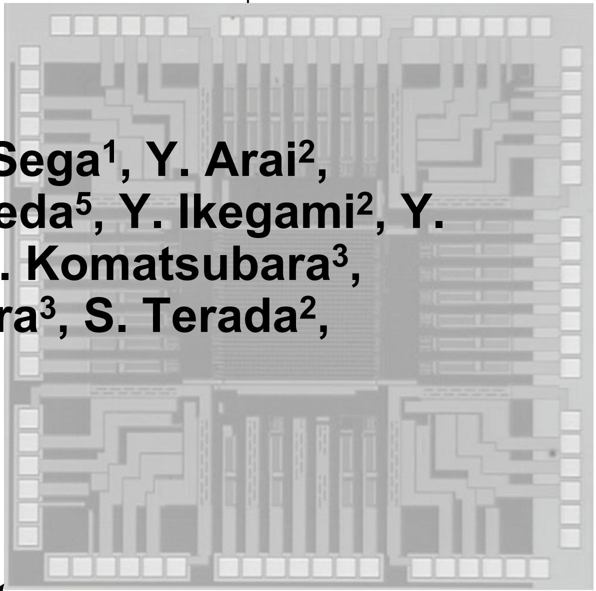
Radiation Resistance of SOI Pixel Sensors Fabricated with OKI 0.15µm FD-SOI Technology



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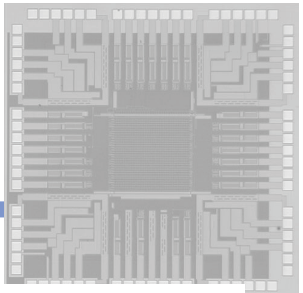


SOI Pixel Detector under development

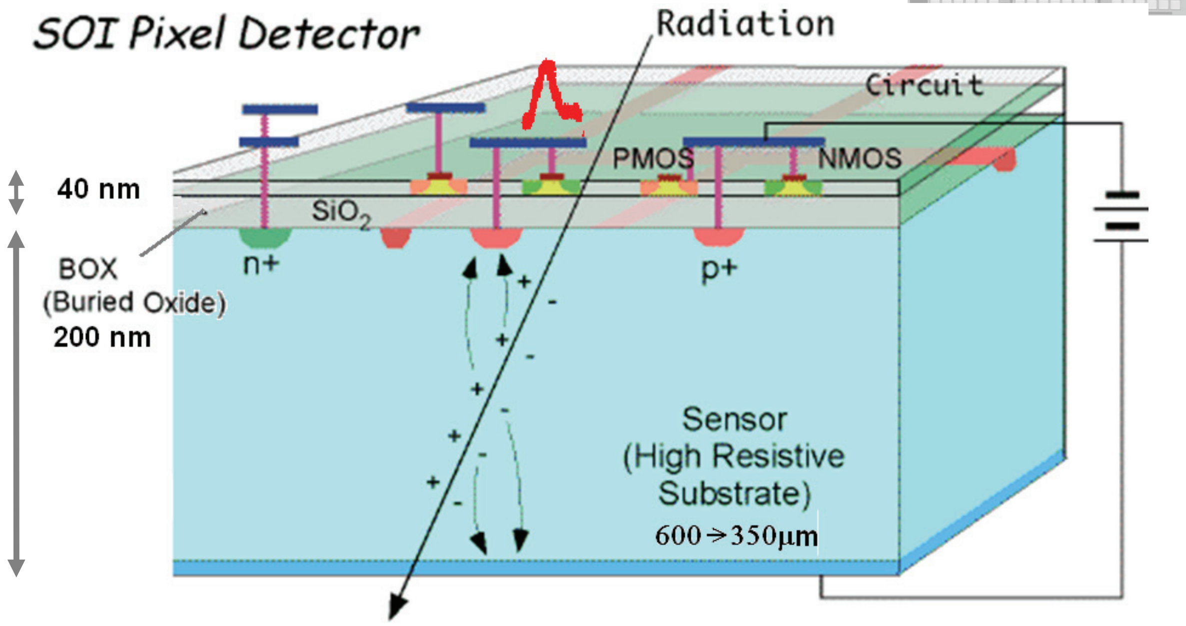
Soitec UNIBOND^{TM} wafer

electronics (p low ρ:18 Ωcm)

sensor (n high ρ:700 Ωcm)

0.15~0.20 μm

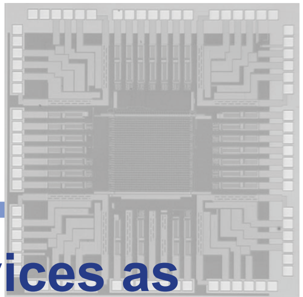
OKI-FD SOI process



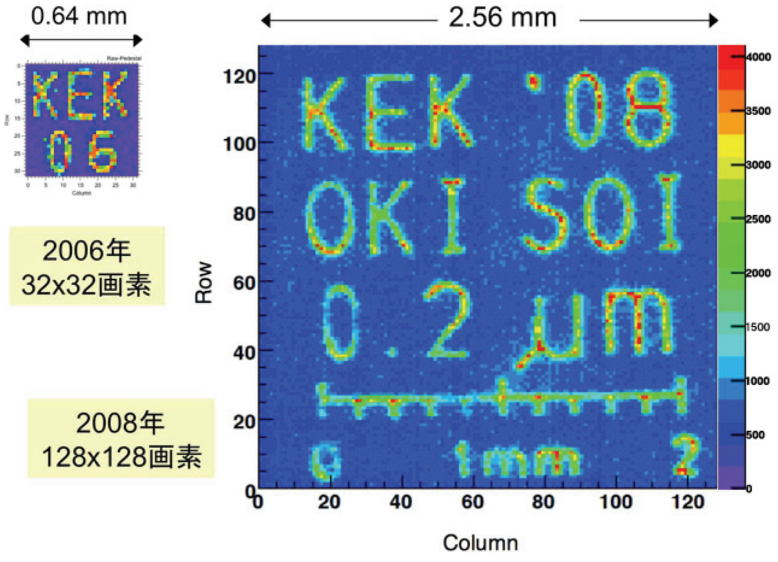
in SOI: BOX isolates the electronics and “handle wafer”(=sensor in our application)

- **small stray cap** **high speed, small power dissipation**
- **complete isolation** **immunity to latch up**
- **bonded SOI** **can optimize resistivity for electronics and sensor**
- **monolithic sensor** **less material, easier in construction**
- **sensitive to positive charges in SiO_2 (radiation damage)**
- **electronics affected by detector bias (back-gate effect)**

SOIPIX Group Activities - history

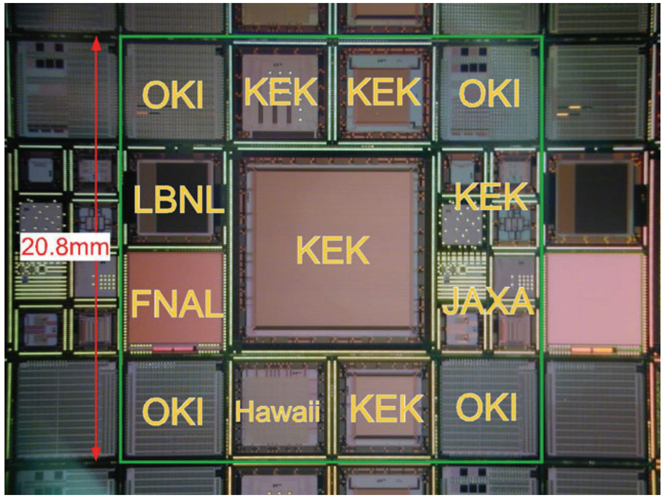


- Group formed in 2005 to develop SOI monolithic pixel devices as KEK-Universities-OKI Electric collaboration
- 1st chips (TOPPIX and other TEGs) in 2006 with 0.15μm
  - develop procedure to fabricate electrodes through BOX
- 2nd round (TOPPIX new, INTPIX, other TEGs) in 2007 with 0.15μm
  - new design/process to suppress early breakdown
  - more reliable electrode fabrication through BOX
- Present round (INTPIX2, CNTPIX, others) with 0.20μm
  - quick performance tests are done. revised sensor delivery in winter

