Space Radiation Effects in Optoelectronics

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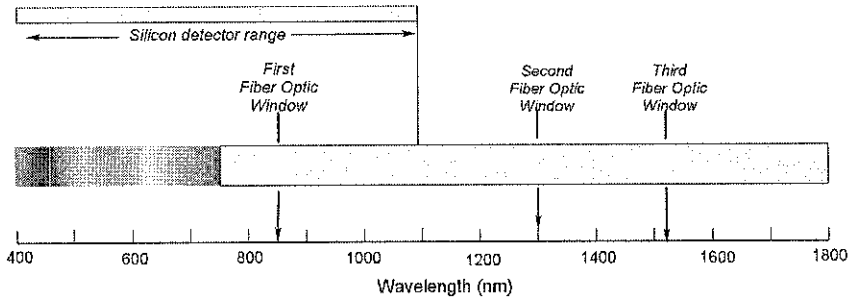
Outline

- Space Environments
- Light-emitting Diodes
- Laser Diodes
- Optical Detectors
- Optical Couplers
- Conclusions

Wavelengths of Interest



Three Fiber Optic Windows

- 850 nm, 1320 nm and 1550 nm
- Some interest in the visible spectrum as well (400 to 700 nm)
- Silicon detectors: limited to 1040 nm (bandgap edge)

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Particles in Space Environments

Trapped Particles in the Van Allen Belts

- Electrons with energies up to several MeV
- Protons with a wide range of energies

Solar Particles (Coronal Mass Ejections)

Galactic Cosmic Rays

- Heavy particles
- Extremely high energies

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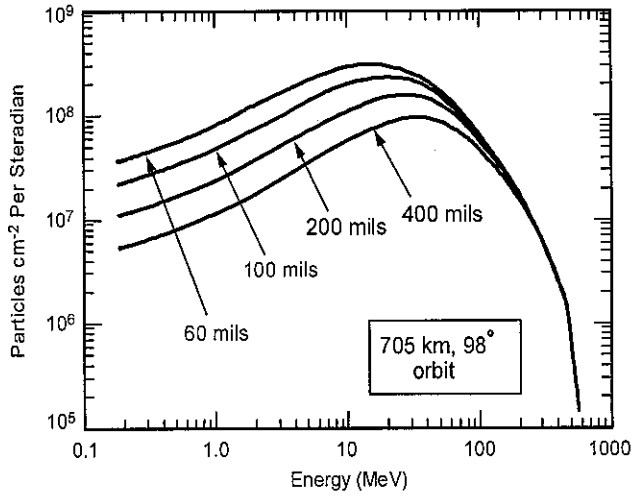
Typical Proton Spectrum

The peak in the proton energy spectrum is typically between 20 and 50 MeV

Adding shielding causes the peak energy to increase



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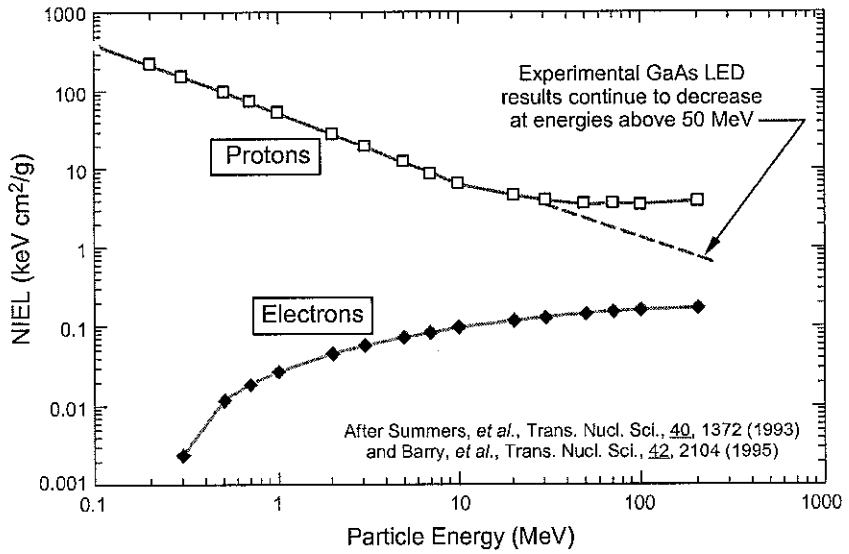
Energy Dependence of Proton Damage in LEDs



