work ; bymid-1960, Ted Quist replaced the min the GaAs program. We then decided also to investigate GaAs alloy diodes. The electrical properties of these diodes differed from those of the diffused diodes. and I suggested to Quist that. as a diagnostic. we look at the recombination radiation of both types of diodes, Quist enlisted Bob Keyes. who had a prism spectrometer, to measure the luminescence. When the forward-bias luminescence from the diffused diode was measured. the output from the detector pinned the recorder. Keyes had to increase the full-scale reading of the recorder by at least three orders of magnitude and close the spectrometer slits to near zero to bring the reading back on scale. The high-efficiency production of forward-bias luminescence from diffused diodes was reported in July of 1962 [8]. Once we discovered the high-efficiency light emission, we realized that a laser might be possible. We turned our attention to the development of the GaAs diode laser and also to a demonstration of the communications potential of high-efficiency luminescence [9]. After hearing our paper [8], a group at General Electric also decided to start an effort to develop the diode laser [10], and the interest of a group at IBM in developing such a laser increased dramatically [10]. These two groups and ours reported diode lasers in November-December 1962 [11]. The diffused GaAs diode had payoffs that we never anticipated.

1.1 GaAs advantages[13]

Some electronic properties of gallium arsenide are superior to those of silicon. It has a higher saturated electron velocity and higher electron mobility, allowing gallium arsenide transistors to function at frequencies in excess of 250 GHz. Unlike silicon junctions, GaAs devices are relatively insensitive to heat owing to their wider bandgap. Also, GaAs devices tend to have less noise than silicon devices, especially at high frequencies. This is a result of higher carrier mobilities and lower resistive device parasitic. These properties recommend GaAs circuitry in mobile phones, satellite communications, microwave point-to-point links and higher frequency radar systems. Another advantage of GaAs is that it has a direct band gap, which means that it can be used to emit light efficiently. Silicon has an indirect bandgap . As a wide direct band gap material with resulting resistance to radiation damage, GaAs is an excellent material for space electronics and optical windows in high power applications. Because of its wide bandgap, pure GaAs is highly resistive. Combined with the high dielectric constant, this property makes GaAs a very good electrical substrate and unlike Si provides natural isolation between devices and circuits.

1.2 RADIATION EFFECT[12]

There are two effects on semiconductor devices: the transient effect which was used to measure the dose rate and the displacement effect, which causes damage. The initially produced defects from gamma irradiation is quite simple and can be expressed as a single displaced lattice atom and its associated vacancy (Frenkel defects) [13]. The Frenkel defects are related with the degradation in the minority carrier lifetime that is usually expressed as:

$$\mathbf{d\,(1/T)\,/\,d\phi = K_t} \qquad \mathbf{(1)}$$

where

K_t = lifetime damage constant

ϕ = radiation fluence

Some literatures discuss the diffusion length damage as

$$\mathbf{(1/L_t^2) = (1/L_o^2) + K_L\,\phi} \qquad \mathbf{(2)}$$

Where

L_t = diffusion length after irradiation

L_o = diffusion length before irradiation

K_L = diffusion length damage constant

The radiation effect on the GaAs diode performances is mainly due to the change in the minority carriers lifetime or diffusion length in the base region which obeys the relations mentioned in equations (1),(2)

2. EXPERIMENTAL PROCEDURE

Measurements during irradiation were executed inside the chamber of the cell (Cesium-137 gamma cell-40 ^{60}Co gamma Cell 220). The general arrangement used to map the dose rate values in the sample chamber (diameter about 15 x 20 cm) of the gamma cell is demonstrated in fig.(1-a). the source elements are in a fixed cylindrical position surrounding the sample chamber. The chamber automatically moves up and out the source area at the end of the exposure time. The result were measured using two methods. The circuit used in the first method is shown in fig(1-b) where the GaAs diode was TGA2304-SCC . A reverse bias voltage up to 50 volts was applied to the diode according to the most sensitivity of a reverse current. In the second method, five diodes were fixed holder and measured by a C-570 curve tracer which was used. C-V measured by two techniques CV-Plotter type 410 and CV-Plotter type Hp 4280A .

