L. 6. 10

# Visible Electroluminescence from Silicon-rich Silicon Oxide

Kwan Sik Cho and Jung H. Shin
Department of Physics, Korea Advanced Institute of Science and Technology

Nae-Man Park, Tae Yeob Kim and Gun Yong Sung
Electronics and Telecommunications Research Institute

IUMRS-ICEM
2004 MRS SPRING MEETING
APRIL 12-16 • SAN FRANCISCO, CA USA

# Outline

- ☐ Introduction
- ☐ Experiments
- ☐ Results & Discussion
  - Optimizing nc-Si luminescence
  - Confirming the existence of nc-Si
  - Electroluminescence from various diode structures
    - n-poly/SRSO/p,p+ sub.
    - ITO/SRSO/p,n sub
    - NiO/SRSO/p-sub.
- ☐ Conclusion

# Si based Optoelectronics

- ❑ Si based optoelectronics
  - Si is the dominant semiconductor material
  - However, optically inactive (indirect band gap) → obstacle to Si-based optoelectronics
  - Si based light source is needed to Si-based optoelectronics

- ❑ Silicon Rich Silicon Oxide (SRSO)
  - nc-Si embedded in $SiO_2$ matrix
  - Band gap widening to visible range by quantum confinement effect
  - Candidate for Si-based light sources

# Si based light source

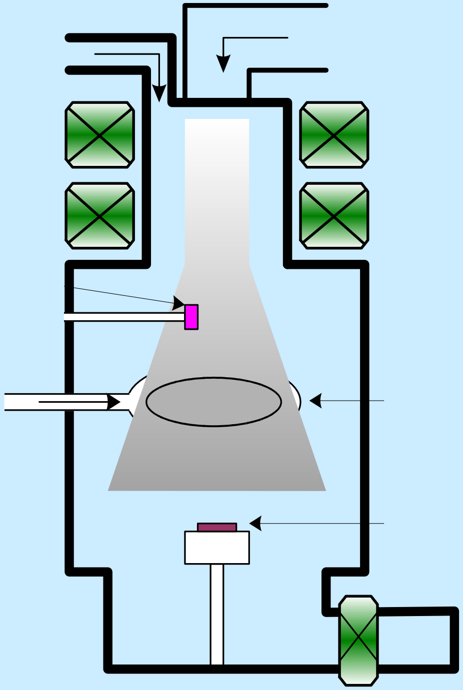
❑ In this study

- develop Si based light source (LED)
- try various diode structure for electroluminescence
    - n-poly/SRSO/p, p+ sub.
    - ITO/SRSO/p,n sub.
    - NiO/SRSO/p sub.

# Thin film deposition

- Sample deposition(ECR PECVD deposition system)
  - Gas Flow : Ar(3.5Sccm) $O_2$(1.6Sccm),
    $SiH_4$(1.1~1.5Sccm)
  - Substrate heating : 450 °C
  - Pressure : ~1 X $10^{-7}$Torr (base)
    ~1 X $10^{-5}$Torr (deposition)

| Sample id # | Gas flow rate (sccm) | |
|---|---|---|
| | $SiH_4$ | $O_2$ |
| M1 | 1.1 | 1.6 |
| M2 | 1.2 | 1.6 |
| M3 | 1.3 | 1.6 |
| M4 | 1.4 | 1.6 |
| M5 | 1.5 | 1.6 |



