Chris Parkes

First Investigation of Lithium Drifted Si Detectors for Harsh Radiation Environments

J. Grant, C. Buttar, M. Brozel

- Lithium Drifted Silicon Detector
- Old (4 years) unirradiated detectors
- Irradiated Detectors
- Conclusions

Lithium Drifted Silicon - Si(Li) – for radiation damage

- Si(Li) is a well established technology for radiation measurement in nuclear and solid state physics, medical physics and space missions
  - Li is used to passivate the acceptors
  - Much greater depletion depths (many mm)

- Charged particle radiation damage results in acceptor introduction
  - Can Li passivate radiation induced acceptor damage?
  - Can Li be introduced to passivate damage as it occurs?

- **“Self-Repairing” Detector ?**

Behaviour of Lithium in Silicon

- Lithium is a very shallow donor in Si (33 meV below E_C)
- It exists as interstitial Li^+ ions
- The Li+ ions are extremely mobile
  - even at room temperature
- Solubility of Lithium in pure Si is very low at room temperature ($\sim 10^{12}$ cm^{-3}).
- BUT Solubility increases if acceptors are present (Fermi level effect)
- Under these conditions the Li ions form nearest neighbour $[Li^+\text{-}A^-]^0$ pairs
- This results in acceptor passivation (not compensation) and also in a high carrier mobility

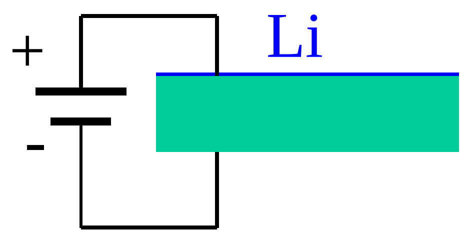
- Use FZ silicon (Oxygen, Li compound produced)

Passivation Mechanism

- Interstitial, positively charged Li ions are trapped by negatively charged acceptor ions as follows:
- $Li^{+} + (\text{Acceptor})^{-} \overset{1\text{ eV}}{\rightleftharpoons} [\,Li - \text{Acceptor}]^{0}$
- The neutral complex is relatively stable and acts only as a dipole scattering centre with short range field.

Lithium Drifting

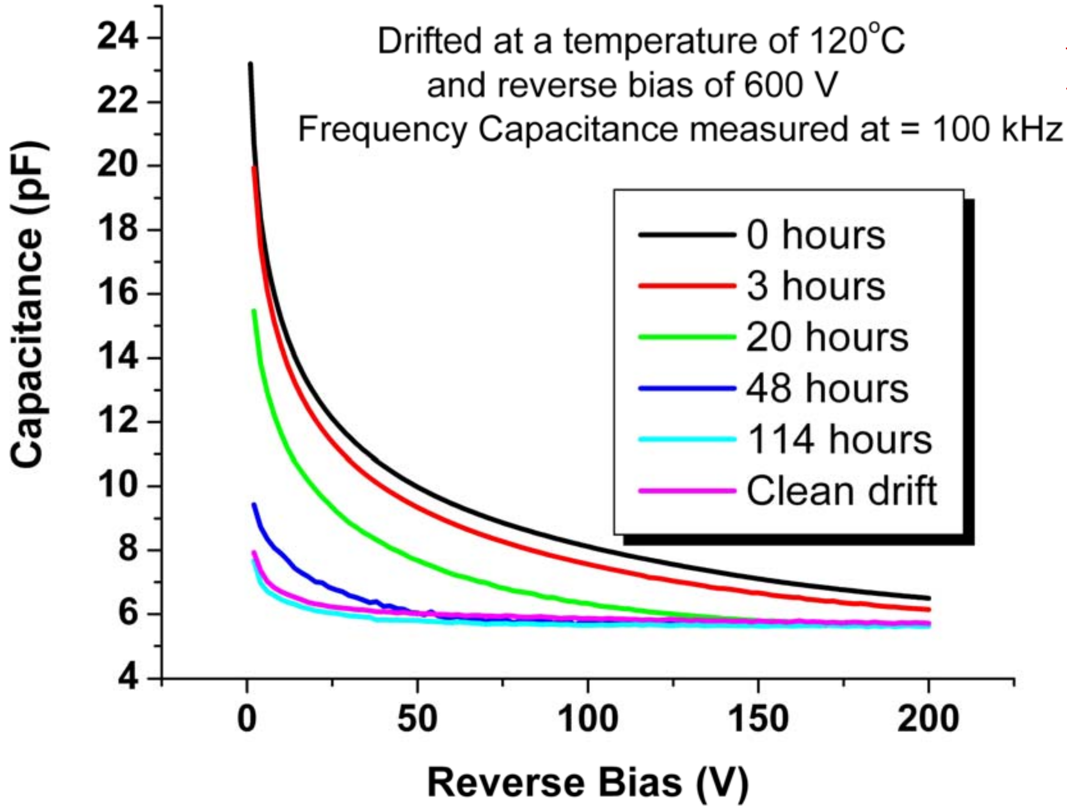
~500V



100^{o}C, hours → days

- Bias
- Temperature
- Time

C-V Recovery of Device after Drift



Four year old device obtained from collaborators

A. Keffousc, A. Cherietc, K. Bourenanec, A. Bourenanec, F. Kezzoulac and H. Menaric

Unité de Développment de la Technologie du Silicium, 02 Bd Frantz Fanon, B.P. 399 Alger-Gare, Algeria

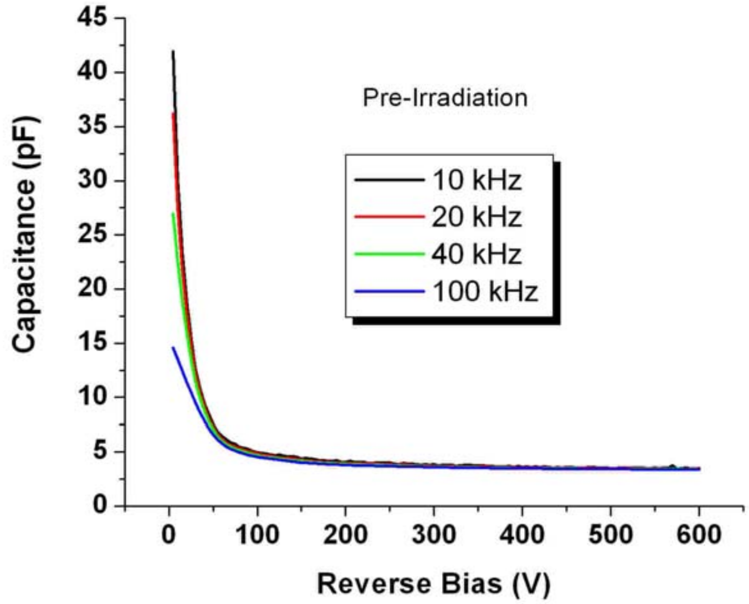
- Evolution of capacitance with drift time
- Recovery of device properties

