ナノブリッジFPGAの加速器実験応用検討

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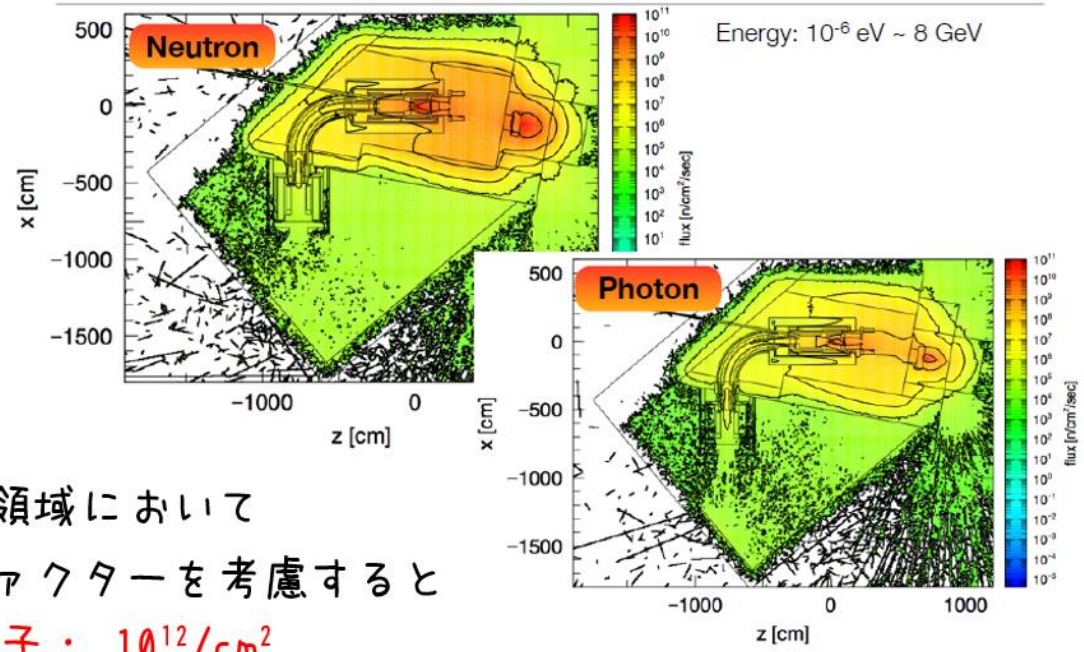
もくじ

- モチベーション
- ナノブリッジFPGA
- 放射線照射試験
- 今後に向けて

（個人的）モチベーション

COMET実験における放射線量

- PHITSによる計算for Phase-I実験



検出器領域において

安全ファクターを考慮すると

中性子： 10^{12}/cm^2

ガンマ線： 1 kGy (200days)

の放射線に耐えられる必要あり

この結果をベースに検出器・エレキパーツ等の対策を考えた

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某セミナースライドより

COMET Phase-II実験はさらに
放射線量が厳しい

早めに対策をうっておきたい

（これまでの対策については
吉田氏発表のとおり）

将来に向けて

- COMET Phase-IIにおいてはさらなるビームの大強度化を予定
- ぼちぼち手を打ちはじめておいた方が良い
- （他の実験でも同じような問題はある）

一例として・・・

ナノブリッジFPGAの応用検討

ナノブリッジFPGA

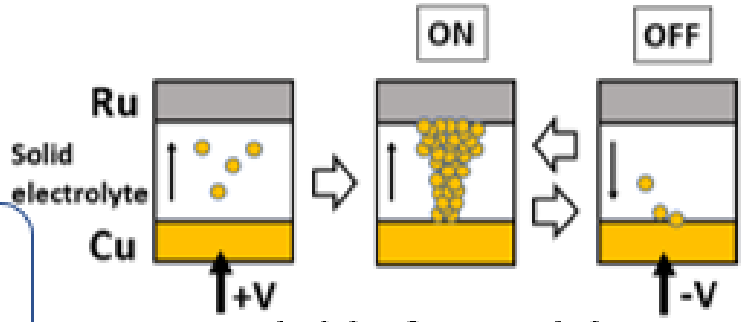
2. Atom switch-based FPGA (AS-FPGA)

Atom switch (AS)

Conductive bridge is formed in polymer solid electrolyte between inert Ru and active Cu electrodes.