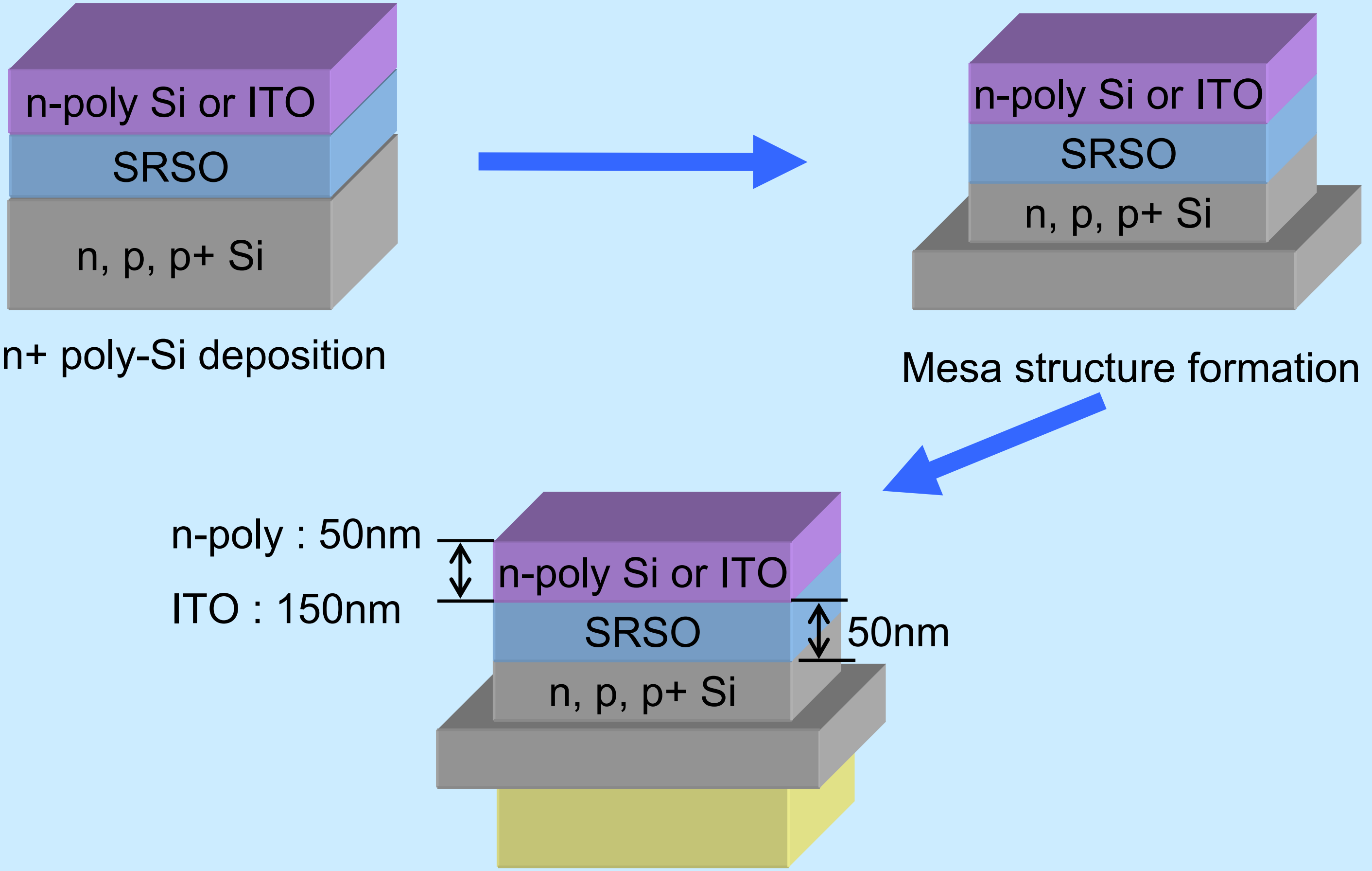
# Experimental details

- Post heat treatments

Furnace annealing in $N_2$ (1100°C, 30min) → Hydrogenation (650°C, 1hr)

- Photoluminescence & Electroluminescence Measurements
  - Pumping Source : 325nm HeCd laser
  - Detector : Charge Coupled Device

