RADIATION TEST WORKSHOP 2016
SEVILLE – SPAIN 31st MARCH – 1st APRIL

Experimental Study of Displacement Damage Test for Space Application

Yu Qingkui

China Aerospace Components Engineering Center
China Academy of Space Technology

中国航天宇航元器件工程中心
China Aerospace Components Engineering Center

China Academy of Space Technology

Outline

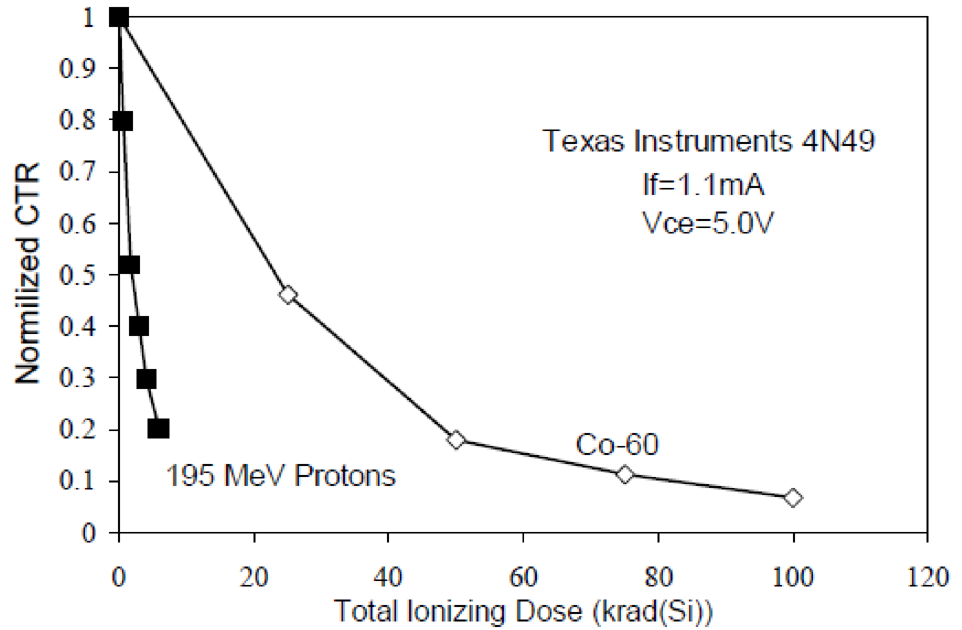
- Introduction
- Experiment and Results
- Discuss
- Summary

Introduction

➢Degradation of optocoupler 4N49 irradiated by proton is more than by Co-60 γ-ray to the same total ionizing dose.

➢Displacement damage test is needed for displacement damage sensitive devices for space application.

- The optocoupler may fail due to displacement damage in space.



Stephen Buchner et al . Proton Test Guideline Development-Lessons Learned

Introduction

- Displacement Damage tests are required for for space project in CAST:
  - •DD qualification test is required for new device
  - •DD evaluation is required for device with no DD test data
- The devices are required for displacement damage test:
  - •CCD, CMOS APS, Optocoupler, LED, photodiode

Introduction

- Displacement damage test guideline or documents issued are as following:
  - NASA/GSFC: Proton Test Guideline Development-Lessons Learned
  - NASA/GSFC: CCD Radiation Effects and Test Issues for Satellite Designers
  - Displacement Damage Test Guideline for 2D Imagers [Christian Peivey, ESCCon2016]

Introduction

- CAST: displacement damage test guideline gives the requirements as following:
  - Source: Proton preferred,
    Neutron may be used for evaluation test
  - No bias required
  - Measurement time after irradiation:24h. Allowed to extend to 168h, if radiation safety required.
  - Sample size: 2/wafer or 11/lot
  - Sample Decap: required for proton irradiation, unless proton energy high enough

Introduction

The equivalent test particle fluence Φ(E)eff :

$$\Phi(E)eff = \frac{DDspecification}{NIEL(E_{test})}$$

$DD_{specification} = D_{DD} \times RDM$, E_{test} is the particle energy used to test

DDD is the Displacement damage dose in space:

$$D_{DD} = \int_{E_{MIN}}^{E_{MAX}} NIEL(E)\, f(E)\, dE$$

NIEL(E) is non-ionizing energy loss, *f(E)* is particle differential energy spectrum in space, E_{MAX} and E_{MIN} are the maximum and minimum particle energy in space.