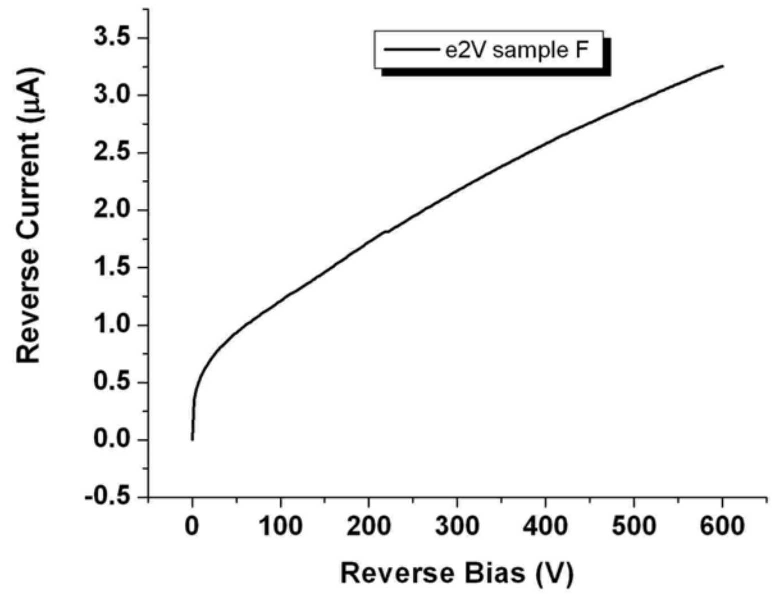
Irradiation Details

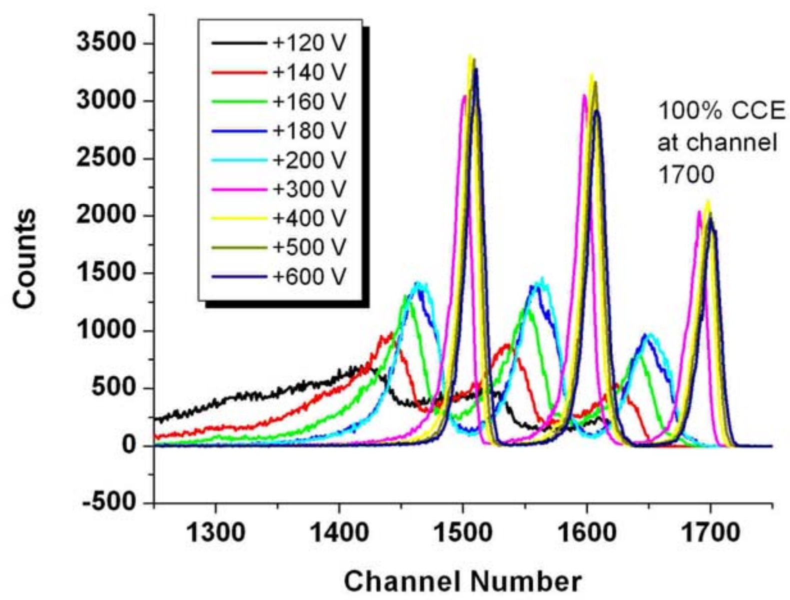
- **Obtained 6 SiLi Pad diodes from e2V plc.**
- **Devices are 4.2 mm thick !**

- **3 devices irradiation with neutrons**
  - **$5x10^{12}n/cm^2$ (1 MeV equiv.)**
- **why low fluence ?**
- 4.2 mm thick not 300 micron
- V_{Dep} calculated after 5 $x10^{12}/cm^2$ >1000 V!!