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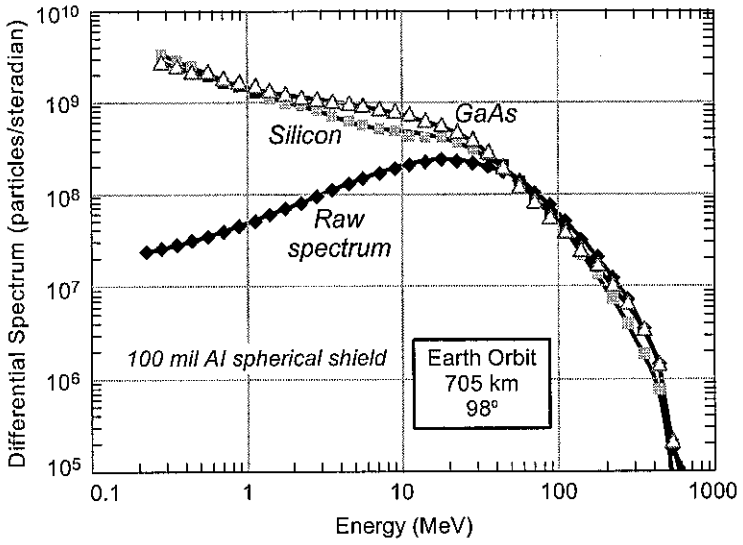
Proton Spectrum Corrected for NIEL Dependence



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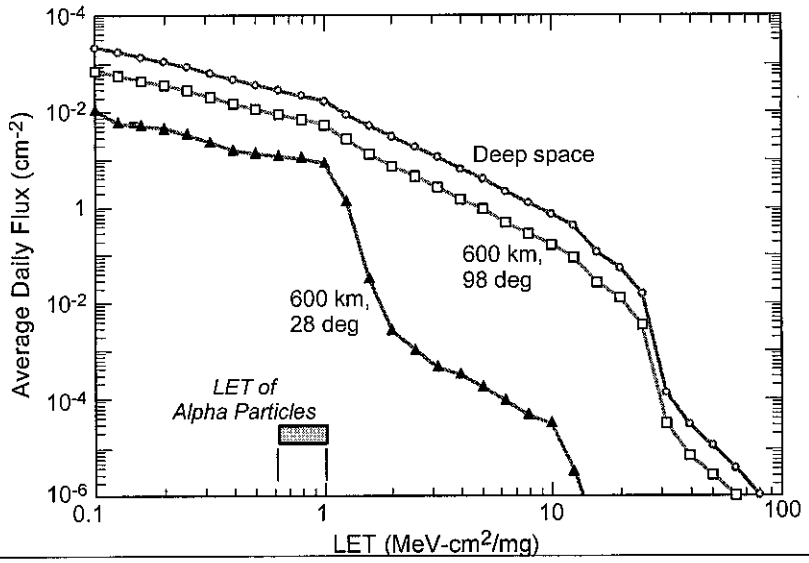
Heavy Ion Distribution in Space



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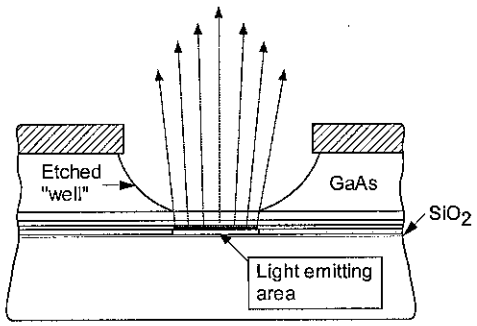
Optical Emitters:
Light Emitting Diodes and Laser Diodes



