

3.4 Plasma Sources

Classification of plasma sources:

according to pressure

- low pressure
- atmospheric pressure

importance of mean free path:

$$\lambda = 1 / n\sigma$$

n – density, σ – collision frequency

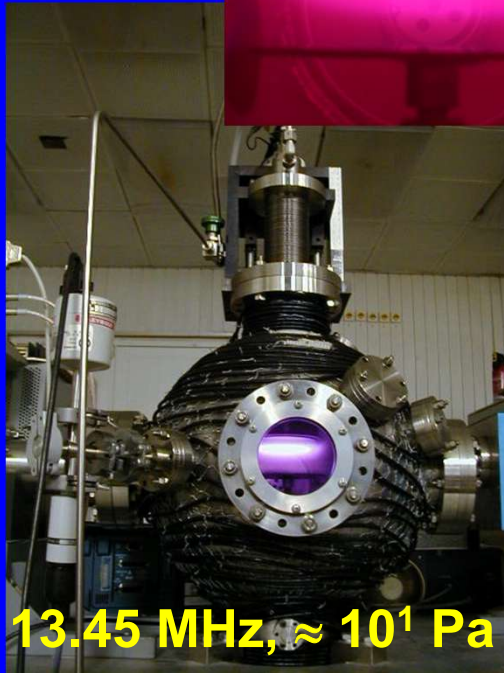
according to excitation frequency

- d.c. (d.c. glow discharge or planar diode, thermionically supported diode, d.c. magnetron, vacuum arc)
- low frequency regime (50 Hz, audio range, low radio frequency up to 1 MHz – usually planar diode configuration)
- high radio frequency (typically 13.56 MHz)
- microwave frequency (typically 2.45 GHz)

importance of electron and ion plasma frequencies:

$$\omega_{pe,i} = \sqrt{\frac{e^2 n_e}{\epsilon_0 m_{e,i}}}$$

Laboratory plasma sources (DPE MU Brno)



13.45 MHz, $\approx 10^1$ Pa

capacitively
coupled RF
discharge



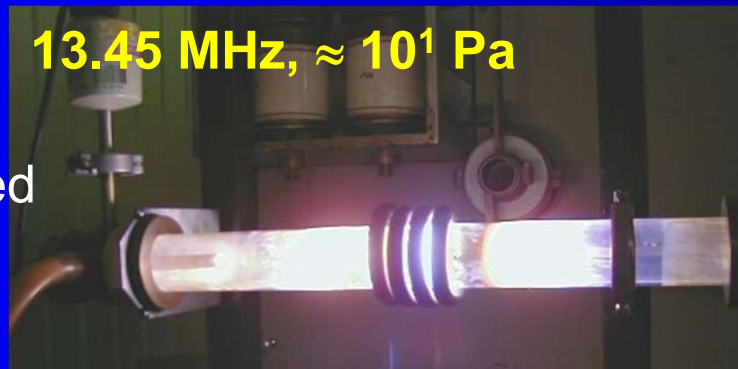
2.45 GHz, $\approx 10^2$ Pa

microwave resonator
discharge (AsTeX)



