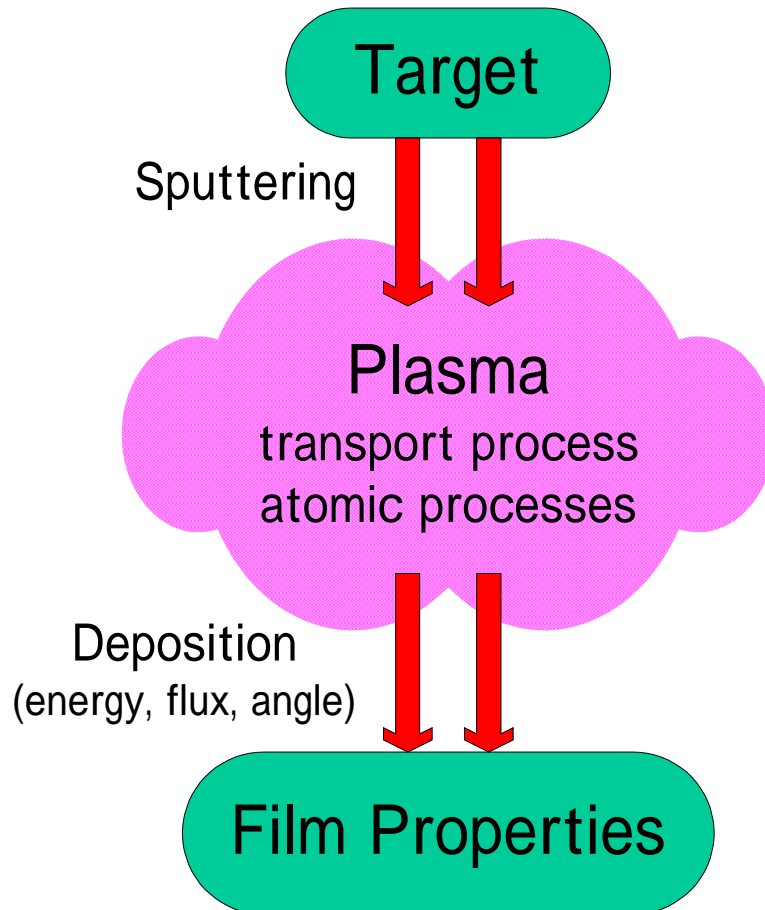


# Evaluation of the spatial density of sputtered particles with Monte Carlo simulation

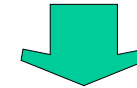
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A novel method to evaluate the spatial density of sputtered particles has been developed using Monte Carlo (MC) simulation. By MC simulation with  $N$  sputtered particles, the residual time of them in a certain volume in the plasma is calculated, while the actual time needed to sputter  $N$  particles is yielded by comparing the simulated deposition flux at the chamber wall with experimentally obtained deposition rate. The mean number of particles in the volume is given by taking the ratio of these two times. The results are compared with recent experiments of optical emission measurement. The effect of the density on OE through the self-absorption process is discussed.

# Backgrounds



To control the film properties,  
Energy / angle of arrival flux  
should be controlled.



Atomic processes in the  
sputtering plasma has come to be  
used (*e.g.* Ionization sputtering).



Evaluation of Atomic density of  
sputtered atoms in the plasma  
has been attracting interests.

# Recent Experiments

- M. F. Dony, *et al.*, JVST A18(3) pp.809 (2000)

Optical absorption measurement of RF magnetron sputtering plasma with Al metal or glass targets (3.3cm in diameter).

Discharge gas was argon. For Al sputtering,  $3.5 \times 10^{11} \text{cm}^{-3}$  was obtained at 40 mTorr 40W, and  $4.8 \times 10^{11} \text{cm}^{-3}$  at 80 mTorr 30W.

- Y. Andrew, *et al.*, J. Appl. Phys. 88(6) pp.3208 (2000)

Optical absorption measurement of ionized sputtering apparatus.