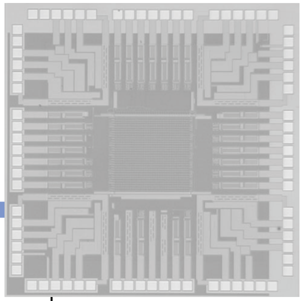


2006年
32x32画素

2008年
128x128画素

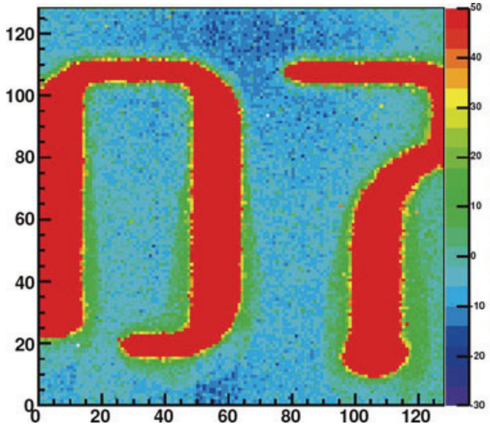


actually, US labs reside together

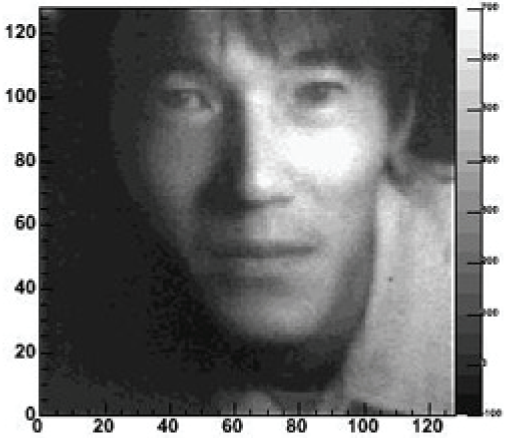


SOIPIX (TOP/INTPIX2) – status and future

- **Detection of visible light confirmed**
- **Detection of X-ray confirmed**



(with a brass mask)

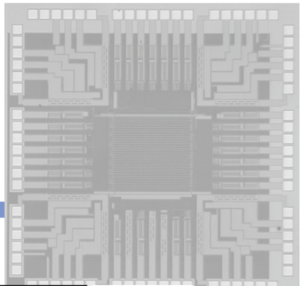


(with a lens in front)

- **Application to HEP (detection of MIP) is limited by**
  - **- applicable bias (130V now), available wafer resistivity (700Ωcm), wafer thickness (350μm)**
  - **- sensitivity to back gate voltage (=detector bias)**
  - **- resistance to radiation**

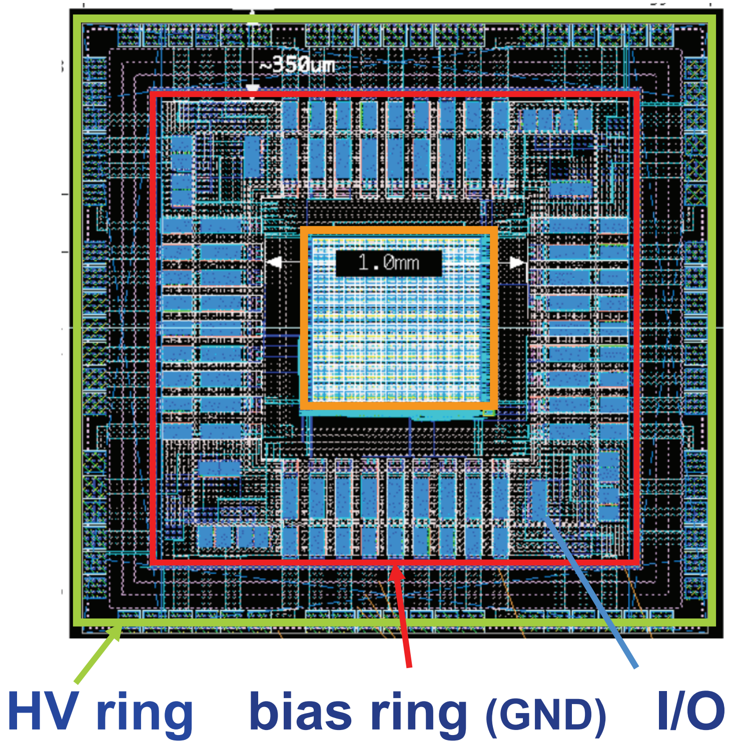
→ irradiated with 70-MeV protons (TOPPIX: 1.2x10^{15} &1.3x10^{16} 1-MeV n/cm^2)

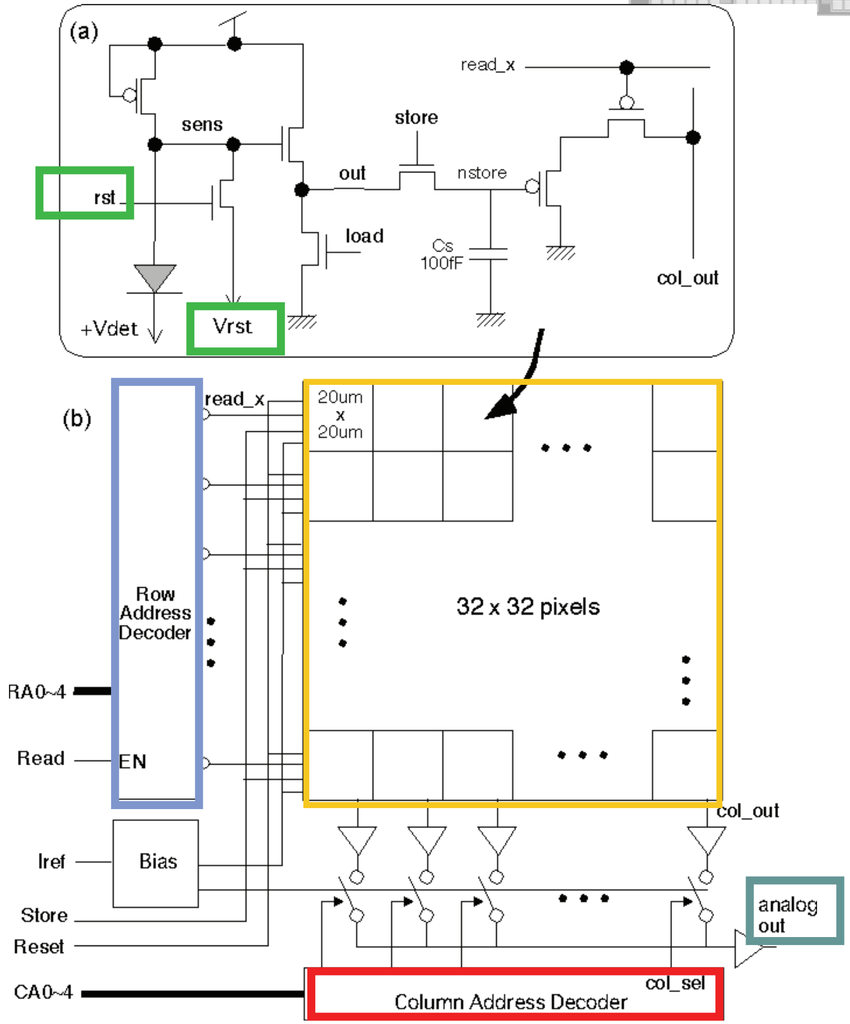
→ irradiated with ^{60}Co (TOPPIX 0.1k~0.6MGy, TrTEG 0.1k~5MGy)



TOPPIX (32x32 pixels each with 20μm square)