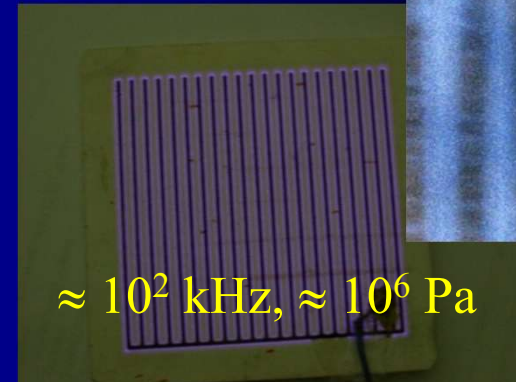
2.45 GHz, $\approx 10^6$ Pa

microwave torch



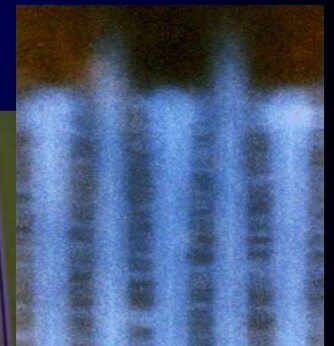
13.45 MHz, $\approx 10^1$ Pa

inductively coupled
RF discharge



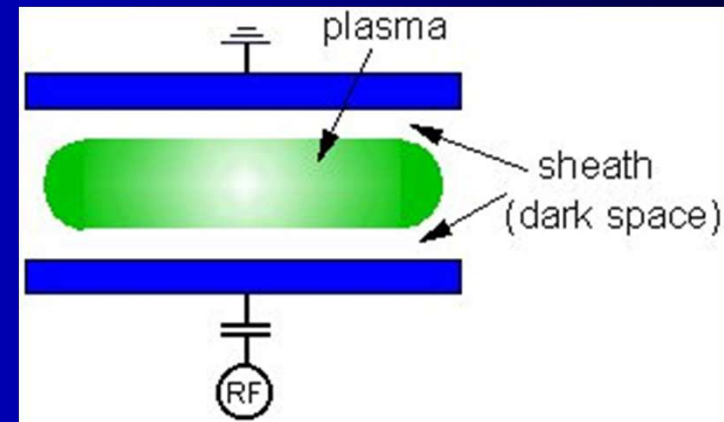
$\approx 10^2$ kHz, $\approx 10^6$ Pa

coplanar barrier discharge
at atmospheric pressure

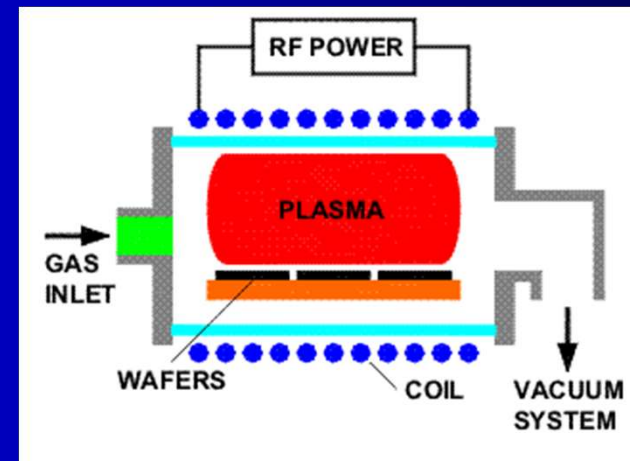


Typical Low Pressure, High Frequency Plasma Sources

○ radio frequency capacitively coupled plasma (CCP)



○ r.f. inductively coupled plasma (ICP)

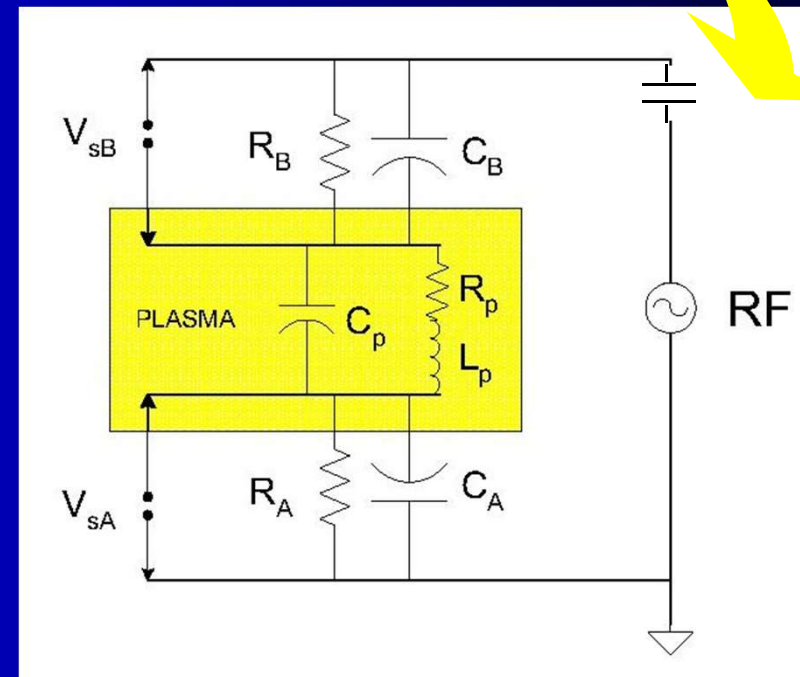
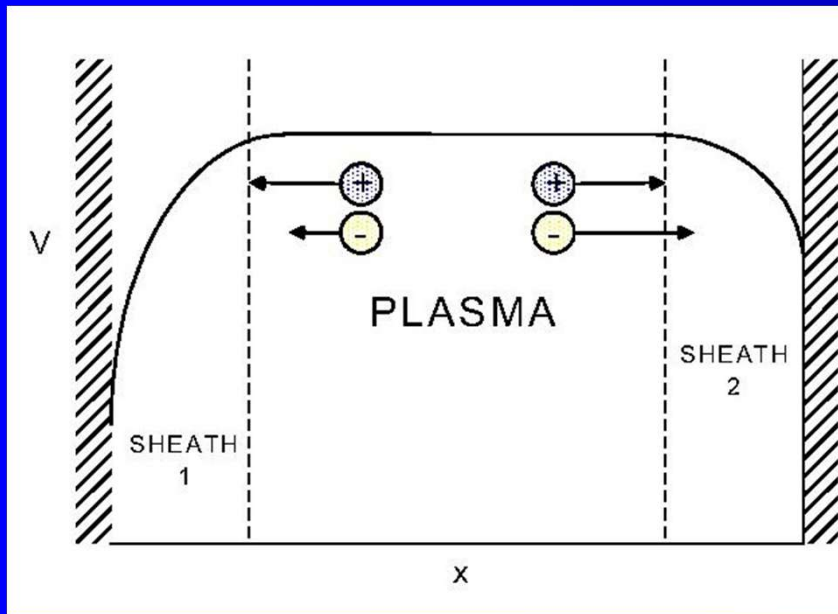
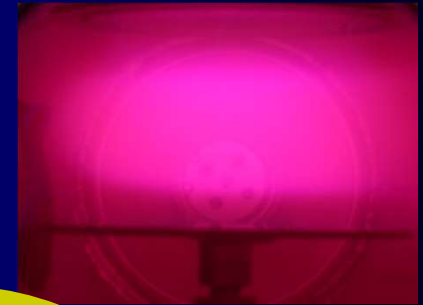


