Electrophysical Department

MICROWAVE POWER ENGINEERING

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Content

- Introduction to microwave power engineering
- Basics of dielectric microwave heating of substances
- Microwave energy for drying various substances
- High-temperature microwave power engineering
- Plasma microwave power engineering
- Ion sources based on electron cyclotron resonance

Leading companies engaged in production of MPE equipment

- LinnHT http://www.linn-high-therm.de/ - Germany
- IMS http://www.industrialmicrowave.com/ - USA
- AMTek Microwaves http://www.4amtek.com/ - USA
- Bionic μFuel https://www.bionic-world.net/ - Germany
- SAIREM http://www.sairem.com/ - France
- LG Electronics http://lg.com - Korea
- Un of Melbourne http://www.microwavewoodprocessing.com/ Australia
- A.C. Metaxas http://www.metaxas-associates.com/ - UK
- AMPERE (Association for Microwave Power in Europe for Research and Education) http://www.ampereeurope.org/ - France
- Puschner Microwave power system https://www.pueschner.com/ - Germany
- Jinan Sheeon https://sheeon.tradees.com/ - China
- NPP Magratep http://magratep.com/ - Russia
- Panasonic https://www.panasonic.com - Japan

Main directions of microwave power engineering

Microwave power engineering is a branch of science that studies the possibilities of using electromagnetic energy of microwave range in various technological processes.

Microwave energy is a science at the intersection of sciences: heat engineering, microwave electrodynamics, plasma chemistry, physical chemistry, medicine, lighting, food production, agriculture.

modern microwave oven

Raytheon RadaRange, 1947

Microwave cooking oven (eventually named the «Radarange») was discovered by **Percy Spencer** in 1945. He worked in Raytheon Inc. USA. First commercially available microwave oven was almost 1.8 metres, weighed 340 kilograms cost about US$ 5,000 ($57,000 in 2019 dollars) and had 3 kilowatts of microwave power.


MICROWAVE POWER ENGINEERING

Edited by ERNEST C. OKRESS

SFD Laboratories Incorporated
A Subsidiary of Varian Associates
Union, New Jersey

VOLUME 2

APPLICATIONS

ACADEMIC PRESS
NEW YORK and LONDON

1 book of Microwave Power Engineering editid by Ernest C. Okress 1967 year at 3 volume

