Similarity of breathing oscillations in magnetron discharges

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September 12, 2021

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Outline

- Background
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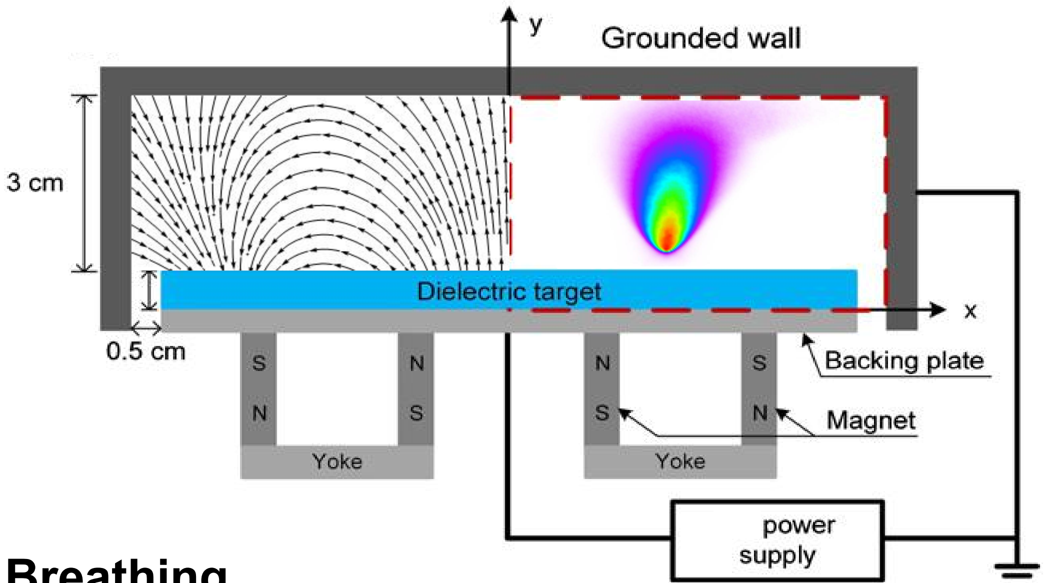
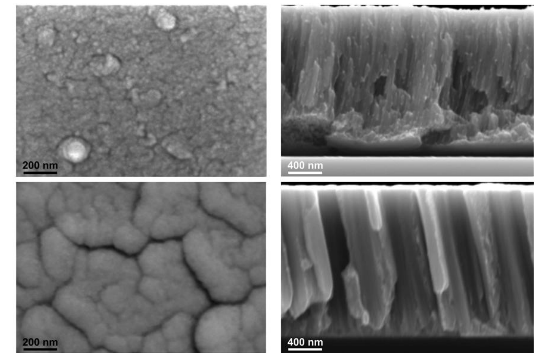
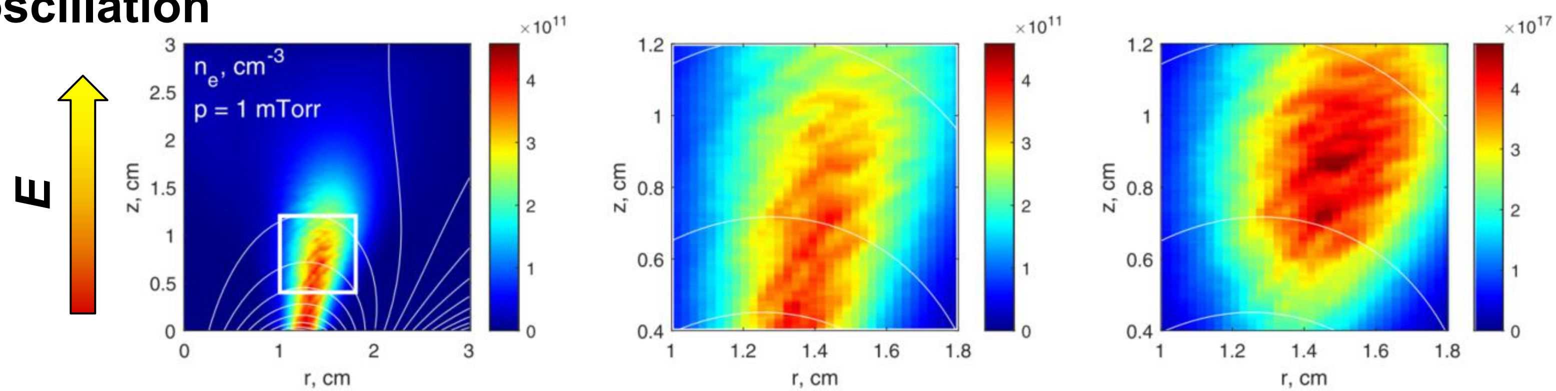
  - Breathing oscillation
  - Similarity law
- Modeling and simulation
- Results and discussion
- Conclusion