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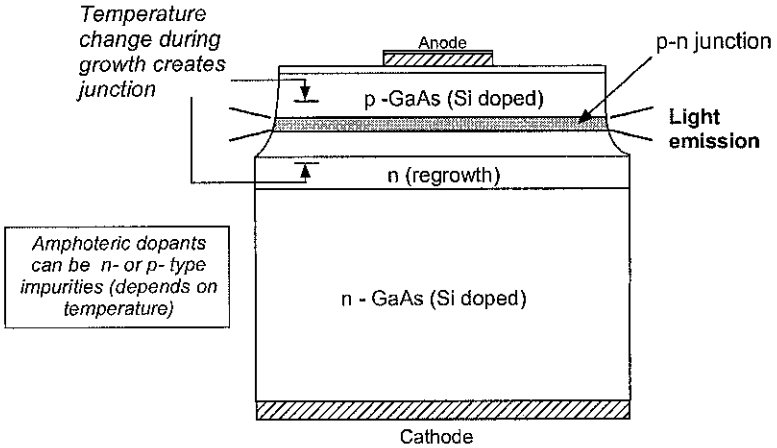
An Amphoterically Doped LED

Simple process developed in 1960's

Highly efficient: 860 – 930 nm



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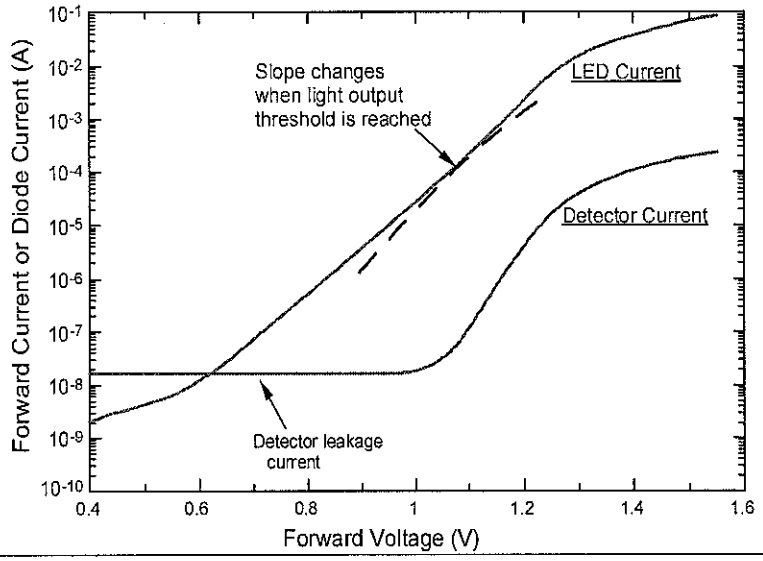
I-V Characteristics of an LED



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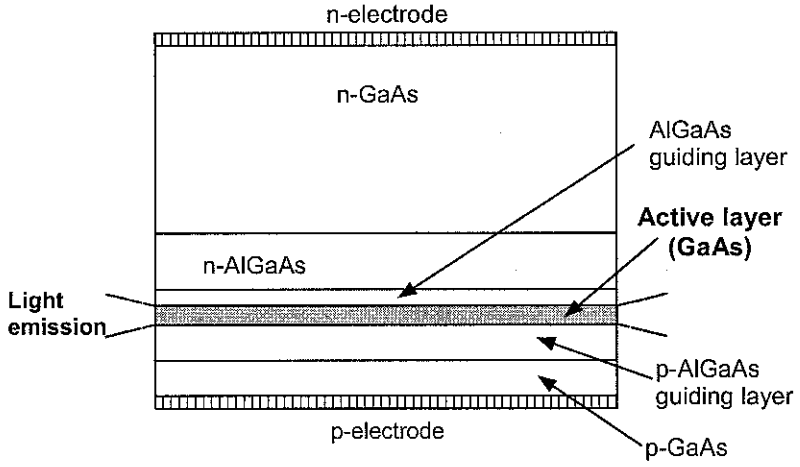
A Double-Heterojunction LED

Complex fabrication process with many layers
Produced LEDs with fast response times