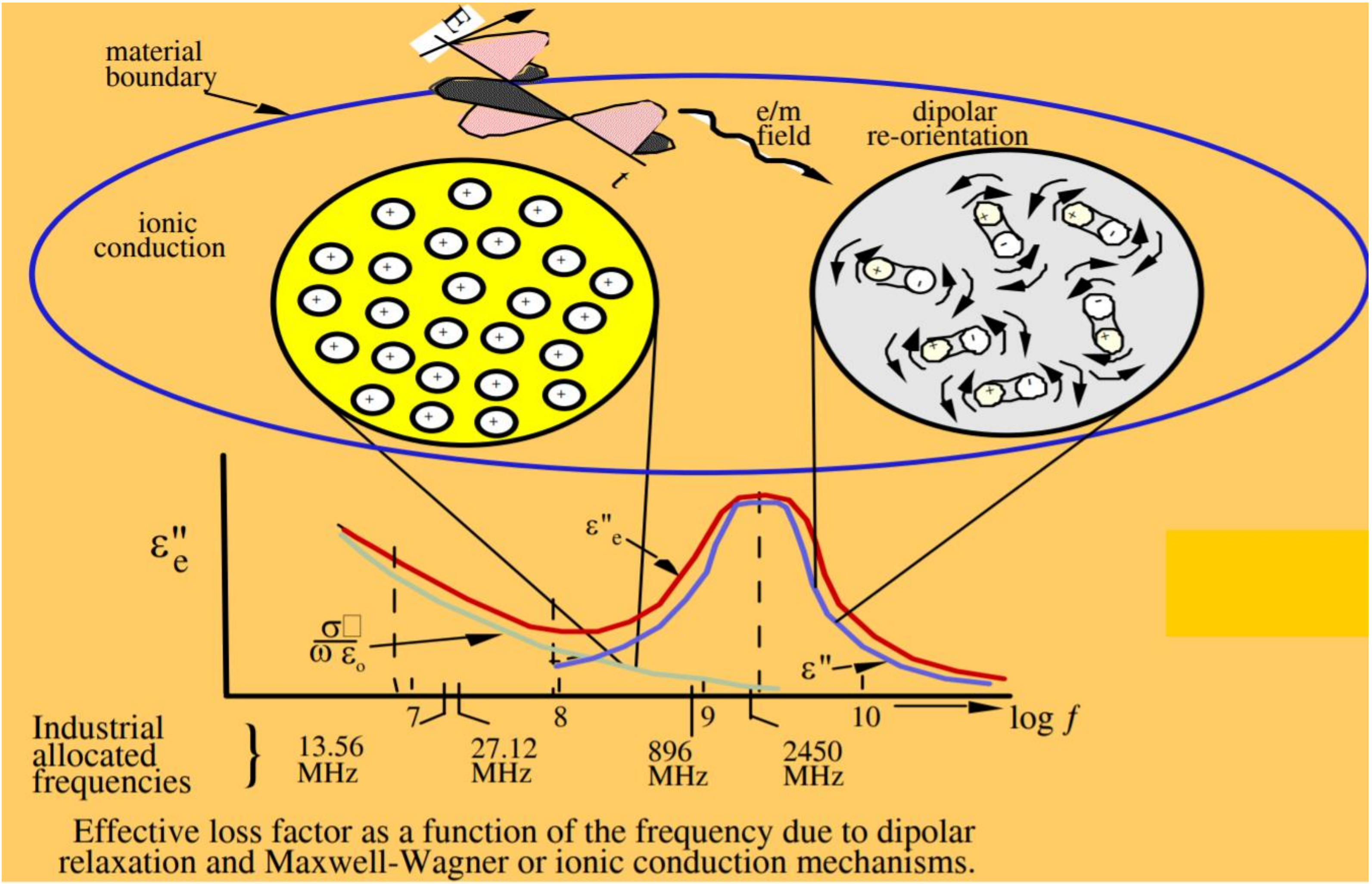
Microwave generators, domestic, industrial, medical applications of microwave energy, as well as the use of charged particles in accelerators are discussed in this book.

Main components of microwave power engineering (by MPE prof. A.N. Didenko):

- Microwave heating basics;
- Microwave electrothermal;
- Microwave drying;
- High temperature microwave heating;
- Plasma microwave energy;
- Microwave light sources;
- Pulse microwave power engineering;
- Long-range microwave transmission

Frequency ranges allowed by the **International Electrotechnical Commission** for use in high-power microwave installations:
433 MHz ±0,2%; 915 MHz±2,73%;
2450 MHz±2,04%; 5800 MHz±1,29%;
22125 MHz±0,56%

Basics of dielectric microwave heating of substances



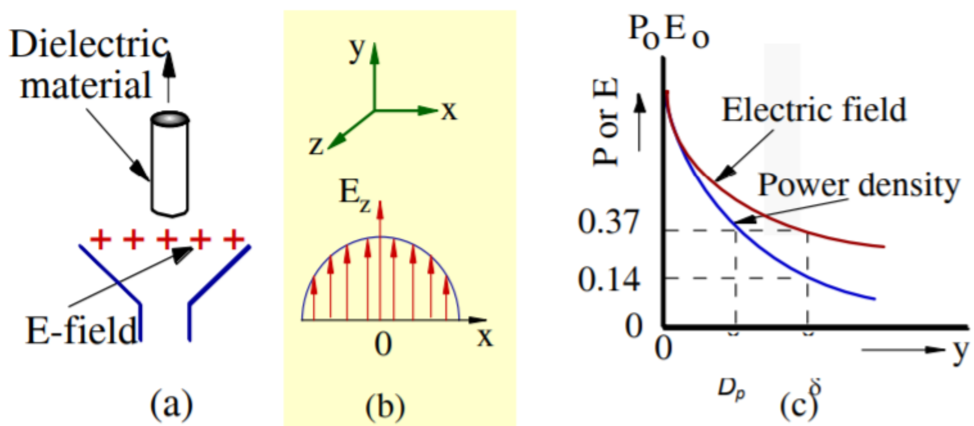
Effective loss factor as a function of the frequency. The inserts show the dipolar re-orientation and conductive loss mechanism

$$\varepsilon = \varepsilon' - j\varepsilon'' = \varepsilon'(1 - jtg\delta)$$ dielectric constant

