Annealing Study of Proton and Pion Irradiated Silicon Pad Detectors

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PH-DT Detector Development

Summer Student Session

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Outlines

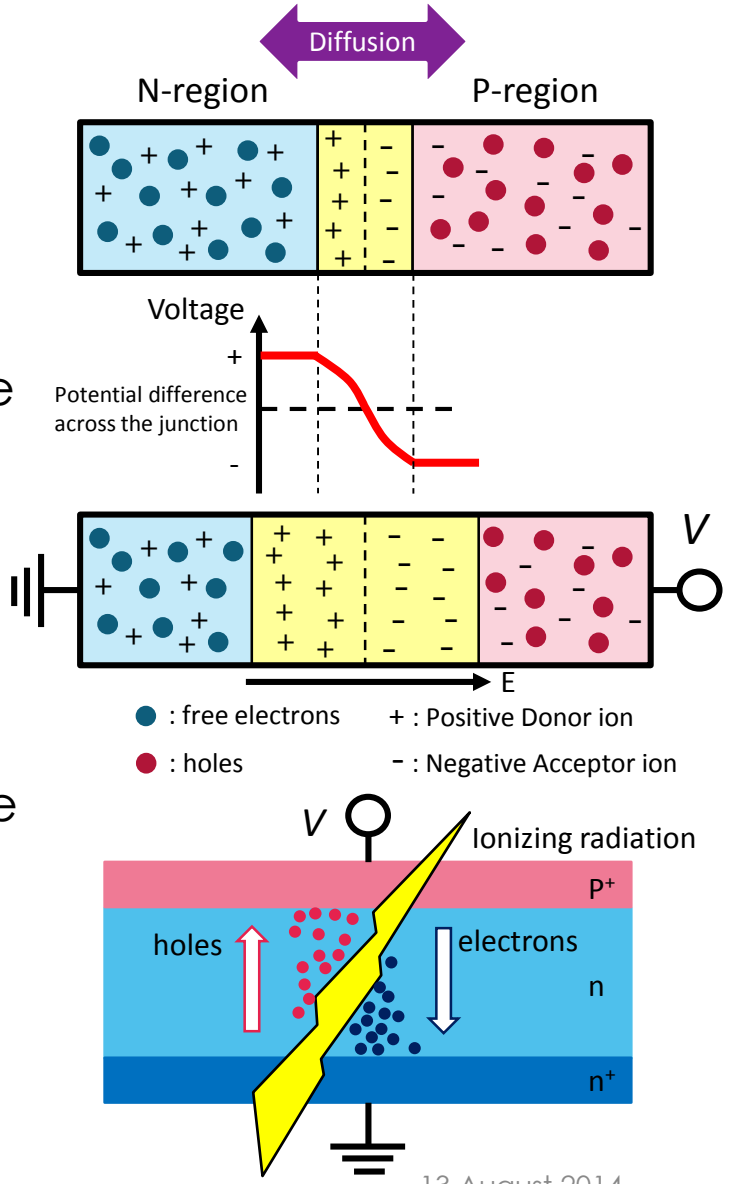
- Silicon Sensors
- Radiation Damage
- Annealing
- Silicon Diodes
- CV/IV Setup
- CV/IV Measurement
- TCT Setup
- TCT Measurement
- Summary & Outlook

Silicon Sensors

- Silicon diode
  - pn-junction : build in **depletion region**
  - Operation voltage : reverse bias voltage

  → **expand** depletion region
  - Detector operation point is above full depletion voltage.

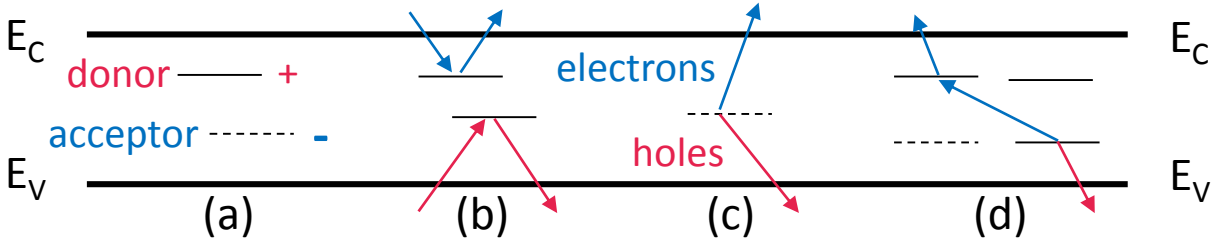
- Detection of ionizing radiation
  - Ionizing radiation creates electron – hole pairs within the depletion region
  - e/h pairs are separated by the electric field in the depletion region
  - **Charge signal** is induced by movement of e/h pair