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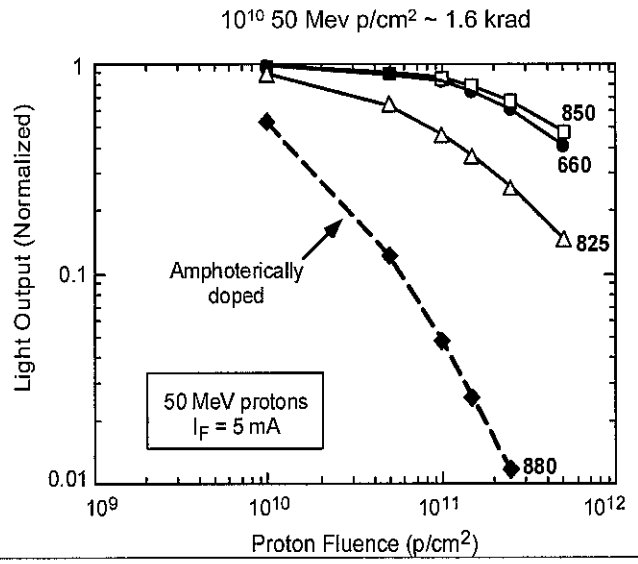
Degradation of LEDs after Proton Irradiation



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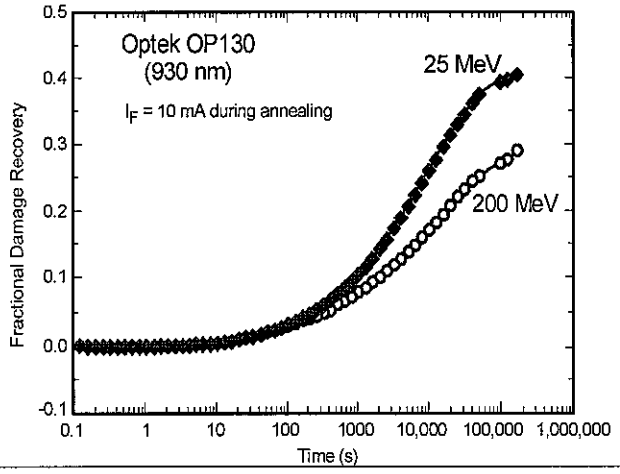
Annealing of Amphoterically Doped LEDs after Proton Irradiation

Annealing does not occur until forward current is applied



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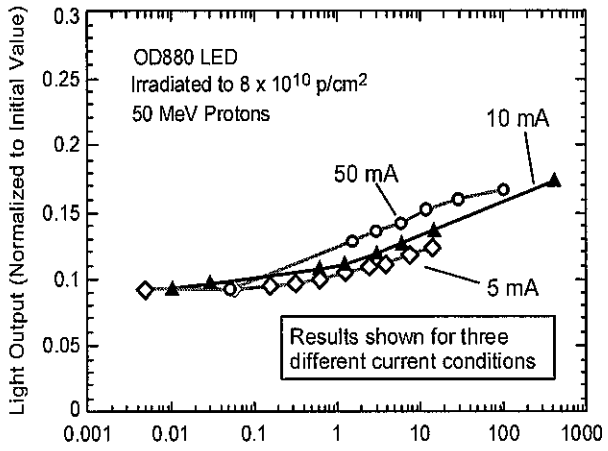
Comparison of LED Annealing with Different Forward Currents

To first order, annealing depends on injected charge



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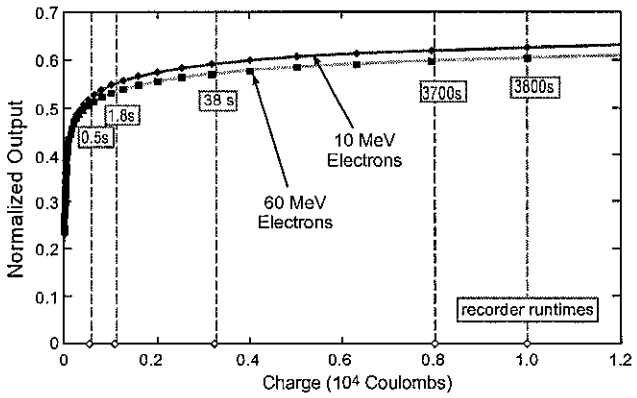
Recovery of LED Damage in Galileo Tape Recorder