Pre-Irradiation

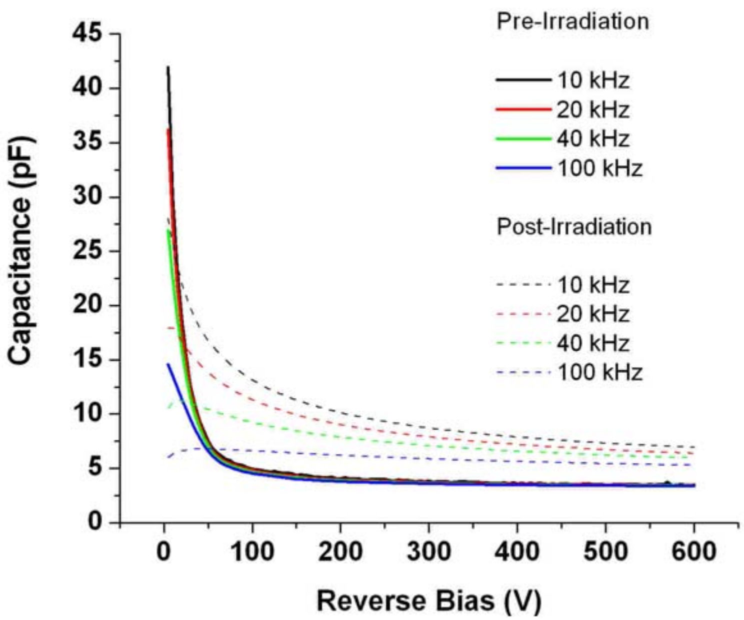


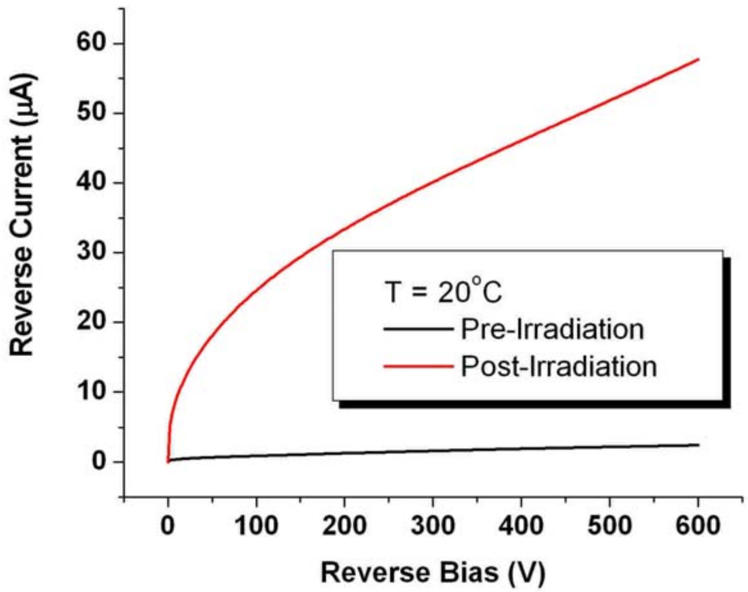




- Properties pre-irradiation
  - V_{Dep} = 200 V
  - 100% CCE
  - Low leakage current

Post-Irradiation

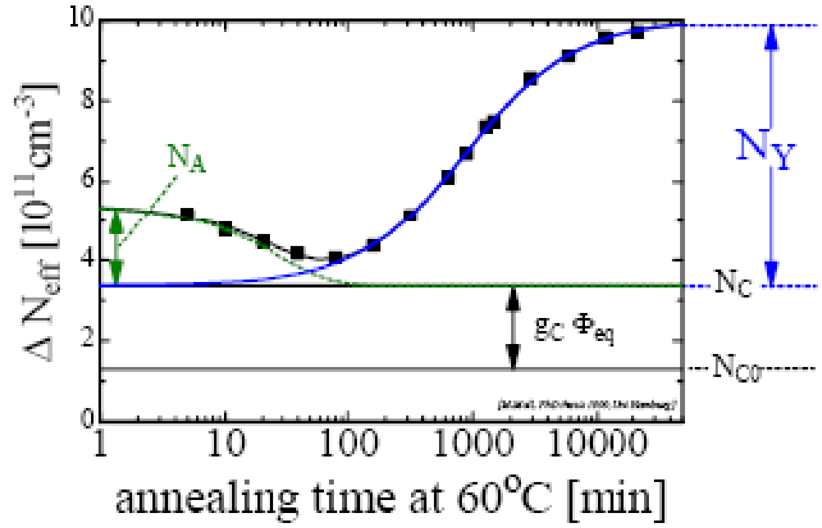




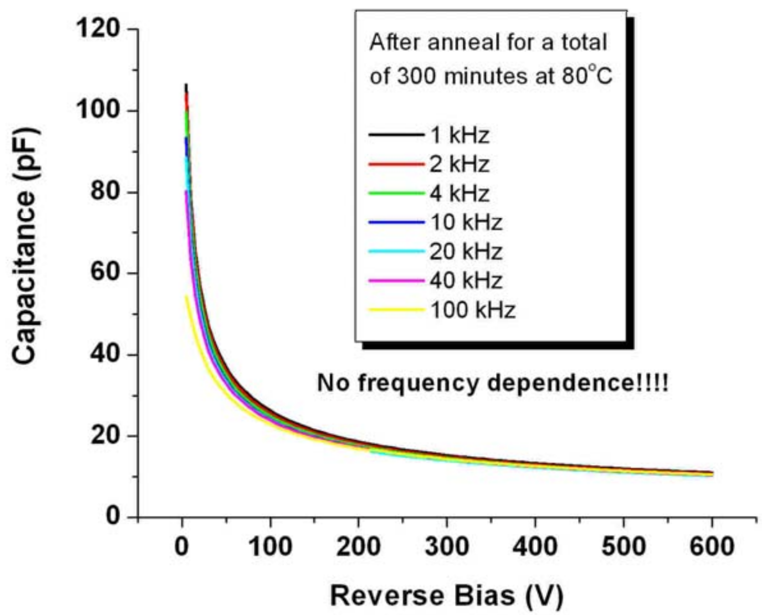
- C-V properties after irradiation show frequency dependence
  - Indicates the presence of deep defect levels (deep acceptors)
- Reverse current increases as expected
- No CCE measurements possible (unable to deplete device)

Annealing – no bias voltage

- Plan:
  - Put into reverse annealing stage
  - Then later start drifting Lithium