Specification

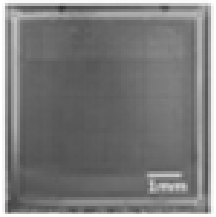
resistances : ON/OFF ~ 2k/200M Ω
# of rewriting times : >10^3
retention time : > 10 years
Switch capacitance : < 0.2 fF
SEU free in principle



Principle of atom switch

AS-FPGA

AS was successfully applied in FPGA for its routing switch and look-up tables [1,2]. AS FPGA was already irradiated with heavy ion and pulsed laser, and the SEU tolerance was confirmed [3].


Photographs of AS-FPGA

Typical spec. of AS-FPGA

Item	Spec.
LUT	33,792
Flip Flop	33,792
BRAM	768
SRAM size	1,536 kbit
rated vol.	1.1V
IO vol.	1.8V
AS bit	50 Mbit
process	40nm

For the accelerator experiment,
more studies with the higher radiation environment are needed.

IEEE NSS 2021 ポスターより

NanoBridge FPGA

- Features
  - Rad-hard (error rate < 1/100)
  - Low power consumption (< 1/10)
- Current status
  - irradiation test with heavy ion and pulsed laser
  - verification test on satellite

In principle OK for our purpose

We need to **confirm feasibility**.

- tolerance to very high radiation level
- usability
- etc...

Irradiation tests

Neutron irradiation tests

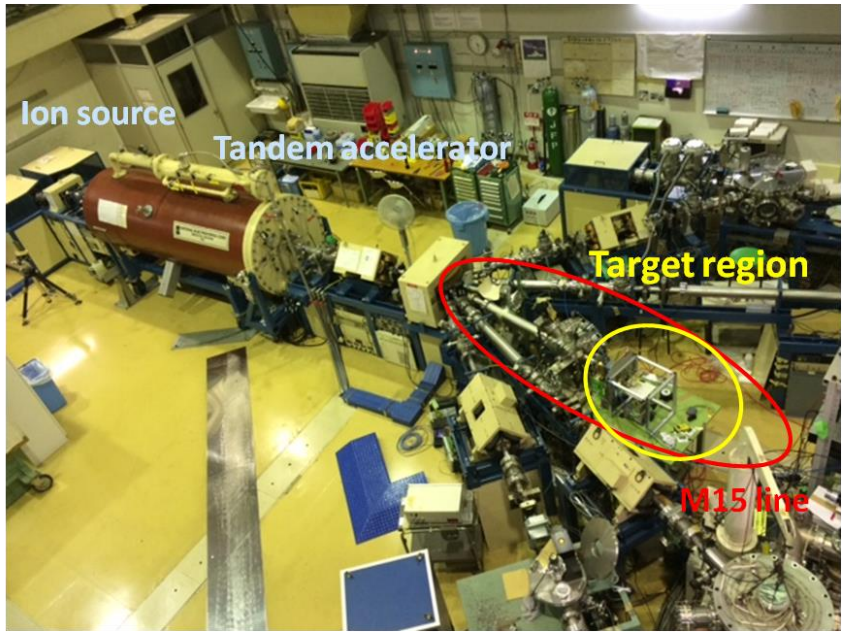
Tandem accelerator @ Kobe Univ.

- Beam : 3 MeV deuteron
- Target : Be (ϕ20 mm)
- Neutron energy : 2 MeV (<7 MeV)
- Flux : 4.9×10^6 Hz/cm^2 @ 10cm from target (beam current = 1 μA)

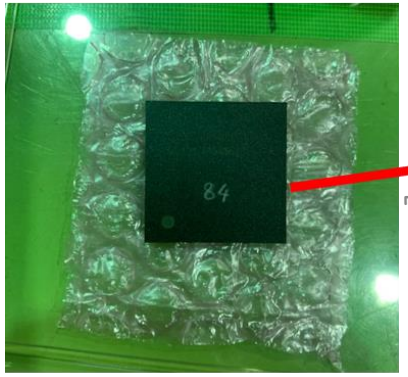
Reactor @ KUR

- Method : Pneumatic Tube
- Rated thermal power : 5 MW
- Neutron energy : broad
- Flux : > 10^{13} Hz/cm^2