Tape recorder stopped working after 34th orbit around Jupiter

Caused by LED degradation in control circuitry

Operation was successfully restored after forward biasing the LED to anneal the damage



After G. Swift, *et al.*, IEEE Trans. Nucl. Sci., December, 2003

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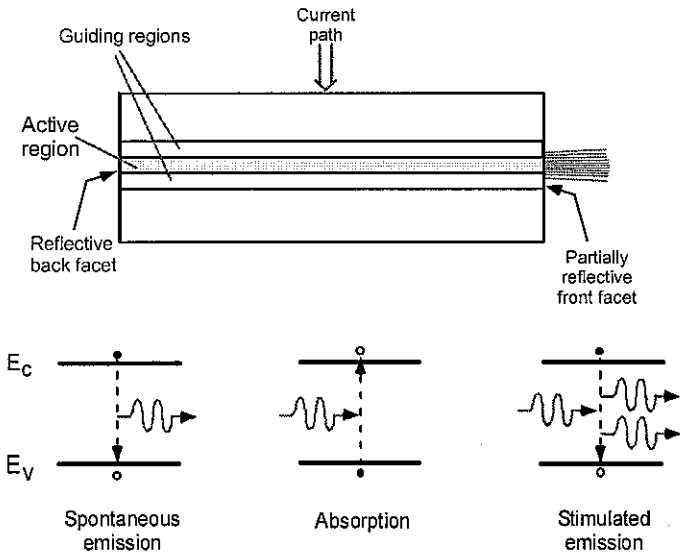
Absorption and Emission Processes for Lasers



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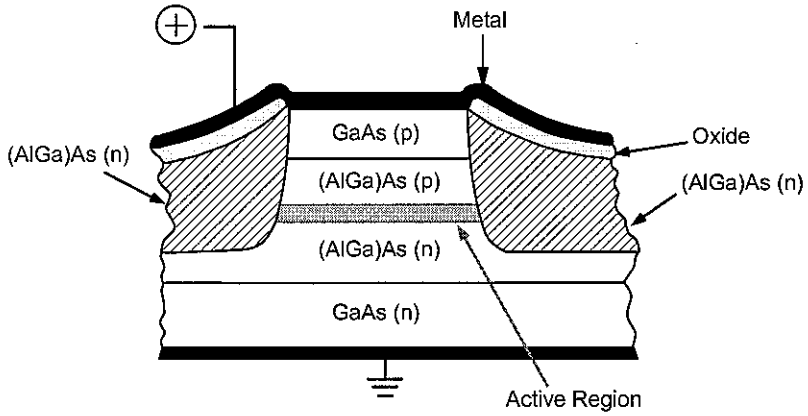
Laser Diodes

Basic five-layer laser

Current is confined to narrow stripe



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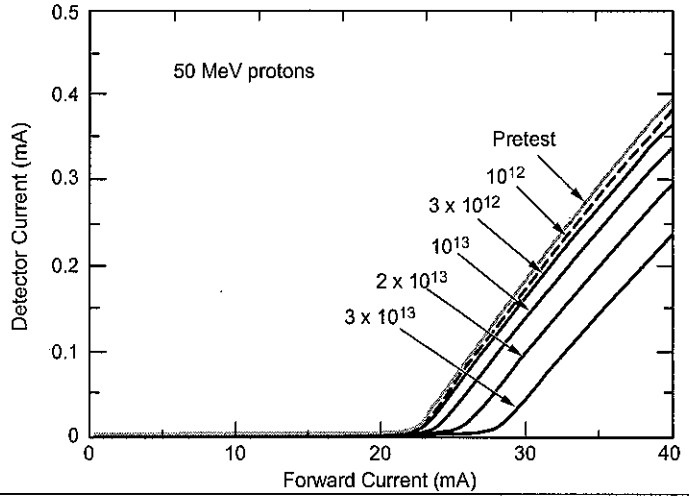
Proton Degradation of a Laser Diode