○ plasma sustained by electromagnetic wave: electron cyclotron resonance, helicon discharge, surface wave discharge

Principle of r.f. CCP discharges

discharge is sustained by r.f. current and voltage coupled via capacitive plasma sheath

electrical circuit usually contains „blocking“ capacitor
 → dc current cannot flow in the circuit

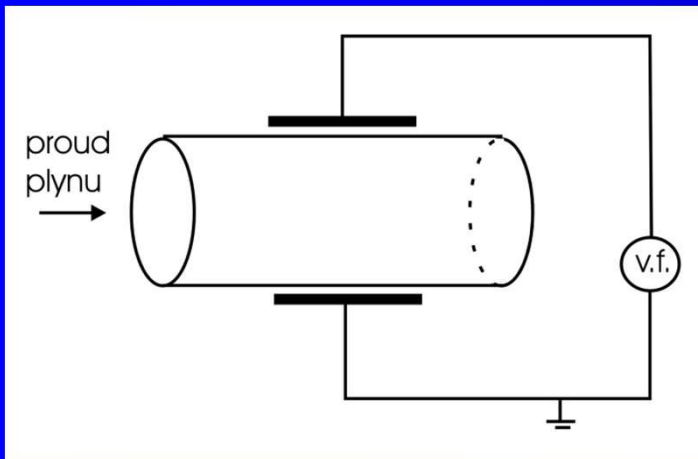


$$\frac{V_{sB}}{V_{sA}} \approx \left(\frac{A_A}{A_B} \right)^q$$

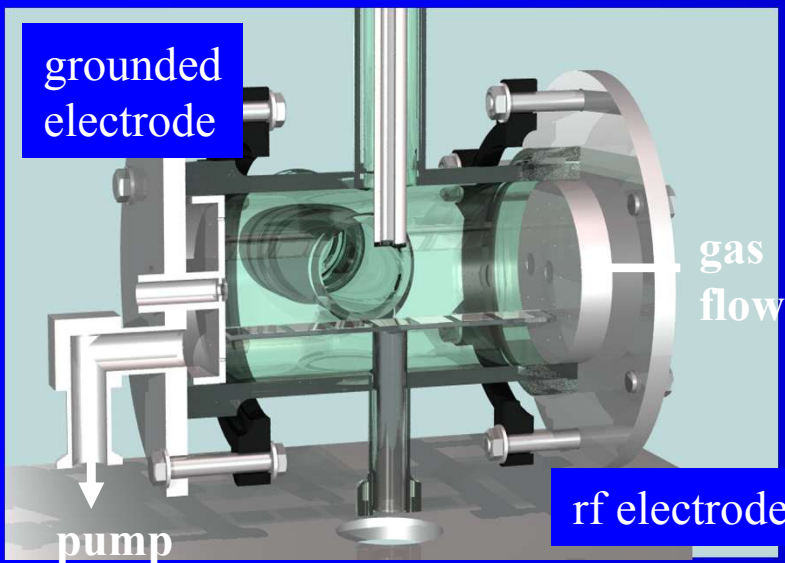
voltage divider action due to displacement current in plasma sheaths

Construction of CCP reactors

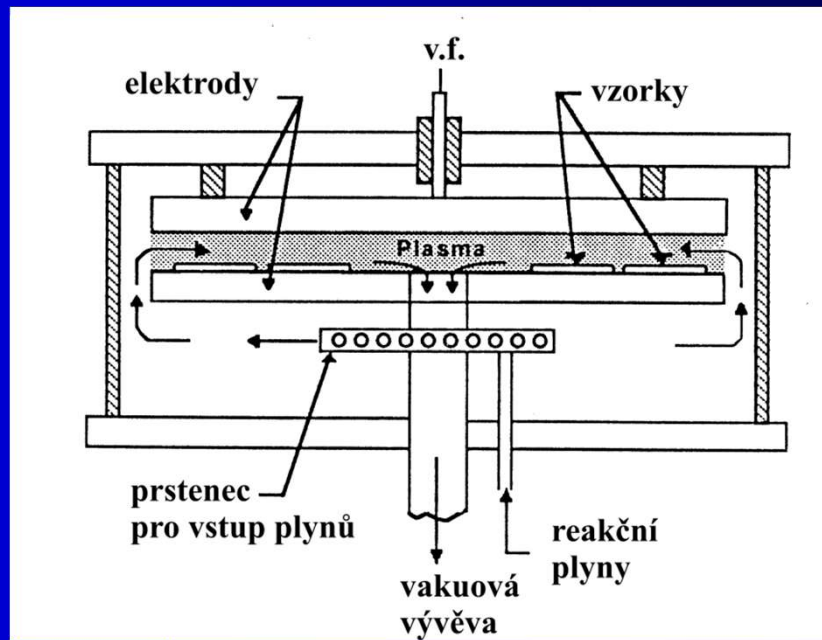
- horizontal reactor
- with outer electrodes



