Computational Microelectronics
L22

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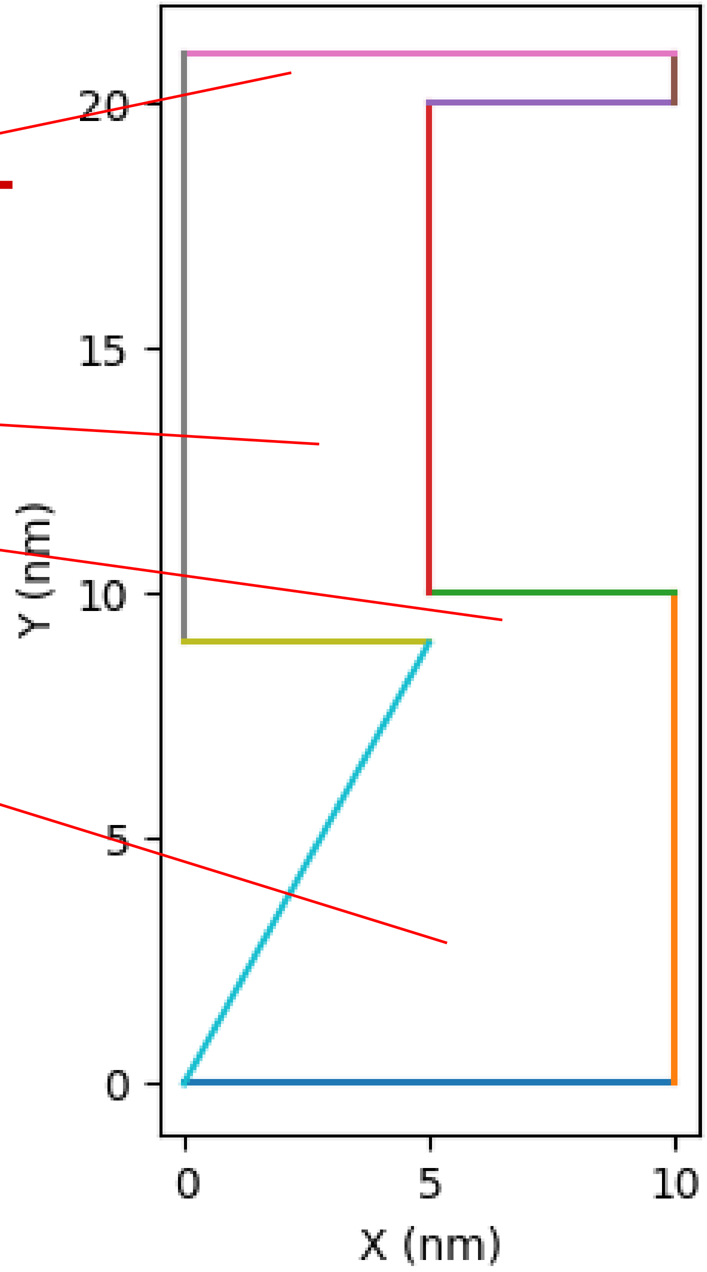
Monte Carlo

Area of a region

- Of course, we can calculate it.
  - It is 67.5 + 10 + 50 + 10 nm^2.
  - In total, 137.5 nm^2.

  - However, it is not a general approach.
- Alternative way to calculate the area?
  - Monte Calro method