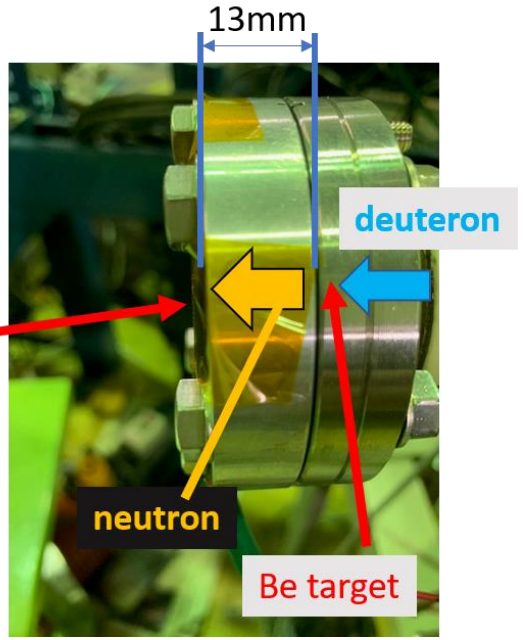
SEU and DDD measurements



Tandem facility



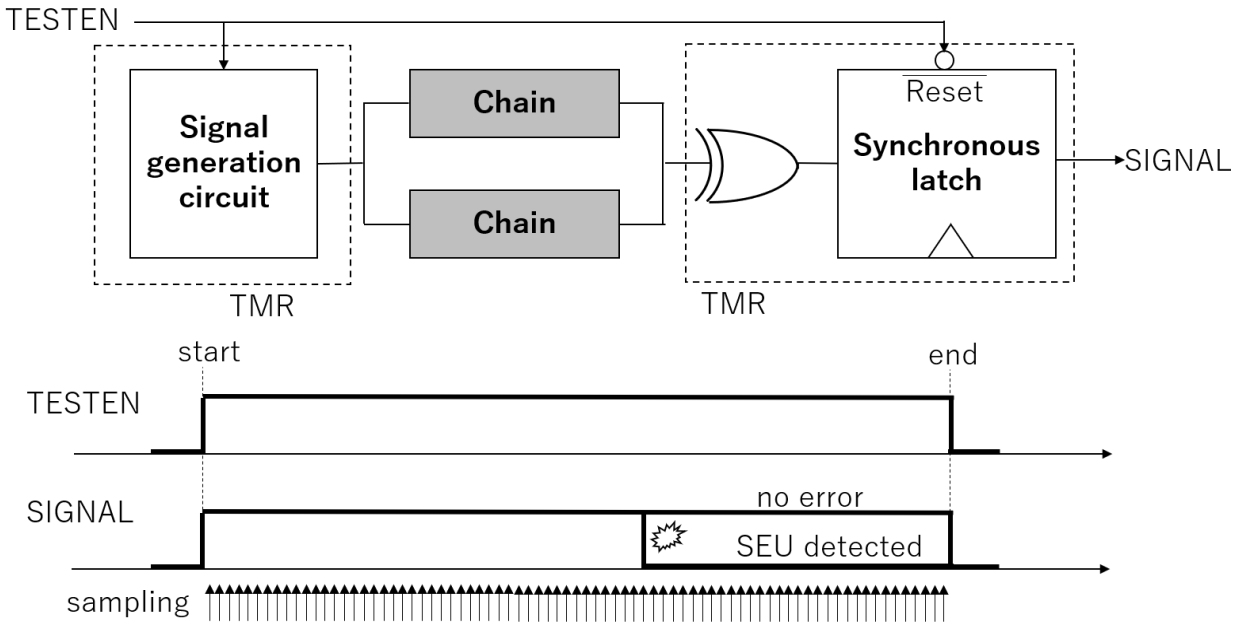
Packaged AS-FPGA



Neutron irradiation tests

SEU counts were measured with 4 types of chains.

NO SEUs were observed in NB!