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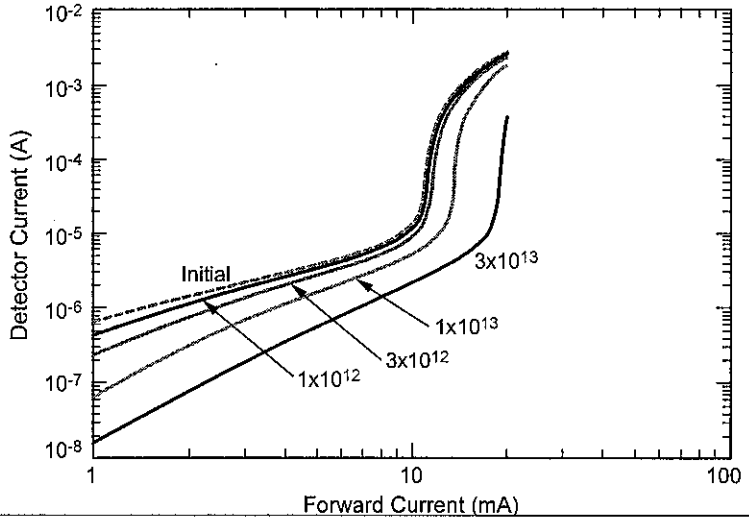
Semi-logarithmic Plot of Laser Degradation



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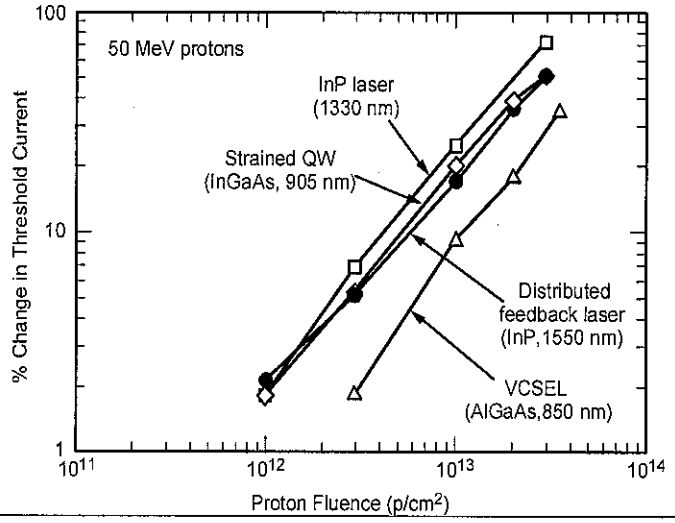
Degradation of Various Types of Lasers



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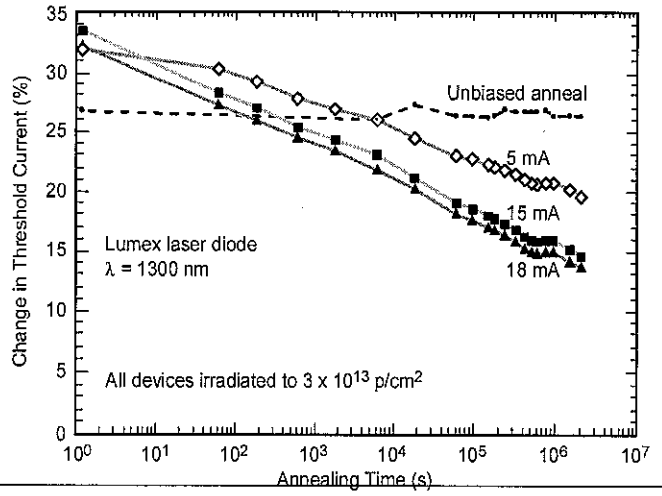
Annealing of Laser Damage