# Diode structure formation



n-poly Si or ITO

SRSO

n, p, p+ Si

n+ poly-Si deposition

n-poly Si or ITO

SRSO

n, p, p+ Si

Mesa structure formation

n-poly : 50nm

ITO : 150nm

n-poly Si or ITO

SRSO

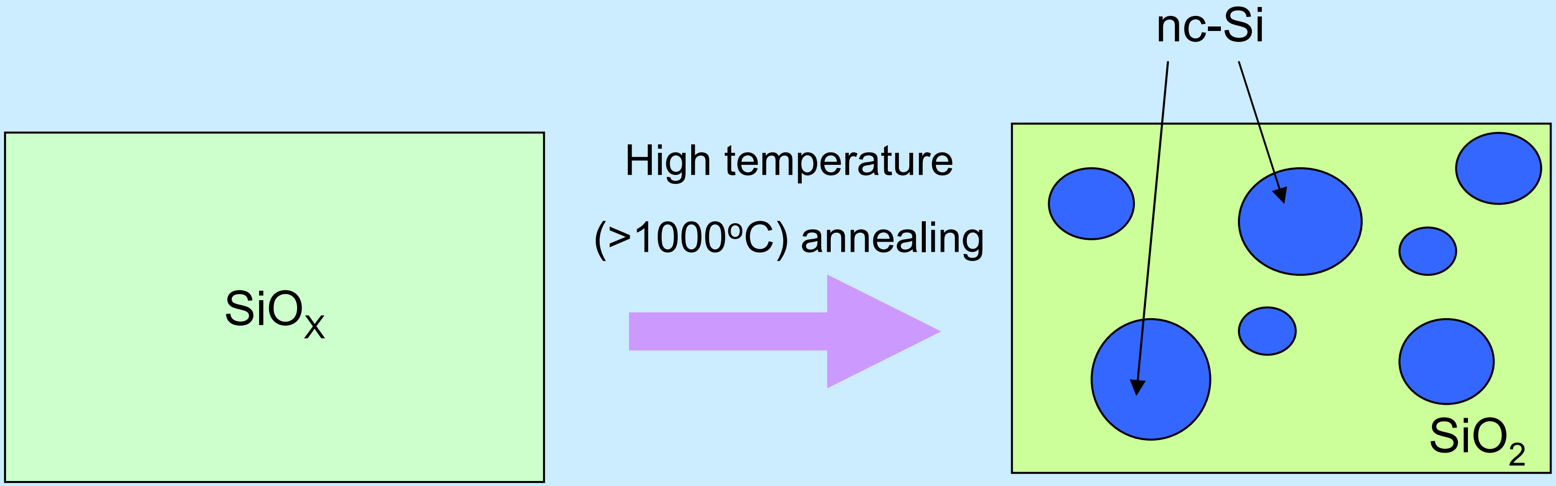
50nm

n, p, p+ Si

Bottom electrode evaporation

# nc-Si formation

- nc-Si formation
  - depositon $SiO_X$ (x<2) films by PECVD method with $SiH_4$ & $O_2$ gases
  - High temperature annealing make Si, $SiO_2$ phase separation → formation nc-Si