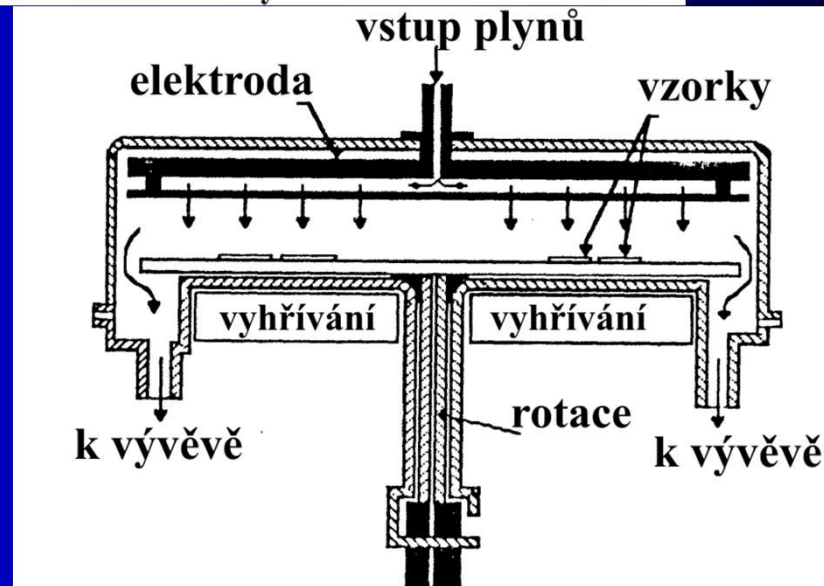
- with inner electrodes



- vertical reactor with inner parallel electrodes (parallel-plate diode discharge)

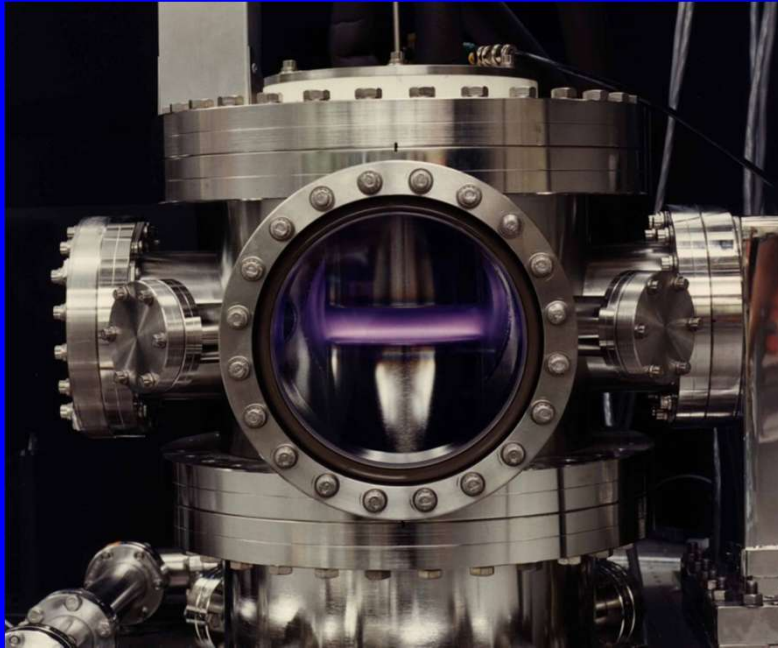


with radial gas flow



with inverse radial flow - showerhead electrode

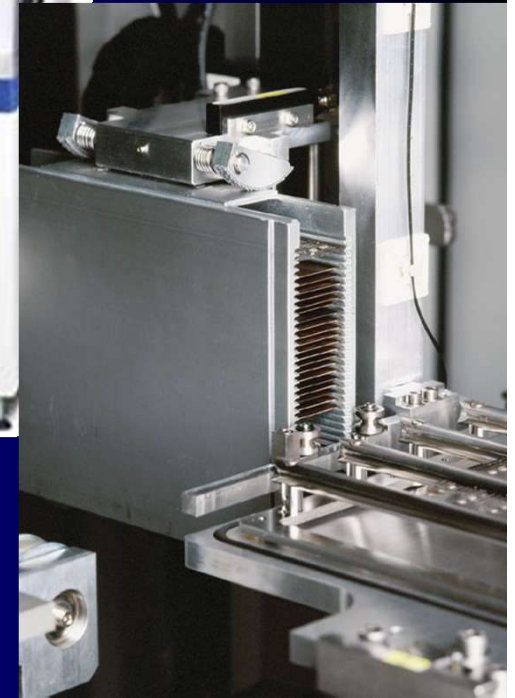
Construction of CCP reactors



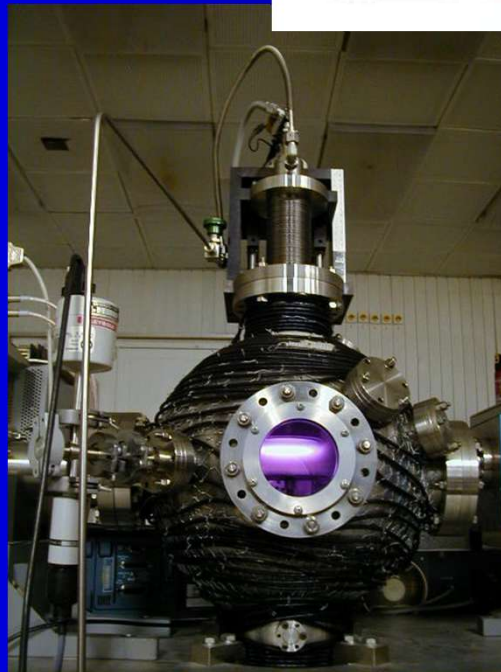
GEC (Gaseous Electronics Conference) reference cell