Magnetron Sputtering discharge



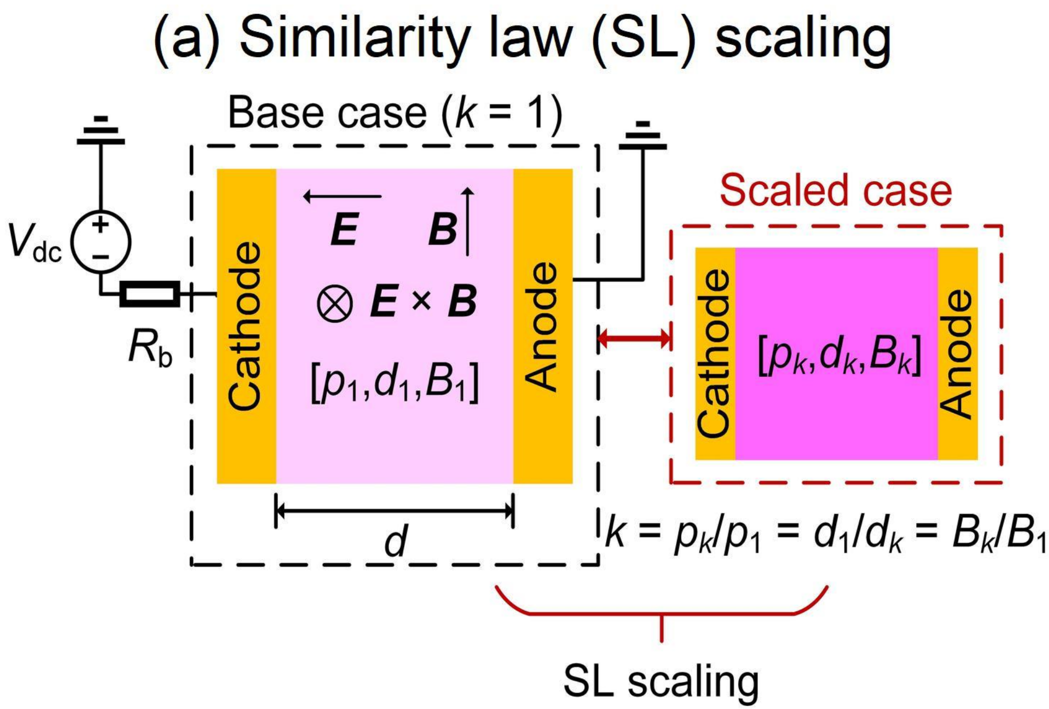


Breathing oscillation



Ryabinkin et al, **PSST** 30, 055009 (2021)

