Lithium Drifted Silicon Detectors for Harsh Radiation Environments

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Introduction

The drifting of lithium ions in silicon was first demonstrated in the 1950s and early 1960s by Pell [1] and others and the technique has been used to convert nominally p-type silicon to a high resistivity form by passivation of acceptors [2]. Li is unique in Si as it is an interstitial species which acts as a shallow donor: diffusion can be observed even at room temperature [1]. In p-type Si, Li atoms form neutral complexes with acceptors that are relatively stable due to the strong electrostatic potential between the constituent ions [2]. As a result, the material becomes high resistivity but high carrier mobility is maintained due this acceptor passivation. It is this behaviour of Li in p-type Si which implies that SiLi devices may be suitable for applications in any area where Si detectors are exposed to high levels of radiation fluence e.g. in space missions and particle physics experiments. It is well known that irradiation damage of Si particle detectors is typified by an increase in acceptor concentration [3], although other degradation modes are also important. Increases in acceptor concentration result in the bias voltage needing to be increased as damage is incurred to maintain the size of the active region. This eventually leads to breakdown of the device. It is believed that Li ions drifting through the p-type bulk will passivate the radiation-induced acceptor centres therefore lowering the full depletion voltage of the detector. In essence the SiLi device would be self-repairing.

Devices

Two Si(Li) devices were fabricated using Pell's drift method at the Unite de Development de la Technologie du Silicium in Algeria [5]. These devices exhibited excellent current-voltage (I-V), capacitance-voltage (C-V) and charge collection efficiency (CCE) properties after fabrication in 2003. Another three devices were kindly supplied by Dr. S Freeman of the University of Manchester. These were commercial and had been stored at room temperature for more than 10 years. When all these devices were characterised in early 2007 they showed significantly degraded DC electronic properties indicating that there was some out-diffusion of the lithium ions in the intervening years. Such degradation after storage at room temperature for extended periods is expected [4].

Results Pre-Drift

Fig. 1 shows original Capacitance against Voltage (C-V) data of a Si(Li) detector, BS01[5]. The near constant value of capacitance at applied bias greater than 20 V indicates nearly complete depletion at this voltage. I-V data under reverse bias reveals a leakage current of 2 μA which is practically independent of voltage up to 600 V. This data is typical of well fabricated SiLi devices . A pulse height spectrum from this device using a single source with the isotopes ^{233}U, ^{239}Pu and ^{241}Am at an applied bias of 300 V is shown in fig. 2 [5]. Good separation of the three alpha peaks is seen.

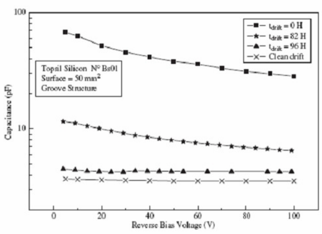


Figure 1

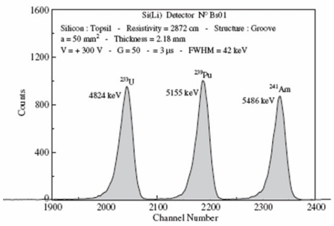
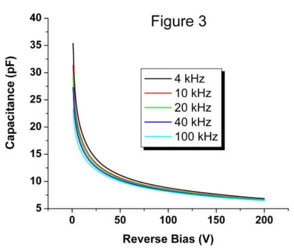
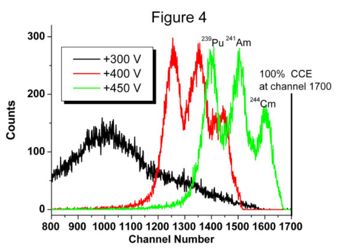


Figure 2

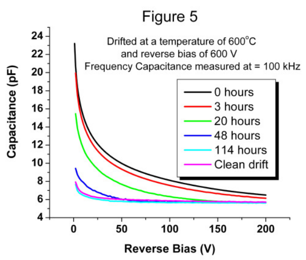
However, Fig. 3 shows similar data from the same device after storage for 4 years. Now the continuous curving of the C-V data up to an applied bias of 200 V shows that complete depletion does not occur until well beyond this value. Note that variable frequency C-V data has shown little evidence of deep level behaviour. Fig. 4 shows Charge Collection Efficiency data on irradiation of the rear contact of this device from a source containing ^{244}Cm, ^{241}Am and ^{239}Pu, before recovery was attempted. Only a single broad peak at lower channel number, demonstrating reduced charge collection efficiency, can be resolved at a reverse bias voltage of + 300V.

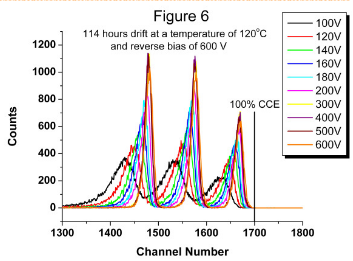




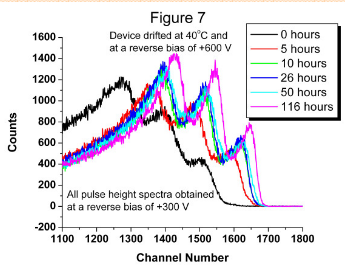
Results Post-Drift

We have applied heat treatments under reverse bias to this and other devices. Fig. 5 shows C-V data from sample BS01, measured at 100kHz, after different drift treatments at 120°C under a bias of 600 V. The reduction in the voltage required to produce full depletion is clear. After drifting, Fig 6. shows that the three alpha peaks can be clearly resolved even at a bias of just 100 V.





Similar beneficial effects were obtained by applying even lower temperature treatments to two other devices. For example, one device was drifted at 40°C at 600 V reverse bias and showed improvements in all characteristics after less than 10 hours treatment (see fig.7). Unfortunately, the remaining two detectors showing more advanced degradation could not be improved to this extent, probably because the thin gold metallisation applied to the rear face was damaged.



Future Work

The next step of this study is to irradiate SiLi devices with 24 GeV/c protons and 1 MeV neutrons to anticipated SLHC fluences and show that not only do the lithium ions passivate the radiation-induced acceptors but also that the lithium drift process occurs quickly enough to protect the detectors when used under room temperature operation.

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