Introduction

Based on the basic theory of Displacement Damage Dose equivalent, the equivalent test fluence can also be calculated:

$$\Phi(E)eff = \frac{\Phi(E1) \bullet NIEL(E1)}{NIEL(E_{test})}$$

$\Phi(E1)$ is the fluence of particle with energy E1

NIEL(E1) is the NIEL of particle with energy E1

NIEL(Etest) is the NIEL of particle used to test

Introduction

- Question:
  - Is displacement damage test methodology applicable to all devices (Silicon, compound device (GaAs ……)) ?
  - How to select particle energy to test?
  - How to considering cooperation of total ionizing dose?
- The purpose of the presentation is to give some experiment results and recommendation.

Outline

- Introduction
- Experiment and Results
- Discuss
- Summary

Experiment

➢ Experimental Samples

Type	Model	note
optocoupler	GH302A	LED: GaAlAs Phototransistor: Silicon
optocoupler	GH302	LED: GaAlAs Phototransistor: Silicon
Solar cell	solar cell	GaAs Single Junction
transistor	2N2222	silicon NPN

- GH302A and GH302 are from different manufacture
- All samples are not radhard

Experiment

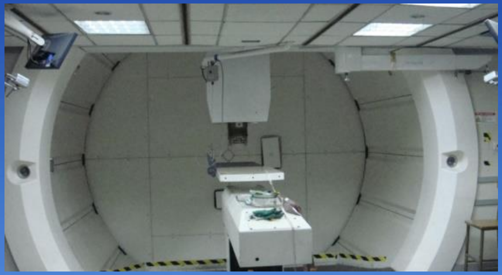
➢ Source:

- Proton

  17, 20, 40, 70, 190MeV proton. Accelerator at PSI, Switzerland and Zibo Wanjie Hospital, China

- Neutron

  Reactor. equivalent 1MeV neutron



- Co-60 γ-ray.

  γ-ray produces little displacement damage. It is used to study the effect of TID

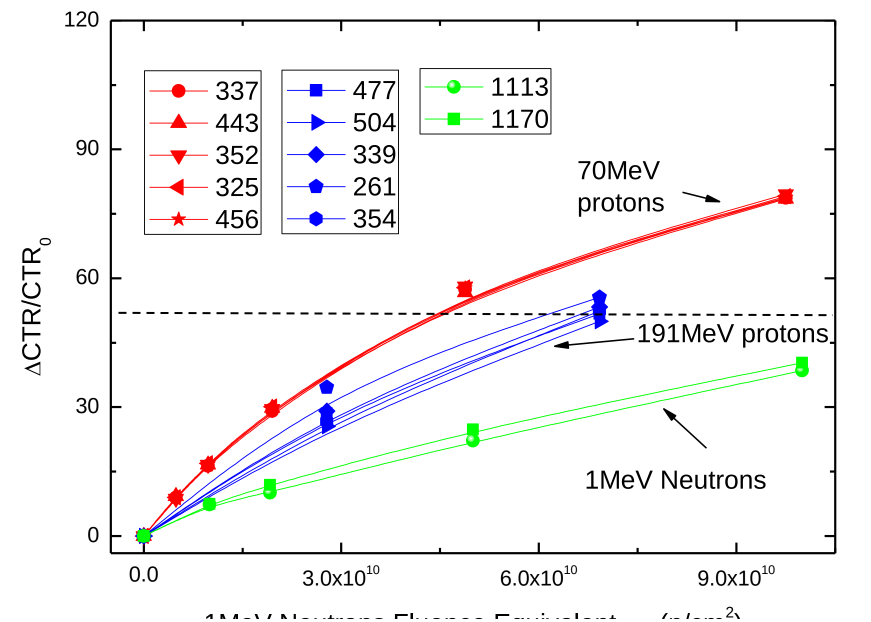
Experiment

- Bias condition during irradiation
  - Most unbiased
  - Some samples: biased in order to study bias effect
- Decap
  - Transistor: delidded
  - solar cell: no cover glass
  - Optocoupler: no delided

Experiment Results

- Different DDD level of GH302 optocoupler is obtained by different particles and different particle energy.