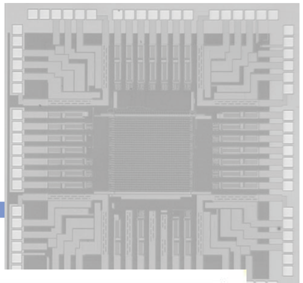
INTPIX2 is a 128x128 version



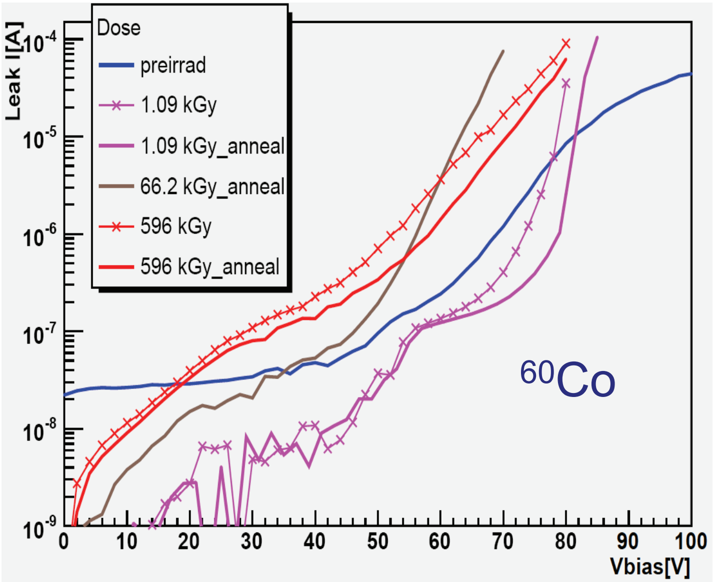


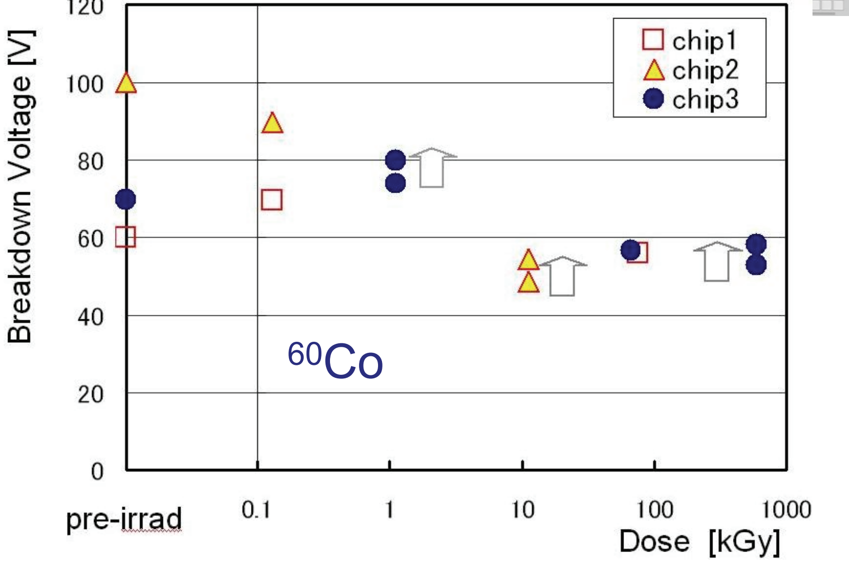
- active pixel sensor
- analog (Aout) selected by row/col addr.
- reset signal used to check the amplif.
- detector biased through HV ring and/or from backside (aluminized)

(1) Leak current (^{60}Co irradiation)

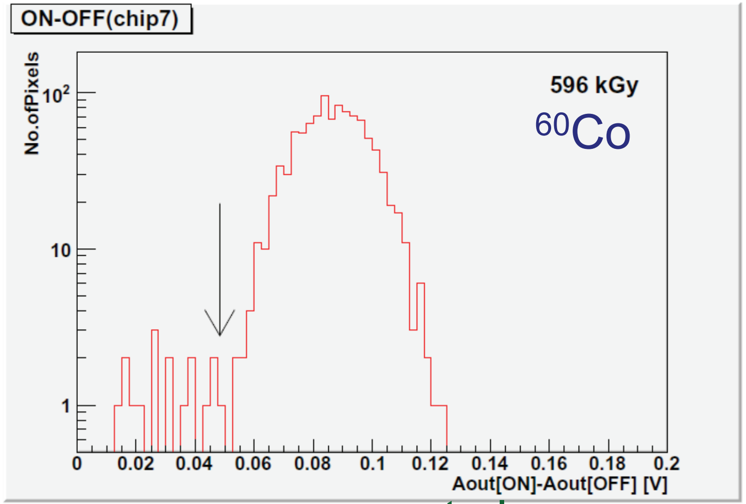


Irradiated with all pins at ground and in room temperature





- breakdown voltage tends to decrease with dose
- no dead channel created after 596 kGy irradiation (response to laser)

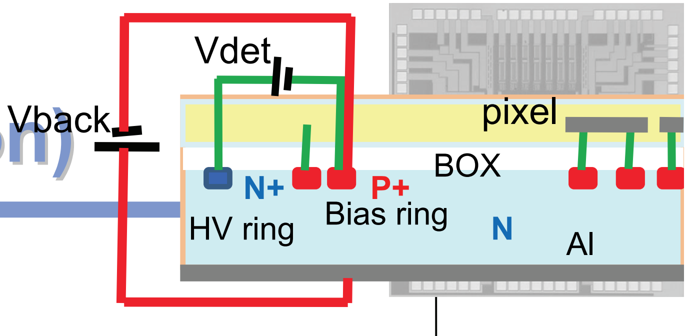


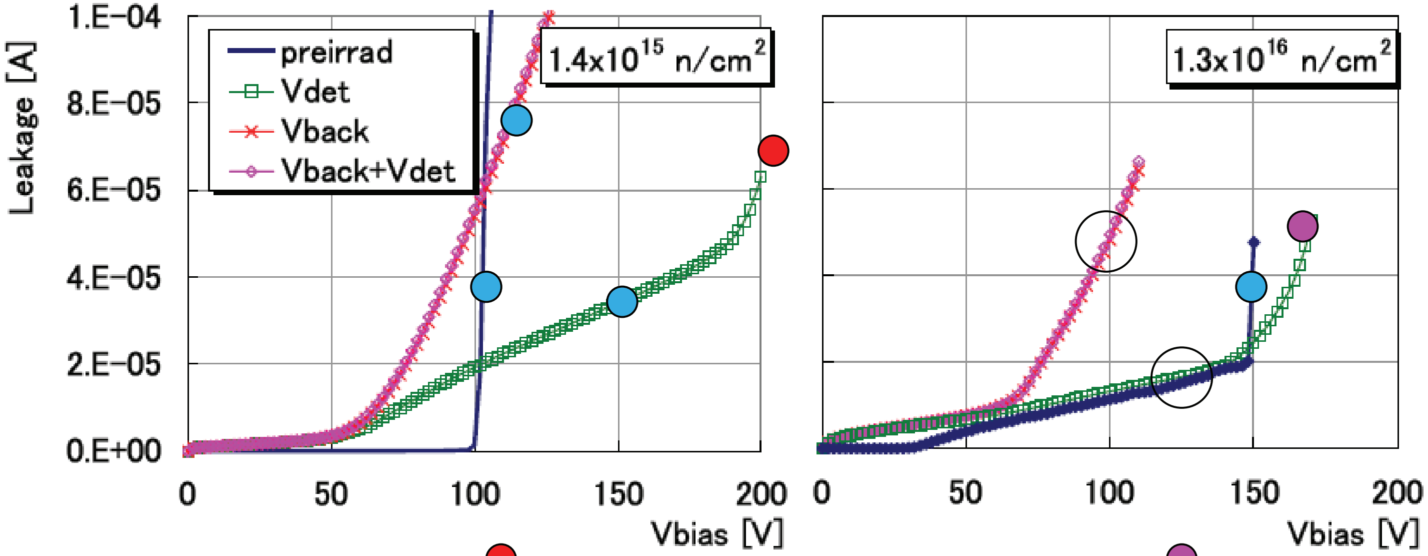
response to laser

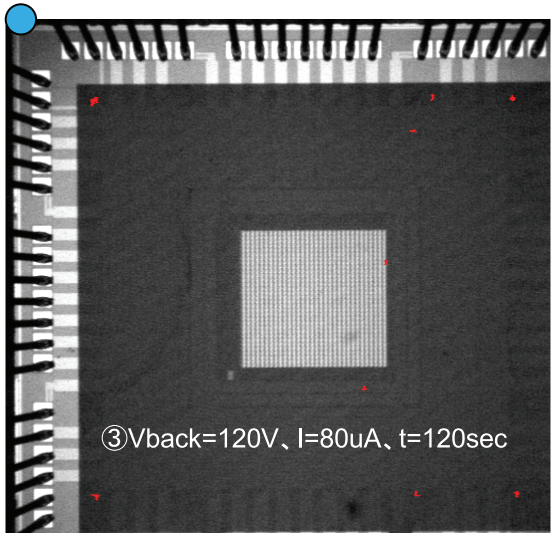
- dead channel fraction (~1%) is improved now to a mil level

