Comparison of the Effects of 51-MeV Protons on Differing Silicon Avalanche Photodiode Structures

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Overview

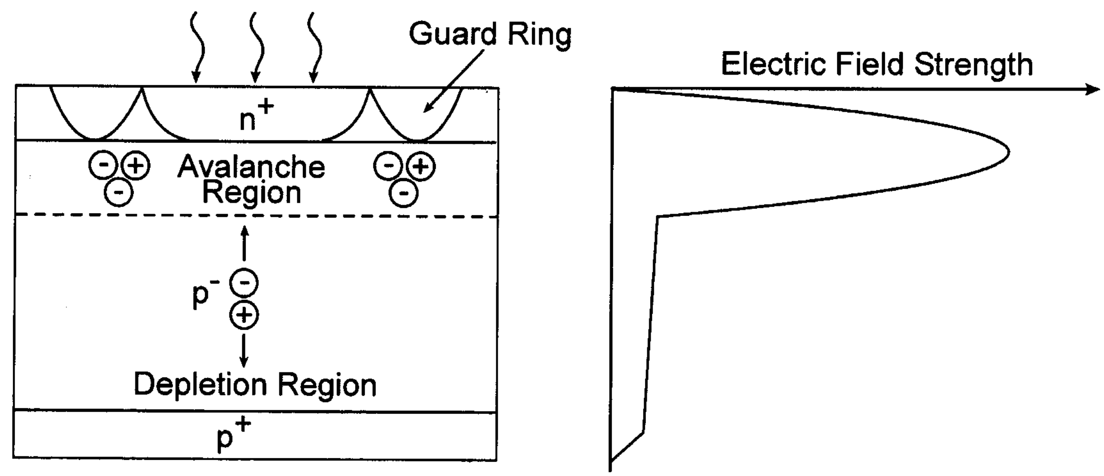
- Context
- Avalanche Photodiode (APD) Operating Principles
- Description of APD Structures in the Study
- Experimental Procedures
- Results
  - Dark Current
  - Noise
- Selection Considerations

Context

- Ongoing interest in space-based light detection and ranging (LIDAR) & optical communications
- Highly sensitive and radiation-tolerant detectors are needed
- Avalanche Photodiodes (APDs) often chosen
  - Low Noise
  - High GAIN

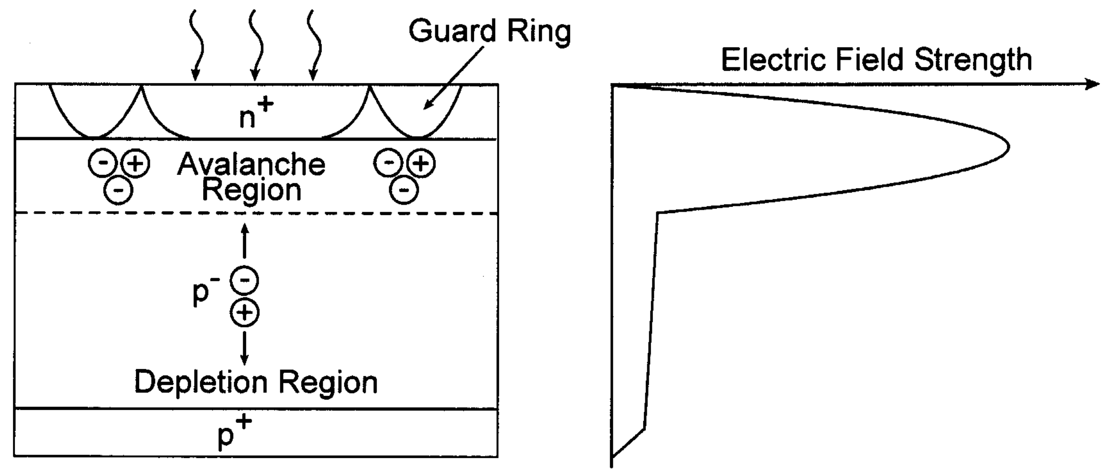
Avalanche Photodiode Principles

- Operate in Fully Depleted Mode
- Light absorbed in Depletion Region
- Depth of p-region depends on intended wavelength