Radiation Source	DDD Level 1MeV n/cm^2
70MeV Proton	3x10^{10}
191MeV Proton	4x10^{10}
Neutron	9x10^{10}



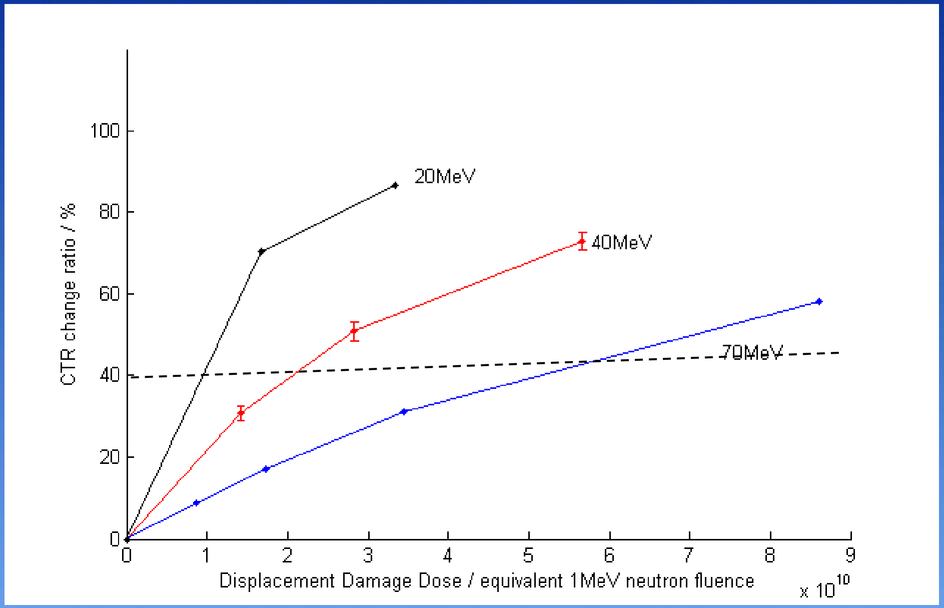
GH302 CTR via displacement damage dose

- 3×10^{10},4×10^{10},9×10^{10} 1MeV•n/cm2 of DDD level are obtained by 70MeV,191MeV and Neutron for the same optocoupler.

Experiment Results

➢The test results of optocouplers GH302A

- Different DDD level is obtained for the same optocoupler by different energy proton.
- Low DDD level is given by low energy proton