Radiation Damage

- If Si diodes are exposed to radiation (proton, neutron, pion , etc…)

→ properties of silicon **change**



- radiation introduces defects within silicon

(a)**: Change of effective number of donors/acceptors**

→ Change of depletion voltage

(b) & (c) : Thermal fluctuation

→ **trapping and de-trapping** of electrons and holes

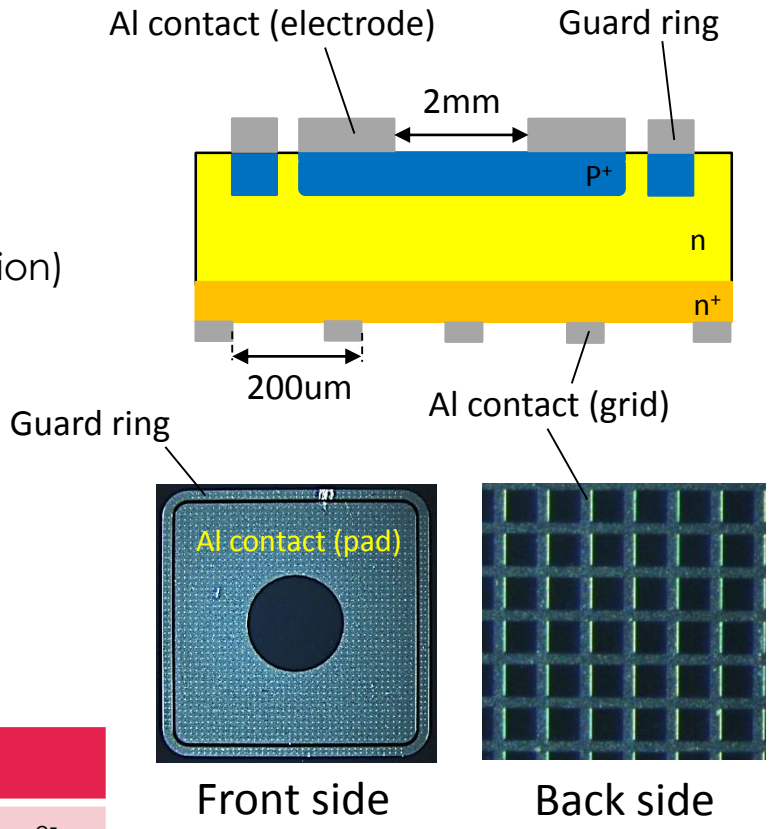
→ charge signal lost (trapping time > 25ns(LHC bunch crossing time))

(d) **: Creation of intermediate levels between valence band and conduction band**

→ Leakage current increase

Silicon Diodes

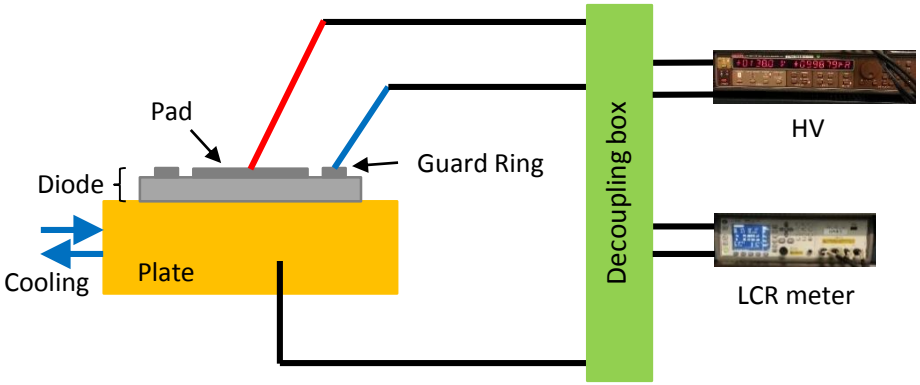
- 14 samples
  - 2 unirradiated samples
  - 2 proton irradiated samples (CERN PS irradiation)
  - 10 pion irradiated samples (PSI irradiation)
- Doping type : p-in-n
- Size : 5.00 mm x 5.00 mm
- Thickness : 300 um
- Thickness of p^+ and n^+ : < 3 um