Avalanche Photodiode Principles

- Electrons transported by DRIFT
- High field Avalanche region at p-n junction
- Multiplication caused by Impact Ionization

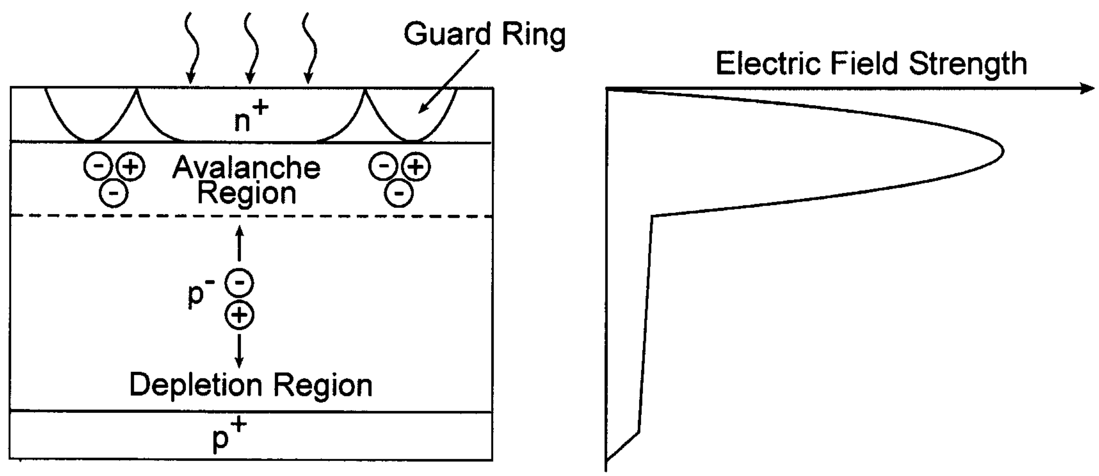


Avalanche Photodiode Principles

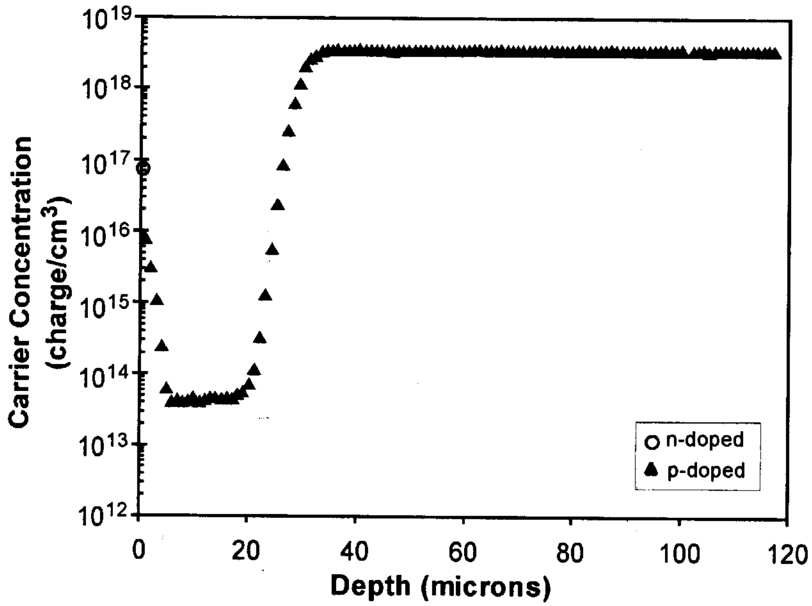
Dark Current Has 2 Components