Cu was sputtered by Ar. 0~200W of DC power was applied to the Cu target of 15cm in diameter.  $10^{12} \sim 10^{13} \text{cm}^{-3}$  of ground state

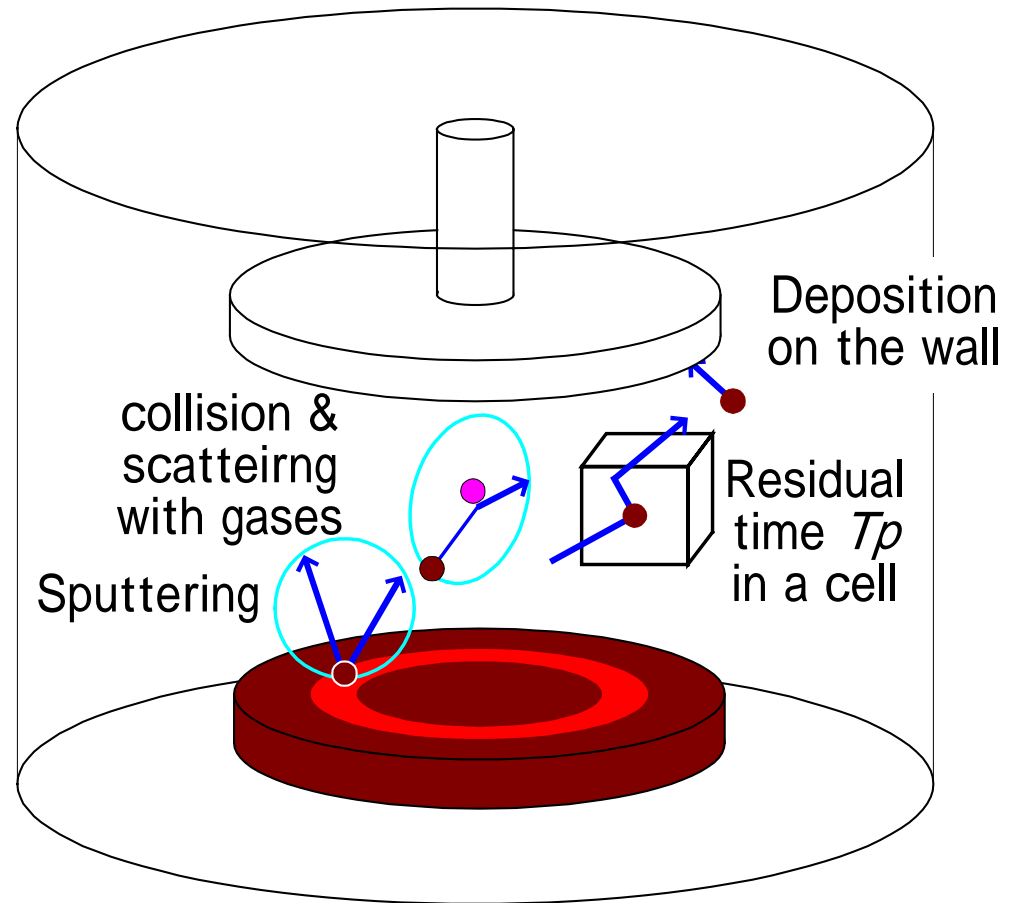
Cu was measured at pressures of 10 and 30 mTorr. Density was increased with the increase of the RF power applied to the inductively coupled coil for ionization enhancement.

# Monte Carlo Simulation (1)

Monte Carlo simulation of the sputtered particles treats the “life” of them through:

1. Sputtering ejection from the target.
2. Collision and scattering with gas atoms.
3. Deposition on the chamber wall.

Since the path and the energy of the particles can be obtained during the simulation, “residual time” of particles in certain cells can be obtained.



## Monte Carlo Simulation (2)

Though sputtered particles from the target have some eV's of kinetic energies initially, they are decelerated by collisions with argon gas atoms until the thermal energy of the gas. Therefore, the proper treatment of the colliding gas motion is necessary to simulate the whole life of sputtered particles, and to obtain the residual time of the particles in cells reasonably.