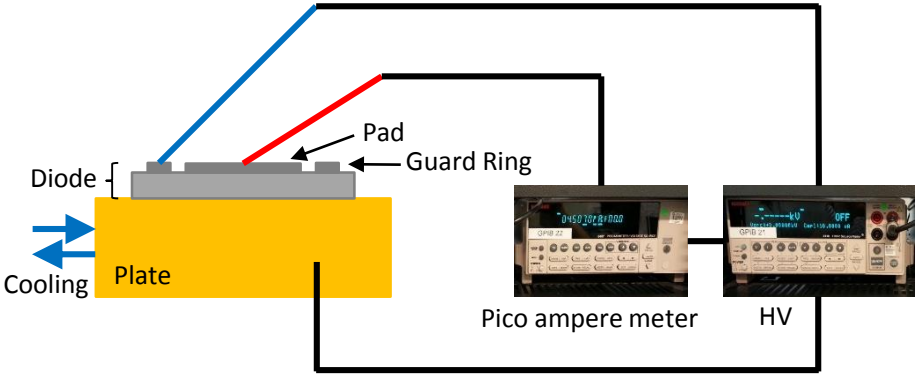
Irradiated samples

Particle	Beam energy	fluences
proton	24 [GeV/c]	1.01, 9.64 [x10^{13} p/cm^2]
pion	300 [MeV/c]	0.0134, 0.0274, 0.0768, 0.241 1.07, 3.70, 10.0, 17.1, 42.6, 51.2 [x10^{13} π/cm^2]

CV/IV Setup



C-V measurement



I-V measurement

- Surface current : read out with the probe needle (Blue)
- Pad current : readout with the probe needle (Red)
- Temperature : -20℃,-10℃, 0℃, +10℃, +20℃
- Frequency (for C-V measurement)
  - Unirradiated diodes : 1k, 10k, 100k, 1M, 10M [Hz]
  - Irradiated diodes : 200, 500, 1k, 5k [Hz]

CV/IV Measurement

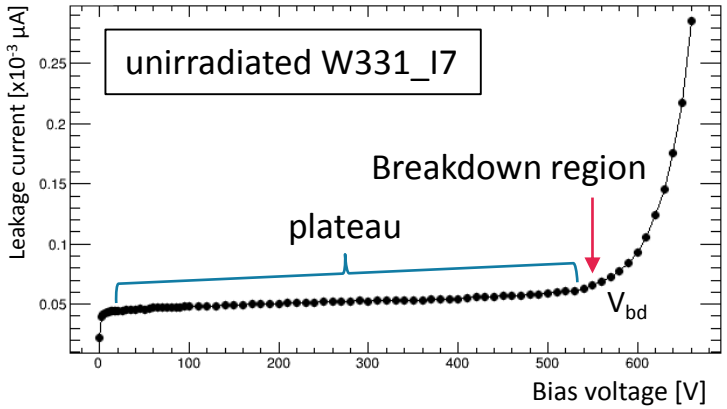
- measure **leakage current** and **capacitance** of diodes against bias voltage
- Above breakdown region, exponential increase of leakage current

- Plot data on double-logarithmic graph of CV

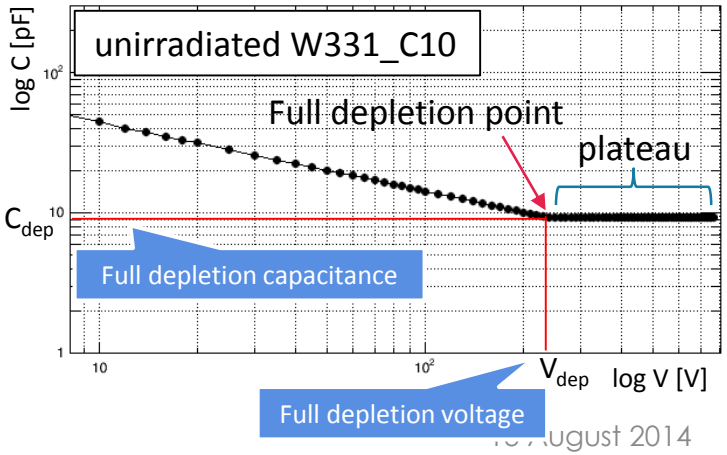
→**Full depletion capacitance and voltage**

- Result
  - $V_{dep} < V_{bd}$ (for all diodes)
  - C_{dep} : 9~11 [pF] (unirradiated)
  - C_{dep} : ~9 [pF] (proton irradiated)