1) **SURFACE currents – NO multiplication**

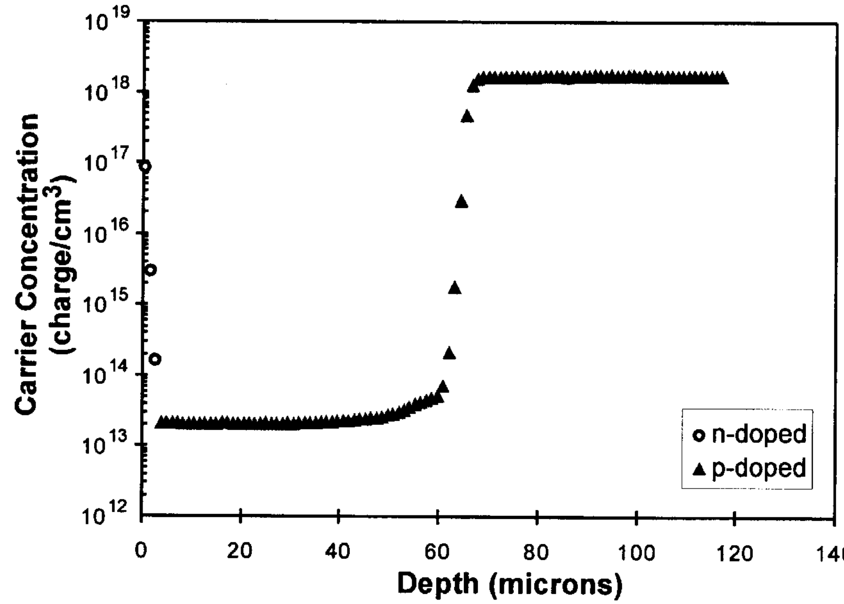
2) **BULK leakage current – GAIN multiplied**



APD Structures in the Study

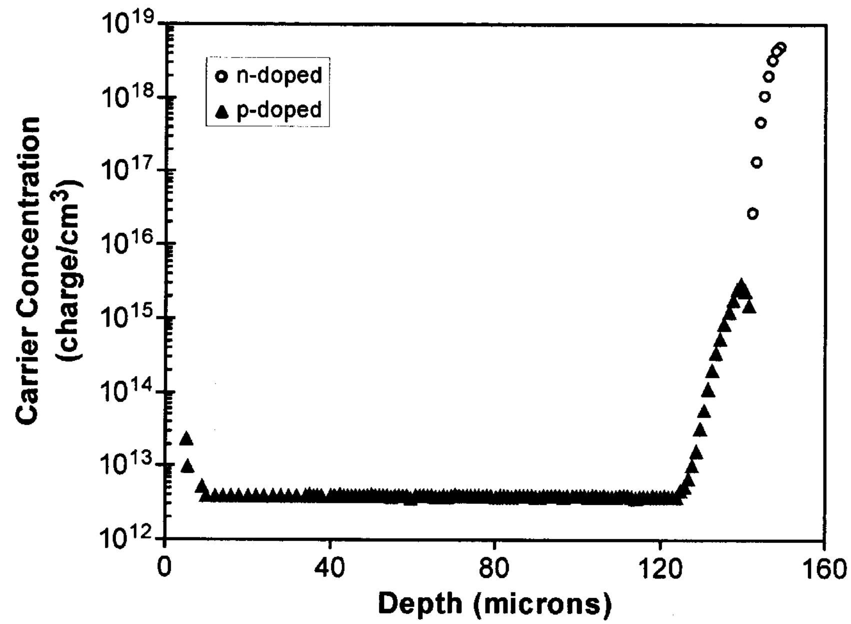


SHALLOW



MEDIUM THICKNESS

APD Structures in the Study



DEEP (IR-Enhanced)