### Conventional MC:

- Neglected the motion of gas atoms.
- Sputtered particles are collide with stationary gases (and decelerated).
- After the thermalization, random walk model is applied.

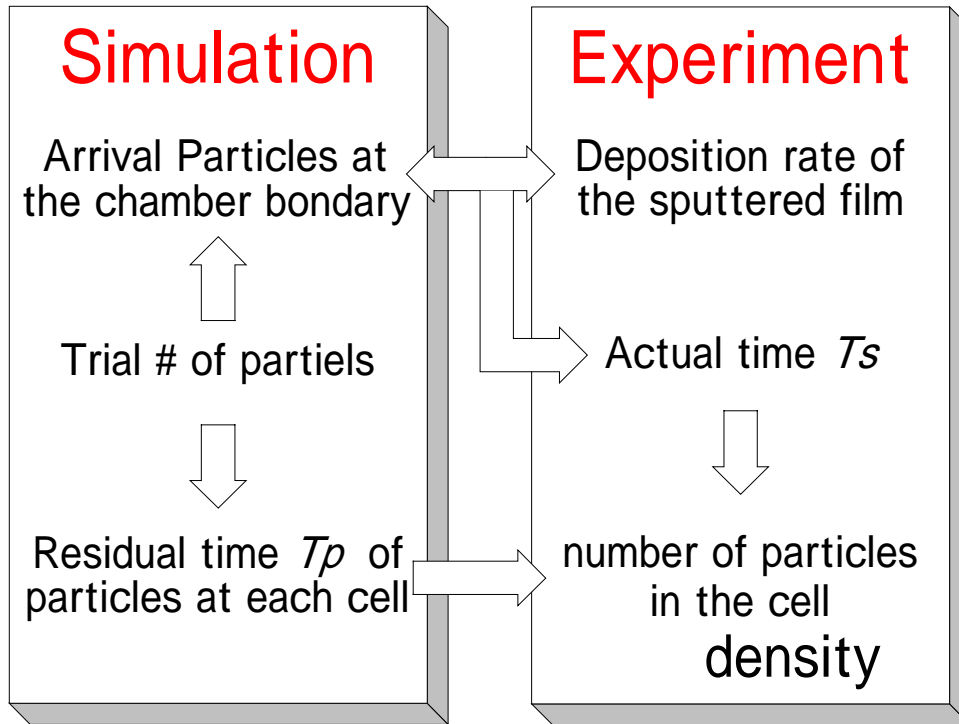
### Our recent model (\*):

- Formalized the velocity distribution of colliding gases (in Maxwellian), considering the kinetic theory of gases.
- Proper simulation is available until low energy region.

(\*) T.Nakano, I.Mori and S.Baba; Appl. Surf. Sci., **113/114** (1997) pp.642

Fortran (partly C) program code is available at <http://surf.ap.seikei.ac.jp/HISPUT/>

# Concept of Density Evaluation



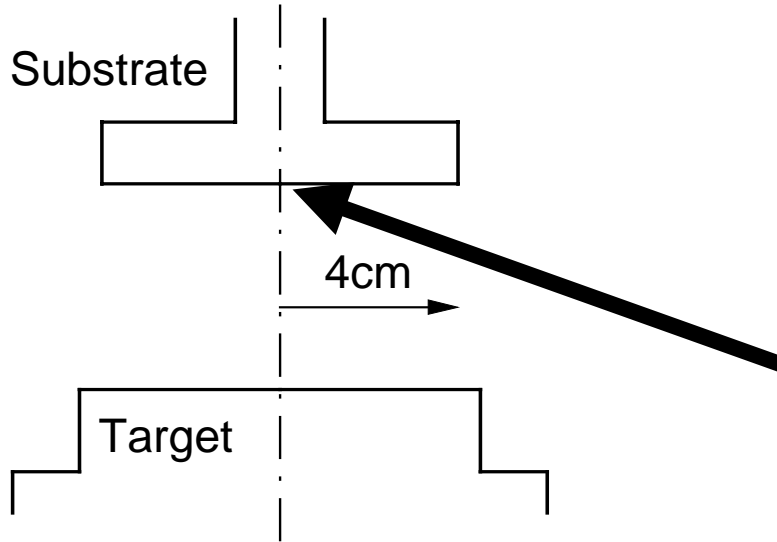
With the simulation, number  $N$  of Cu atoms (typically  $\sim 10^5$ ) are tested and:

1. arrival number of atoms at the wall
2. residual time  $T_p$  at each cell are calculated.