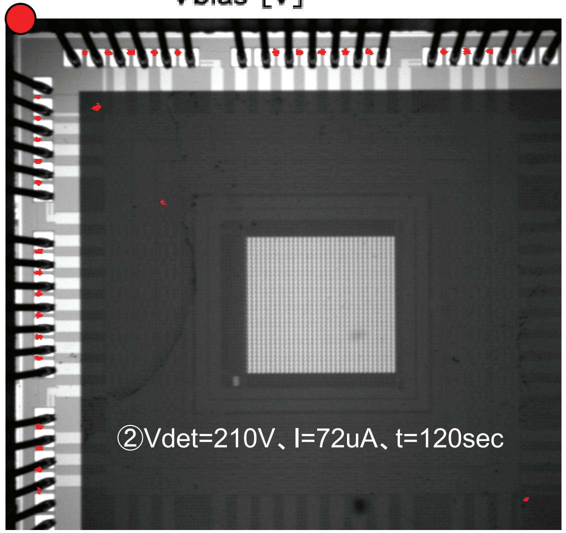
(2) Leak current (proton irradiation)

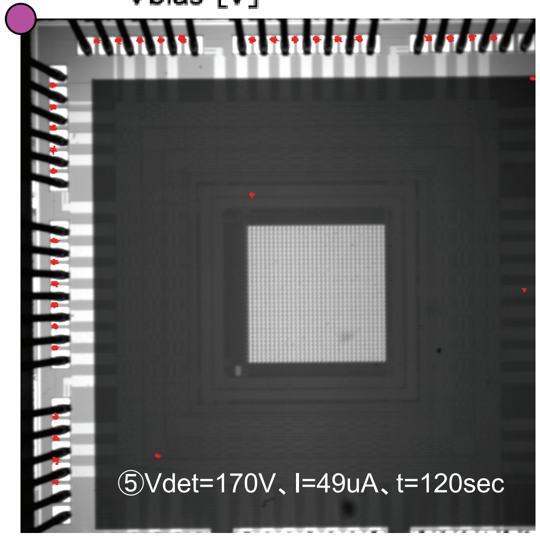
Irradiated with all pins at ground and at -10°C



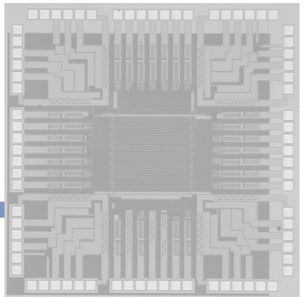


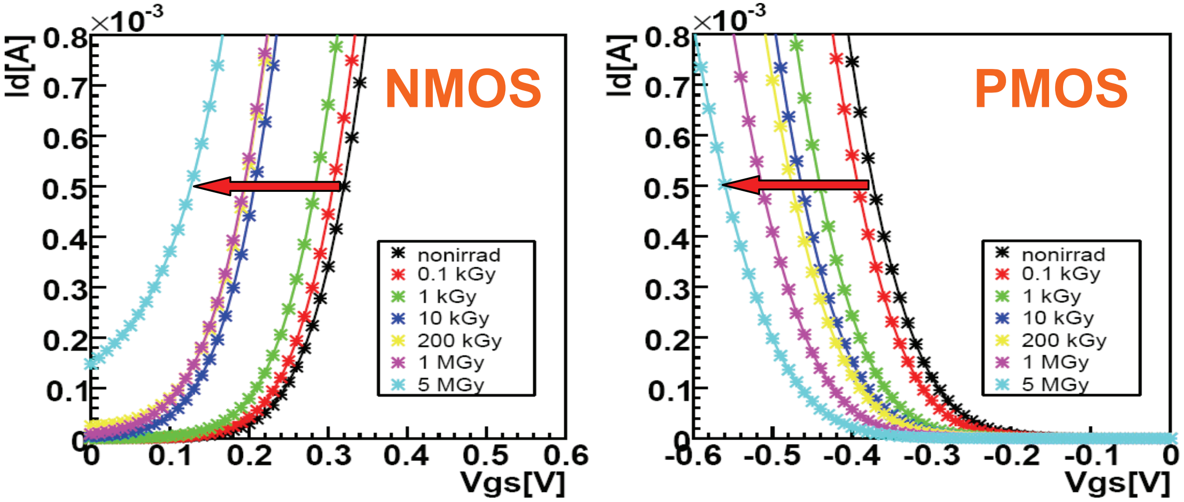

③Vback=120V、I=80uA、t=120sec


②Vdet=210V、I=72uA、t=120sec


⑤Vdet=170V、I=49uA、t=120sec

(3) Transistor Vth shifts (TrTEG)