Similarity law



$$G(x_1, t_1) = k^{\alpha[G]} G(x_k, t_k)$$

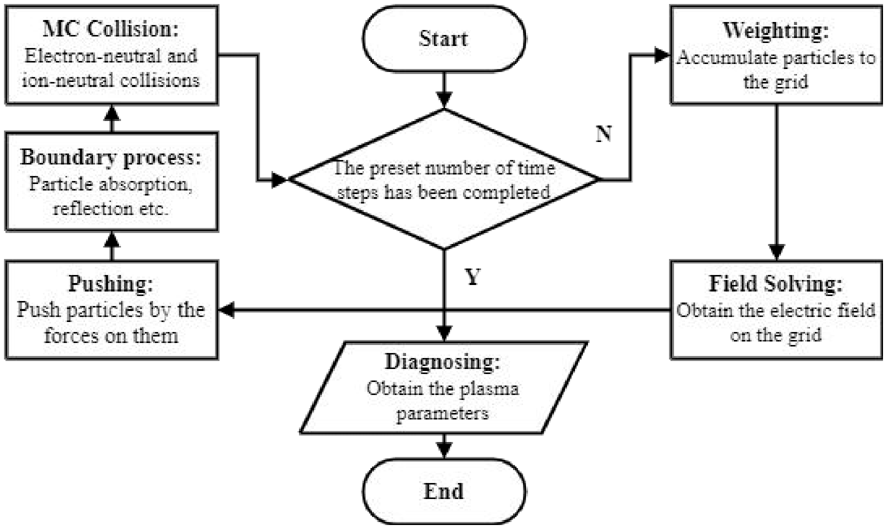
k: scaling factor
α: similarity factor

$$\alpha[n_e] = \alpha[\boldsymbol{J}_e] = -2$$
$$\alpha[\boldsymbol{E}] = \alpha[p] = \alpha[B] = \alpha[f] = -1$$
$$\alpha[V] = \alpha[\varepsilon_e] = \alpha[\boldsymbol{u}_e] = \alpha[B/p] = \alpha[pd] = 0$$
$$\alpha[x] = \alpha[t] = \alpha[d] = 1$$

similarity invariants

n_e: electron density
$\boldsymbol{J}_e$: electron current density
$\boldsymbol{E}$: electric field
p: pressure
B: magnetic field
f: frequency
V: electric potential
ε_e: electron energy
$\boldsymbol{u}_e$: electron velocity
x: position
t: time
d: gap distance

Particle-In-Cell/Monte Carlo Collision (PIC/MCC)



ASTRA code

Yangyang Fu†, Huihui Wang, Bocong Zheng†, et al, APL 118, 174101 (2021).
Bocong Zheng et al, PSST 30, 035019 (2021).
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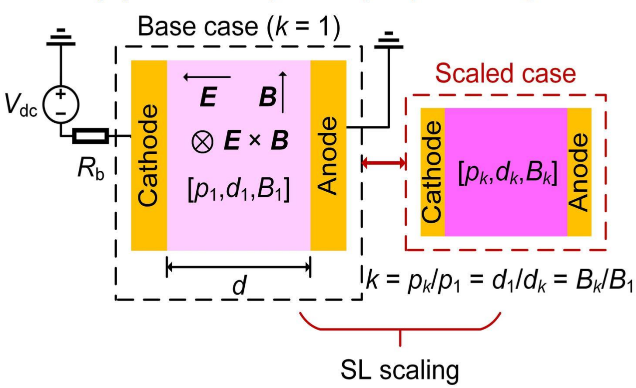
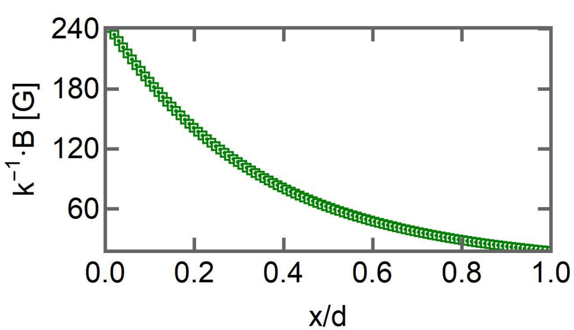
(a) Similarity law (SL) scaling