3. RESULTS and DISCUSSION

Fig.(2) shows the relation between the reverse voltage and capacitance, hence it can deduce the impurity concentration of the base

$N_A = 3.4 \times 10^{15}\ cm^{-3}$

by absorbed dose it is possible changing the rate of doping (see the table (1)) because of changing the value of capacitance due to creation electron- hole pair in the depletion layer which change the dielectric constant. Little bit change by means gamma rays but by electron or neutron particles cause big change . for this reason, the fast neutrons uses in fabrication of semiconductor doping.

Fig. (3) shows the I-V characteristics of GaAs diode in the forward bias Before and after gamma irradiation. There is very small effect in . The forward due to resistance of GaAs material to radiation[12,13].

Fig.(4) shows the I-V characteristics of GaAs diode in the reverse bias. Before and during gamma irradiation. The ionization in the depletion layer due to the irradiation causes increasing in the photocurrent. The dose rate is directly proportional with photocurrent. By distributing the diodes inside the chamber (Fig. 1b) can measure the dose rate in each diode position according to the value of photocurrent.

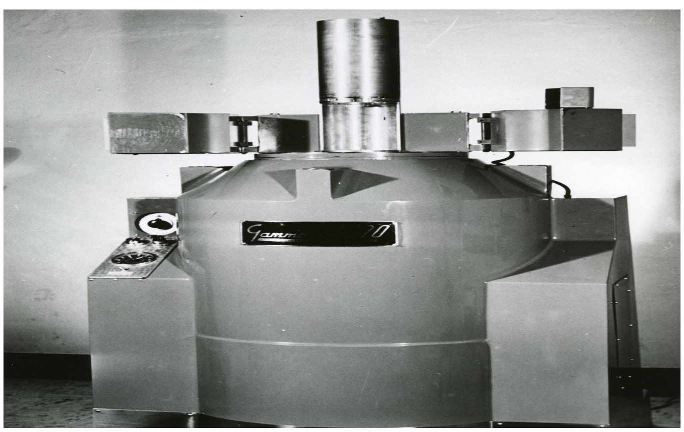

Fig.(1a) Gamma cell-220 chamber

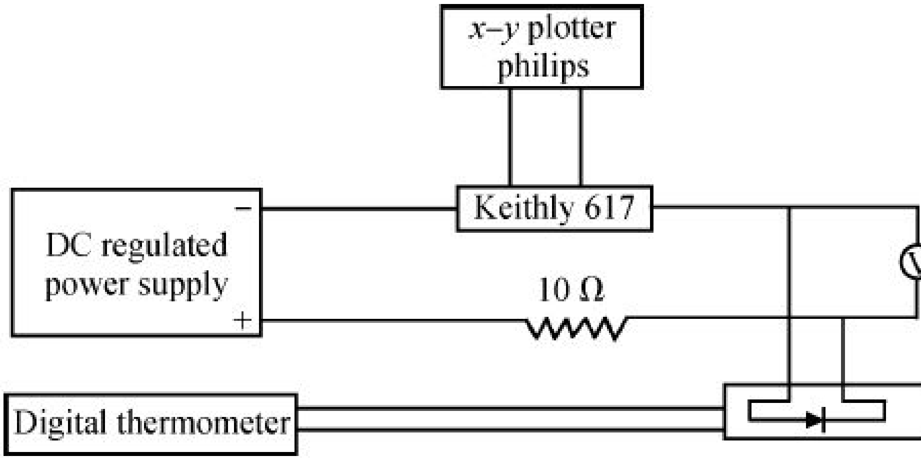

Fig.(1b) Circuit diagram for I-V measurements (during, before and after irradiation).

Fig.(5) shows the relation between the photocurrent and dose rate for different sources of gamma rays which is linear. This result gives us chance to determine the dose rate of any source of gamma rays. Also measuring the dose rate at any position. This paper consider important step to measure the distribution doses .