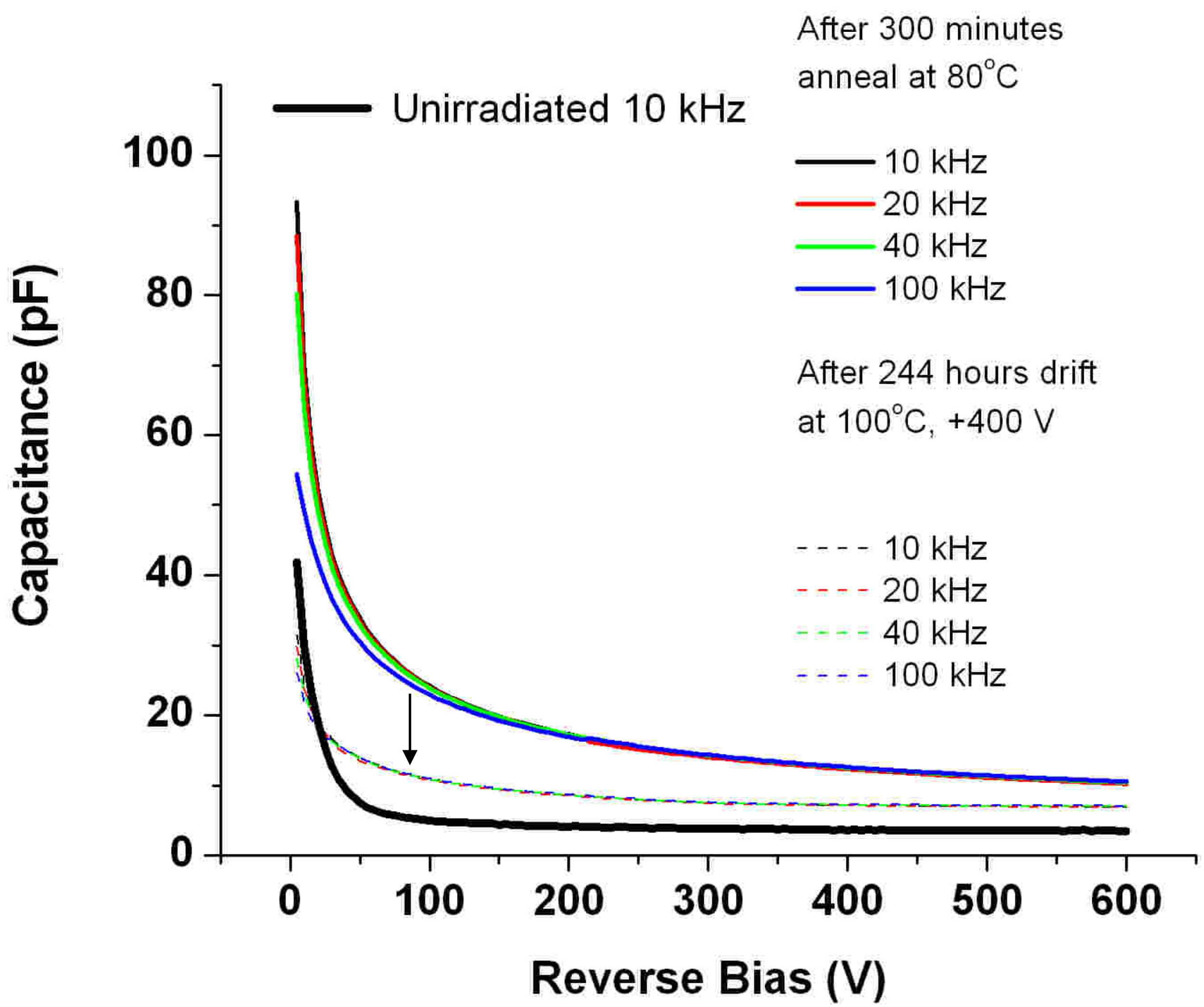
- Reality:
  - Annealed at 80^{o}C for 300 minutes



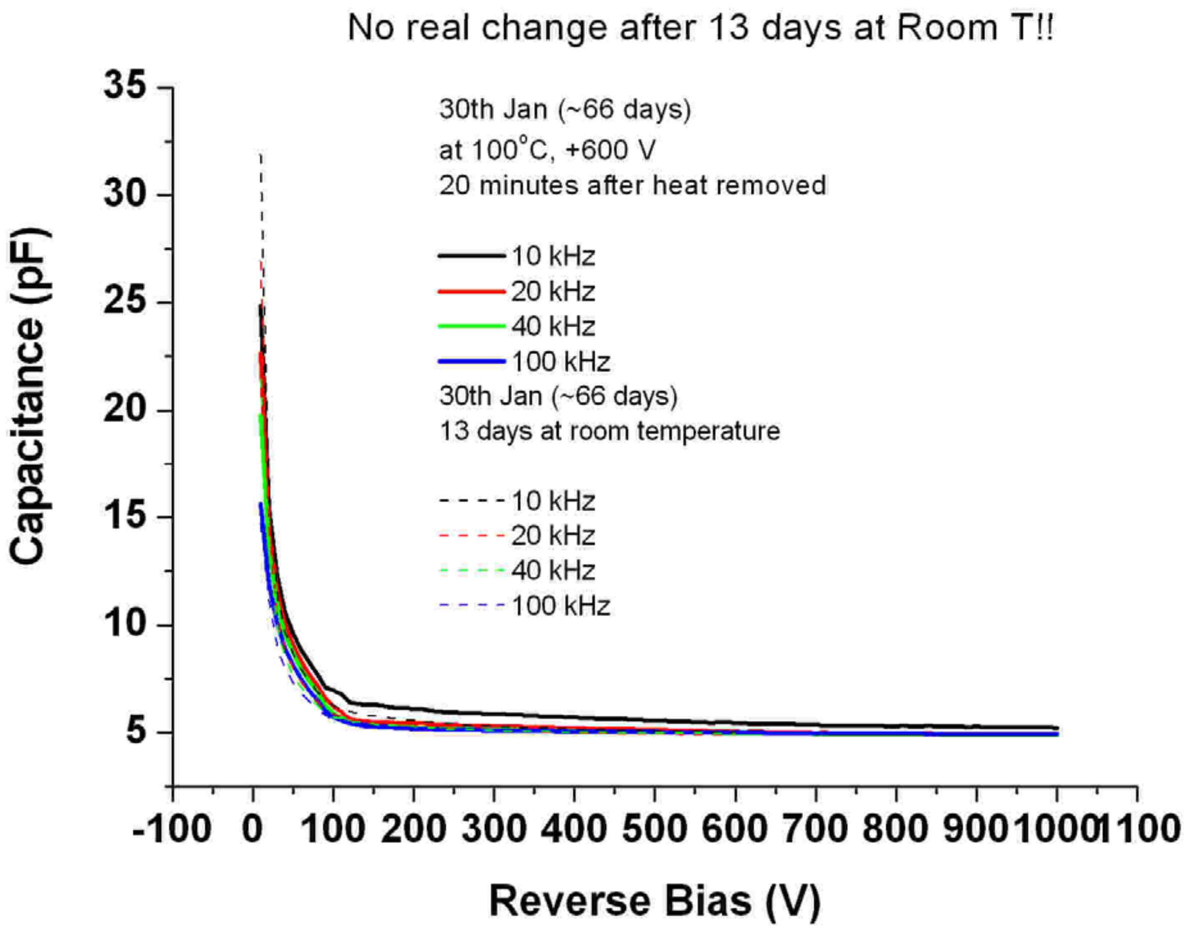
No frequency dependence

Totally unexpected!