Experimental Procedure

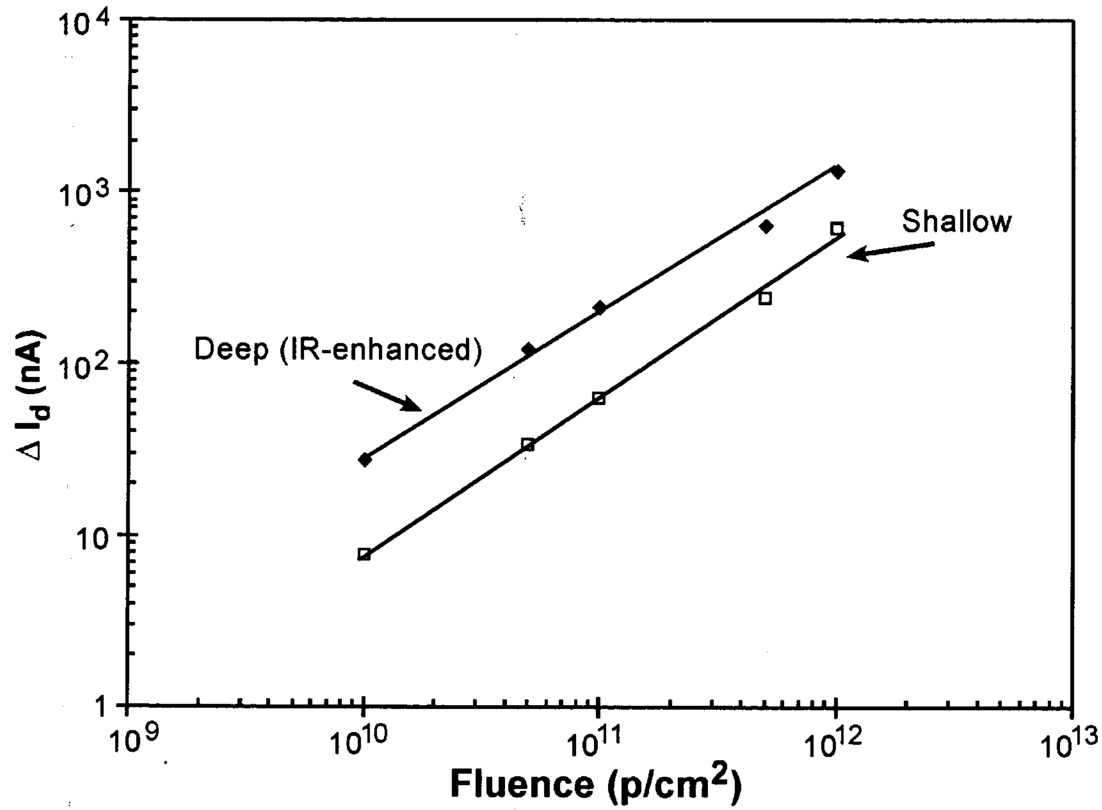
- Biased and un-biased irradiations with 51-MeV protons to 10^{12} p/cm^2
- Maintained constant BIAS = pre-irradiation GAIN of 100
- Characterization performed at 22°C
- Dark Current
- Noise
  - Low noise transimpedence amplifier; dynamic signal analyzer
- Supplemental irradiations with Co-60 for diagnostic purposes