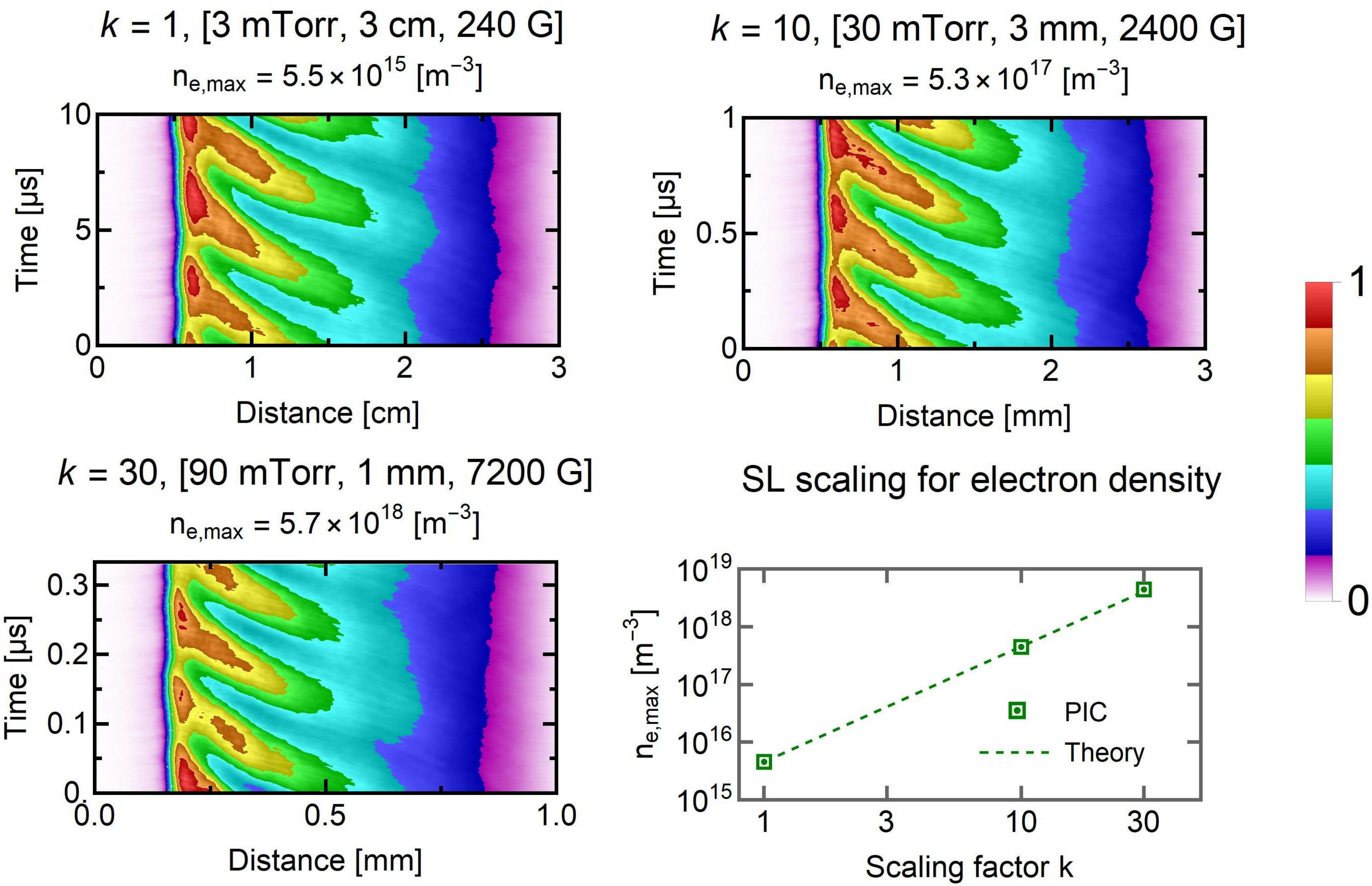


(b) Magnetic field distribution