$SiO_X$

High temperature

(>1000°C) annealing

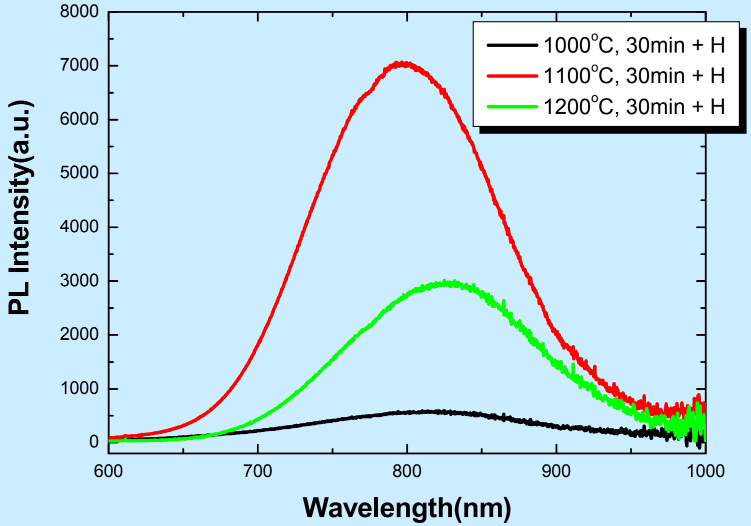
nc-Si

$SiO_2$

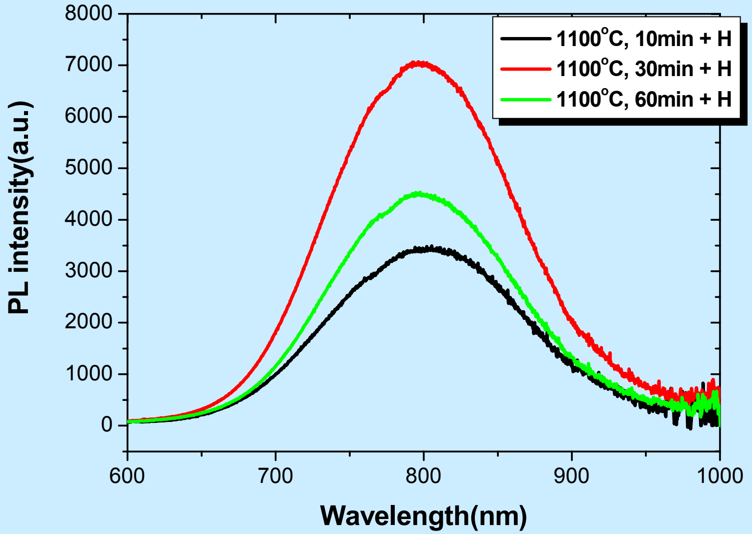
As grown

After annealing

# Optimizing nc-Si luminescence



PL spectra with different annealing temperature, fixed time(30min)

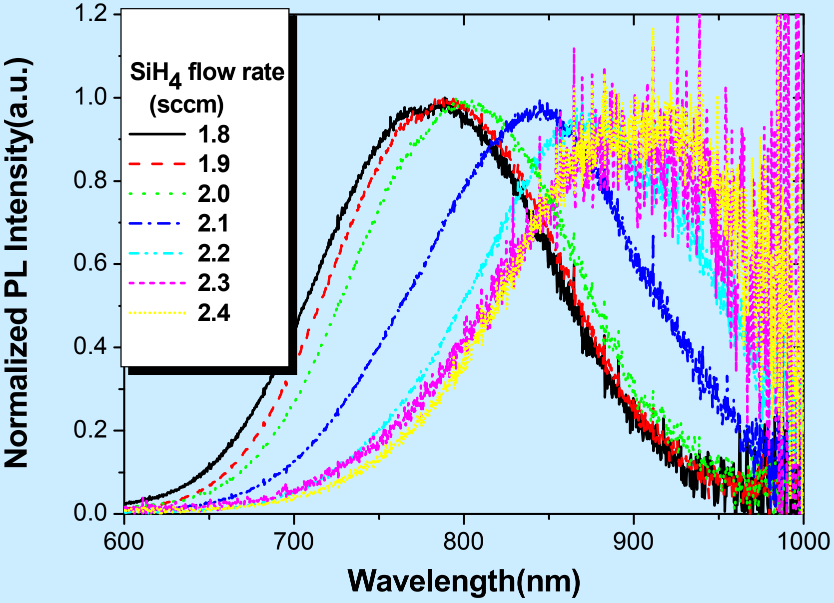


PL spectra with different annealing time, fixed temperature(1100ºC)

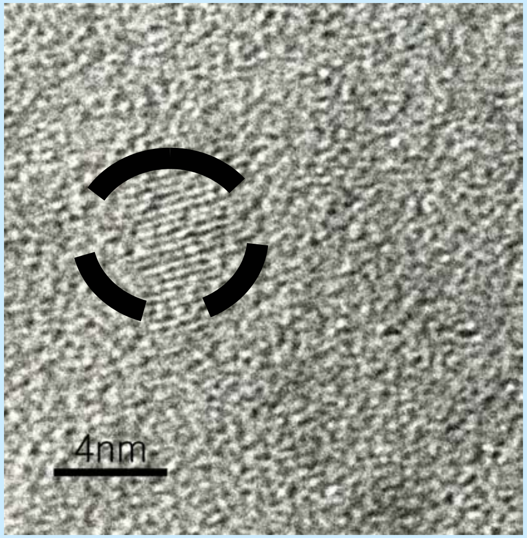
❑ 1100ºC, 30min is optimum annealing condition