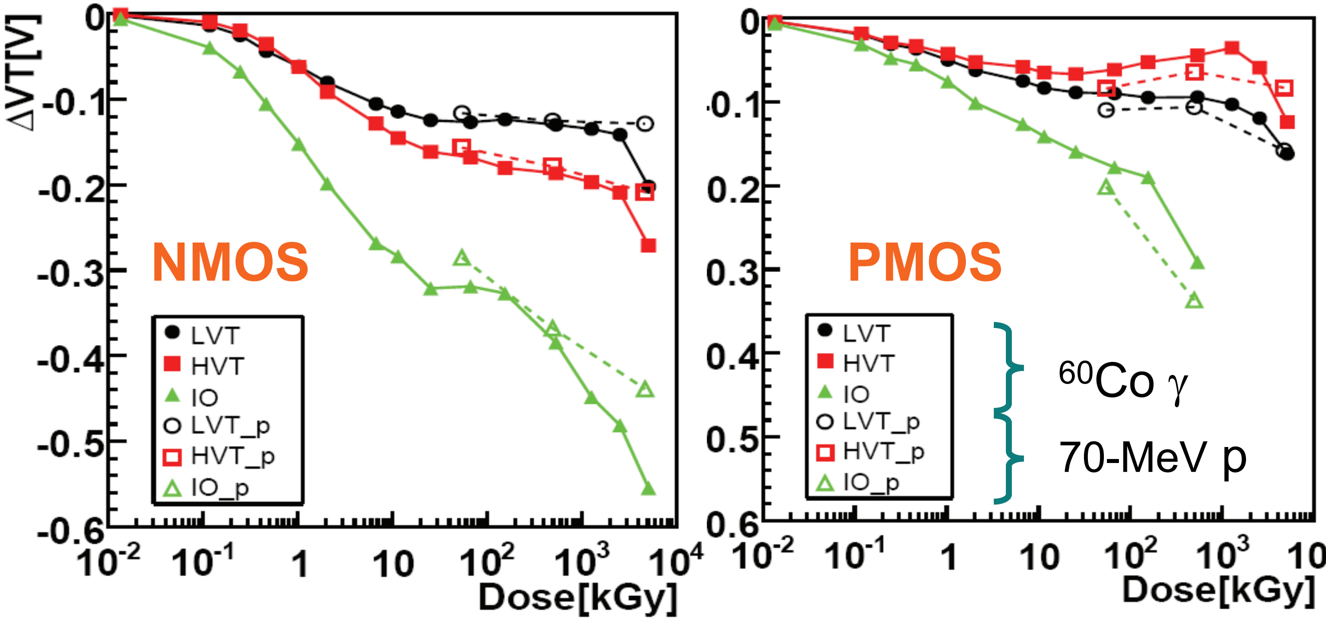




require more negative to cancel the positive charges accumulated in oxide layers

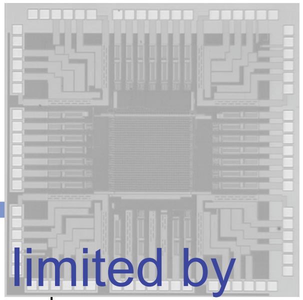
T_{OX}

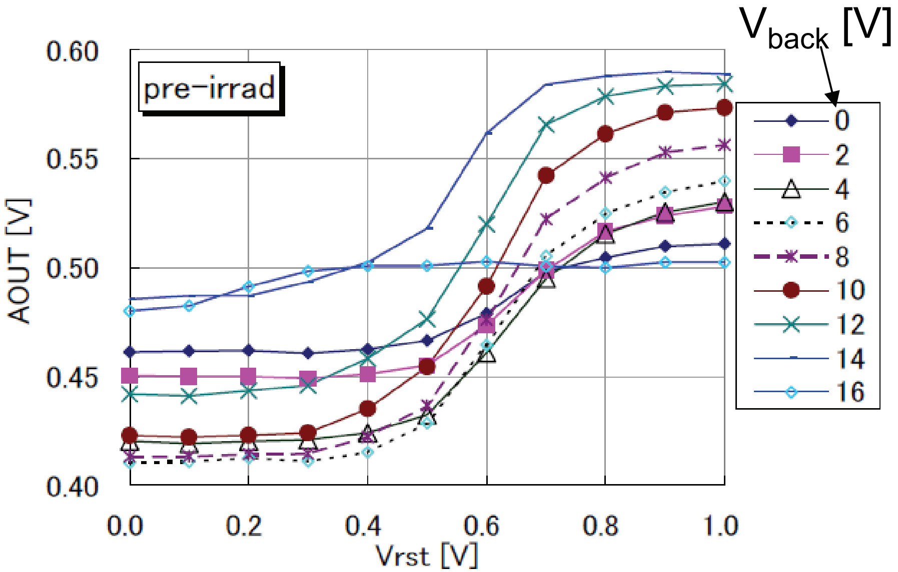
LVT: 2.5nm (Vth~0.2V)
HVT: 2.5nm (Vth~0.4V)
I/O : 5.0nm (Vth~0.5V)



- in reasonable agreement between γ and p irradiation
- Vth shift depends primary on T_{ox}, Vth
- Vth shift saturates above ~10kGy for LVT/HVT

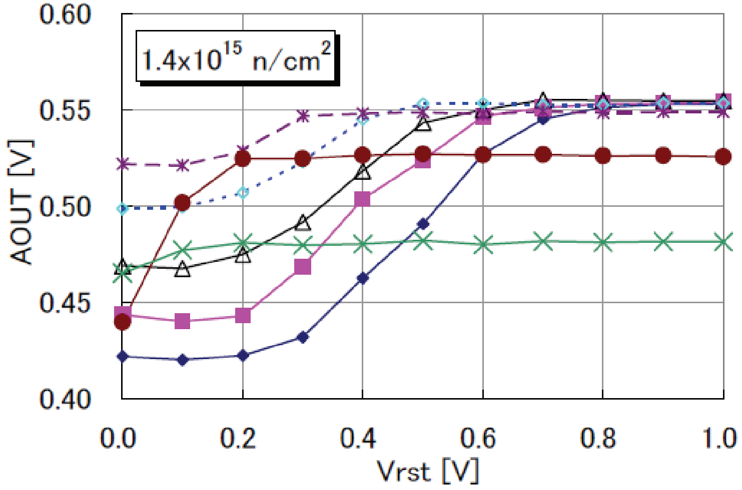
(4) Response to Reset (before and after proton irrad)

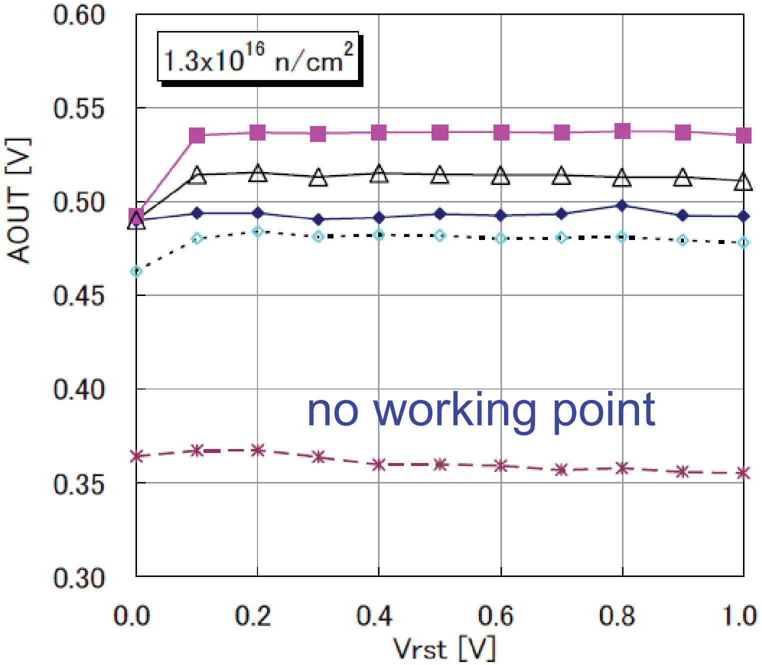




- amplifier performance is limited by back-gate effect
- working region exists after $1.4x10^{15}$ n/cm^2, though narrowed by irradiation
- not working after $1.3x10^{16}$. Rst is not transferred.

(explained by transistor Vth shifts)