Reactive Ion Etcher (RIE)
R.F. Diode

DPE MU Brno



UCP Processing Ltd.
(Balzers)

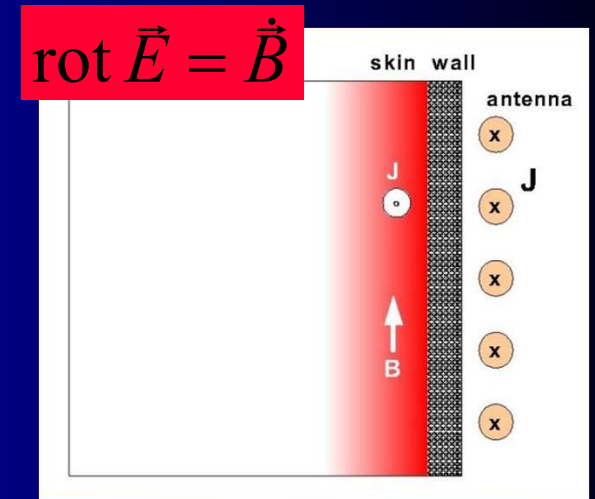


Principle of ICP discharges

r.f. antenna in the form of coil attached to dielectric window – electromagnet creating rf mg field – induction of rf el field

Energy of electrical field is transferred to the electrons in thin „skin“ layer.

- non-collisional processes – electrons „collide“ with induced oscillating el. field
- energy is dissipated by collisional (ohmic) processes

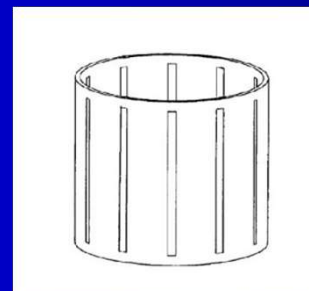
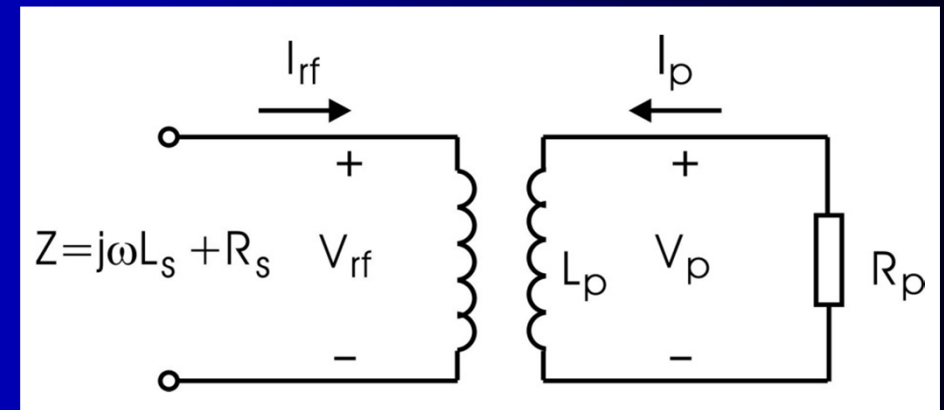


skin depth (collisionless)

$$\delta_s = \delta_c \equiv c / \omega_p$$

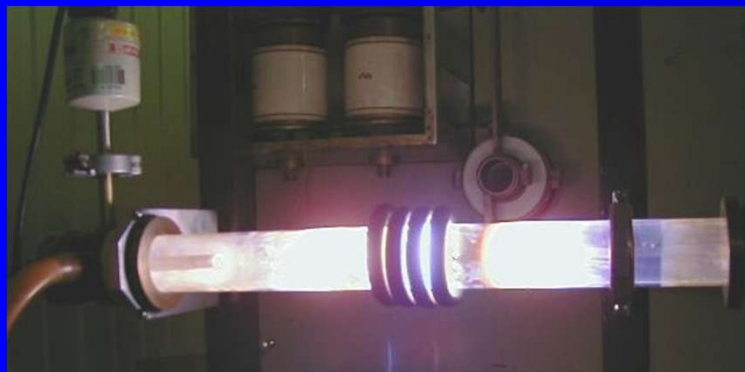
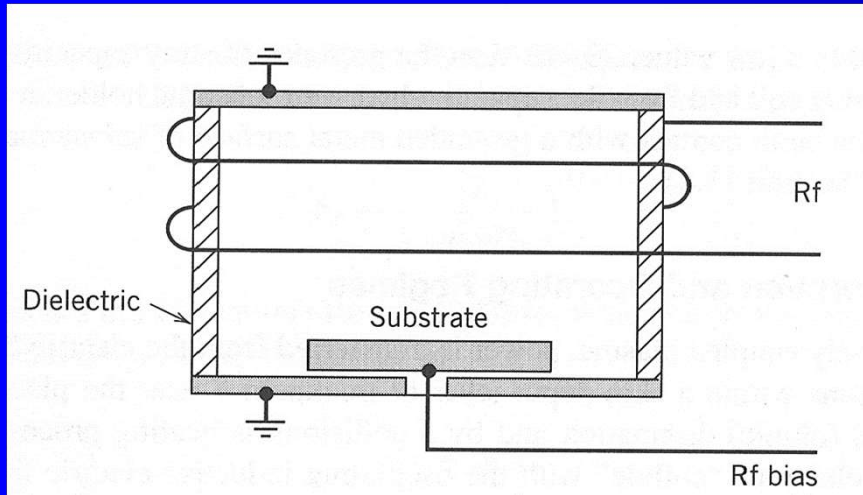
☞ non-capacitive coupling is a key point for low voltages (typically 20-30 V) in sheaths at electrodes and reactor walls