Lithium Drifting - Capacitance

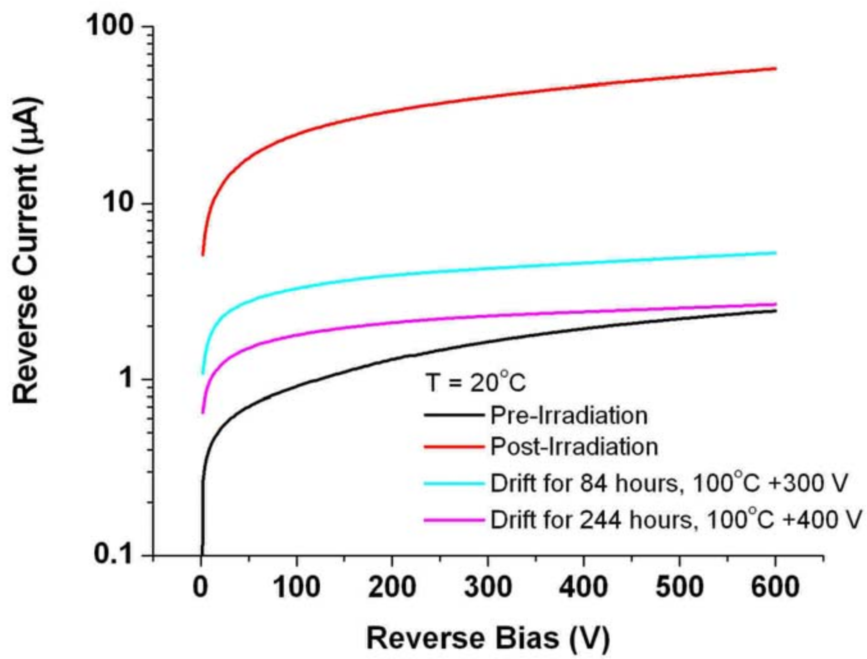


Lithium Drifting - long term



- Behaviour appears stable
  - Li Drifting up to 66 days
  - Operation at room temp for further 13 days

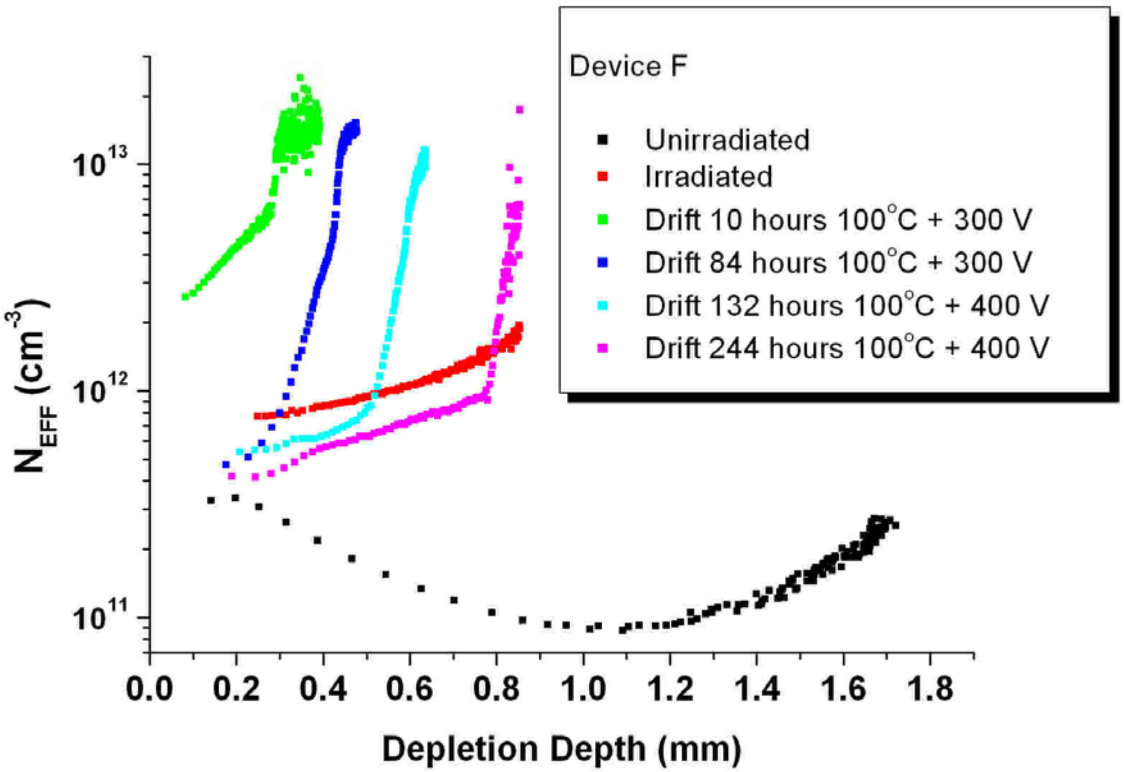
Li Drifting - Leakage Current



- Reverse Leakage current reduces with drift time
- No CCE measurements as cannot fully deplete

Differential Capacitance

NEFF versus Depth, from differential capacitance method, dC/dV



- Depletion Depth values not correct (factor of 2.5 too small)
- Unirradiated value does not match
- N_{EFF} decreasing with drift time

•Hitting drifting “wall” ?

Conclusions

- Initial explorative studies on thick devices show:
  - Li passivates radiation damage in Si
    - Reduction in capacitance with drift time
  - Long drift times and high voltages required for repair
    - 66 days at ~600V at 100^{o}C