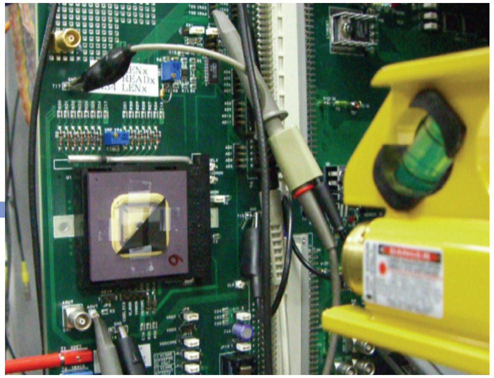




no working point

(5) Response to Laser

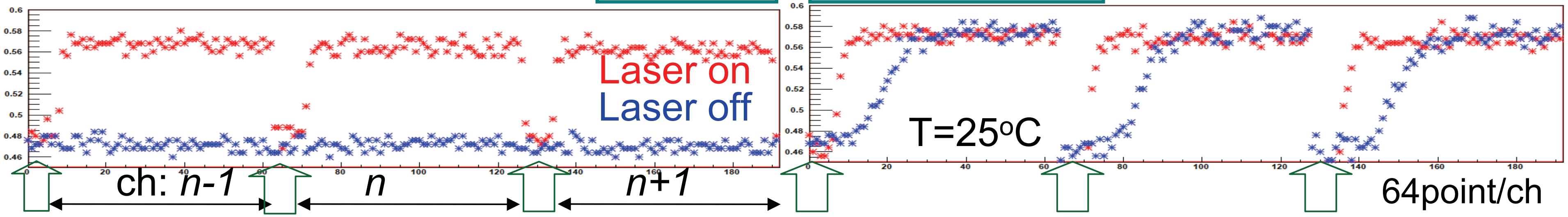
λ=640nm CW

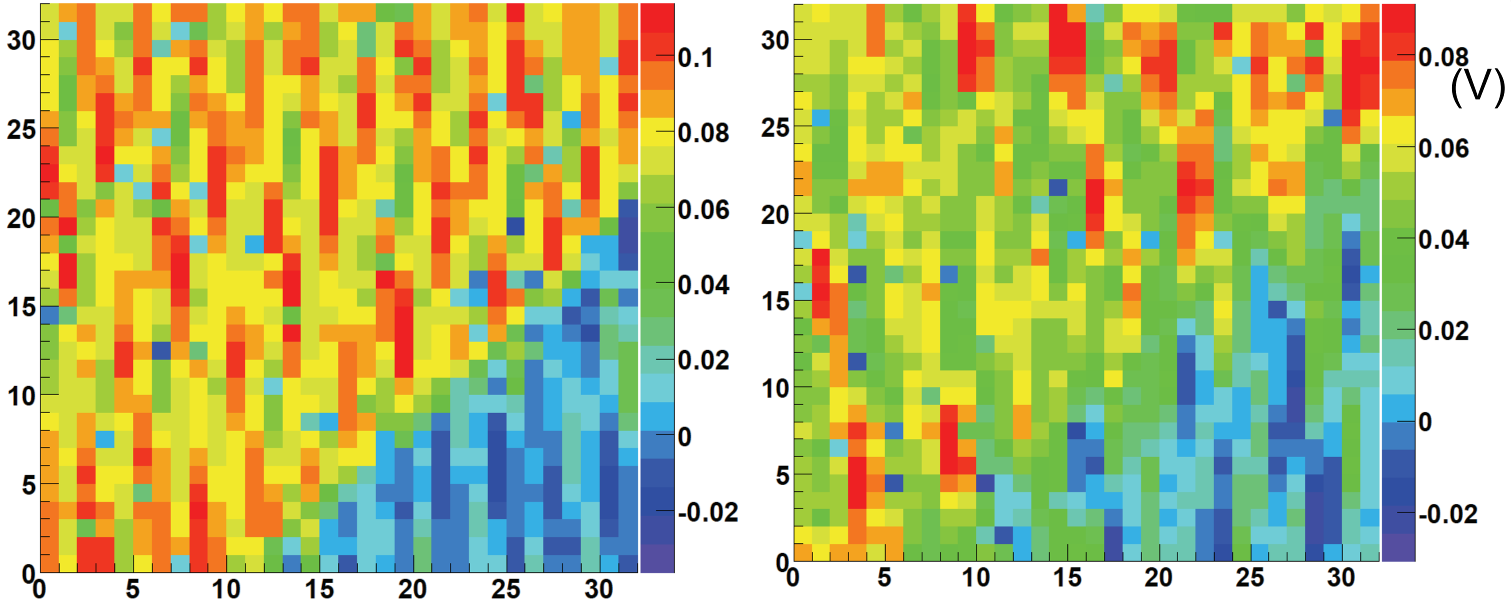


Vdet=2V

pre-irrad

1.4×10^{15} n/cm^2

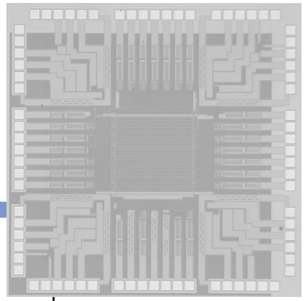


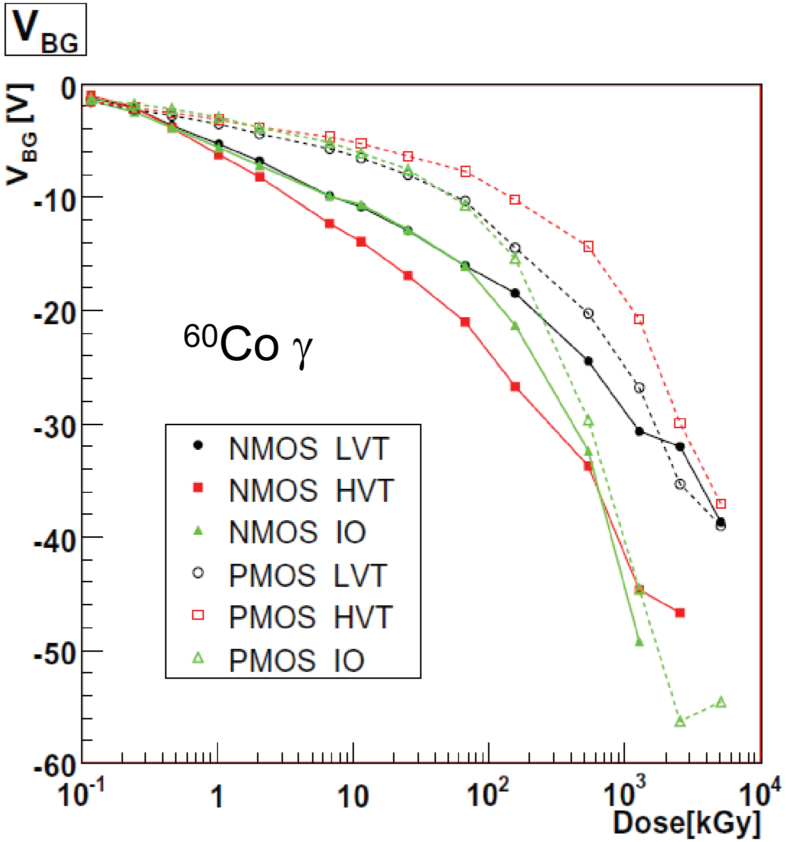


TOPPIX-n stays sensitive after 1.4×10^{15} n/cm^2 (no type inversion occurred?)

- dead channel fraction (~1%) is improved now to a mil level

(6) Hint for improvement





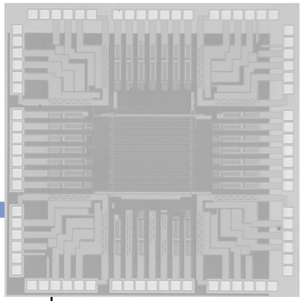
optimum voltage applied to the back to correct for the threshold shifts (^{60}Co TrTEG)

Transistor I_D-V_{GS} characteristics can be recovered to of non-irradiated level by applying negative voltage to the back.

➡ Wider working region is expected for p-bulk sensor, where negative bias is applied to the back (optimum voltages are not very different among the transistor types)

Simulation work is on-going to optimize the back-gate effects

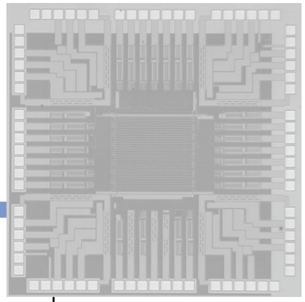
Summary



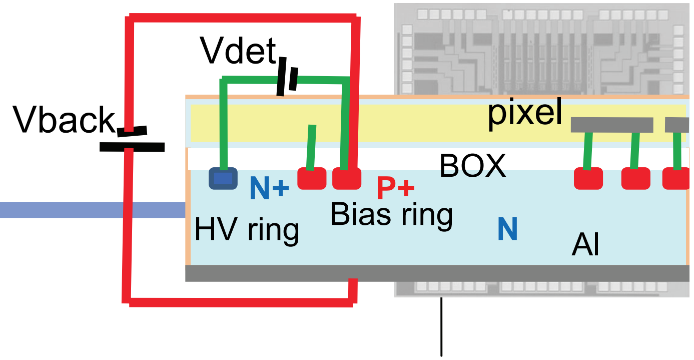
- We are developing SOI monolithic pixel devices and performed a series of radiation resistance tests on the 1st devices.
- Electronics working region of TOPPIX is modified by proton and γ irradiations, as explained by transistor threshold shift (evaluated with TrTEG),
  - after 1.4×10^{15} n_{eq}/cm^2 or 0.60 MGy, response to laser is seen with no increase in the dead channels
  - After 1.3×10^{16} n_{eq}/cm^2 , no response to laser, as explained that RESET is not transferred properly due to large threshold shift

    possibility of no bulk type inversion up to1.4×10^{15} n_{eq}/cm^2
- Investigation started to adopt p-bulk SOI wafers where Vth shift should be partially compensated by negative voltages to the back.