☞ Faraday shielding is used to suppress capacitive coupling (high voltage on the coil)

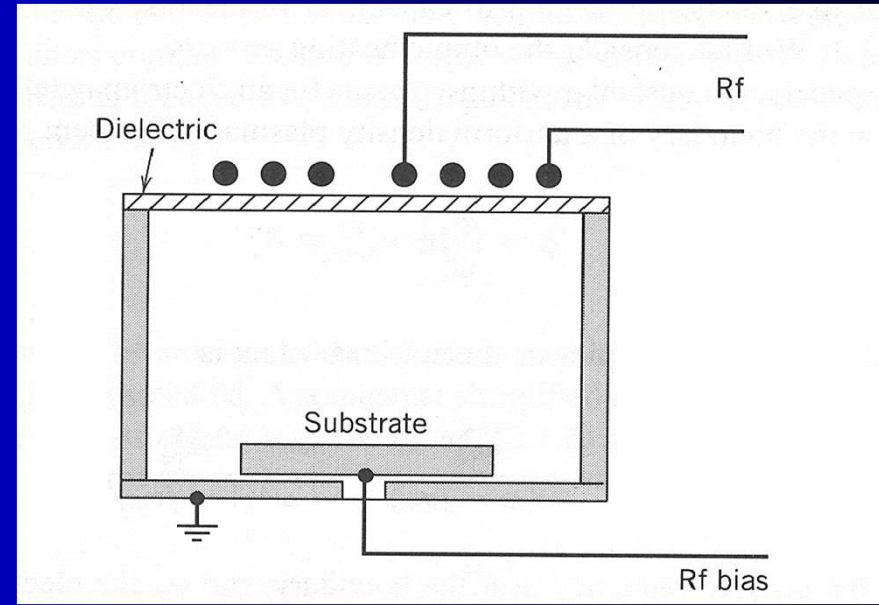


Construction of ICP reactors

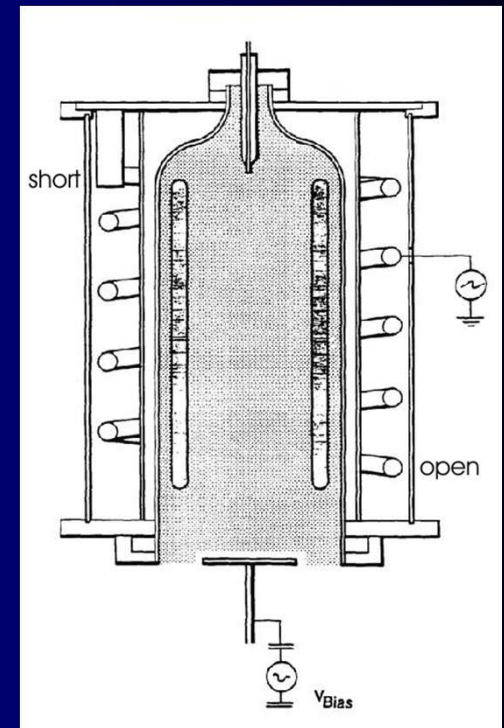
○ cylindrical geometry



○ planar geometry



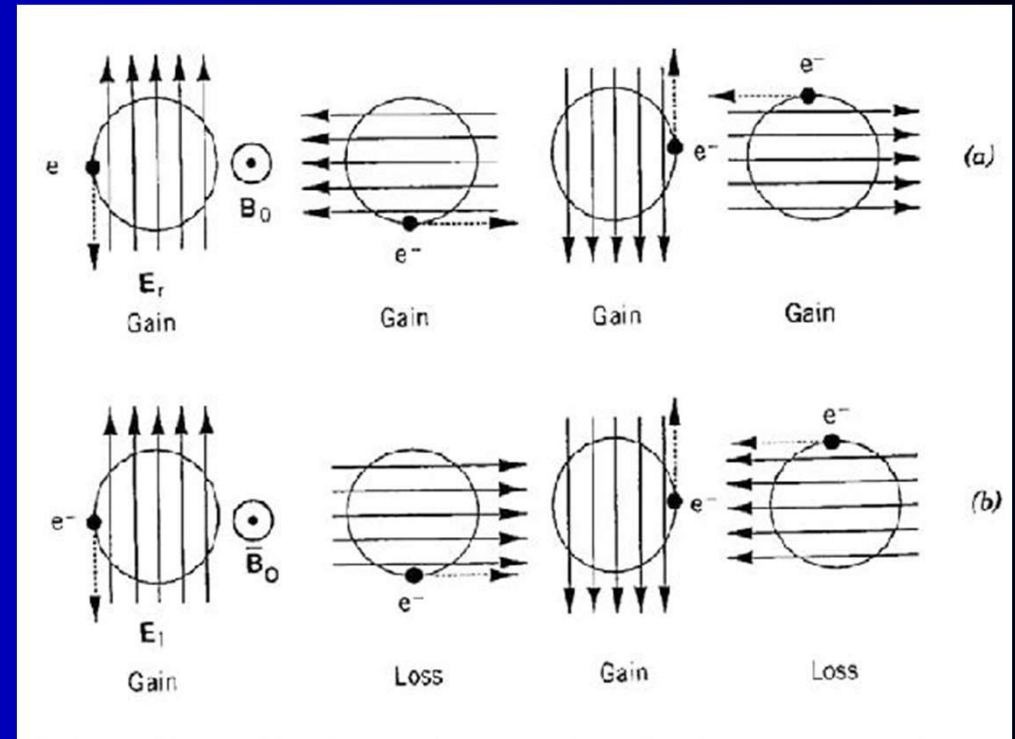
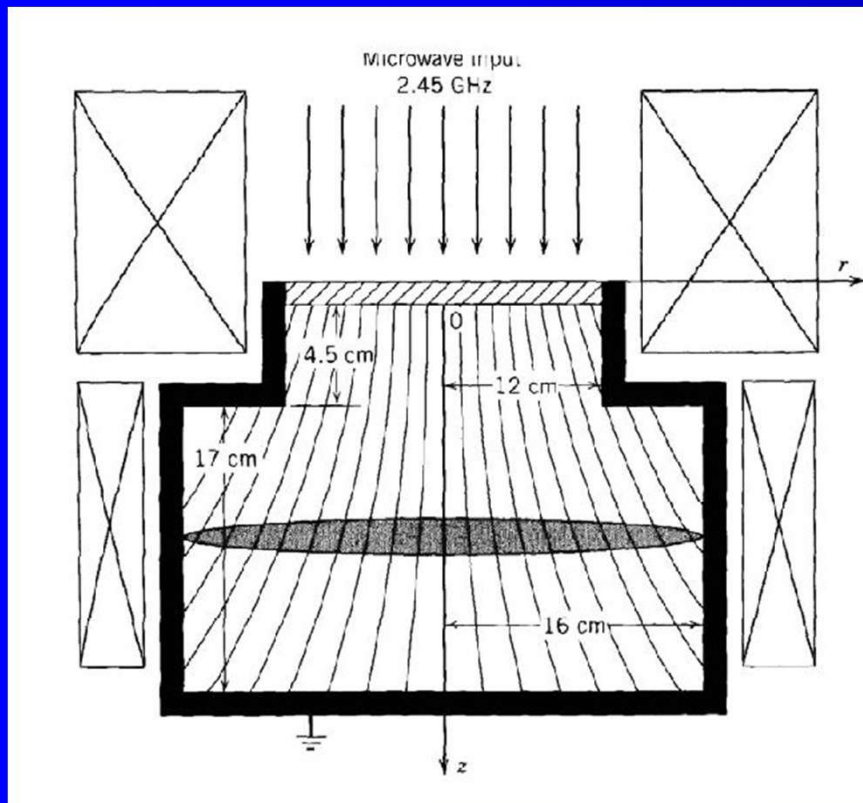
○ helical resonator



Principle of ECR discharges

elektrony rotují kolem siločár magnetického pole s **elektronovou cyklotronovou