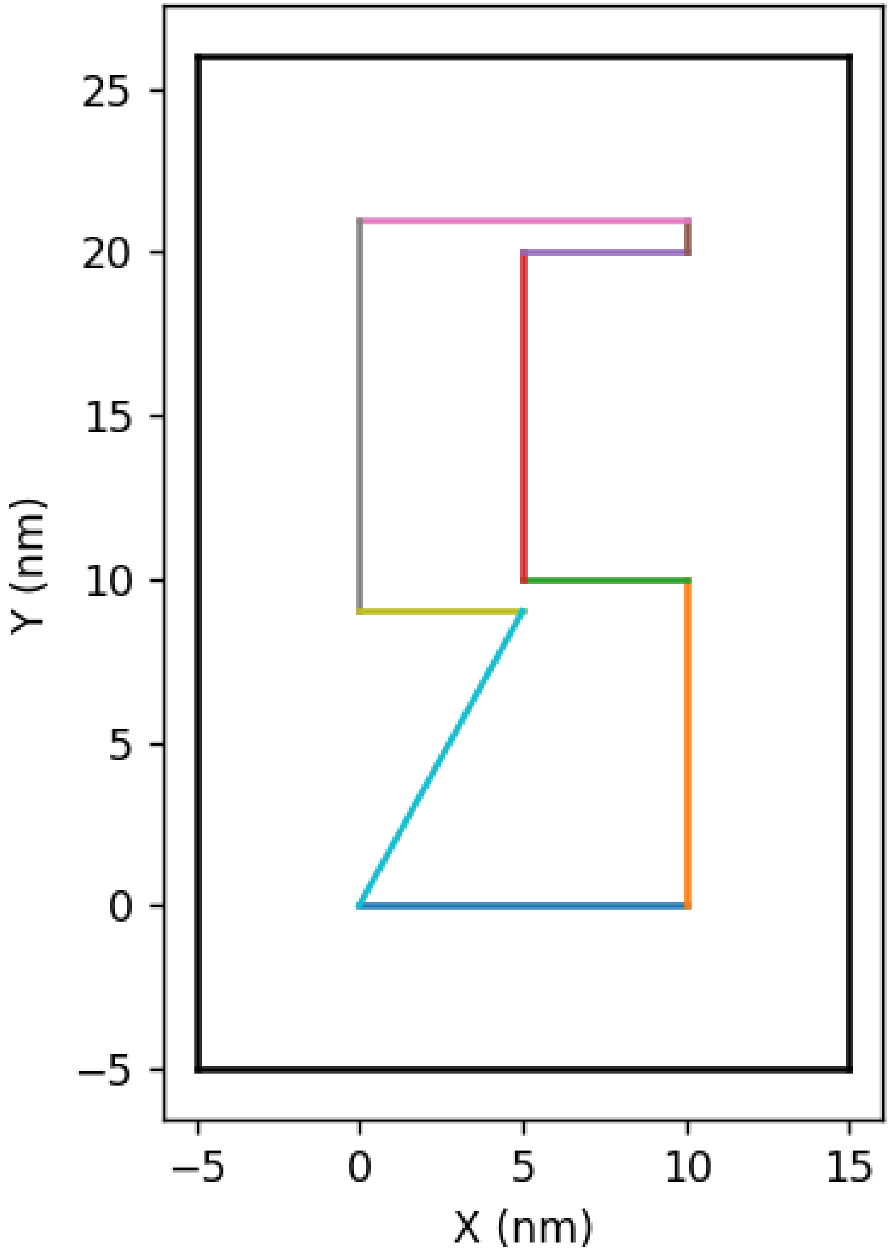
Monte Carlo (City)

- The Monte Carlo Casino is located there.
  - Gambling is closely related with the random number generation.

Monte Carlo Casino (Wikipedia)

