Expected leakage current for the ATLAS Upgrade Si detectors

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Abstract

From measurements of the leakage currents in neutron irradiated Silicon detectors, we derive the expected leakage currents at proposed operating voltages for the ATLAS Upgrade. The expected heat flux at -40 °C and the expected strip leakage currents at several operating temperatures are calculated.

1. Basic Equations

The leakage current I generated during irradiation:

$$\frac{I}{Volume} = \alpha \cdot \Phi \qquad (1)$$

where $\alpha = 4 \cdot 10^{-17}$ A/cm for 1MeV neutrons (measured at 20°C after canonical annealing) [1]. A decrease in leakage current by lowering the temperature is required to permit higher operating voltage, decrease the noise and avoid self-heating effects. The current depends on the absolute temperature T:

$$I(T) \ \alpha \ \ T^2 \exp(-\frac{E}{2kT}) \quad . \qquad (2)$$

The leakage current mainly originates by the presence of generation-recombination deep levels close to mid-gap. Experimentally we find that the activation energy E/2 is close to 0.6 eV for irradiated detectors [2].

2. Measurements

We used 4 SMART detectors [3] irradiated with neutrons at Louvain to a 1 MeV neutron equivalent fluence of $4*10^{14}$ neq/cm^2. The fluence is known to 10%. The active area of the detectors is 1.44 cm^2. The thickness' of the detectors are 300 μm and 200 μm respectively, and we scale the currents to 300 μm. Current - voltage (i-V) scans were performed at three temperatures: room temperature, -10 °C and -20 °C. Low temperature is obtained by spilling liquid nitrogen into the bottom of a thermally insulated box containing the sample holder. The temperature is sensed with a Pt resistor (Pt100) to a fraction of 1°C. The room temperature measurements show a certain amount of self heating. Using the data at -10 °C and -20 °C, we find for E in equation (2) values from 1.17 – 1.22 eV, with 1.19 eV as the average, in agreement with Ref. [2].

3. Determination of a(T)

The leakage currents are determined at a temperature of -20 °C and a bias voltage of 500 V. The average is 10.7 ± 1.5 μA. To account for the canonical annealing, we correct this value by 13% down. There is no systematic difference between the 200 μm FZ and 300 μm MCz detectors. In Table I we show the value for the damage constant α at room temperature (‘RD50”), To = +20 °C, and an effective α from our measurement at -20 °C, α(-20 °C), and how they can be extrapolation to different temperatures T. The effective α(T) is calculated for different temperatures using two different values for E in eq. (2): the value E = 1.2 eV of this experiment and Ref.[2], and the band gap energy E = 1.12 eV, respectively. The numbers in bold should be the same, and we see a worse agreement when using the band gap energy in eq. (2). The experimental values might be lower than the extrapolated ones due to partial depletion of the detectors at 500V, but on the other hand we do not observe that the thinner FZ detectors have a different current, as mentioned above.

Table I: Effective Damage constants $\alpha(T)^*$ for different temperatures

	To [^{o}C]	α(To)	E = 1.2 eV		E = 1.12 eV	
			α(-20C)	α(-40C)	α(-20C)	α(-40C)
RD50	20	4.0E-17	**7.0E-19**	5.6E-20	**8.9E-19**	8.4E-20
Measured	-20	**5.4E-19**		4.3E-20		5.0E-20

$*$ α(T) has units of A/cm.

From Table I, we have an effective damage constant at -40 °C of $\alpha(-40\ ^\circ C) = 4.3*10^{-20}$ A/cm. For different operating temperatures, the heat flux can be calculated using eq. (2) with E = 1.2 eV.

4. Heat Flux for the ATLAS Upgrade

For thermal run-away calculations, we determine the heat flux = power/area at a temperature of -40 °C for short strips of 320 μm thickness after a neutron fluence of $1*10^{15}$ neq/cm^2. The expected heat flux is P/A(-40 °C) = 0.69 mW/cm^2, with a 20% uncertainty. Since this assumes the same depletion thickness as at the fluence of $4*10^{14}$ neq/cm^2, this is a conservative number.

5. Strip leakage currents for the ATLAS Upgrade

The leakage currents i(leak) in 320 μm thick detectors are shown for four temperatures in Table II for both short strips (2.4 cm length, 76 μm pitch, fluence = $1*10^{15}$ neq/cm^2) and long strips (9.6 cm length, 76 μm pitch, fluence = $5*10^{14}$ neq/cm^2). Since this assumes the same depletion thickness as at the fluence of $4*10^{14}$ neq/cm^2, this is a conservative number.

Table II: Leakage currents per strip for different operating temperatures

			i[leak) [A] @ Temperaturre T			
	L [cm]	F [neq/cm^2]	-15 C	-20 C	-30 C	-40 C
Short strips	2.4	1.0E+15	5.6E-07	3.1E-07	9.3E-08	2.5E-08
Long strips	9.6	5.0E+14	1.1E-06	6.3E-07	1.9E-07	5.0E-08

6. Conclusions

We re-evaluated the leakage currents expected in the ATLAS Upgrade silicon detectors with direct i-V measurements of neutron irradiated SSD. The heat flux expected at -40 °C in the ATLAS Update silicon detectors operated at 500V is P/A(-40 °C) = 0.69 mW/cm^2, with a 20% uncertainty.

The expected leakage currents at -15 °C are 0.56 μA in the short strips ($1*10^{15}$ neq/cm^2) and 1.1 μA in the long strips ($5*10^{14}$ neq/cm^2), respectively. This agrees reasonably well with N. Unno's prediction of 0.71 uA and 1.4 uA for the same conditions.

7. References

[1] M. Bruzzi, IEEE Trans. Nucl. Sci., 48, 4 (2001).

[2] E. Barberis et al., Nucl. Inst. Meth. *A* 326 (1993) 373-380.

[3] M. Bruzzi et al., Nucl. Inst. Meth. A 552 (2005) 20-26.