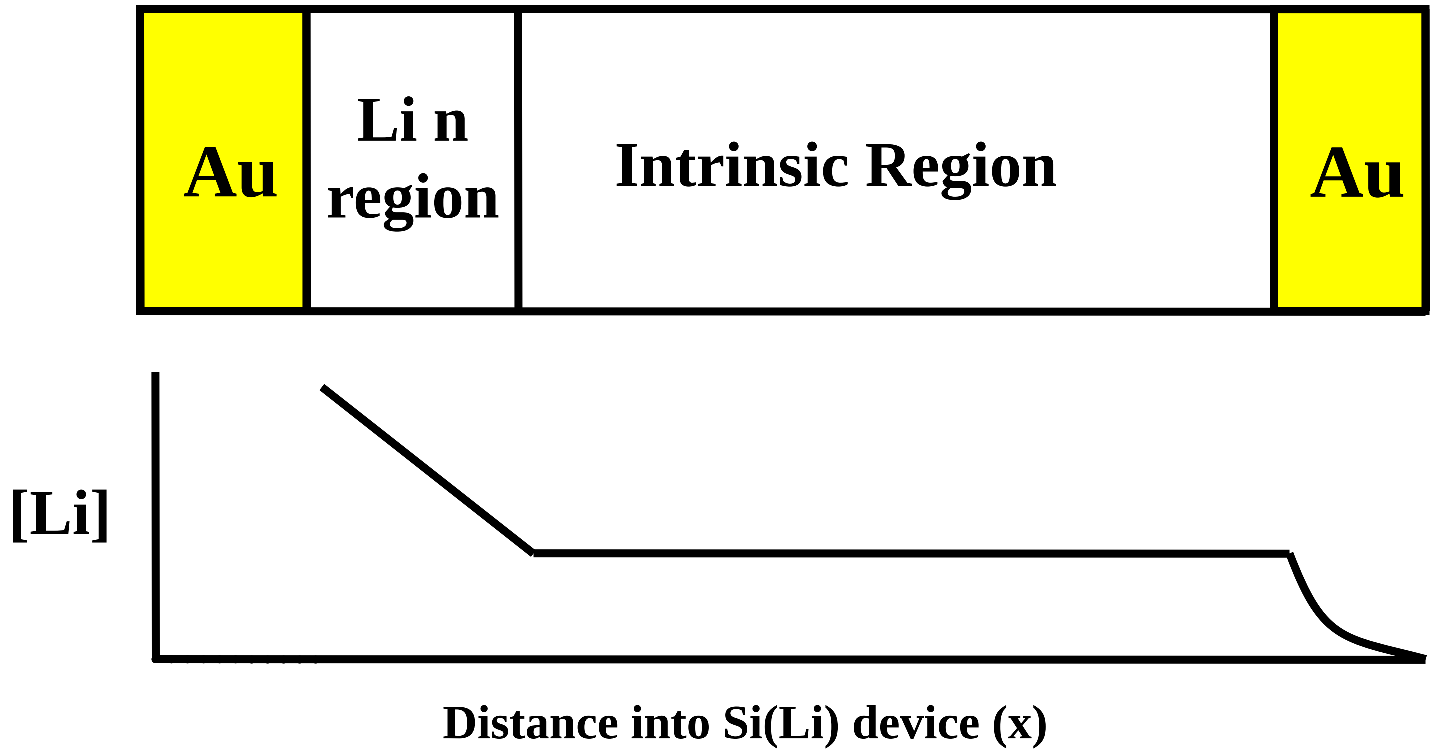
- Practicalities
  - In experiments radiation dose accumulated over time
  - Ideally passivate as defects created
  - Applied field also used to drift

- Future Activities
  - Thin devices at higher fluence
  - Explore parameter space in more detail: Voltage, temperature, time
  - Measure CCE, require to fully deplete detectors