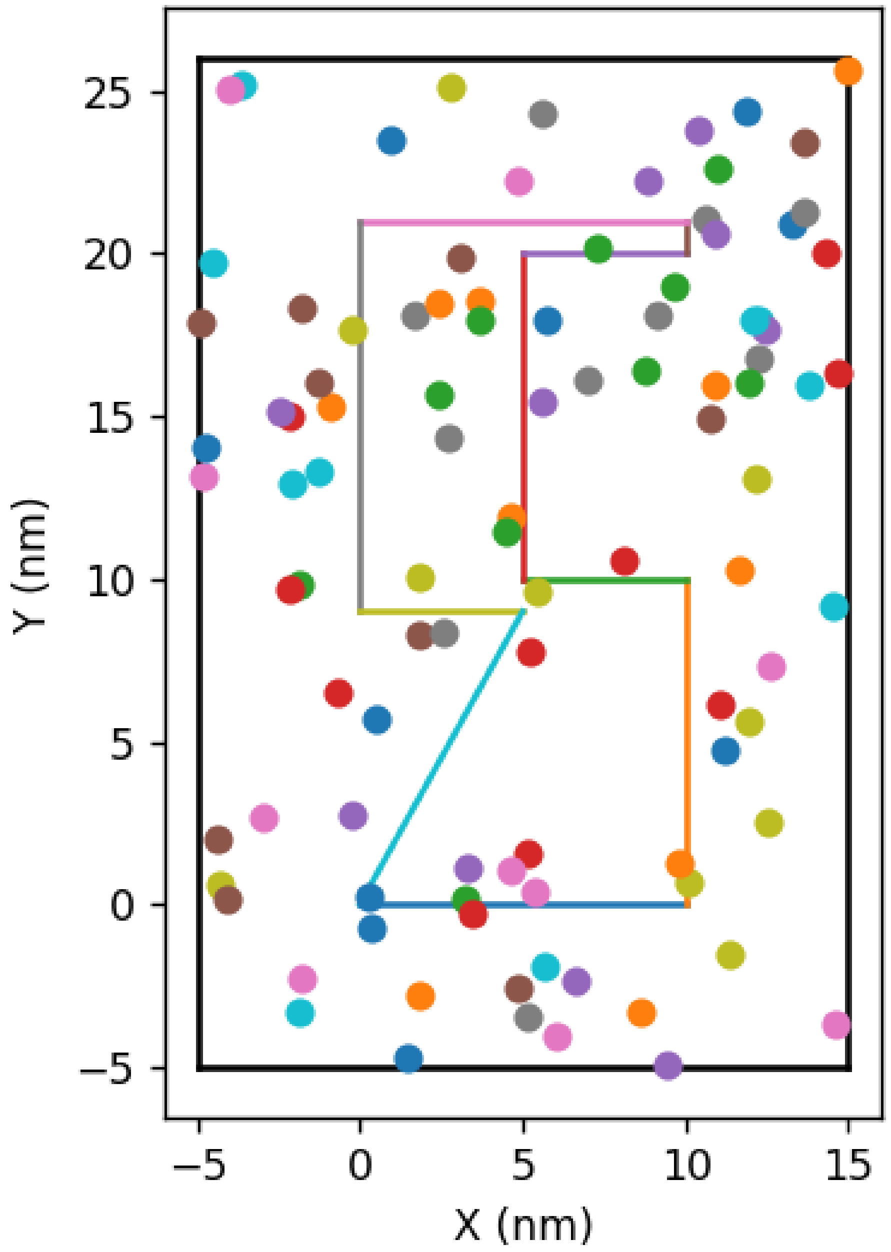
Set a bounding box

- With a sufficient margin
  - In this example, the area of box is 620 nm^2.
  - When a position is selected randomly, $$\frac{137.5}{620} = 0.22177$$ is the probability to be located inside.
  - Try several points.



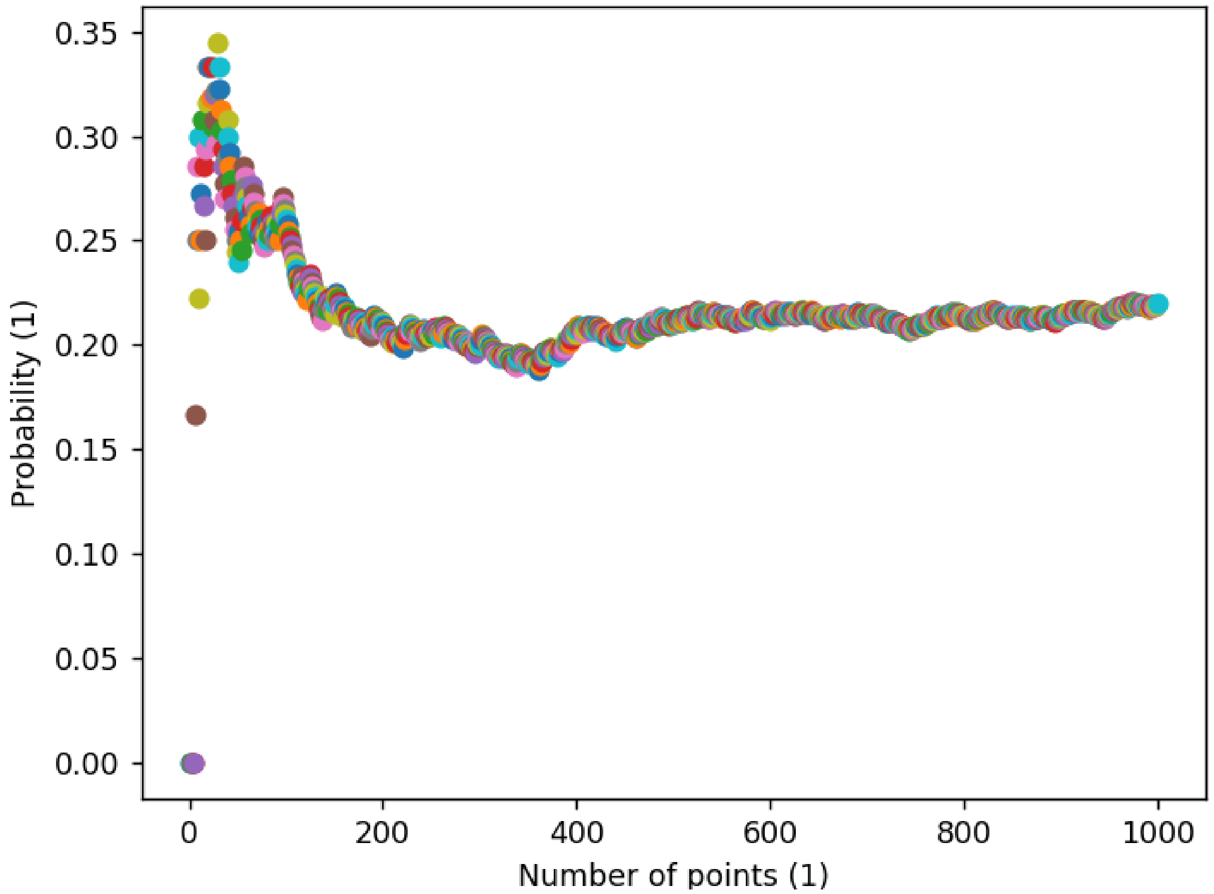
100 random points

- Count the numbers of points inside.
  - Then, we will get an estimated probability.
  - In this particular case, it it 20. (Not bad)