for nc-Si luminescence in SRSO thin film

# Confirming the existence of nc-Si



**Normalized PL spectra with varying SiH$_4$ flow rate**



**HRTEM image of the sample after 1100°C, 30min + Hydrogenation**

- ☐ The PL spectra show typical Gaussian-shape nc-Si luminescence

  and PL peak position (nc-Si size) is controlled by changing SiH$_4$ flow rate

- ☐ HRTEM image shows nc-Si(~5nm) embedded in SiO$_2$ matrix

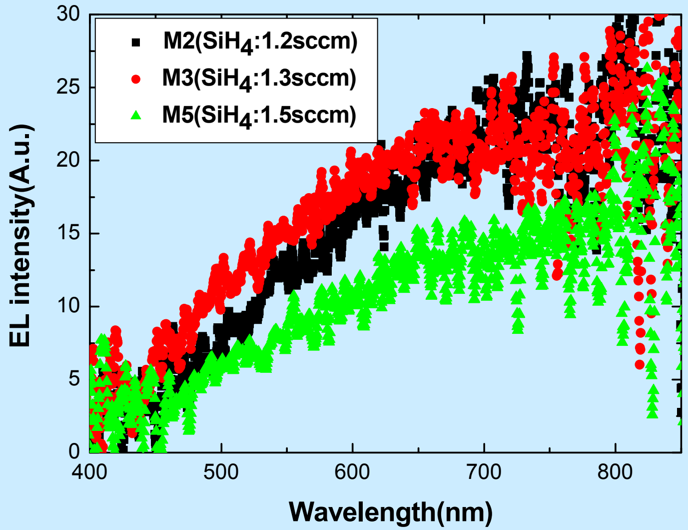
# Electroluminescence : (n-poly/SRSO/p+ sub) structure

EL from M5 ($SiH_4$ : 1.5sccm)

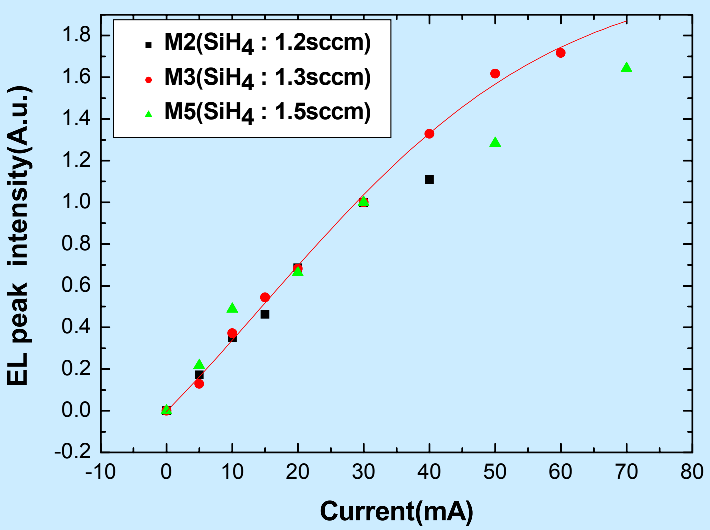
Reverse bias(80V) condition

- ☐ We observed white electroluminescence
  - edge-emitting EL
  - n-poly layer has the advantage of carrier injection but absorbs the emitted light

# Electroluminescence : (n-poly/SRSO/p+ sub) structure



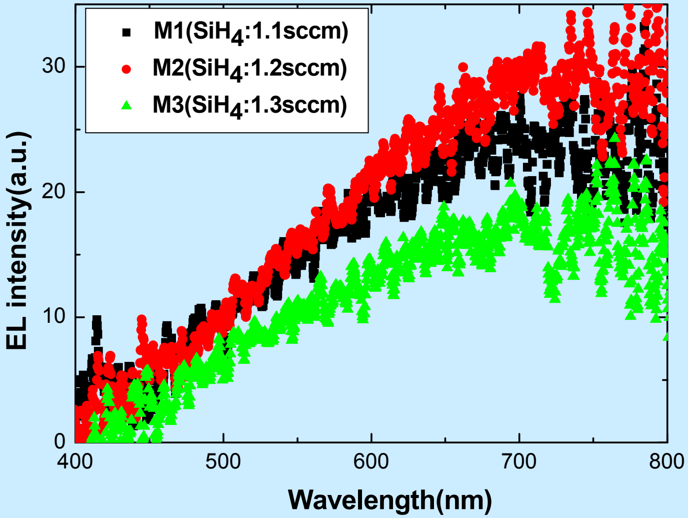
EL spectra with a current density of 4A/cm$^2$ (reverse biased)



EL intensity at 730nm vs. current density under reverse bias conditions (Normalized at 30mA)

- ☐ We obtained broad band EL spectra from p+ sub. structure
  - We could obtain EL spectra only reverse biased condition
  - EL peak position was fixed at ~730nm
  - EL intensity increases with increased driving currents

# Electroluminescence : (n-poly/SRSO/p sub) structure



EL spectra with a current density of 4A/cm$^2$ (reverse biased)

☐ We obtained broad EL spectra from p sub. structure

- edge-emitting EL under reverse bias condition
- EL peak position was fixed at ~ 730nm