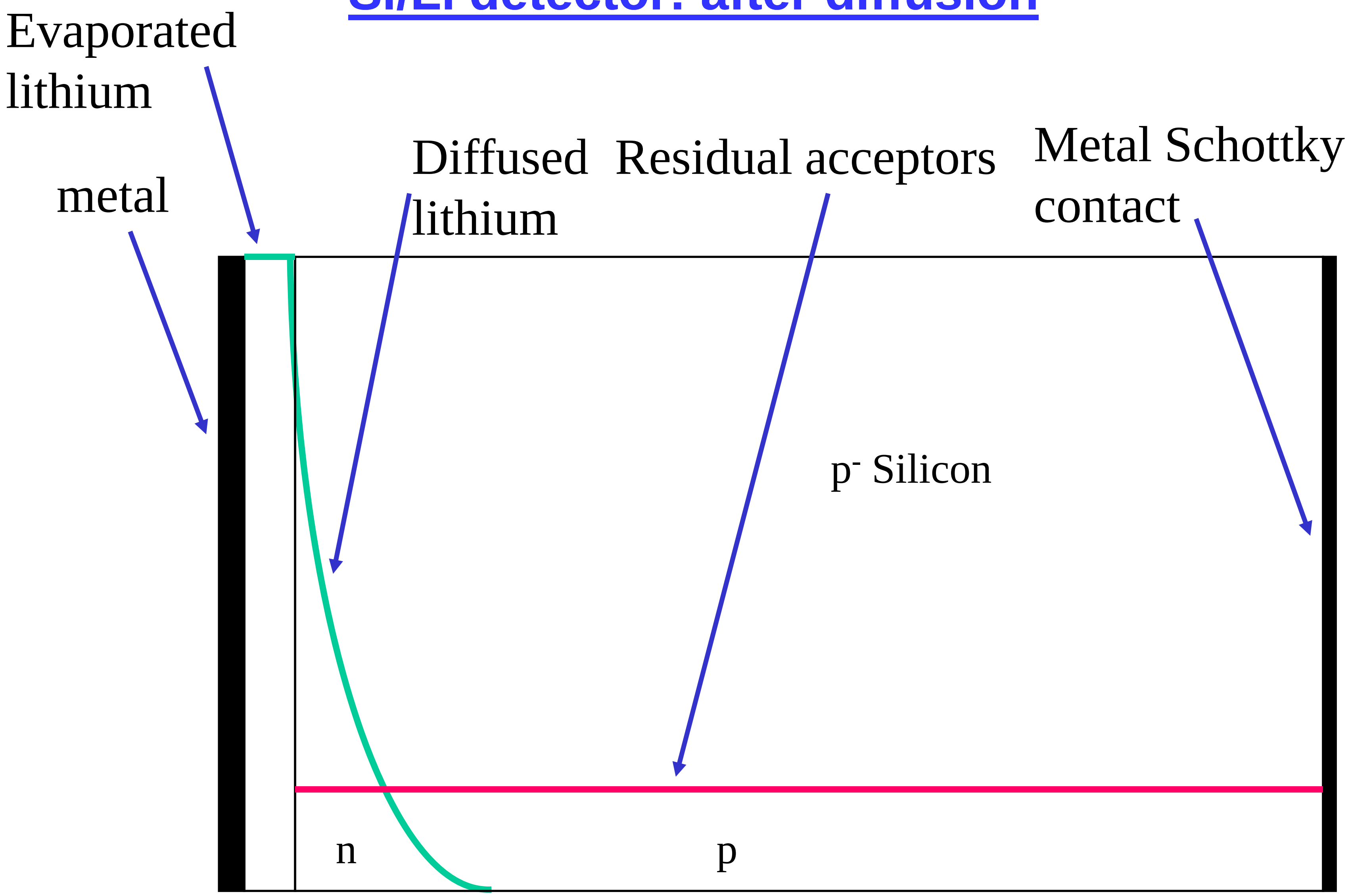
Back-Up Slides

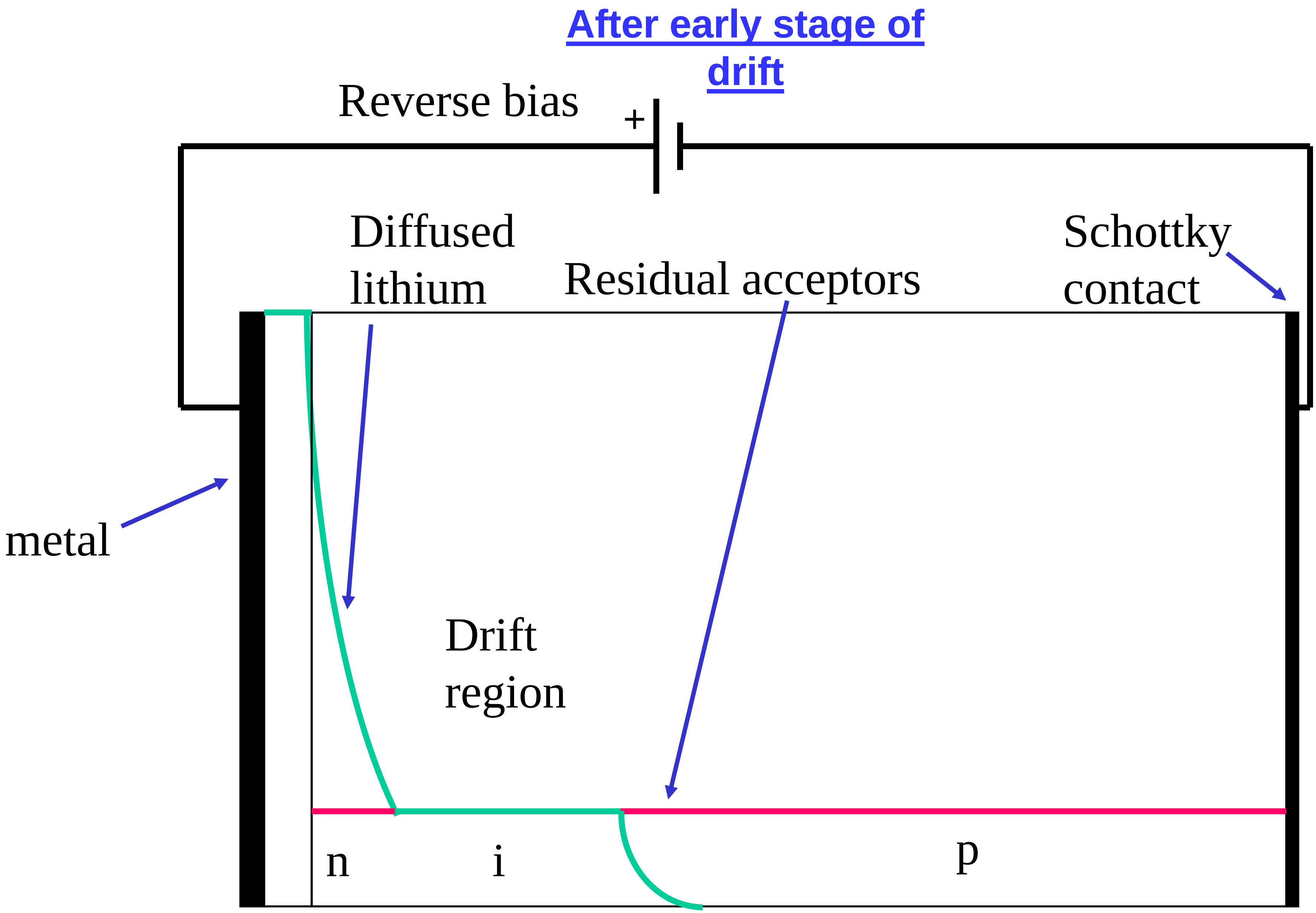
A Lithium Drifted Particle Detector

- Li ions are easily introduced in Si by diffusion and drifting (Pell 1961)
- Nowadays commercial Si(Li) devices are produced by evaporating Li onto one side of the Si sample and then evaporating Au on top.
- Au is typically used to produce a rear contact
- The device is then reverse biased and heated to a temperature of around 100°C
- The Li ions are attracted toward the rear contact and passivate the acceptors