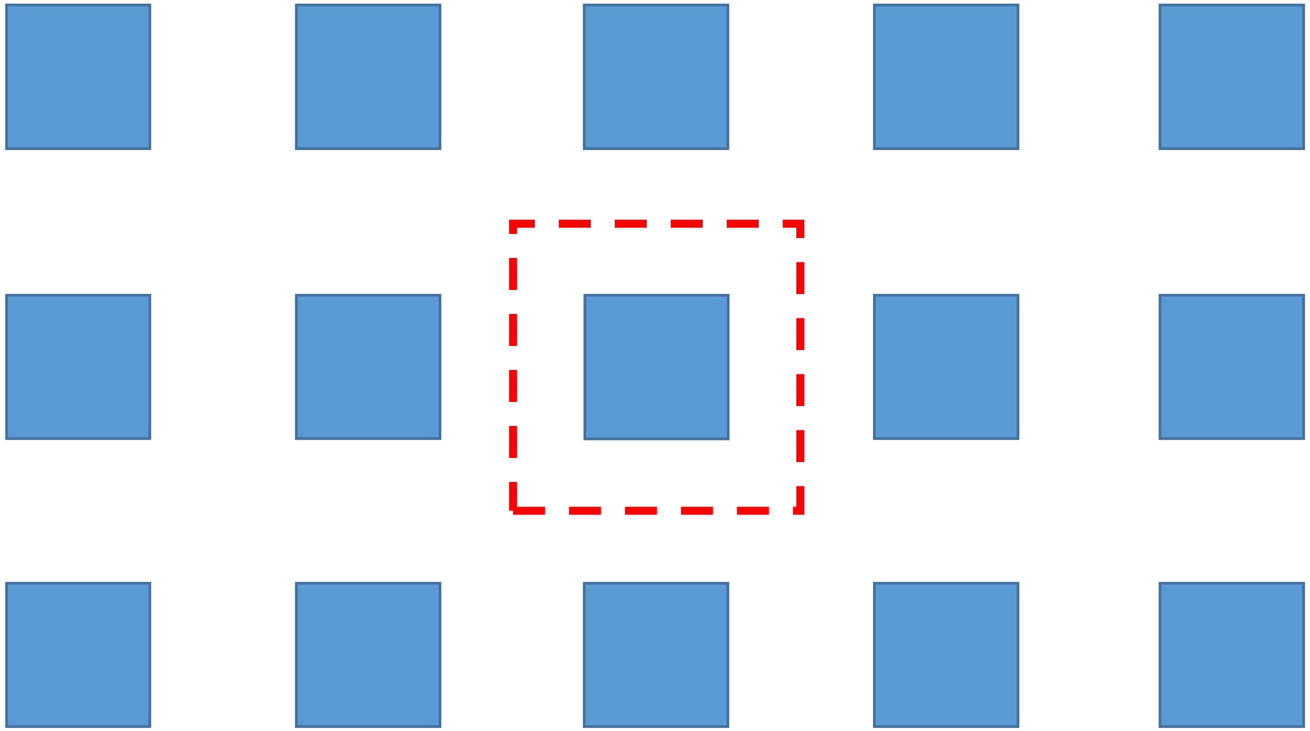
Probability

- Increase the number of points. (Up to 1 k points)
  - The probability approaches to 22 %.



Why do we need random numbers?

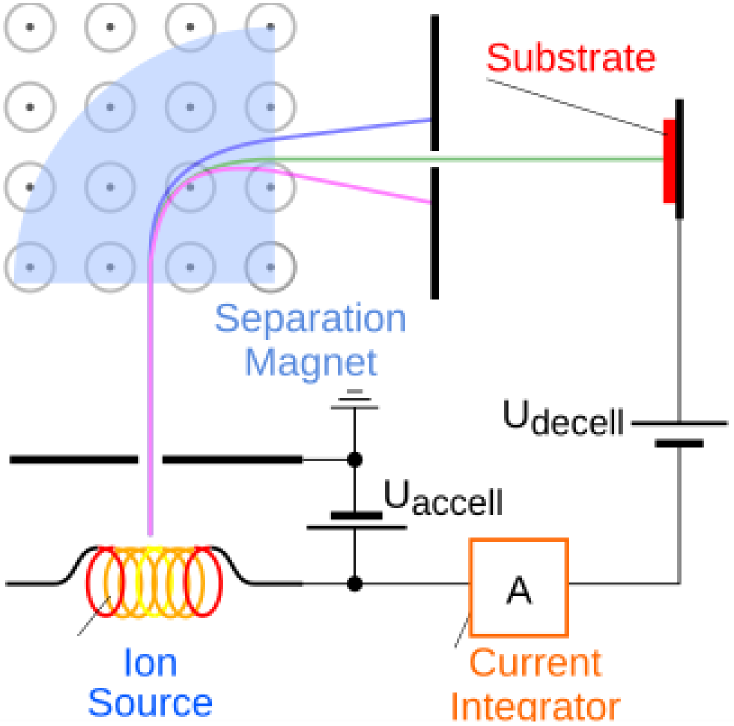
- We are visiting the entire space (the bounding box).
  - The uniform sampling may work.
  - A counter example is shown.
  - Its coverage is ~ 25 %.