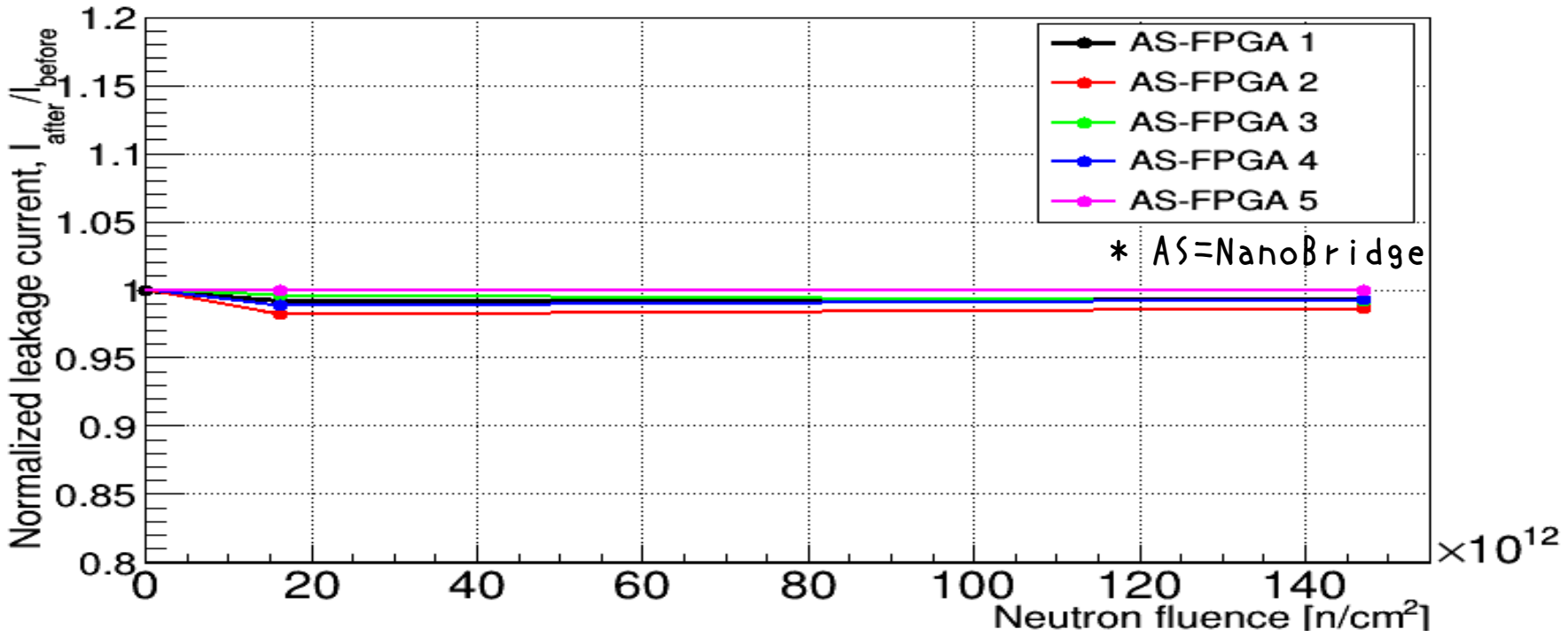
Schematic view of evaluation circuit for SEU

Results of SEU counts

DUT type	Scale	Neutron fluence(n/cm^2)	SEU counts
SRAM	2 kbit	1.6 x 10^{11}	5
NB1	96 CLBs	3.6 x 10^{11}	0
NB2	368 CLBs	1.7 x 10^{11}	0
DFF+AS	468 CLBs	1.5 x 10^{11}	0

Neutron irradiation tests

Leakage current was measured before/after irradiation.