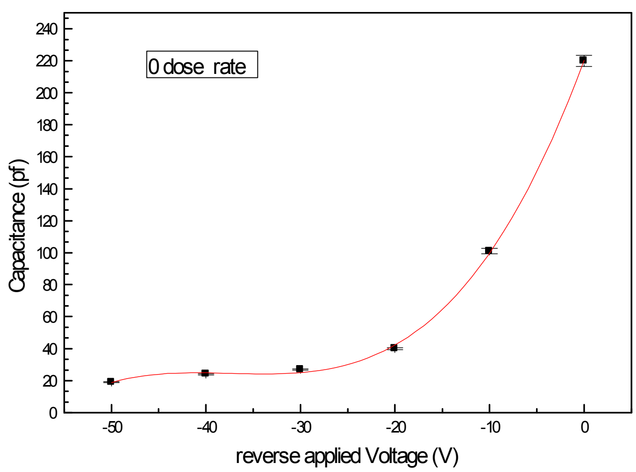

Fig.(2) Relation between th reverse applied voltage and capacitance of TGA2304-SCC GaAs diode at room temperature

0 Gy	10 MGy	33 MGy
3.4×10^{15}	3.1×10^{15}	1.6×10^{15}

Table (1) shows the changing of doping by high dose absorbed Gamma irradiation

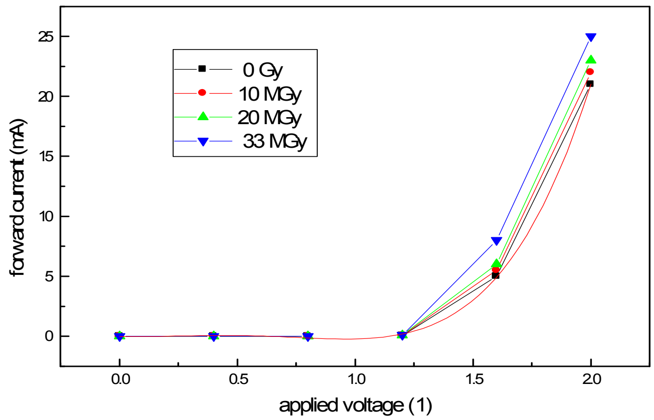

Fig. (3) I-V characteristics of GaAs diode in the forward bias before and after gamma irradiation

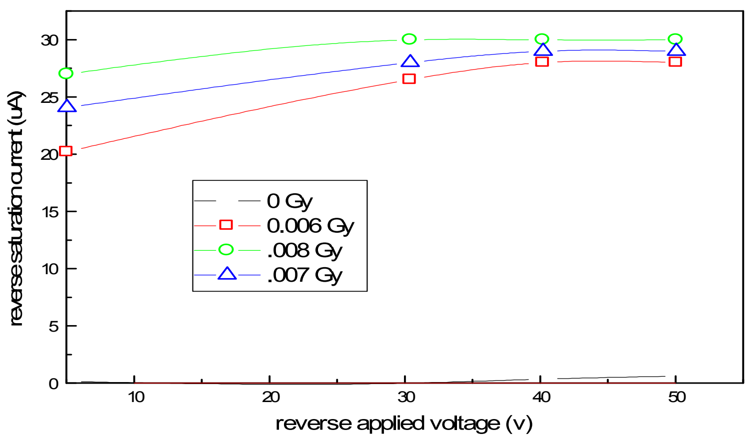

Fig.(4) I-V characteristics of GaAs diode in the reverse bias before and during irradiation with different doses rate

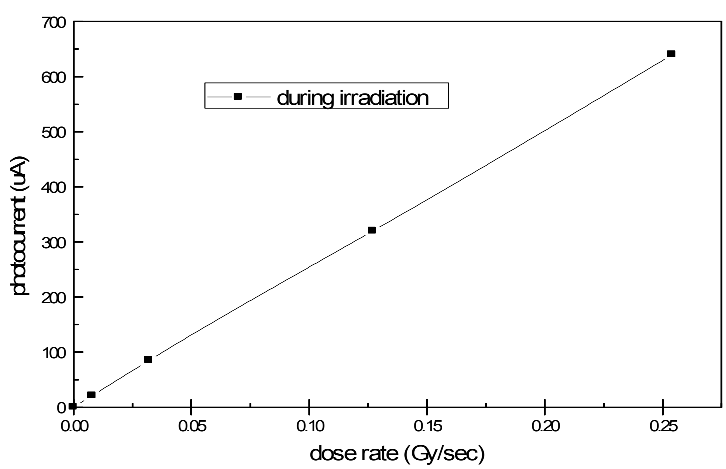

Fig.(5) photocurrent of GaAs diode as a function of gamma dose rate Different sources at 0 voltage

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