Effect of Proton Damage on Dark Current

- Dark current increased by 2 orders of magnitude

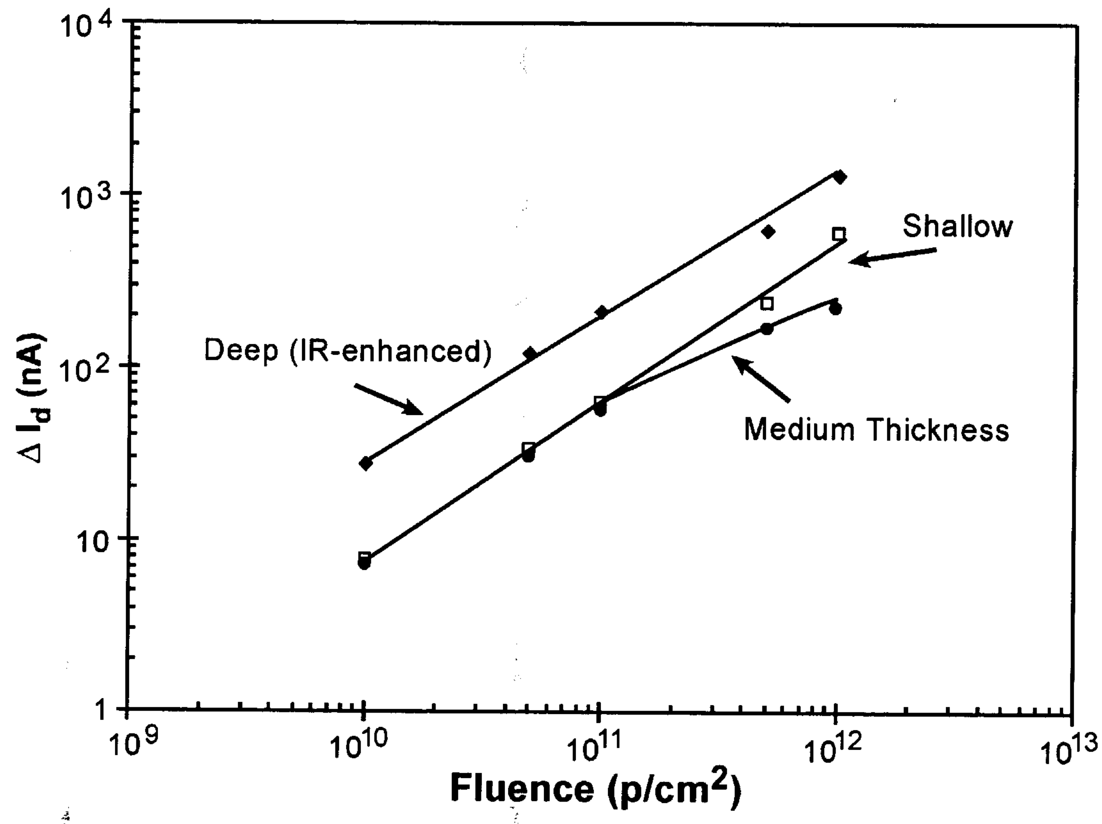
- Volume dependence of bulk dark current