frekvencí**, která je v **rezonanci** s frekvencí elmag pole, a takto získávají energii

$$\omega = \omega_c = eB / m$$

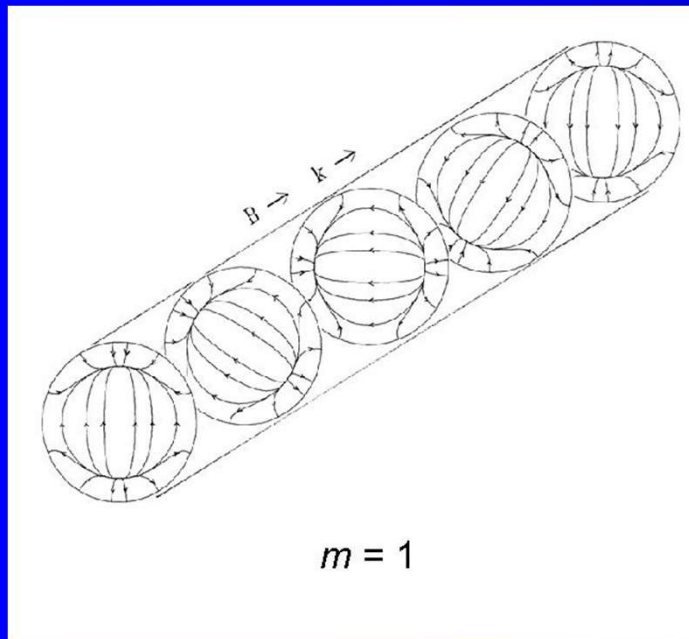


$$f = 2,45 \text{ GHz} \Rightarrow B = 875 \text{ G}$$

Princip helikonového výboje (helicon wave source)

Pomocí speciální rf antény (13,56 MHz) se generuje **helikonová vlna**, která postupuje podél vnějšího mg pole. Tato vlna způsobuje velmi efektivní ionizaci => vysoké hustoty plazmatu.