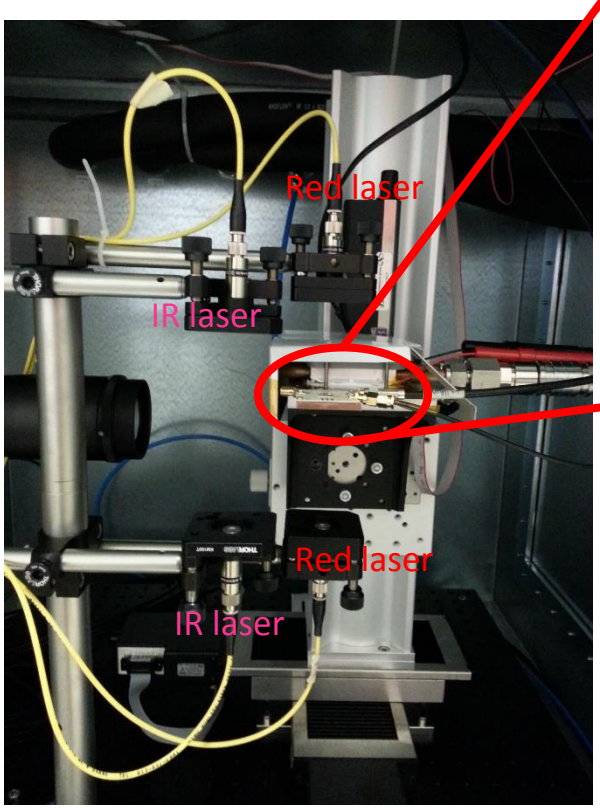
IV measurement

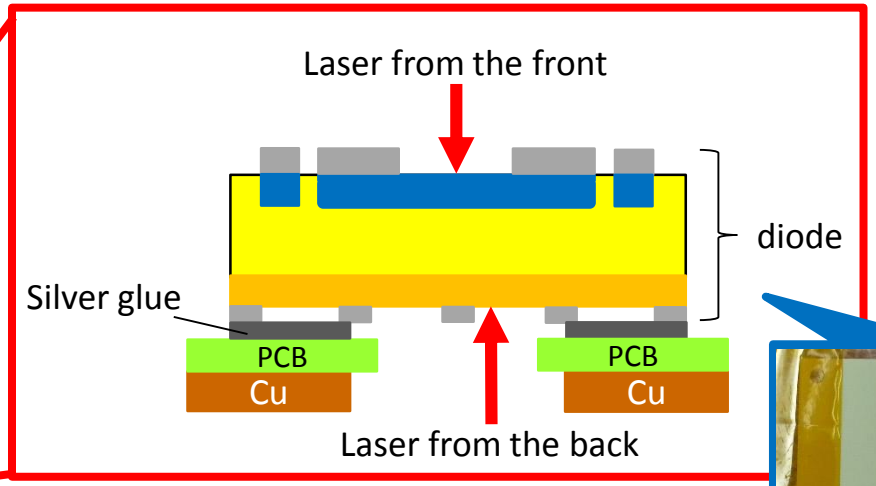


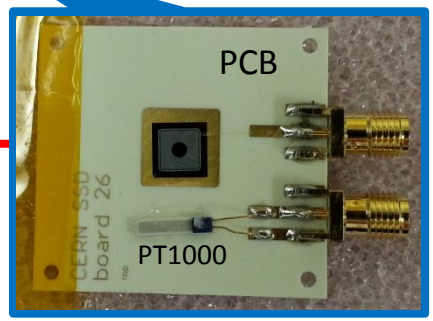
CV measurement



TCT Setup







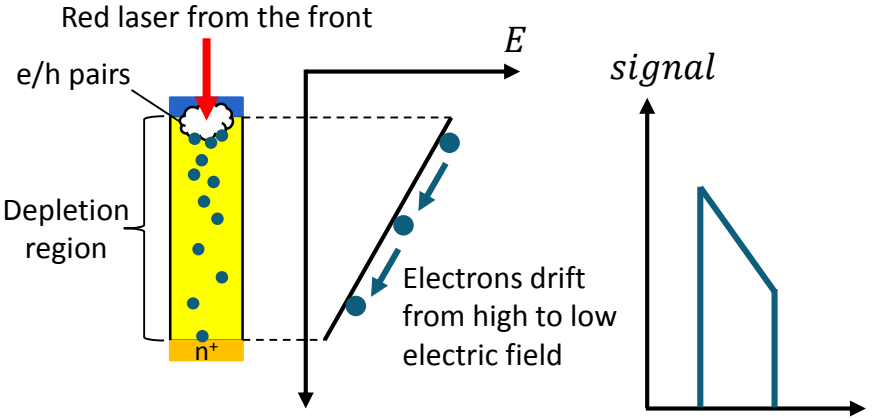
- Used laser : Red (660nm), IR (1064nm)
- Max bias voltage = -1000V
- Temperature : -20℃, 0℃, +20℃
- Measured points
  - in the circle hole (front side of diodes)
  - in the gap of grid (back side of diodes)