Ion implantation

Ion implantation

- Accelerated ions (~ keV)
  - Precise control of energy and dose



Schematic of ion implanter (Wikipedia)

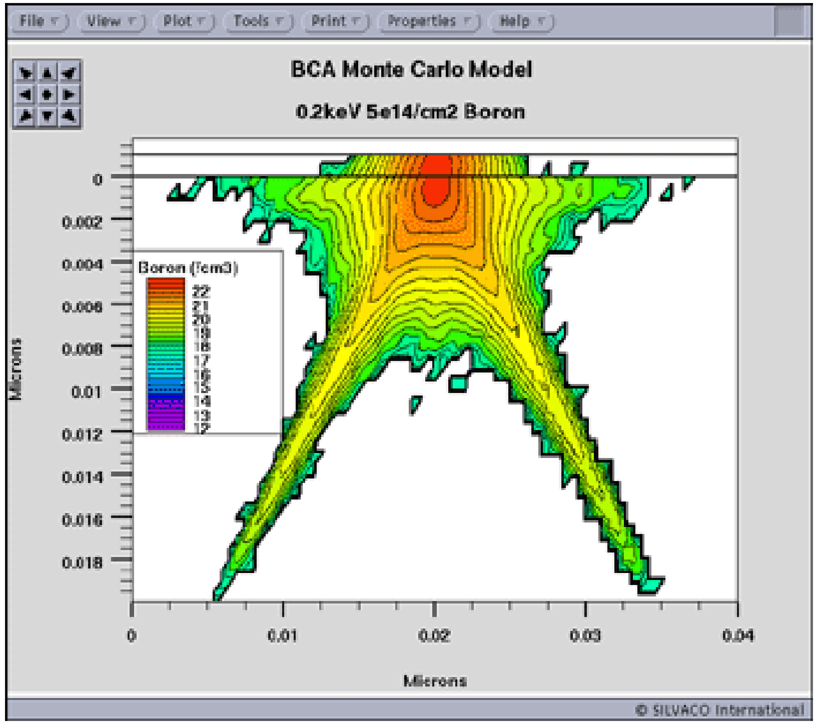
Ion implanter (isrc.snu.ac.kr)

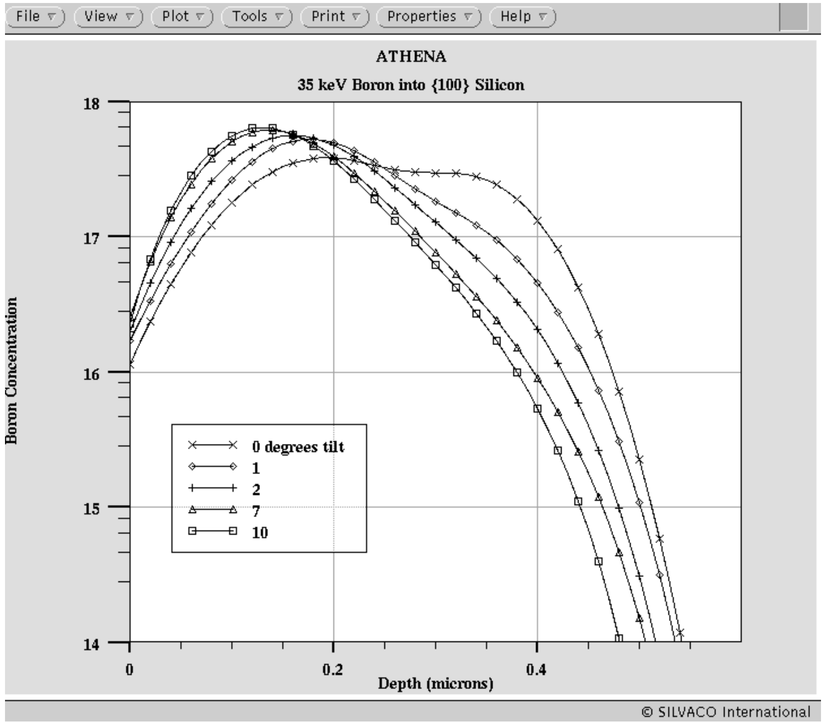
Doping profile

- Double-Pearson function
  - For a more realistic profile, Monte Carlo simulation is widely used.
  - Energy loss