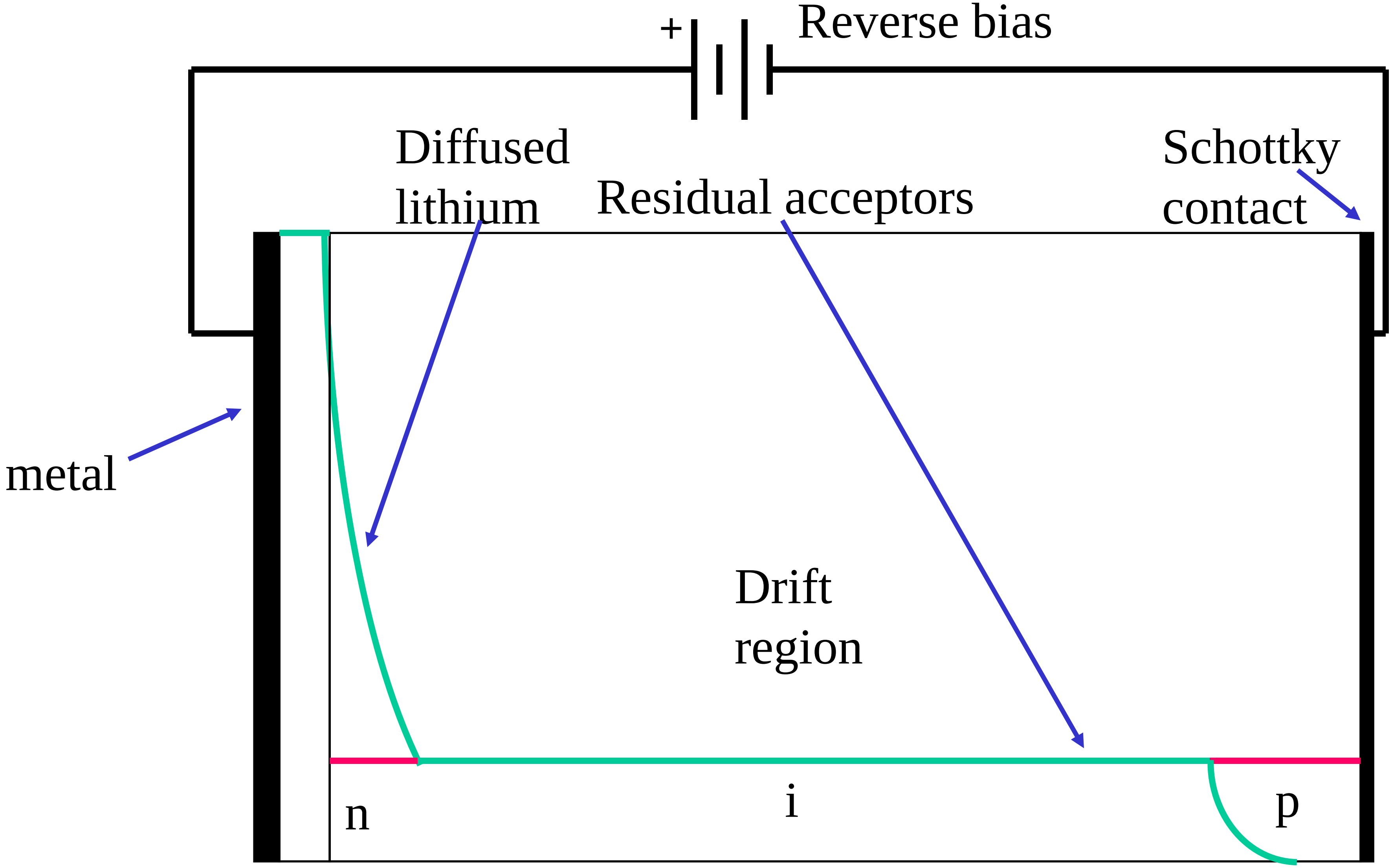
Si/Li detector: after diffusion



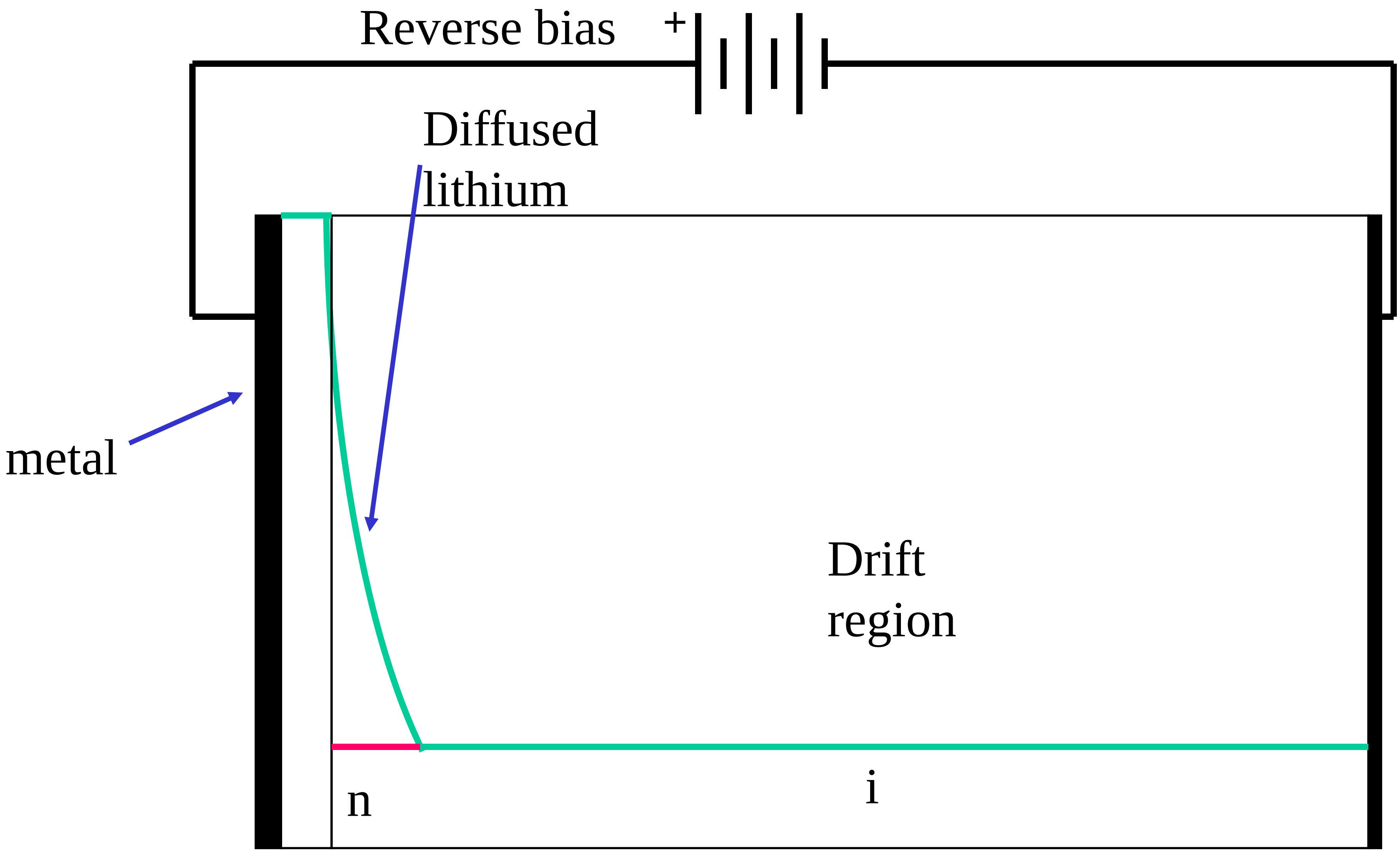


After early stage of drift
Reverse bias
+
Diffused lithium
Residual acceptors
Schottky contact
metal
Drift region
n
i
p

After more drift



Completed drift



Drift and Detection

- Note that the bias polarity for drift is the same as that for detector operation.
- (This is important!)