Annealing proceeds more rapidly when lasers operate above threshold



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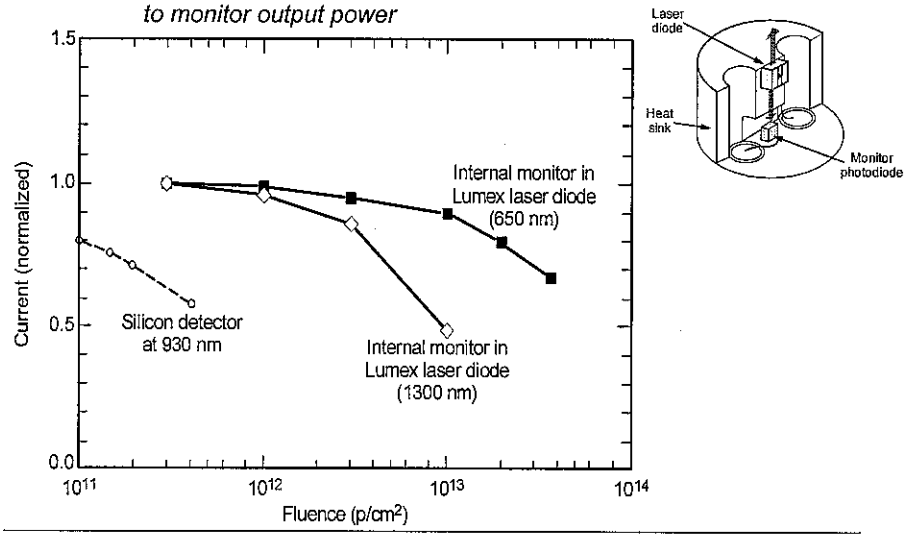
Photodiode Degradation

Many lasers contain internal diodes to monitor output power



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Optical Emitter Degradation: Summary

Amphoterically doped LEDs are one of the most sensitive components that can be used in space

Often used in optocouplers

Device Type	Approximate Threshold for Degradation	Annealing Properties	Comments
Amphoterically Doped LED	5×10^9 p/cm^2	Strong	Extremely sensitive to radiation damage
Heterojunction LED	1×10^{11} p/cm^2	Very weak	
Laser Diode	1×10^{12} p/cm^2	Very Strong	Monitor diode degradation may be more significant

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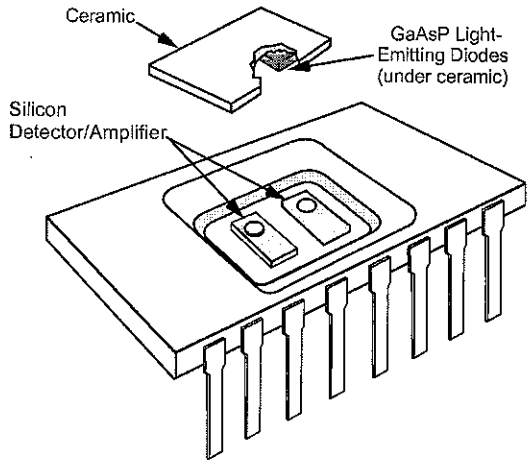
Optocouplers



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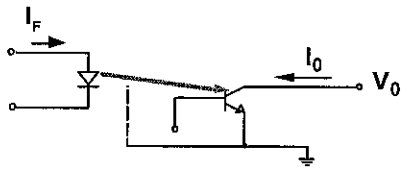
Optical Couplers

Permanent damage effects are covered in the notes

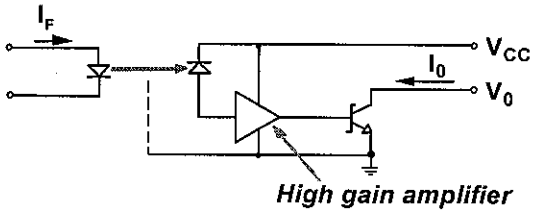
We will concentrate on transient effects during the presentation

- Usually dominated by charge collection in the large area photodiode
- Only important for optocouplers with high-gain amplifiers