- Linearity of displacement damage



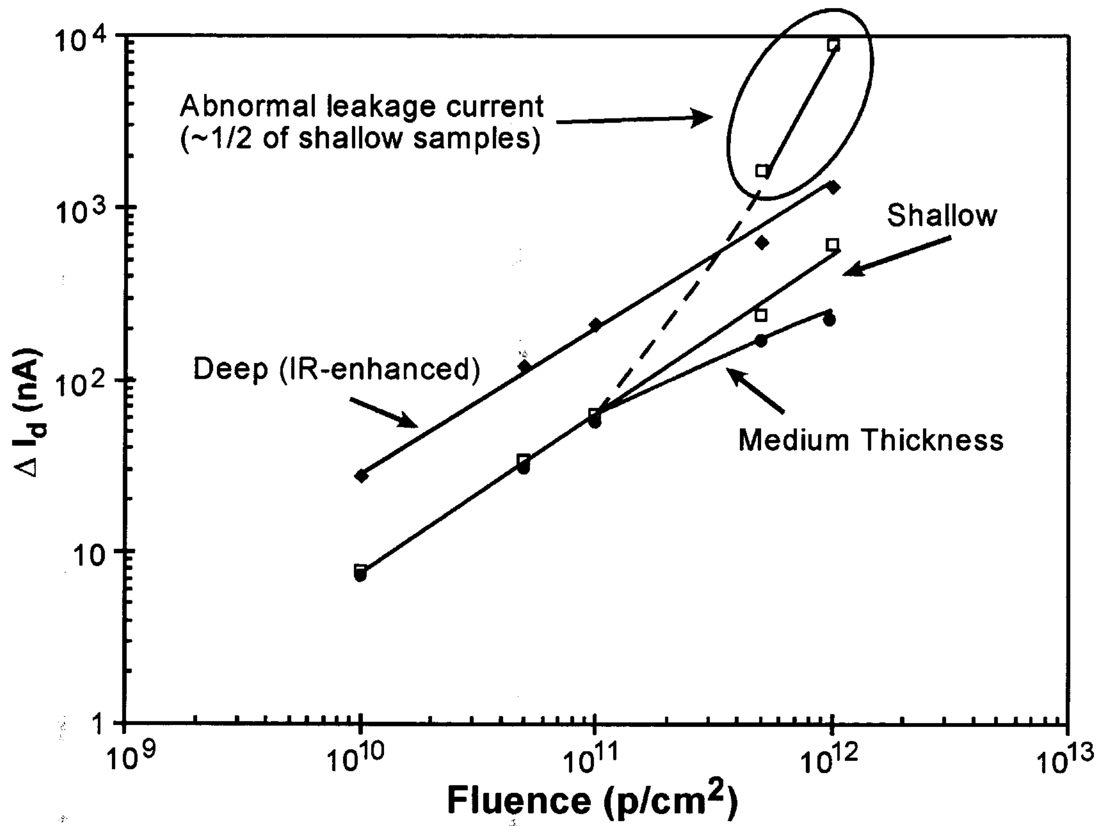
Effect of Proton Damage on Dark Current

- Not a simple volume argument…
- Doping of Depletion Region will affect damage constants



Effect of Proton Damage on Dark Current

- **Part-to-Part variability in SHALLOW structure**
- **I_d increased by 3 orders of magnitude in 50% of samples; departure from linearity**

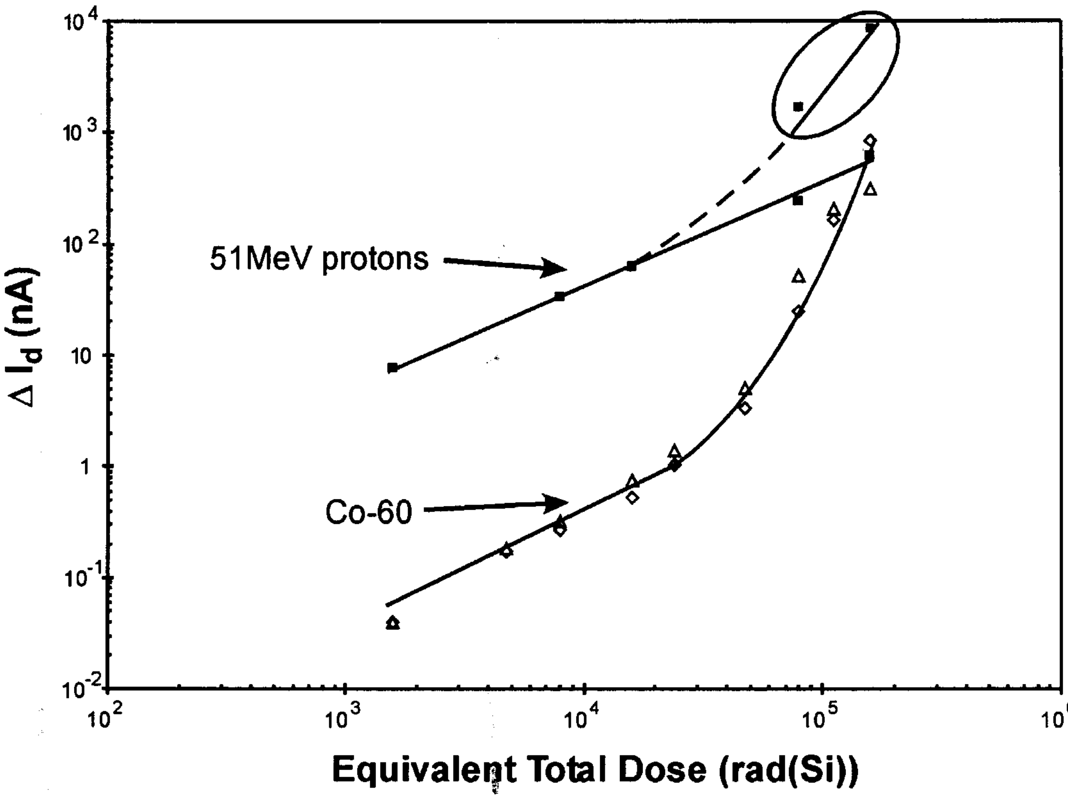


Comparison of Cobalt-60 and Proton Damage for APD with Large Increase in Dark Current

