RADIATION DAMAGES OF PHOTODEVICE AND ITS SUBSTRATE MATERIAL

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ABSTRACT

γ-radiation damage study of photodevice and its substrate shows that γ-radiation makes the light current, current amplification factor and respond time of devices decreased, dark current increased, but junction capacitance unchanged basicly. The resistivity of substrate was slowly increased. The analysis of positron annihilation lifetime spectra demonstrated that the second lifetime component τ_2 was reduced, but the corresponding intensity I_2 raised. Those indicate the macroscopic and microscopic changes in substrate after γ-irradiation.

Keywords: Irradiation Photodevice Positron annihilation

1 INTRODUCTION

Silicon photosensitive devices have been widely used in many fields of techniques because of their advantages of being small, light weight, easy to use and low cost. It is necessary to consider the influence of radiation when the devices are used in nuclear power engineering or other nuclear techniques and space techniques. The radiation damage of devices has been studied for many years, and results show that the damages are produced after especially neutron irradiation. However, people know not too much about γ-radiation damage to photosensitive devices, particularly about the damage to substrate materials. This paper gives some information about γ-radiation damages to photosensitive semiconductor devices and the substrate, including the macroscopic electrical parameters and microscopic structures.

2 EXPERIMENTAL

a. Three groups of photo-diodes (2CU79) and photo-transistors (3DU31), were irradiated by γ-rays from nuclear reactor, and Cd shielding was used to absorb therm-neutrons, the radiation doses were 10^4, 10^5 and 10^6 Gy(Si), respectively. The macroscopic electrical parameters, including light current, current amplification factor, respond time. dark current and junction capacitance, were measured before and after γ-irradiation, and also after 72 h of annealing at 180 °C.

b. The substrate materials of photodevices, which are low resistivity (~10Ω · cm)

N type Si, were irradiated by γ-rays from ^{60}Co. The resistivities of substrates and the positron annihilation lifetime spectra with different γ doses were measured before and after γ-irradiation.

3 RESULTS AND DISCUSSION

a. It is seen from Table 1,2 that after γ-irradiation the light current (I_p), current amplification factor (β) and respond time (t) of photo-devices decreased, but dark current (I_d) increased and junction capasitance (C) was uneffected. The higher γ-radiation doses were used, the more changes of parameters could be observed.

Table 1

Electrical parameter changes of 2CU79

Dose	I_p		I_d		C_p
Gy(Si)	1	2	1	2	1
0	1		1		1
10^4	0.870	0.960	1.23	1.10	0.98
10^5	0.675	0.787	1.37	1.24	0.99
10^6	0.563	0.607	3.06	2.58	1.02

Table 2

The electrical parameter changes of 3DU31

Dose	I_p		I_d		β		t	
Gy(Si)	1	2	1	2	1	2	1	2
0	1		1		1		1	
10^4	0.740	0.935	1.55	1.26	0.69	0.95	0.45	0.89
10^5	0.375	0.591	1.91	1.68	0.57	0.65	0.32	0.68
10^6	0.242	0.342	6.21	4.62	0.47	0.55	0.17	0.67

1: Before annealing 2: After 72 h of annealing at 180°C

After 72 h of annealing at 180 °C, the electric parameters of photodevices were not restored, it indicates that γ-radiation makes not only instant damage but also partially permenant damage.

b. The resistivities of substrates before and after γ-irradiation are presented in Table 3. The results show that the resistivity after γ-irradiation increased slowly with the increase of γ-dose.

Table 3

The resistivities ρ of substrate Ω · cm

Sample	0 Gy	10^3 Gy	10^4 Gy	10^5 Gy
1	14.5	14.3	16.3	19.0
2	13.2	14.1	16.2	18.4

The results of positron annihilation lifetime before and after γ-irradiation are listed in Table 4. The results show that the microscopic defects and charge states in substrate were changed after γ-irradiation, which can be seen from the changes of positron annihilation lifetime spectra. τ_2 decrease and I_2 increases, the changes depend on radiation dose.

The positron annihilation lifetime spectra were measured two times under the same condition. It is noticed that τ_2 and I_2 in the second spectrum are different from the first one, it seems that the damage was partially "restored", alikely "annealing" after the second time positron irradiation.

c. It is known that photo-ionization effect takes place easily, and electron, ion or hole will be produced in material after γ-irradiation. A photon from ^{60}Co ($E_\gamma = 1.17$

and 1.33 MeV) transfers its energy to a lattice via mainly photo–electron production or Compton scattering. Those "excess" electrons (photo–electron and Compton electron) will change the electrical properties of substrate[1]. Calculation indicates that the displacement effect may be created in material when the energy of γ rays is greater than 250 keV (for Si), Dugdale[2] first demonstrated that energetic photon (γ-rays of energy in the MeV range) are capable of displacing atoms in solid. Oen and Holmes[3] have made extensive calculations of atomic displacement cross–section for both the Compton process and the photo–electric process.

Both ionization and displacement effects will induce defects in material, the defects make excelent recombination centers, or scattering centers. Therefore, the irradiation will decrease the lifetime of excess electron–hole pairs or, more commonly, the lifetime of minority carriers and effect mobility as well as carrier concentration. Those make the electrical properties changed.

The increase of resistivity after γ-irradiation demonstrates that displacement effect and then "carrier removal" took place in material.

Table 4

The results of positron annihilation lifetime

Sample	Dose/Gy	τ_2/ps	I_2	X^2	Sample	Dose/Gy	τ_2/ps	I_2	X^2
	0	285±14	27.45±5.66	1.282		0	287±11	23.94±7.71	0.903
	10^3	261±11	39.59±6.99	1.068		10^3	242±11	40.19±7.36	1.227
1	10^4	231±5	60.16±5.51	1.289	2	10^4	238±5	61.58±5.01	1.183
	10^4*	255±9	44.41±6.65	1.272		10^4*	253±9	46.02±6.67	1.005
	10^5	227±5	65.71±4.89	1.401		10^5	233±6	65.16±5.57	1.331
	10^5*	256±10	45.21±7.27	1.216		10^5*	259±12	42.88±8.03	1.175

* The second measurement under the same condition

The positron annihilation technique is very useful for studying defects in semiconductors since the annihilation of trapped positrons are influenced by the charge of the defects[4] and the electrons in the valence band[5]. The results of positron annihilation show that the microscopic structure of substrate is changed after γ-irradiation. This problem will be discussed in more detail in a saparate paper.

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