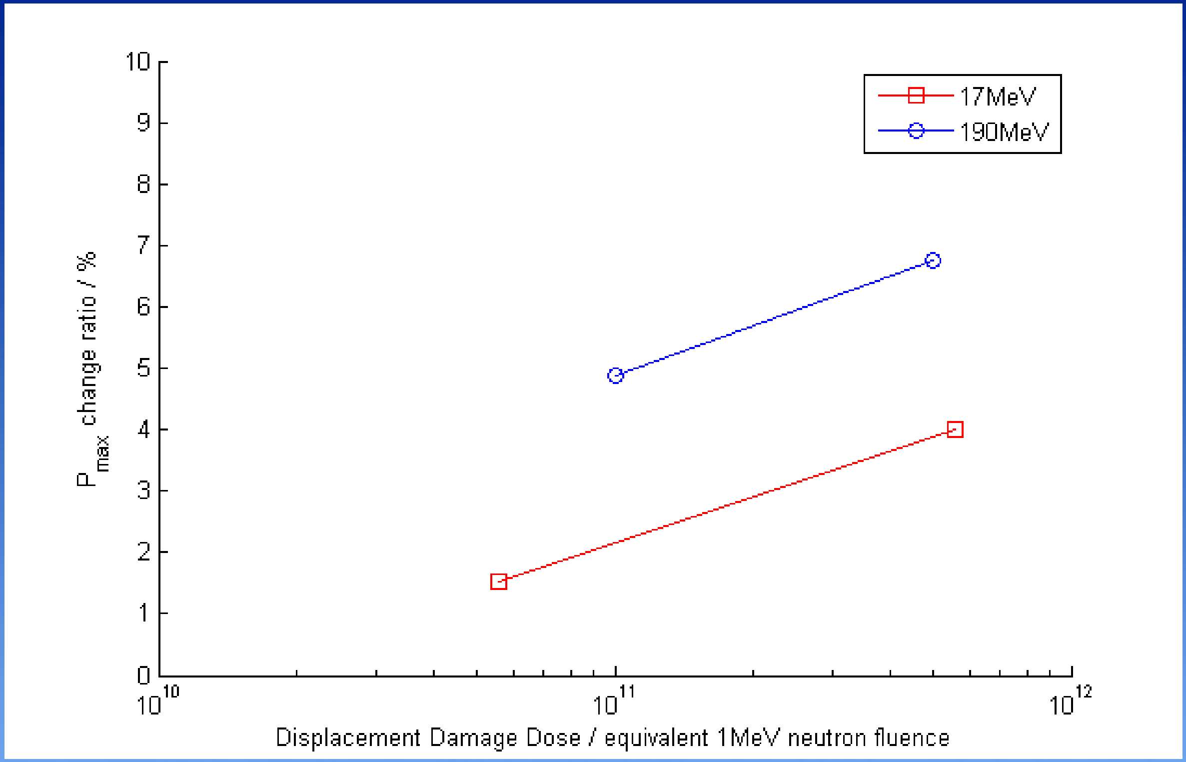


Optocouplers GH302A CTR change via incident proton

Experiment Results

The test results of GaAs Solar cell are the same:

Low DDD level is obtained by low-energy proton

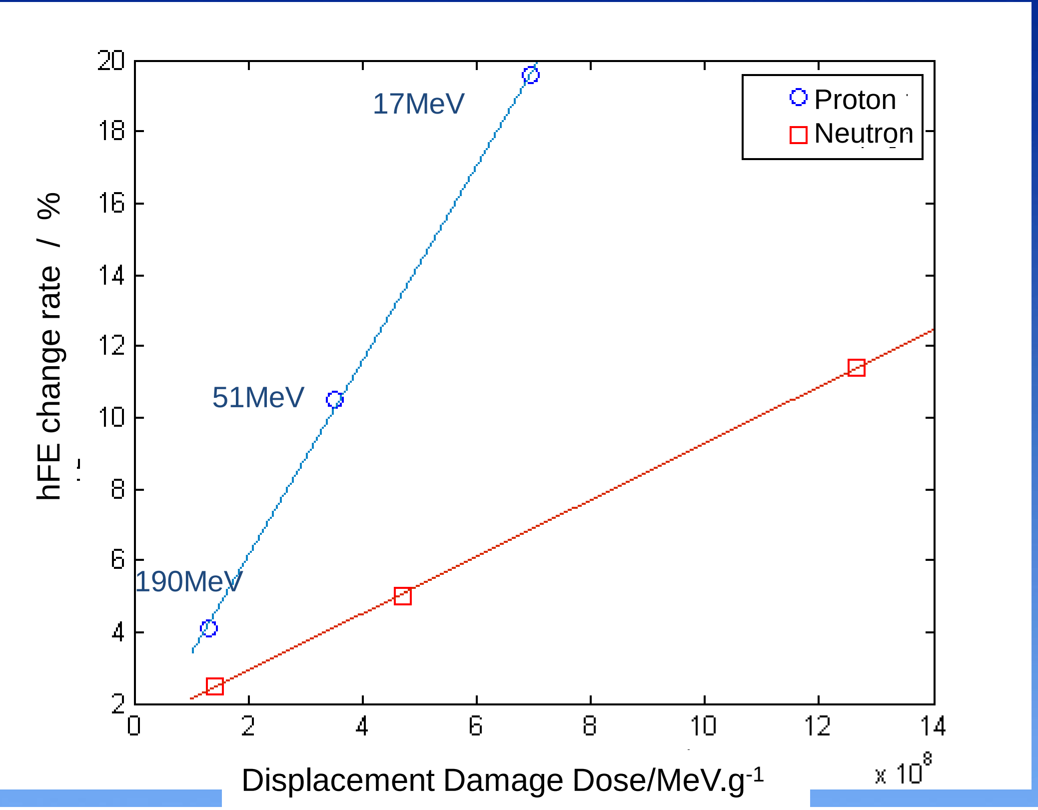


solar cell maximum output power via displacement damage dose

Experiment Results

➢ Results of silicon transistor:

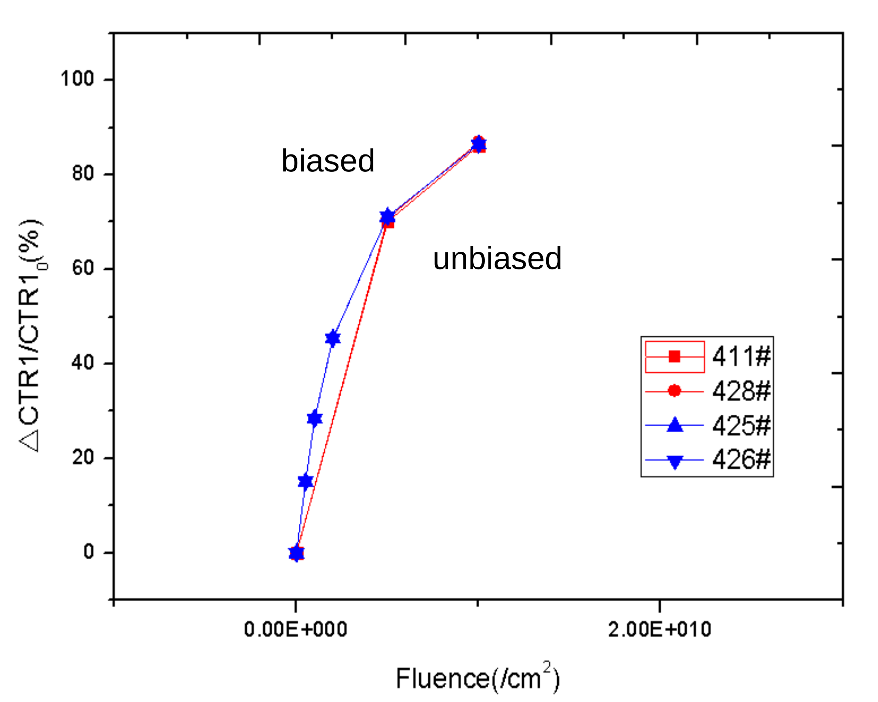
- A linear relationship between degradation and displacement damage dose
- more degrade by protons than by neutrons



2N2222 HFE change via displacement damage dose

Experiment Results

Experimental result shows no bias effect. No obvious degradation recover after 168h~2y room temperature annealing.



Optocoupler GH302 Irradiated under bias & unbiased

GH302 CTR degradation during irradiation and annealing

Measurement step		CTR degradation
Flux /cm2	0	0%
	5.00E+09	8.7%
	1.00E+10	17.0%
	2.00E+10	31.0%
	5.00E+10	58.1%
	1.00E+11	79.2%
Room temperature annealing	168h	78.4%
	2years	78.9%

➢Unbiased condition and 24h or 168h measurement time are acceptable

Outline

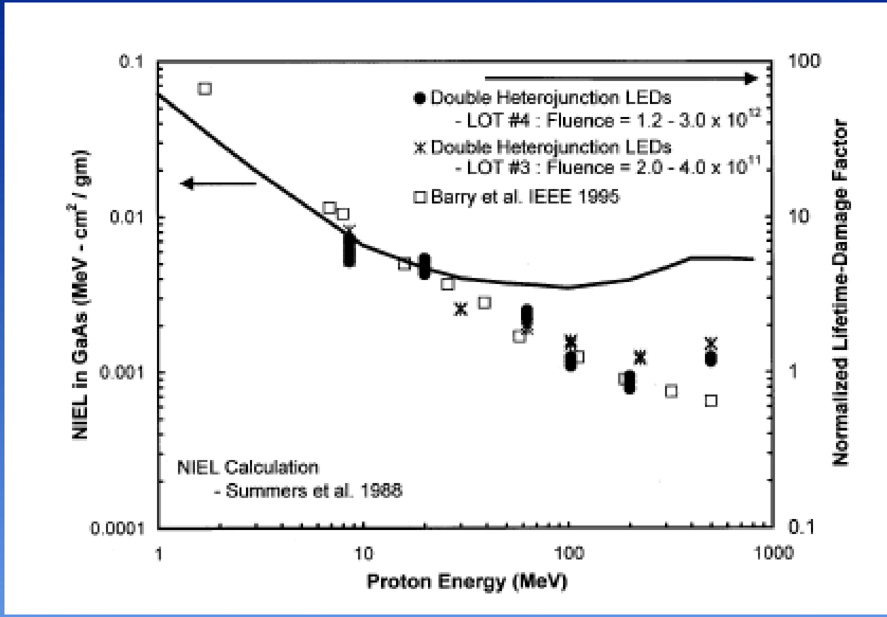
- Introduction
- Experiment and Results
- Discuss
- Summary

Discuss

➢ Different DDD levels are obtained by different energy proton (20,40,70,190MeV) for GaAlAs LED and GaAs solar cell.