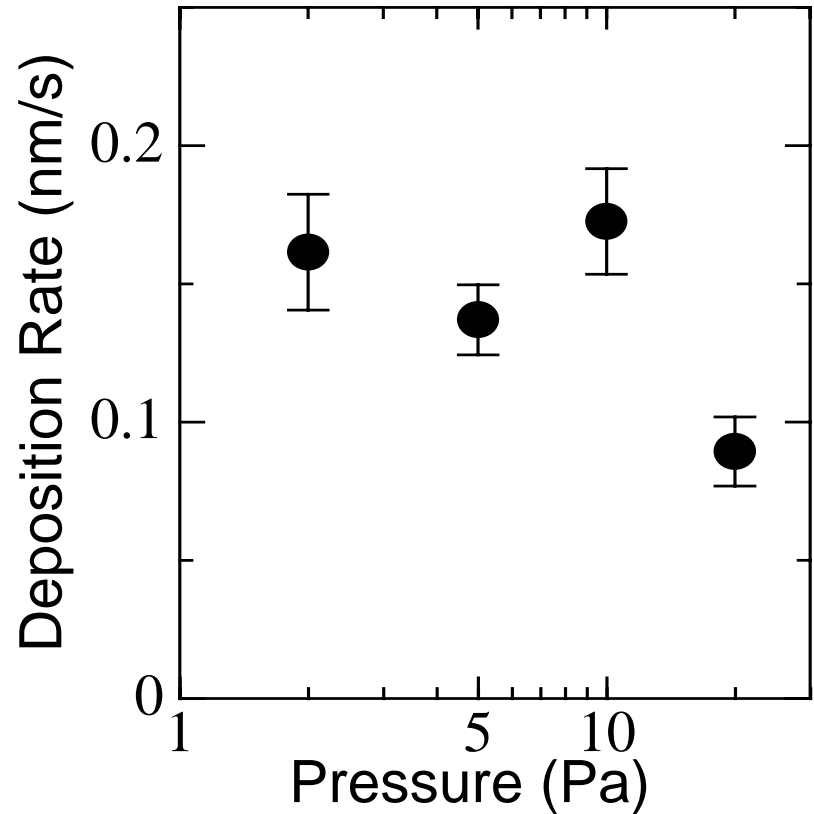
(1) is compared with the experimental deposition rate, and the time  $T_s$  corresponding to the simulation of  $N$  particles is determined.

Dividing  $T_p$  by  $T_s$ , the mean number of particles inside each cell is determined, then the density is obtained.