# Electroluminescence : (ITO/SRSO/p,n sub) structure

Active layer : M5 ($SiH_4$:1.5sccm), forward biased condition

EL from (ITO/SRSO/p sub)

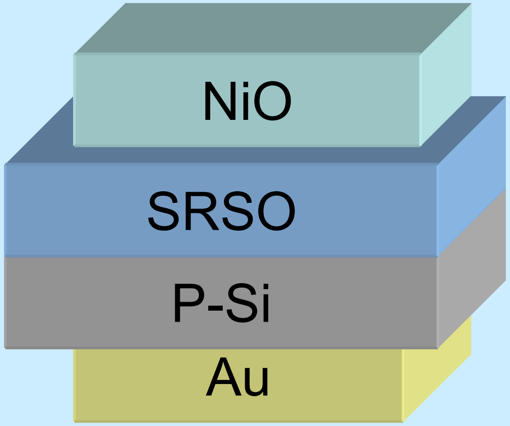
EL from (ITO/SRSO/n sub)

☐ We observed EL with the naked eye

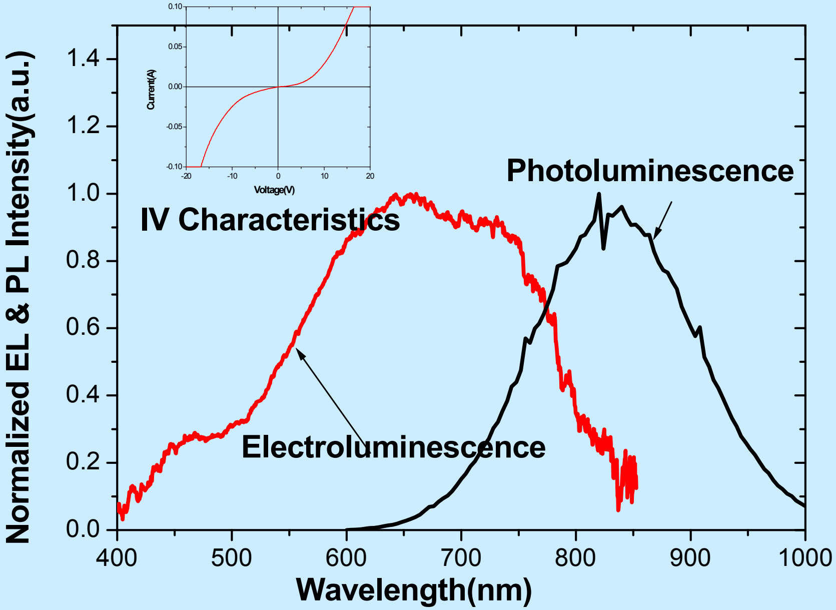
- We observed EL in both reverse and forward biased case
- EL intensity was not sufficiently large to obtain EL spectra
- Emitting light passed ITO layer without significant absorption
- We observed brighter EL from n-sub. structure than from p-sub. structure

→ impact excitation with hot electrons

# Electroluminescence : (NiO/SRSO/p-sub) structure



Sample structure



EL & PL spectra from NiO/SRSO/p-sub structure

(inset : IV characteristic curve)

❑ The EL was obtained in both forward and reverse biased cases

❑ IV characteristic curve is symmetric

❑ EL and PL spectra have different peak position

→ Impact excitation is the main excitation mechanism of nc-Si

# Discussion

❑ Discussion

- It is known that electroluminescence of nc-Si is originated from impact-excitation with hot electrons1)
- In (n-poly/SRSO/p, p+ sub.) structure, we observed EL only under reverse bias condition
- In our case, impact excitation with hot electrons from p sub. not n-poly layer is beneficial for electroluminescence

❑ Further study

- We must reach a compromise between optical & electrical properties of the materials
- Improvement of carrier injection & light extraction

---

1) Appl. Phys. A Vol 74, G. Franzo *et al.*

# Conclusion

- We obtained
  - Typical nc-Si luminescence after post annealing
  - Optimum annealing condition for nc-Si luminescence :

    1100$^{o}$C, 30 min(in $N_2$) + Hydrogenation(650$^{o}$C, 1hr)

- We demonstrated
  - Visible light EL from SRSO thin films with different structures
    - EL peak position was fixed at ~730nm
    - nc-Si is excited mainly by impact excitation with hot electrons