Mg pole má tři funkce (a) zvětšuje tloušťku skinové vrstvy, (b) pomáhá udržet delší dobu elektrony, (c) je dalším volným parametrem pro zlepšení uniformity hustoty



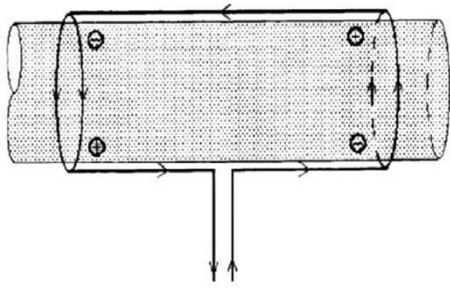
$$k = \frac{\omega \omega_p^2}{k_z \omega_c c^2}$$

$$\cos \theta = k_z / k$$

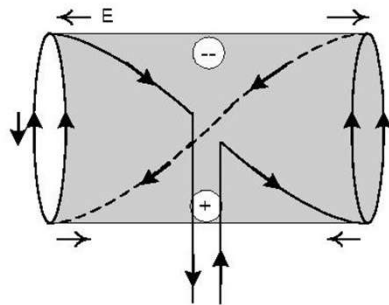
θ je úhel mezi směrem šíření (vlnovým vektorem k) a vnějším mg. polem B_0

$$\vec{B} = \vec{B}(r) e^{i(m\theta + kz - \omega t)}$$

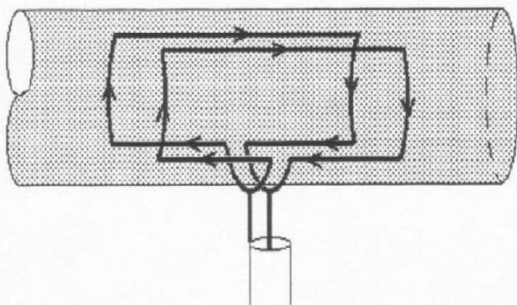
Konstrukce helikonových zdrojů



Nagoya Type III



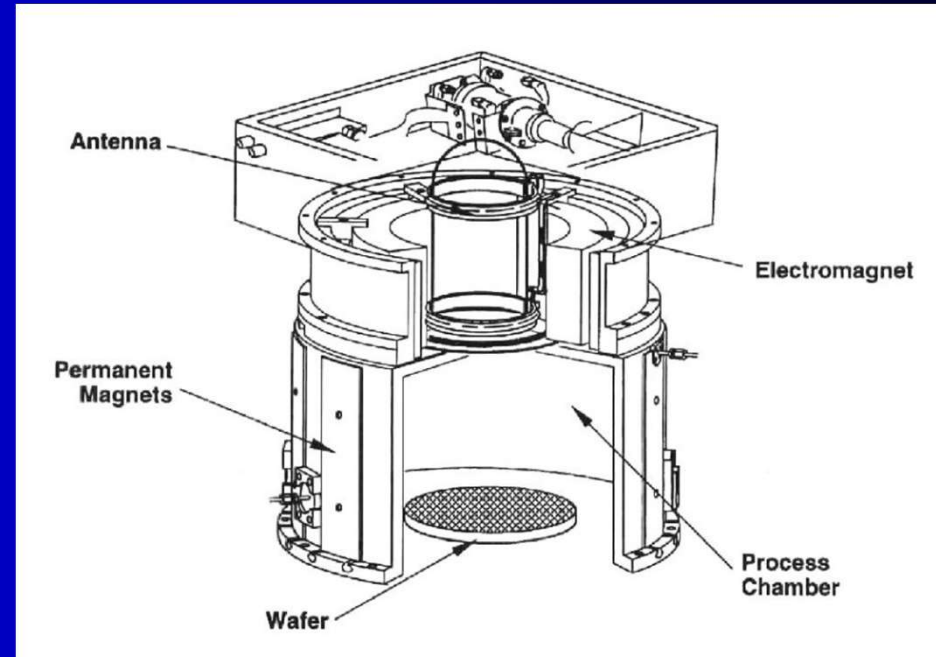
Half helical



Double saddle coil

podle konstrukce antény je možné generovat určitý mód helikonové vlny

díky vysoké hustotě generovaného plazmatu se používají v „downstream“ konfiguraci



MORI PMT komerční zdroj

Comparison of (high f, low p) plasma sources

plasma source	frequency	density [cm ⁻³]	el. temper. [eV]	mg. field
CCP	r.f.	10 ⁹ -10 ¹¹	1-5	no
ICP	r.f.	10 ¹¹ -10 ¹² ($\leq 10^{13}$)	2-7	optional
ECR	m.w.	10 ¹⁰ -10 ¹²	2-7	875 G
helicon	r.f.	10 ¹¹ -10 ¹² (10 ¹¹ -10 ¹⁴)	2-7	20-200 G