TCT Measurement

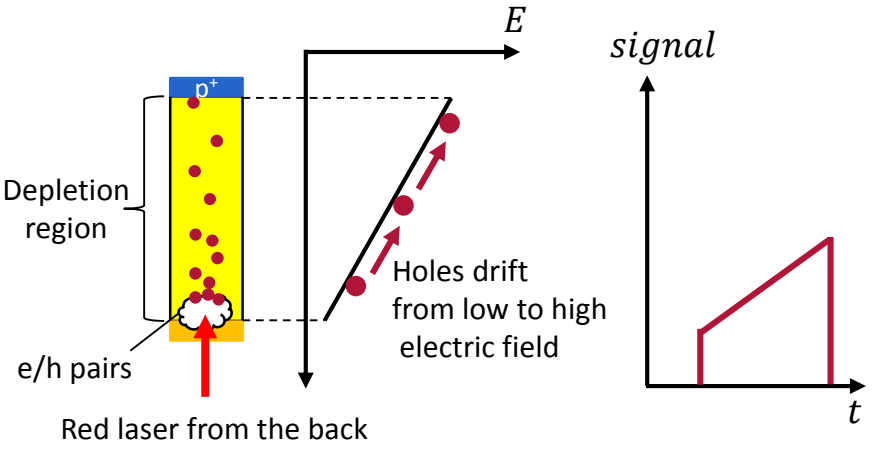
- TCT : Transient Current Technique
- enables to study the influence of radiation damage in sensor material
- use **picosecond laser pulse**

- The signal of **electron** is obtained by red laser shoot from **the front** of diodes
- The signal of **hole** is obtained by red laser shoot from **the back** of diodes

- $I_{signal} \propto E$ (by Ramo's theorem)



The signal of electron for unirradiated diodes (Red laser)



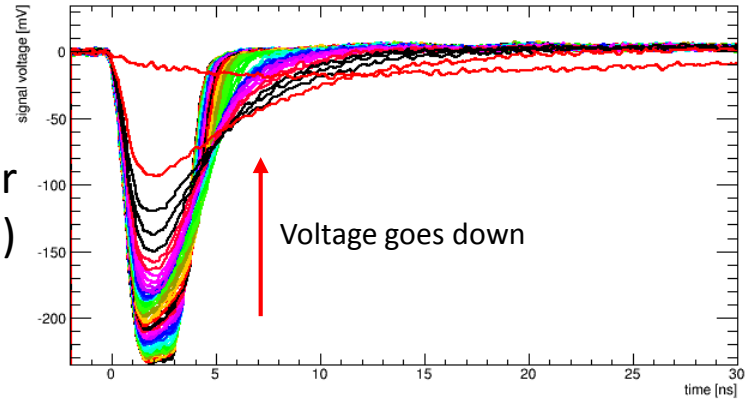
The signal of hole for unirradiated diodes (Red laser)