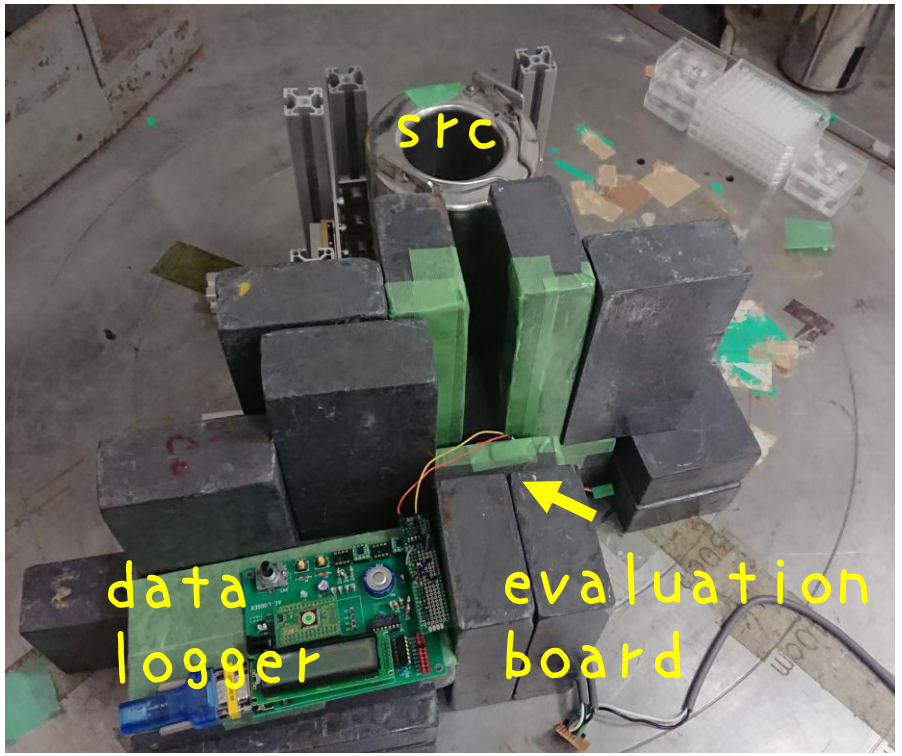
NO DDDs were observed!

Irradiation tests

gamma-ray irradiation tests

RI Center @ Tokyo Institute of Technology & QST

- Src : Co-60
- Dose rate : 500 Gy/h
- Total dose : 10 kGy

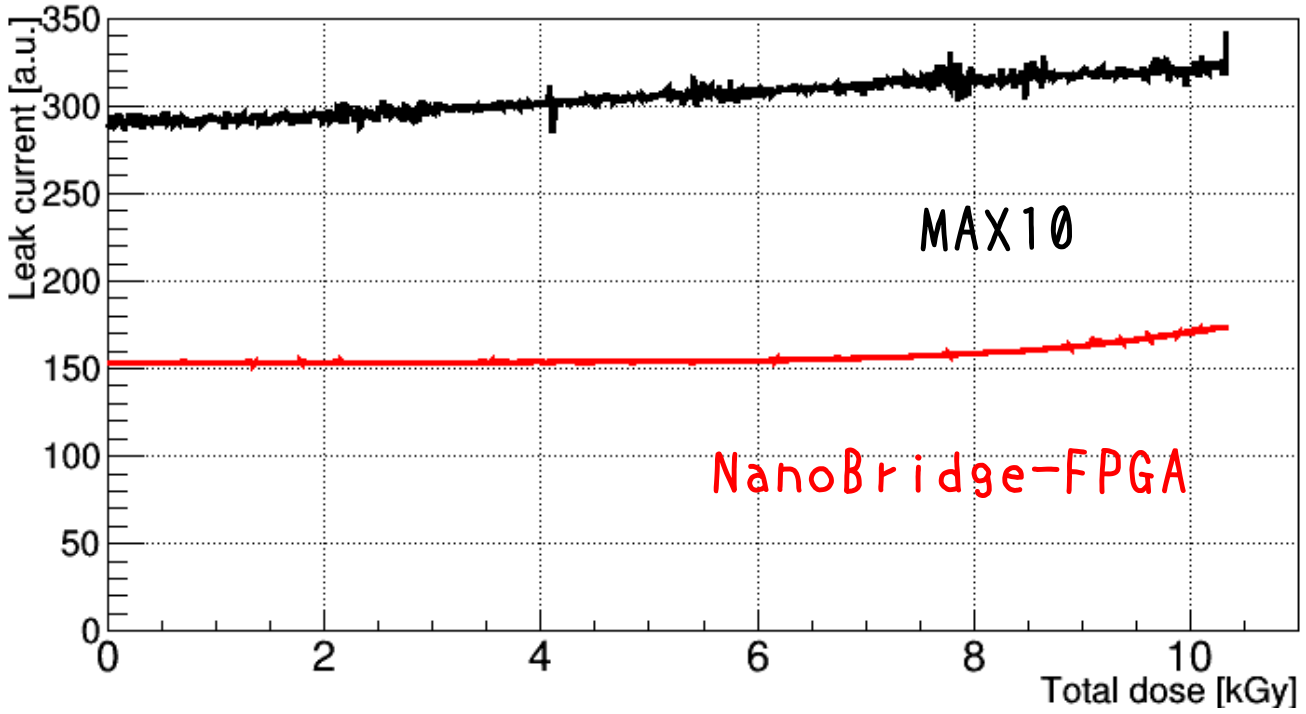


Experimental setup

TID measurements

gamma-ray irradiation tests

Leakage current were measured during irradiation.