- At low fluences, both show linear relationship between damage and dose

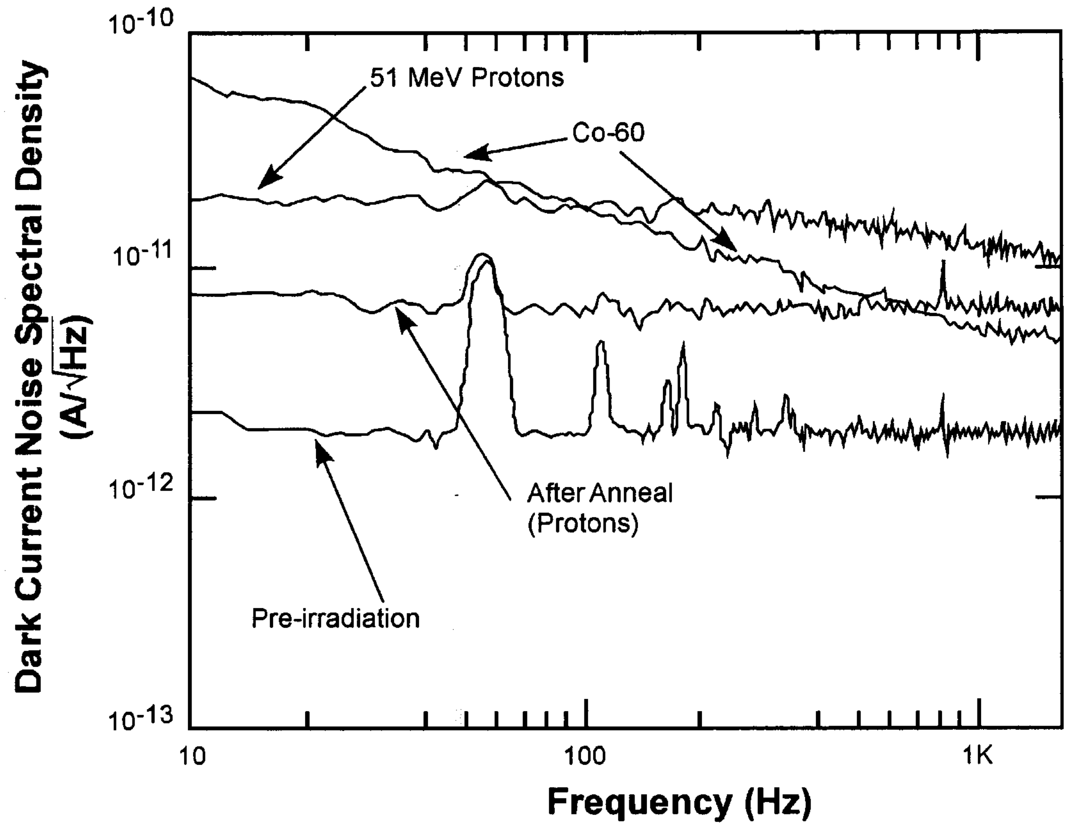
- Ionization damage important above 25 krad(Si)

- High I_d due to SURFACE Damage [4 Guard Rings]



Noise Data

- Increases in 1/f-type noise linked to surface currents
- Ionization damage causes surface effects
- Charge trapping between guard rings can induce n-type layers, letting surface currents flow



Mechanisms

- **Displacement Damage important at lower fluences => Gain-Multiplied Bulk Dark Current**
  - **Depends on volume of depletion region**
  - **However, damage constants for lightly doped material have not been investigated in detail**
- **Ionization damage (charge trapping) can become important at higher fluences => Surface I_d**
  - **Can occur in very shallow devices**
- **Carrier removal in p-region => ineffective guard rings**
- **Bulk damage => high frequency noise**
- **Surface damage => 1/f-type noise**

Selection Considerations

- APDs with Shallow Construction Generally Preferred (except for long wavelengths)
  - Reducing volume generally reduces bulk dark current sensitivity from g-r centers
  - Carrier concentration in depletion region must also be considered

- Device architecture (guard rings) and possible surface effects must be considered
  - Part-to-Part Variation is possible; test with adequate sample size

- Carrier removal may cause dopant inversion at high fluences => increasing surface currents or causing device failure