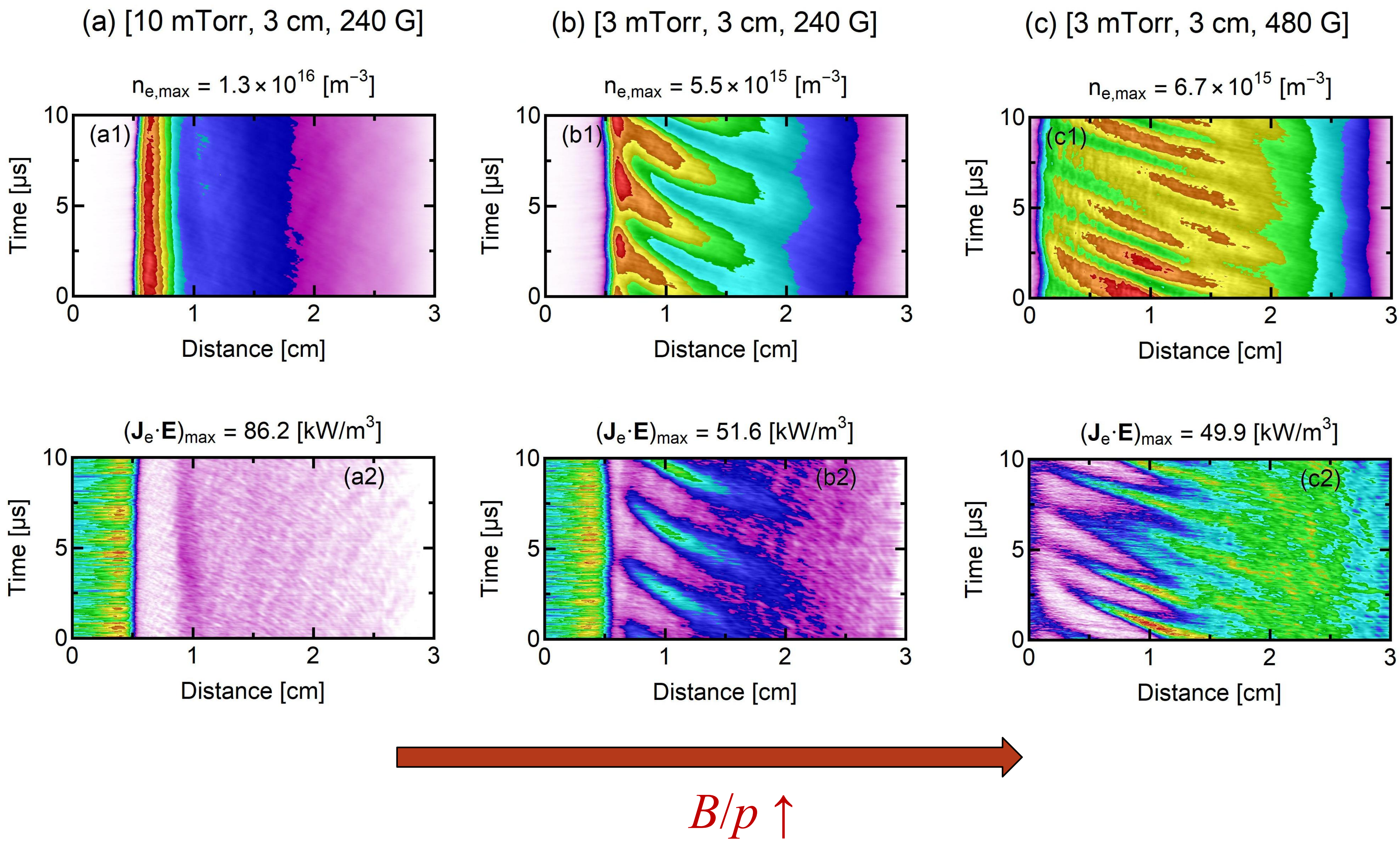
Base conditions:
p = 3 mTorr
d = 3 cm
B = 240 G