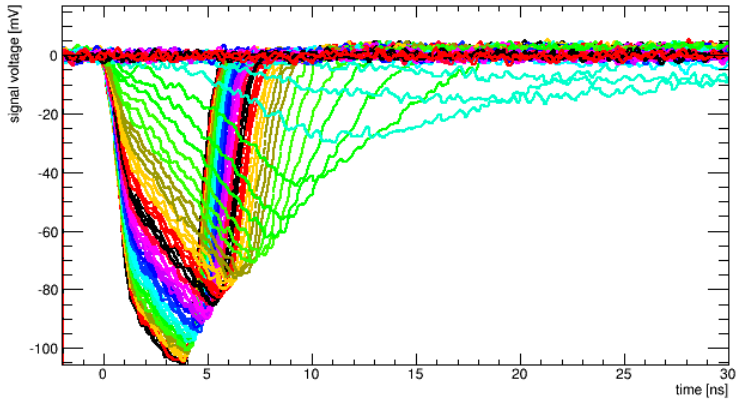
TCT Measurement

Laser from the front

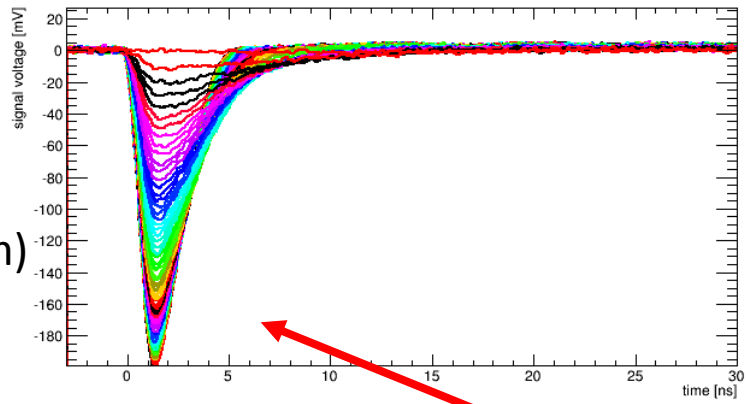
Laser from the back

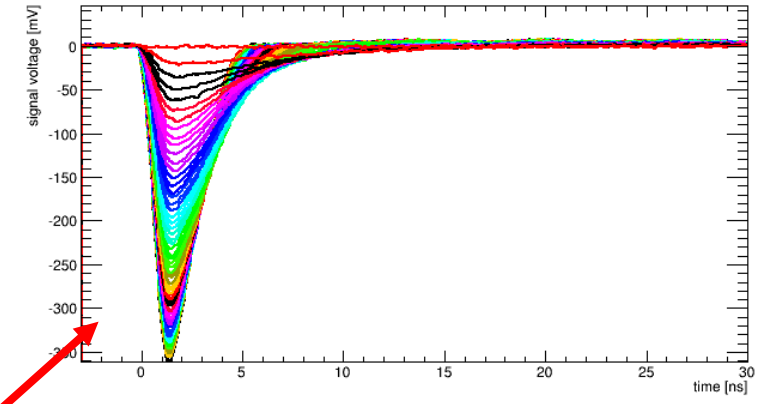
Red laser (660nm)





IR laser (1064nm)





almost same

Summary & Outlook

- So far
  - CV, IV measurement of unirradiated and proton irradiated diodes
  - TCT measurement of unirradiated diodes
- Now
  - CV, IV measurement of pion irradiated diodes
- Outlook
  - Annealing study (CV,IV and TCT measurement)
  - Comparison with the simulation of aneealing

Step	1	2	3	4	5	6
Annealing time [min]	10	70	80	160	320	640
Total annealing time [min]	10	80	160	320	640	1280

Annealing temperature : 60℃

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- **The proton accelerator facility at PSI**

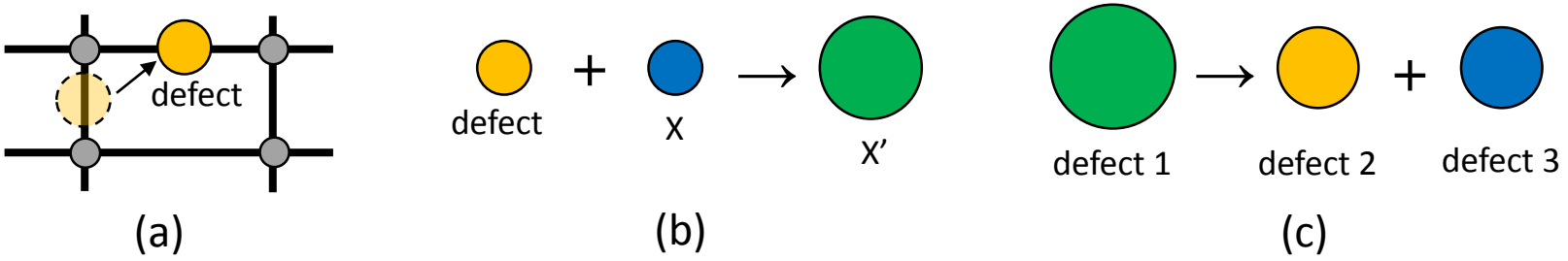
Special thanks to all of SSD lab members for their help and the good time !!

Backup

Annealing

- Long term performance after aging
- Process : warming up high temperature (60℃, 80℃)

→ **change** of defect properties



(a): **Migration** through the silicon lattice

(b): **Complex formation** (X is same defect, different defect, silicon lattice, etc…)

(c): **Dissociation** (the lattice vibration energy > the binding energy)