➢The experiment results agree with Reed Report:

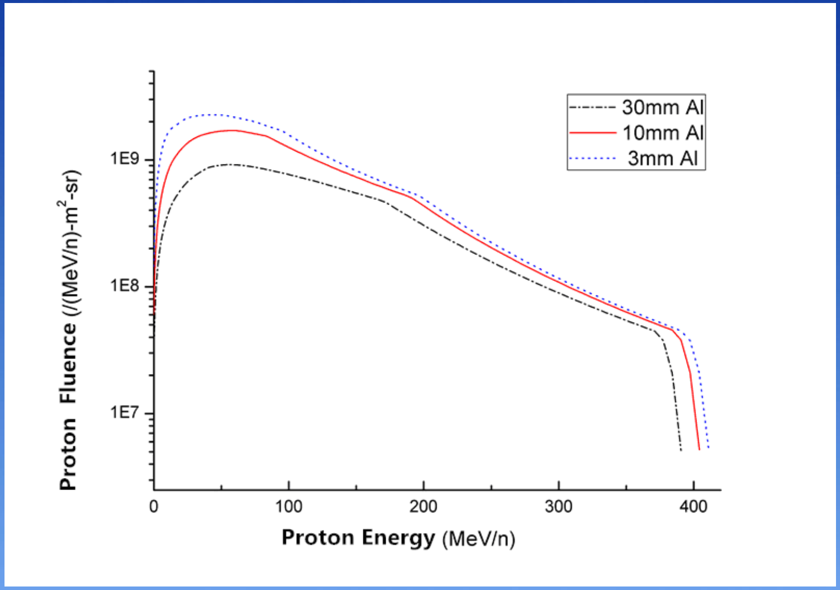
•At high energy, NIEL no more keep the same relationship with degradation.



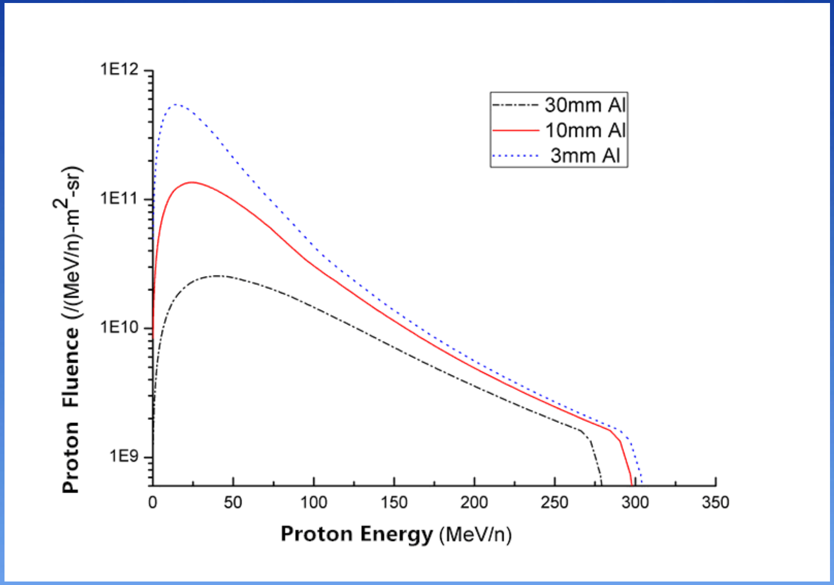
R. A. Reed, et al. IEEE Nuc. Sci. 47(6), Dcember 2000:2492-2499

Discuss

The space radiation environment is different at different orbit. The proton energy should be selected according the proton energy spectrum in spacecraft.