Spatiotemporal profiles of electron densities



Scale-invariant breathing oscillations

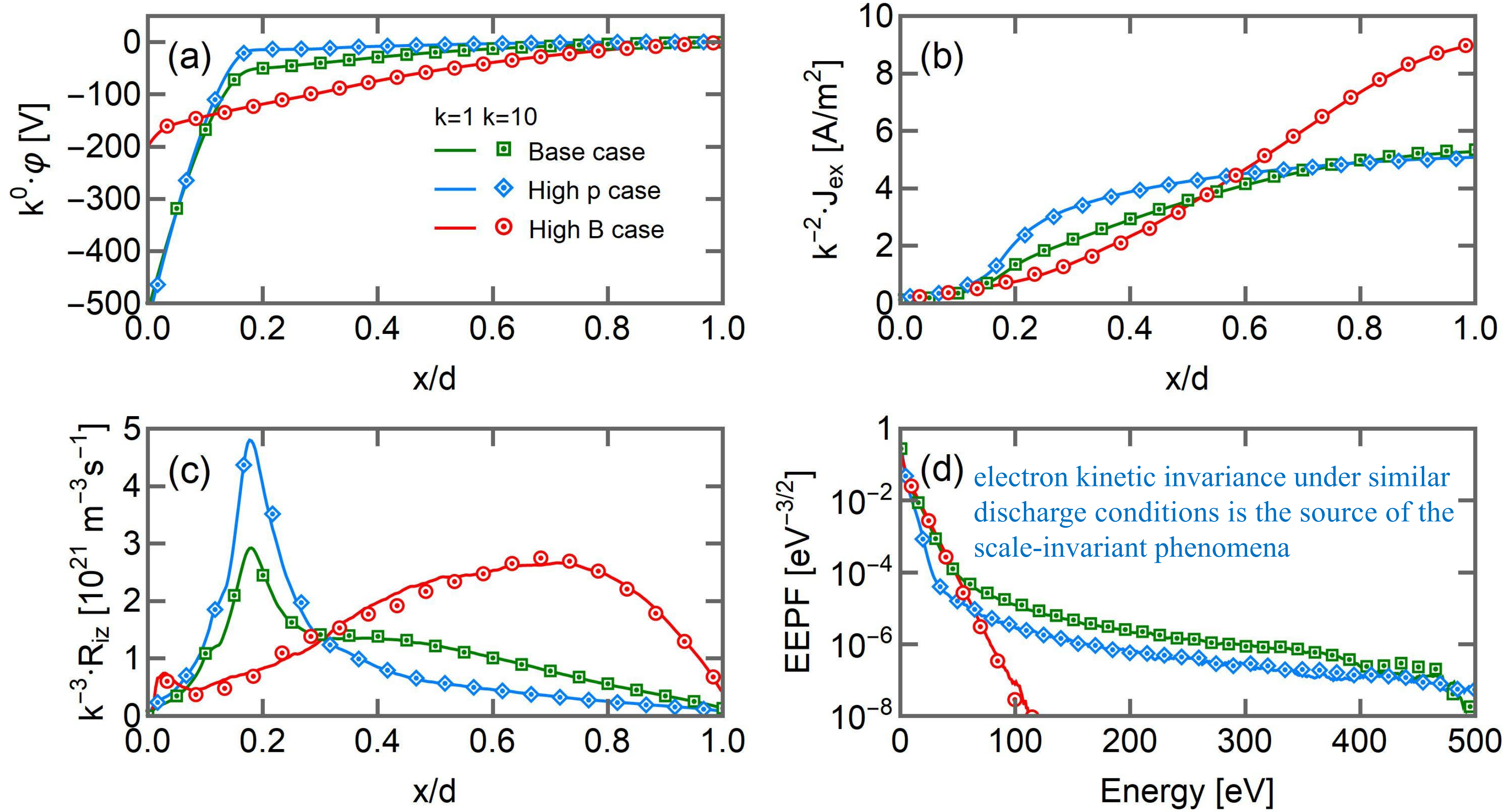
Influence of pressure and magnetic field