    Nuclear scattering

    Electron scattering

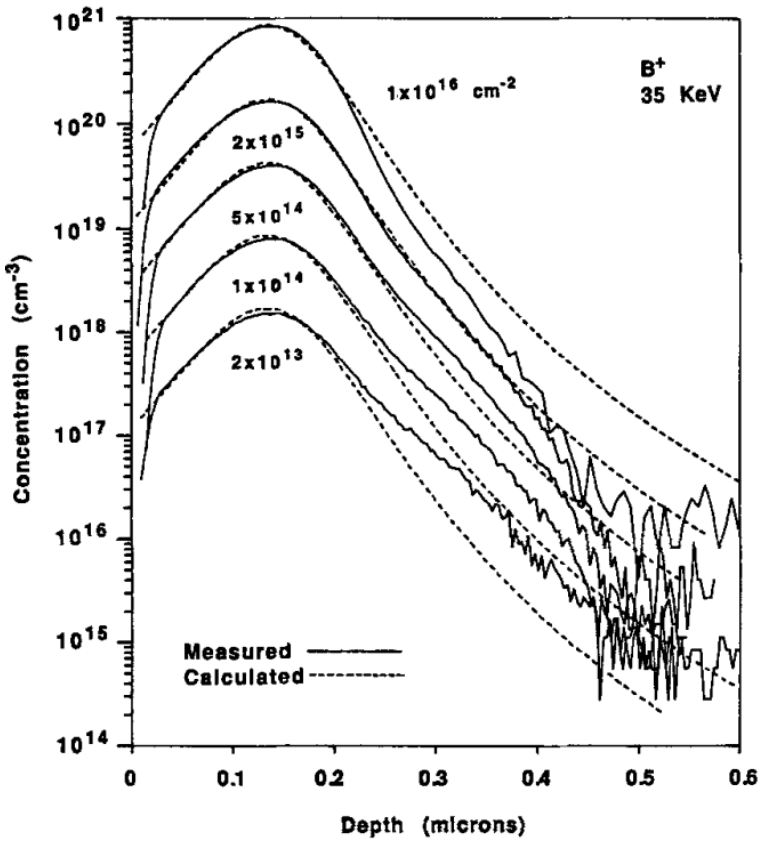




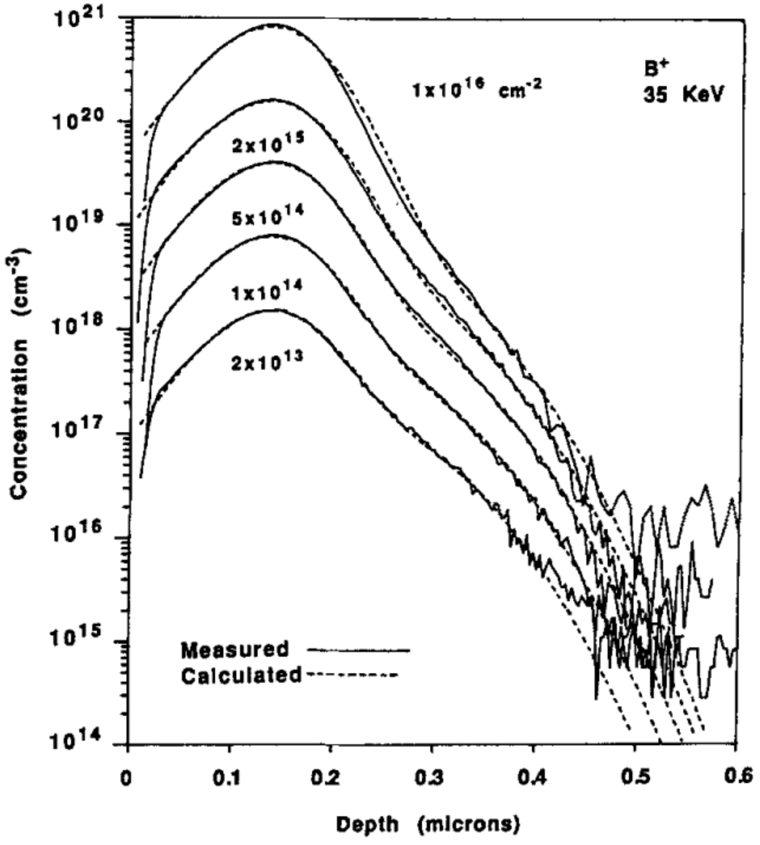
Monte Carlo BCA (binary collision approximation) simulation result and depth profiles (Silvaco)

Analytic profile

- Dual-Pearson model
  - Head and tail, $f_p(x) = \text{ratio}\ f_{head}(x) + (1 - \text{ratio})\ f_{tail}(x)$



Single- and double-Pearson functions (A. F. Tasch, JECS, 1989)