a) LEO



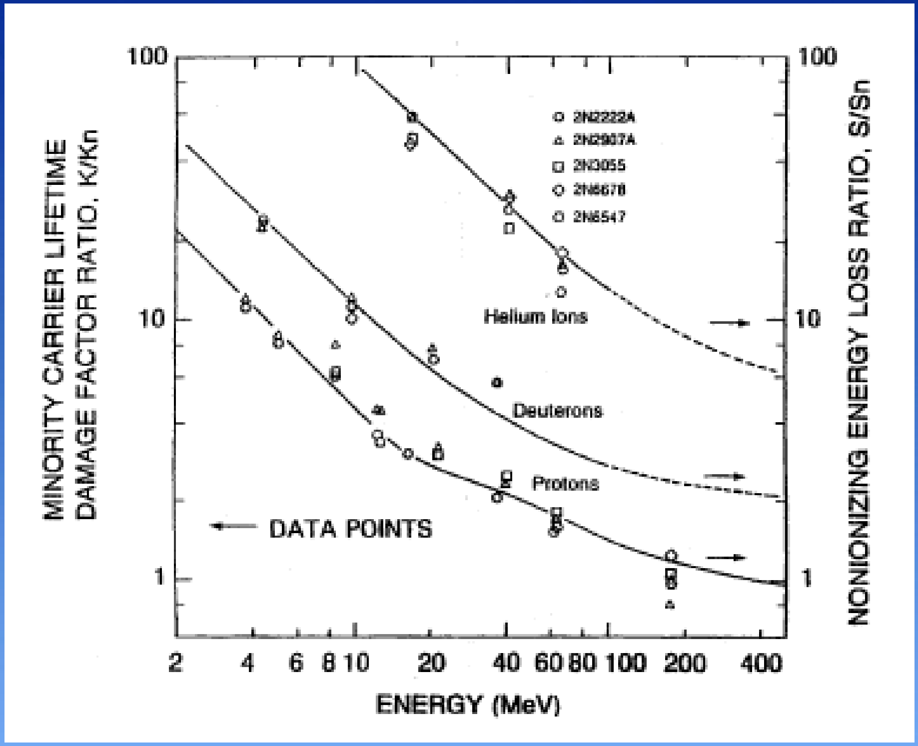
b) GEO

Proton differential energy spectrum in orbit

Discuss

- For silicon device, the degradation shows relationship with displacement damage dose.

- The experiment results agree with SUMM Report:
  - For Silicon devices, NIEL keep relationship with degradation.



Discuss

- Experiment results show that different DDD level can obtained by proton and neutron
- Proton is preferred to perform ground DDD test
- Neutron may gives underestimate test results.

Discuss

same time：TID+DDD

e p e p e p e p

Discuss

➢ To investigate total ionizing dose effect, two tests are performed

1) Proton irradiation

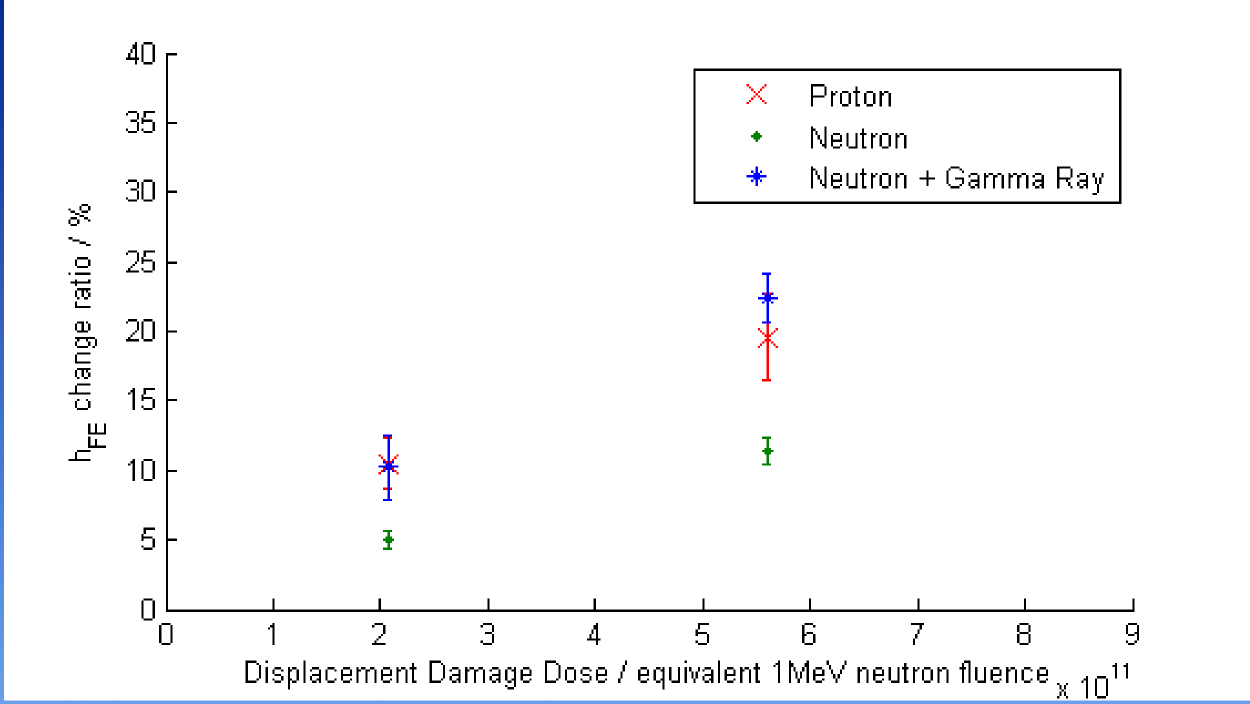
2) γ-ray irradiation + neutrons irradiation: First irradiated by γ-ray, then irradiated by neutrons