Optocouplers are heavily overdriven *(on or off)*



(a) Basic optocoupler



(b) Integrated amplifier

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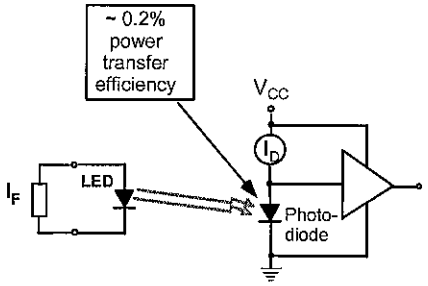
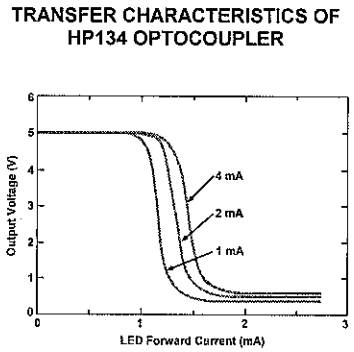
Transient Sensitivity of High-Speed Optocouplers





Charge sensitivity for an optocoupler with 20 ns response time is ~ 100 femtocoulombs!

Heavy-ion upset at LET values ~ 0.1 MeV-cm²/mg

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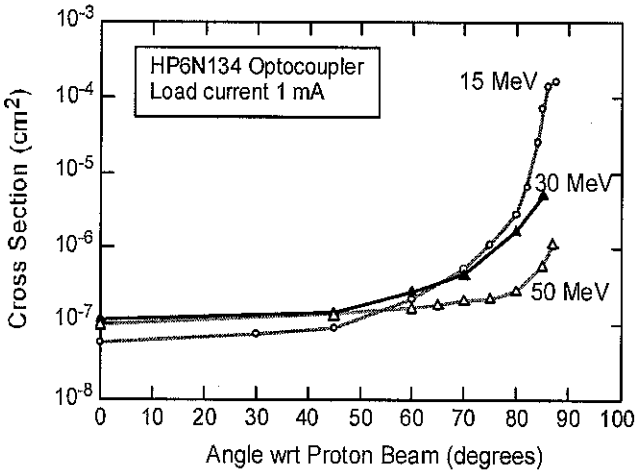
Dependence of Optocoupler Cross Section on Angle During Proton Testing

Angular dependence is caused by direct ionization from protons in large diameter photodiode

Effective LET for direct ionization is ~ 0.007 MeV-cm²/mg



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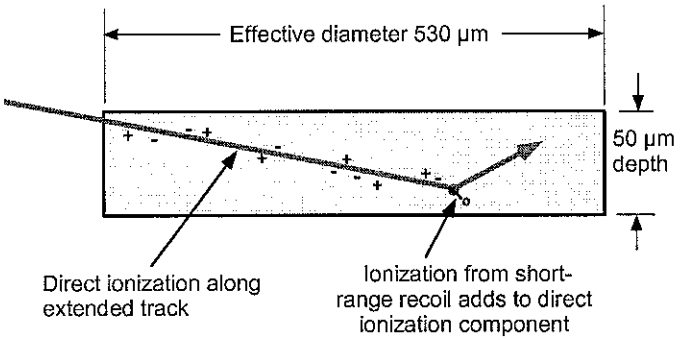
Two Mechanisms Contribute to the Angular Dependence of the Cross Section

Direct ionization LET is ~ 0.01 MeV-cm^2/mg

Long path length provides significant total charge at extreme angles



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Summary *(displacement damage)*

Optical Emitters

- Discussed operating principles
- Emphasized importance of proton displacement damage
  - •Some ty pes of optical emitters are severely degraded by protons with an effective total dose of 1-2 krad
  - •Compar ed degradation of LEDs and lasers
  - •Discu ssed injection-enhanced annealing

Optocoupler Displacement Damage

- Strongly affected by the type of LED used in the optocoupler
- Decrease in diffusion length of conventional photodetectors and phototransistors dominates damage for optocouplers with less sensitive LEDs

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Summary (*transient effects)*

Optocouplers
- Very basic subsystem
- High-bandwidth optocouplers are extremely sensitive to SEU
- Dominated by charge collection in the phototransistors

Proton Upset Has Strong Angular Dependence
- Caused by direct ionization along the large track length
- Requires testing at different angles

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