Simple model

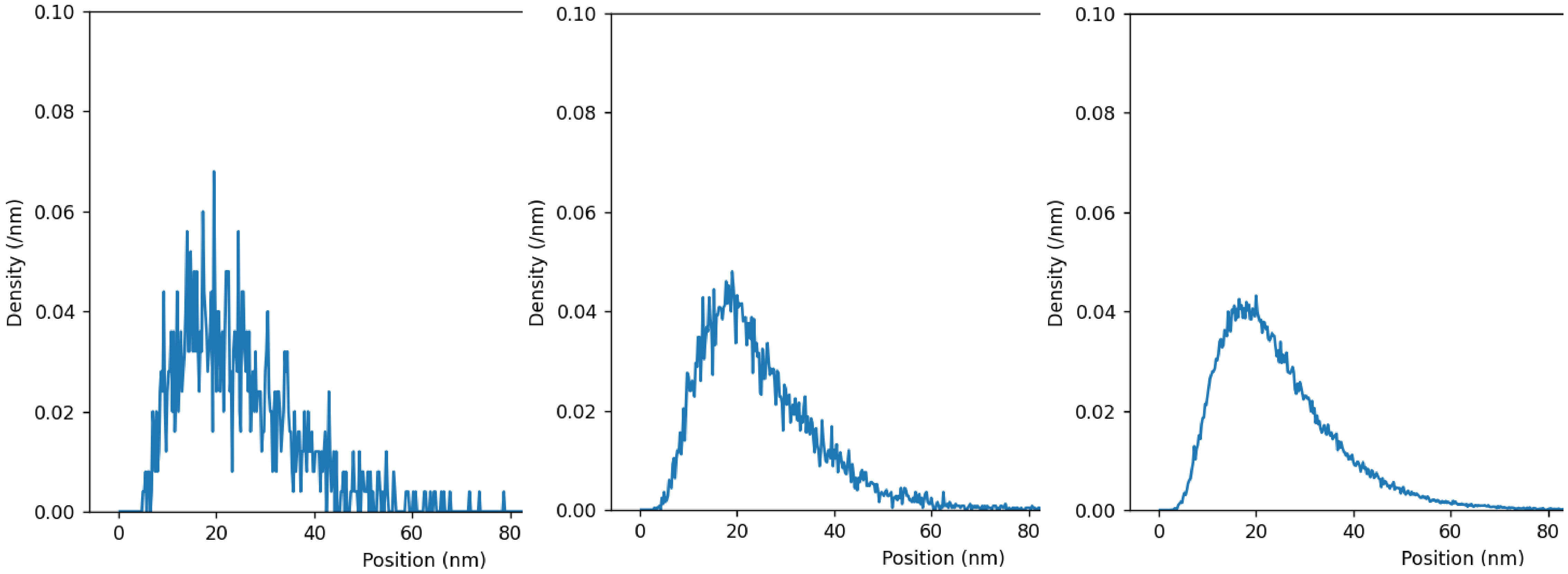
- A moving ion and a resting silicon atom
  - 30 keV ion
  - 0.25 nm is the real-space spacing.
  - For every scattering, the impurity ion loses 40 % of its energy.
  - For every step, the scattering probability is calculated:

$$P(E) = \frac{0.75\ \mathrm{keV}}{E}$$

  - When the energy becomes lower than 1 keV, it is assumed that the ion stops.