Proton (equivalent 1MeV neutron/ cm^2)	γ-ray+ neutrons	
	γ-ray	neutrons
2.07×10^{11} (51MeV)	15.6krad(Si)	2.07×10^{11}
5.56×10^{11} (17MeV)	36.9krad(Si)	5.56×10^{11}

Discuss

Test results approve TID contribution!

- TID and DDD should be evaluated at the same time.
- The test samples should be same ones.



2N2222 HFE degrade via incident particle dose

- The DDD and TID qualification test samples are now in different subgroup.
- The qualification test samples should be in the same subgroup.

TABLE V. Group E (RHA) TCI/QCI test for class Q, class V and class Y.

Subgroups	Tests 1/ 2/	MIL-STD-883 test method and conditions Minimum sample size quantity (accept no.)		
		Class Q (class level B)	Class V (class level S)	Class Y (class level S)
Subgroup 1 3/ 4/	Neutron irradiation test (Displacement Damage test)			
	a. Qualification test	a.TM 1017 at 25°C 2(0) devices/wafer or 5(0) devices/wafer lot or 11(0) devices/inspection lot 5/	a.TM 1017 at 25°C 2(0) devices/wafer or 11(0) devices/wafer lot 6/	a.TM 1017 at 25°C 2(0) devices/wafer or 11(0) devices/wafer lot 6/
	b. QCI/TCI test	b. TM 1017 at 25°C 2(0) devices/wafer or 5(0) devices/wafer lot or 11(0) devices/inspection lot 5/	b. TM 1017 at 25°C 2(0) devices/wafer or 11(0) devices/wafer lot 6/	b. TM 1017 at 25°C 2(0) devices/wafer or 11(0) devices/wafer lot 6/
	c. Endpoint electrical parameters test	c. As specified in accordance with device specification	c. As specified in accordance with device specification	c. As specified in accordance with device specification
Subgroup 2 3/ 7/ 9/ 10/	Total ionization dose (TID)			
	a. Qualification test	a. TM 1019 at 25°C maximum supply voltage 2(0) devices/wafer or 5(0) devices/wafer lot or 22(0) devices/inspection lot 8/	a.TM 1019 at 25°C maximum supply voltage 2(0) devices/wafer or 22(0) devices/wafer lot or 1(0) devices/wafer + 4(0) SEC or test structures/ wafer or 5(0)devices/wafer lot + 4(0) SEC or test structures/ wafer	a.TM 1019 at 25°C maximum supply voltage 2(0) devices/wafer or 22(0) devices/wafer lot or 1(0) devices/wafer + 4(0) SEC or test structures/ wafer or 5(0)devices/wafer lot + 4(0) SEC or test structures/ wafer
	b. QCI/TCI test	b. TM 1019 at 25°C maximum supply voltage 2(0) devices/wafer or 5(0) devices/wafer lot or 22(0) devices/inspection lot 8/	b.TM 1019 at 25°C maximum supply voltage 2(0) devices/wafer or 22(0) devices/wafer lot or 1(0) devices/wafer + 4(0) SEC or test structures/ wafer or 5(0)devices/wafer lot + 4(0) SEC or test structures/ wafer	b.TM 1019 at 25°C maximum supply voltage 2(0) devices/wafer or 22(0) devices/wafer lot or 1(0) devices/wafer + 4(0) SEC or test structures/ wafer or 5(0)devices/wafer lot + 4(0) SEC or test structures/ wafer
	c. Endpoint electrical parameters test	c. As specified in accordance with device specification	c. As specified in accordance with device specification	c. As specified in accordance with device specification

Summary

1) The different DD level may be obtained by different particles.
2) Proton is preferred. The energy of proton should be selected based on the proton energy spectrum inside of the spacecraft.
3) Neutron may gives underestimate test results.
4) TID and DDD should be tested on the same group samples.

Thank for your attention!

This work is partially supported by the National Nature Science Foundation of China 11475256.