Back Up

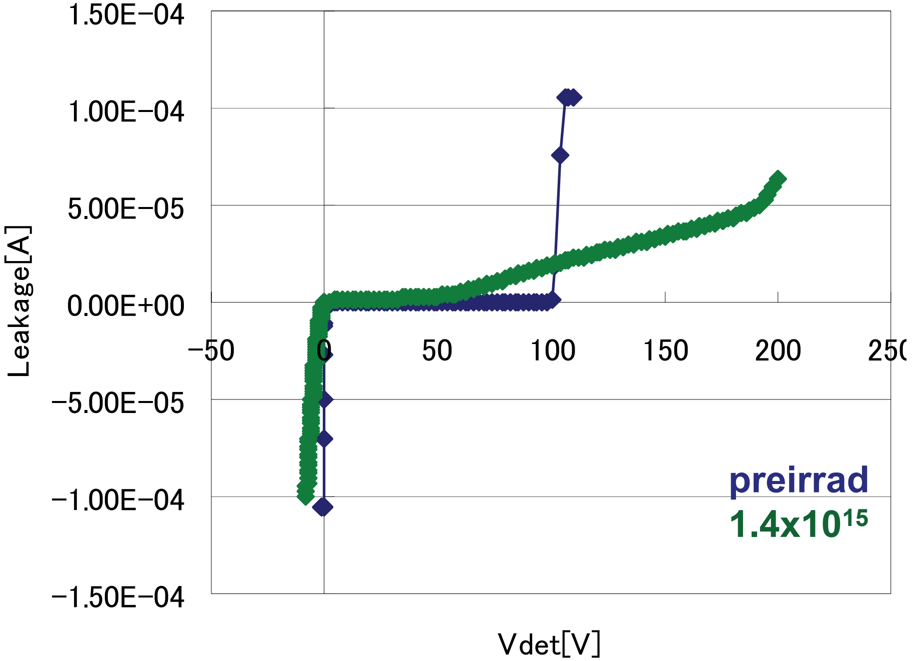


Leak current



annealing：40min at 60℃ + testing at room temp

$1.4\text{x}10^{15}$



$1.3\text{x}10^{16}$

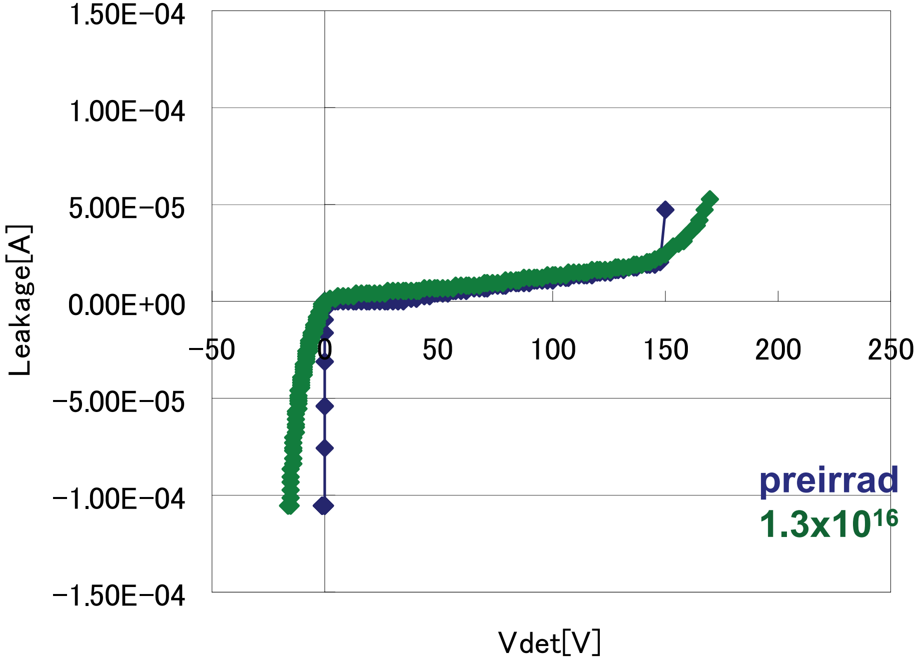
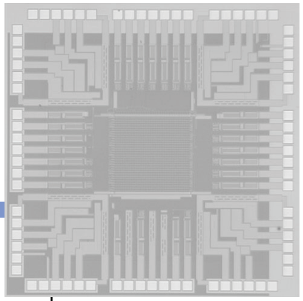
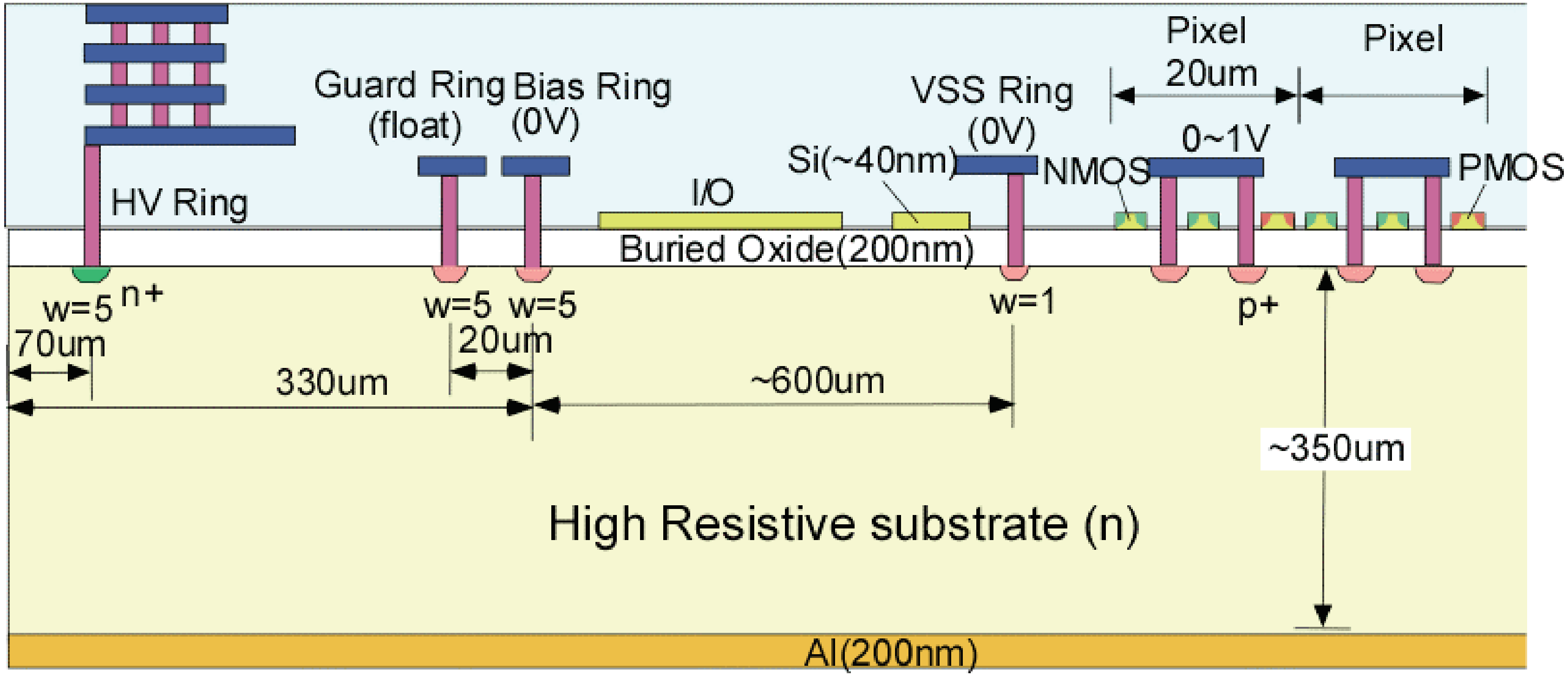