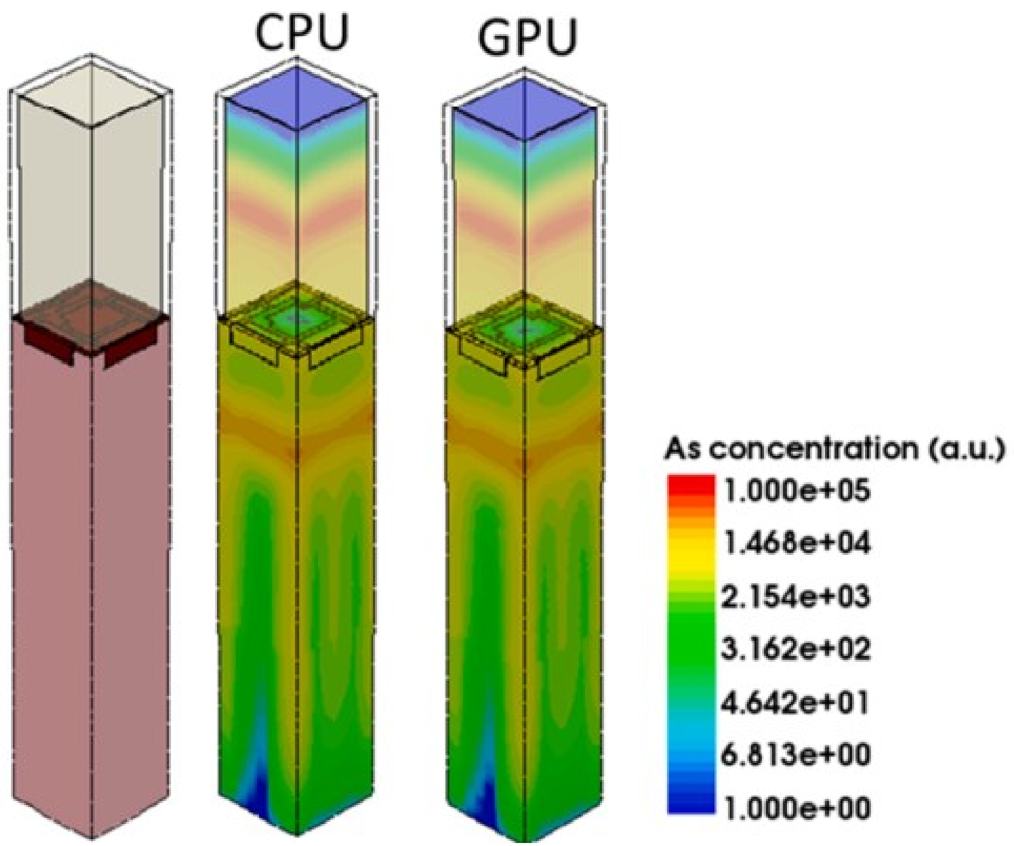
Different sample numbers

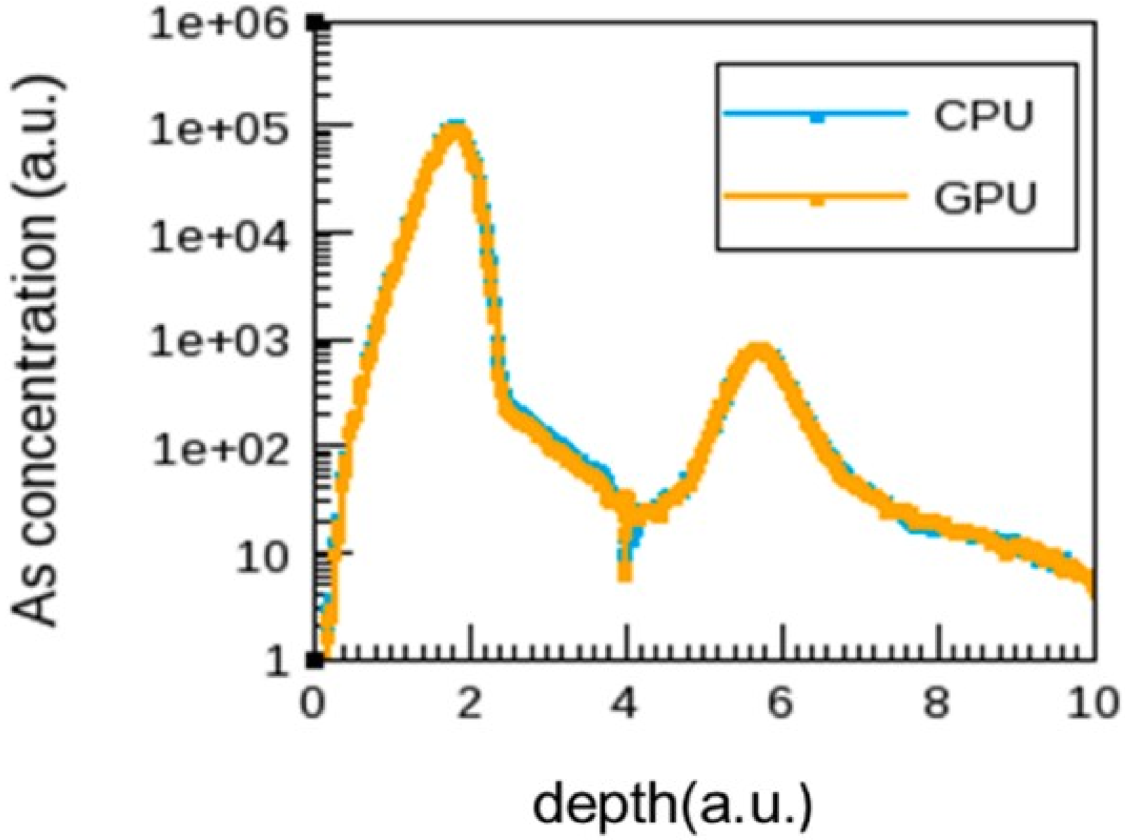
- Distribution of a implanted single ion
  - 1 k, 10 k, and 100 k samples



Implementational issue

- GPU implementation for fast simulation





Deep implantation of As into CIS with 3 MeV energy (F. Machida, SSE, 2023)

Homework#22 (The last one)

- Due: AM08:00, December 10 (Next Tuesday)
- Problem#1
  - Write your own code for the ion implantation. Improve its physical model.

Thank you for your attention!