# Deposition Experiments

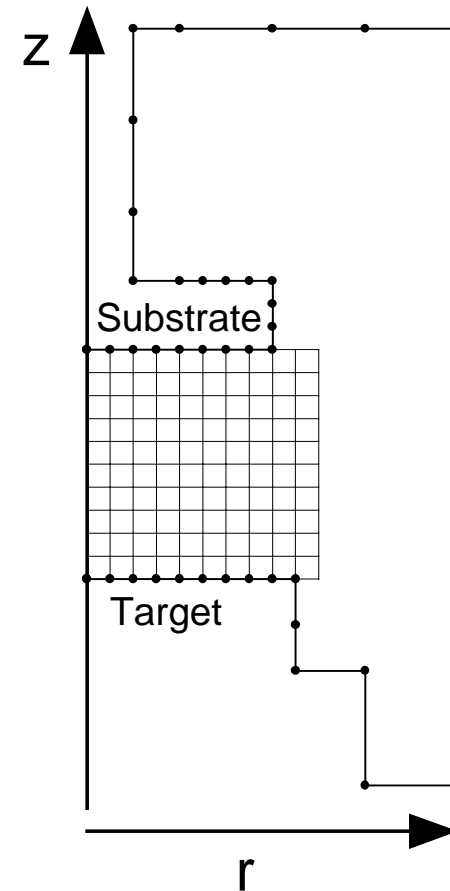


DC Magnetron Sputtering  
Target Cu / Gas Ar  
Power 100W

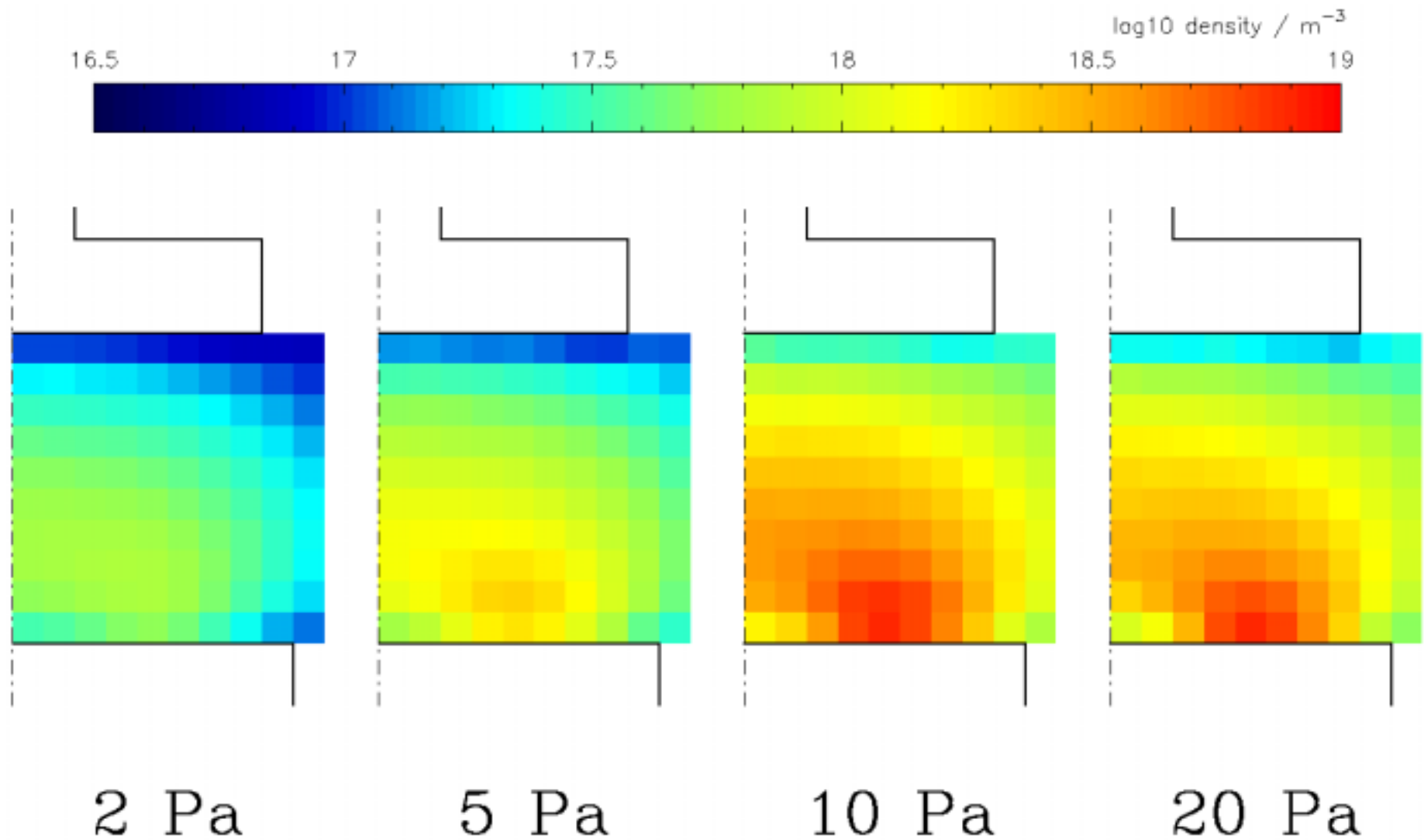


# Simulation Conditions

- Axisymmetric system, with radius of 8cm and height of 16.5cm
- Distribution of the ejection position on the target is determined so that the depth profile of erosion track (at around  $r=2\text{cm}$ ) is reproduced. Thompson's energy distribution is used.
- Maxwellian gas motion is considered on collision & scattering events.
- Temperature and density profiles of the gas inside the chamber is assumed to be uniform.
- Sticking coefficient is unity on the chamber wall.