NO change was seen up to 6 kGy.

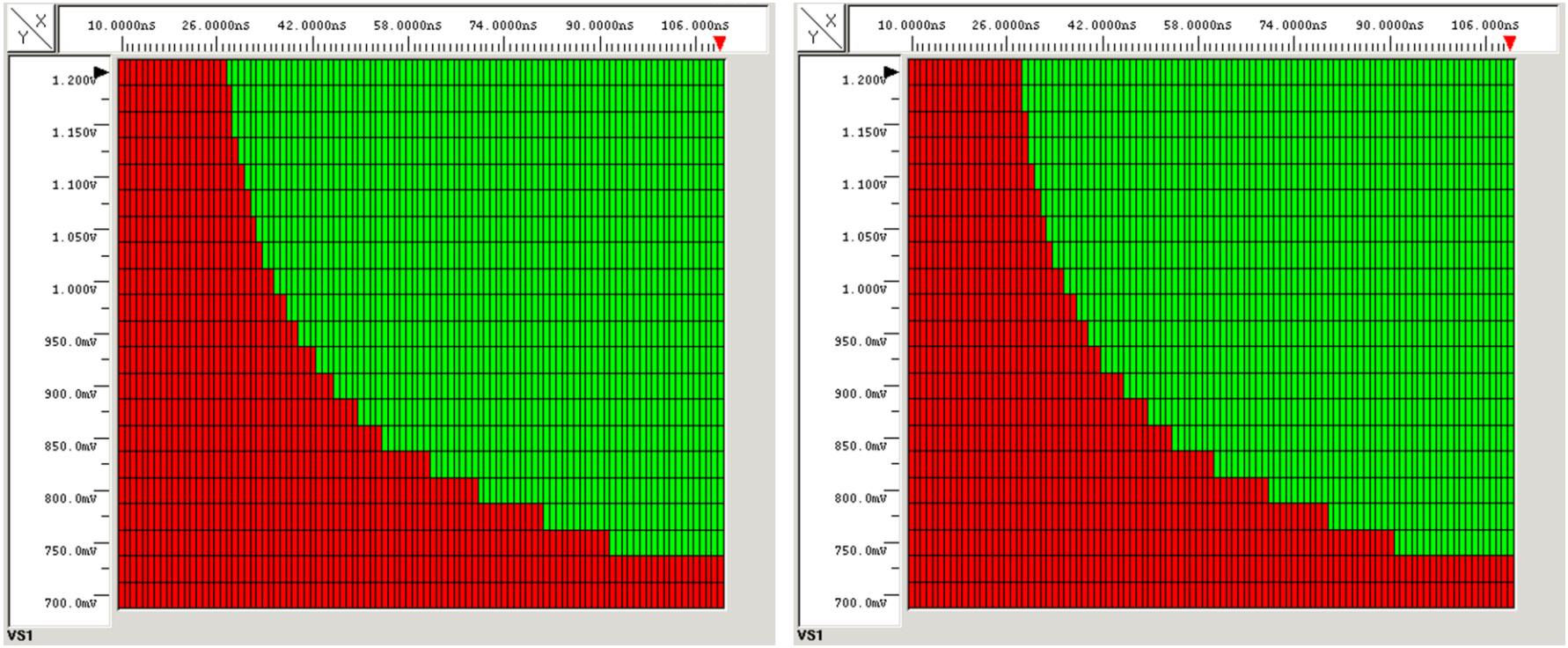
After 6 kGy, leakage current increased slightly due to degradation in CMOS.

gamma-ray irradiation tests

Shmoo plot

before irradiation

after 10 kGy irradiation



NO change in signal delay was seen after 10 kGy irradiation.

Future works

It was found that NB-FPGA had potential to use for our experiment.

- (Irradiation tests with higher level)
- Construction of evaluation board
- and more...
  - usability
  - speed
  - etc...

Let me know if you are interested in the development.

まとめ

- 将来に向けたrad-hard FPGAの検討
- ナノブリッジFPGAの放射線耐性を調査
- 今後開発を進める予定

- 共同で何かやりたい方募集