Time-averaged results

Electric potential

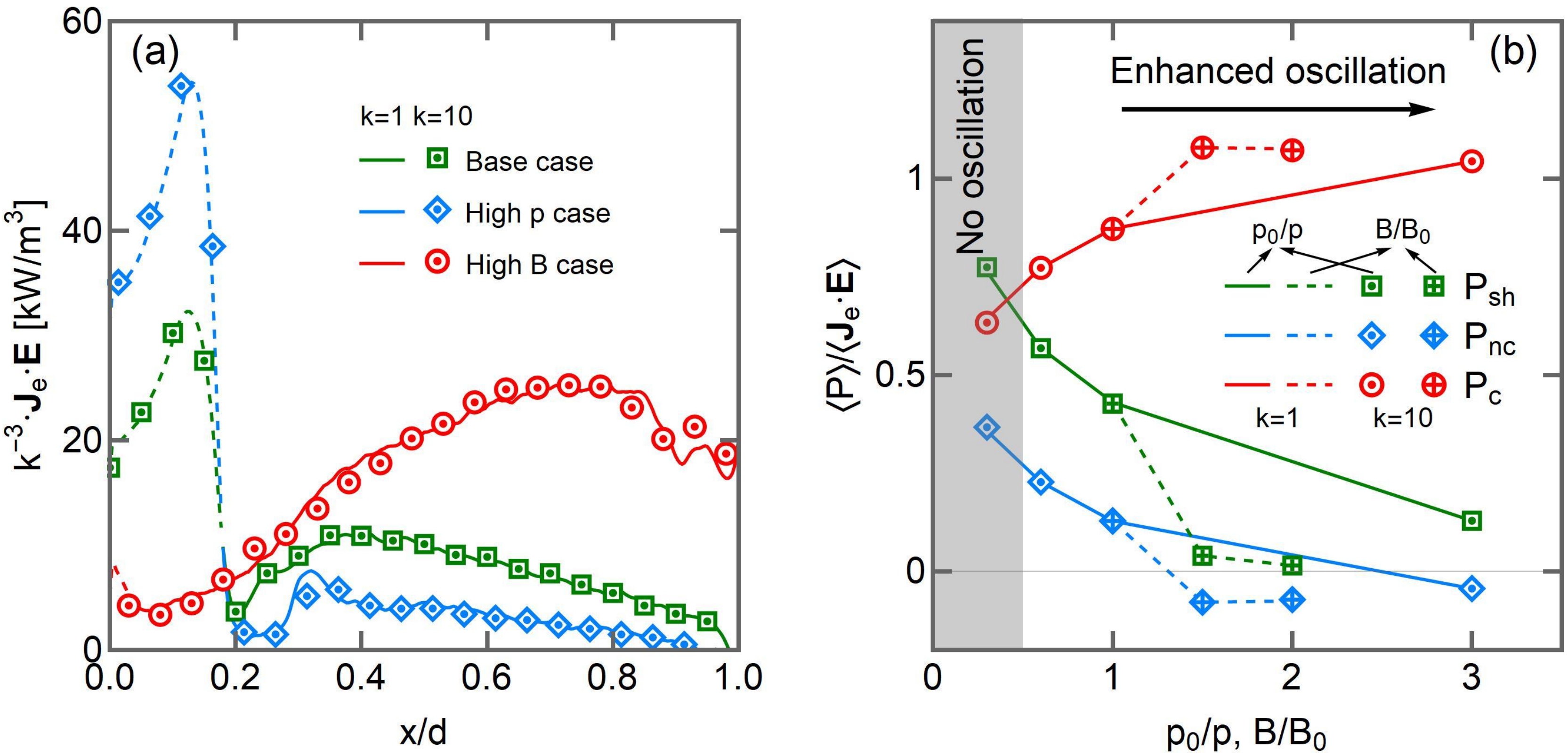
Electron current density



Ionization rate

Electron energy probability function

Transition of electron heating mechanism



B/p ↑ (as does pd ↑)

Conclusion

- We verify the similarity law (SL) in magnetron discharges via particle-in-cell/Monte Carlo collision (PIC/MCC) simulations, and observe the scale-invariant breathing oscillations.
- The plasma oscillations are induced by increasing the similarity invariant B/p.
- Reducing B/p or pd, the breathing oscillations are suppressed due to the increase in wavelength or the decrease in characteristic scale of discharge.
- With the onset and development of breathing oscillations, the electron energization mechanism shifts from sheath energization to Ohmic heating in the ionization region.
- The breathing oscillations and electron energization mechanism remains unchanged under similar conditions.

Thank you

- The slides can be downloaded at bczheng.com/talks/Zheng21_ICOPS.pdf
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