exhibit diode-like IV even after $1\text{x}10^{16}$ n/cm^2

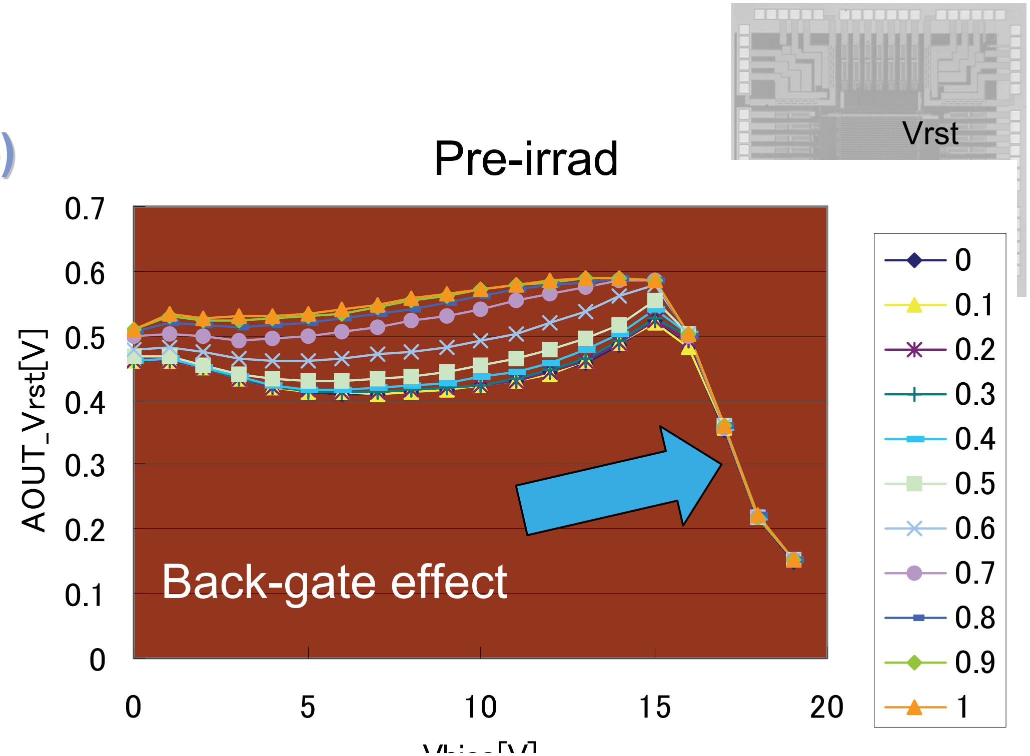
TOPPIXN Details around the edge



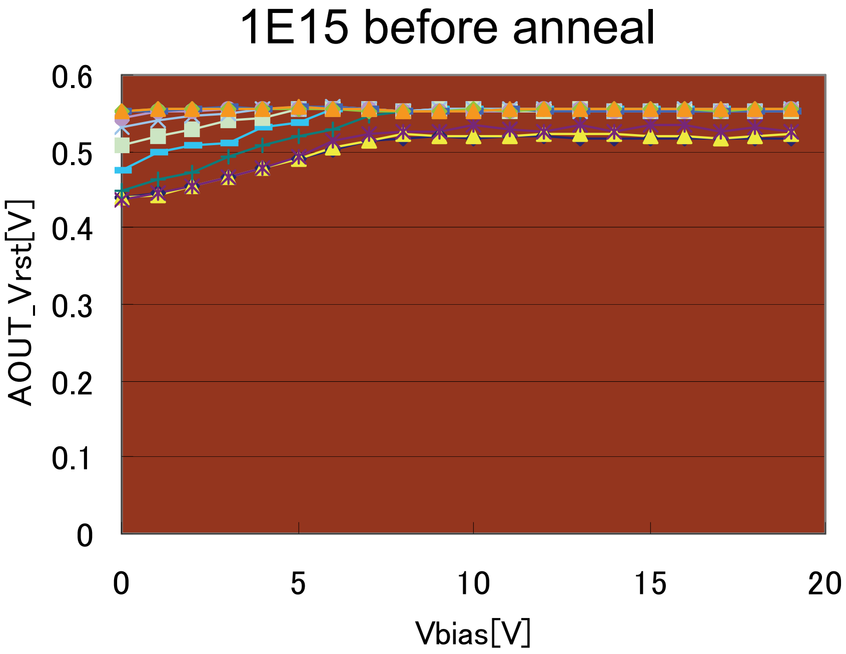


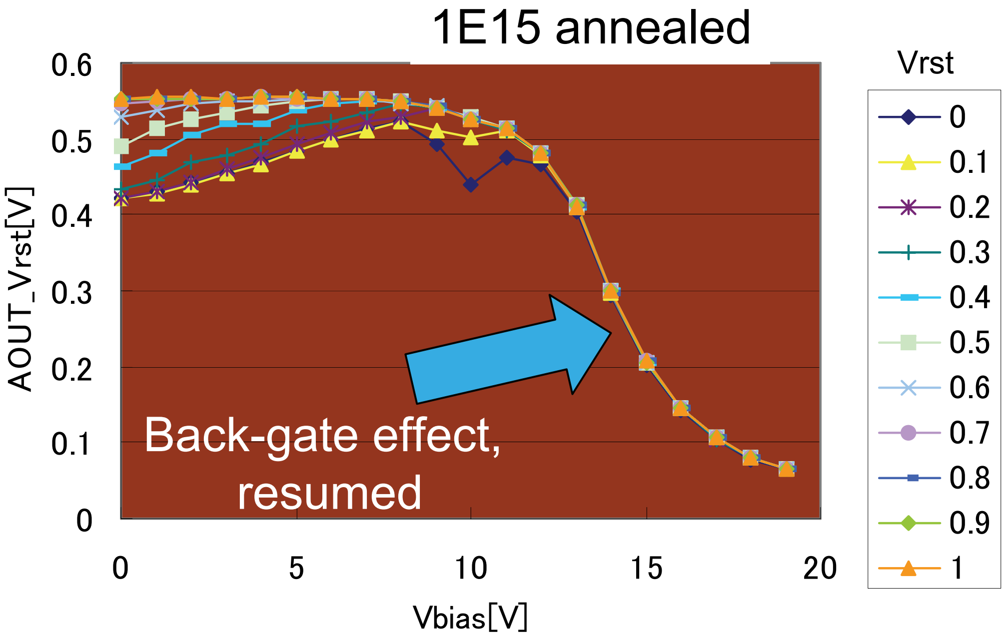
(This figure is not to scale)

Response to Reset (1E15)


Pre-irrad

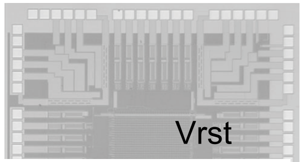
Back-gate effect


1E15 before anneal

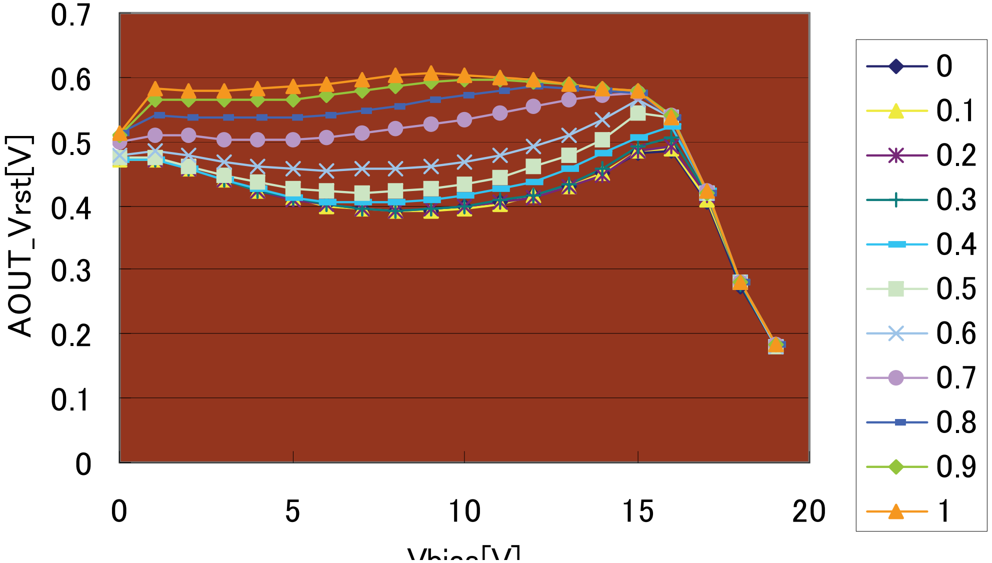

1E15 annealed

Back-gate effect, resumed

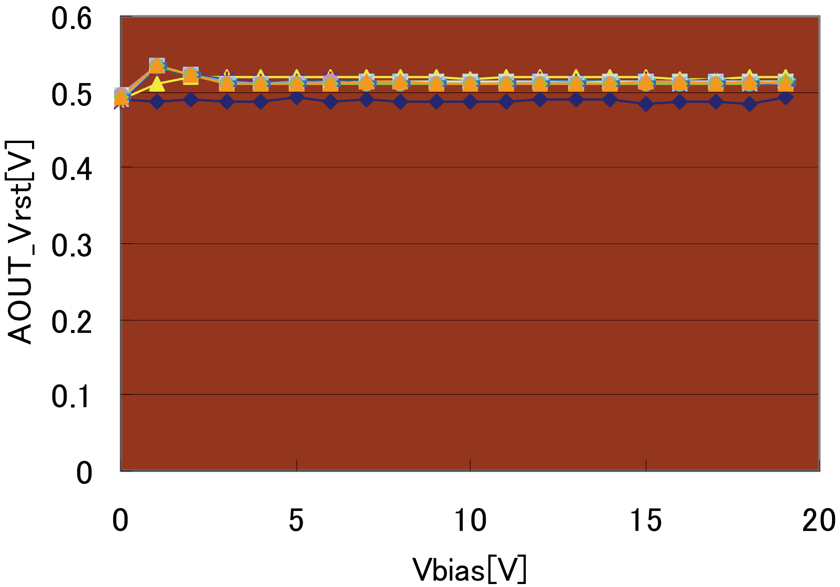
Response to Reset (1E16)



Pre-irrad



1E16 before anneal



1E16 annealed