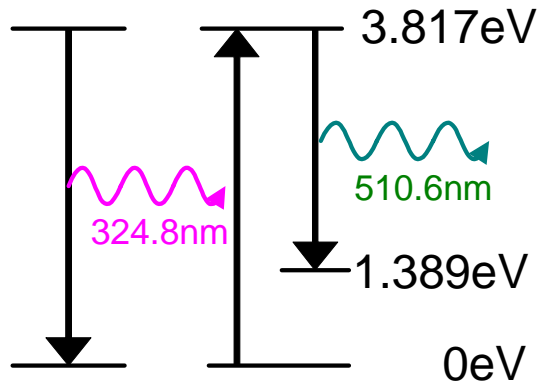


# Calculated Cu density



# Self absorption effect in OES of Cu

T. Nakano, N. Ohnuki, S. Baba: Vacuum (in press)



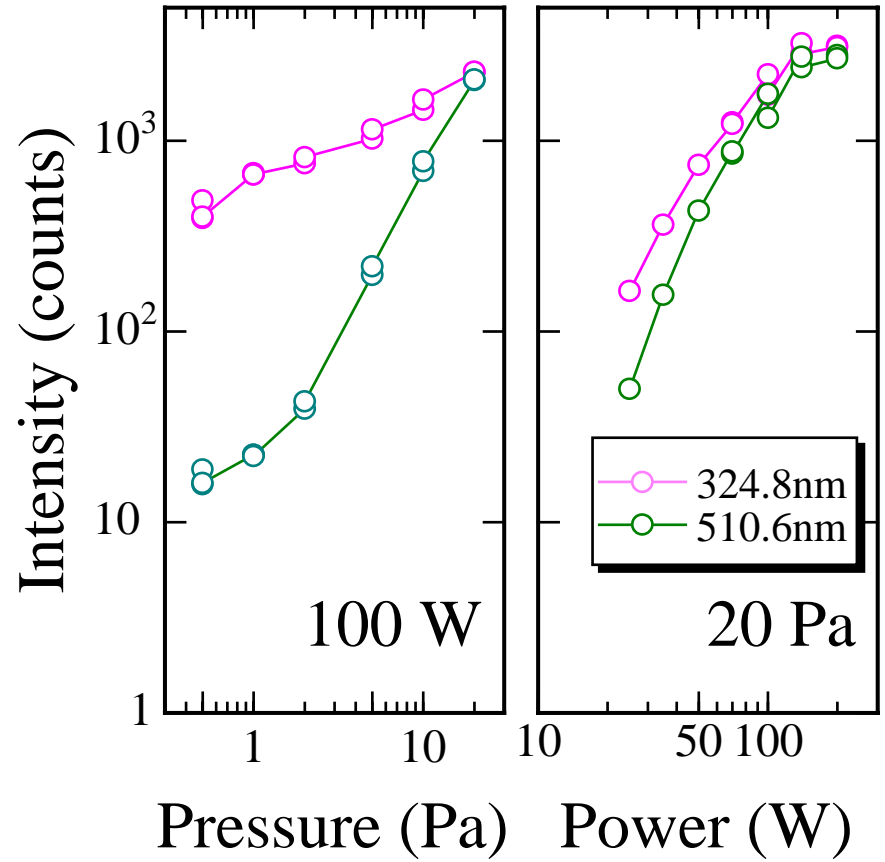
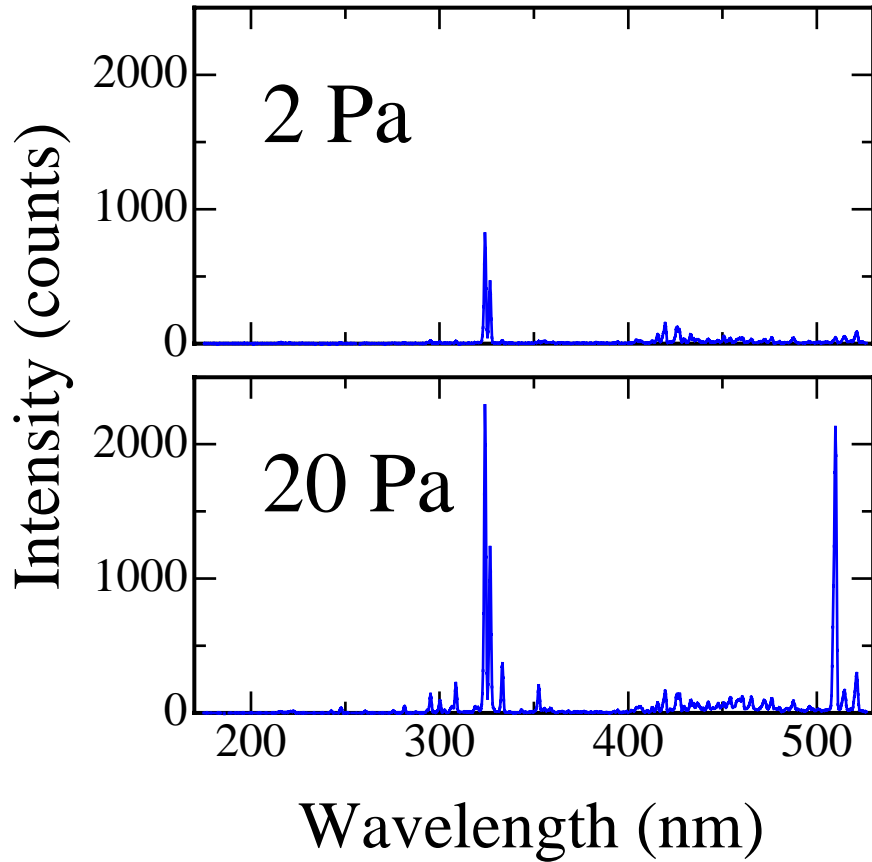
From the Cu sputtering plasma, two strong emission lines from Cu neutral can be observed at 324.8nm and 510.6 nm. These transitions share the same initial state. The final state of the former is the ground state while the latter is not.

Therefore, as the density of Cu atom (mostly at ground state) increases, the 324 emission is absorbed by ambient Cu atoms, and shows more gentle increase compared to the 510 emission.

Decay length of 324.8 nm emission depends on the Cu density. Considering the chamber size, the density calculated by MC simulation can reasonably explain the behavior of OE's.

$n \text{ (m}^{-3}\text{)}$	$\lambda_{324} \text{ (m)}$
$10^{16}$	$0.66 \times 10^{-1}$
$10^{17}$	$0.66 \times 10^{-2}$
$10^{18}$	$0.66 \times 10^{-3}$

# OES from Cu/Ar plasma



## Summary

- The method to estimate the spatial density of sputtered particles has been developed based on the MC simulation of particle transport process.
- As the gas pressure increases, the Cu density becomes larger. It may be due to the shorter mean free path (hence the smaller diffusion coefficient) of sputtered Cu atoms at higher pressures.
- The result of the simulation agrees in magnitude with recent experimental results using the optical absorption technique. It also successfully explains the relative decrease of optical emission intensity at 324.8 nm from Cu neutrals.