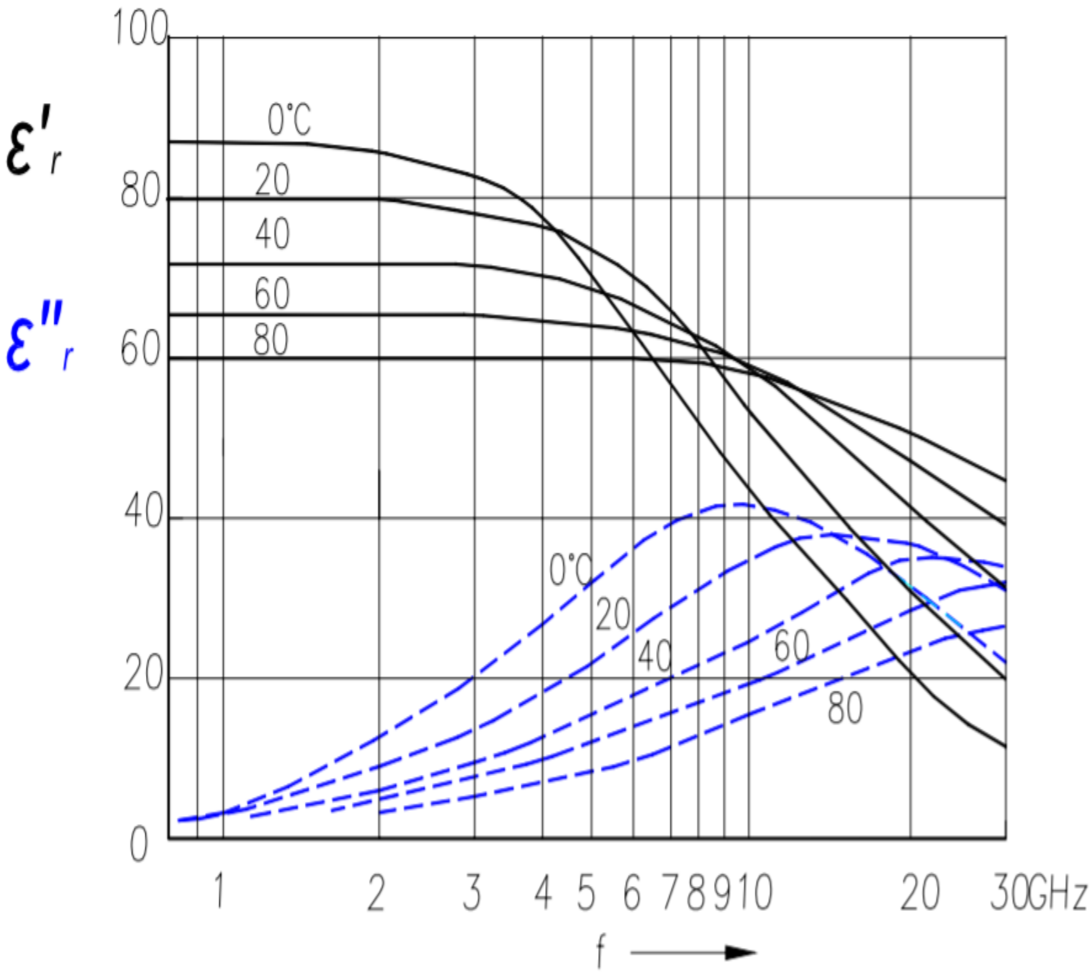
$$\delta = \frac{\lambda}{\pi\sqrt{\varepsilon\prime}tg\delta} = \frac{\lambda\sqrt{\varepsilon\prime}}{\pi\varepsilon\prime\prime}$$ penetration depth at which the electric field is weakened by e = 2.718 times

$$\alpha_{Д} = \frac{\pi}{\lambda}\sqrt{\varepsilon'}tg\delta$$ microwave field attenuation coefficient in dielectric

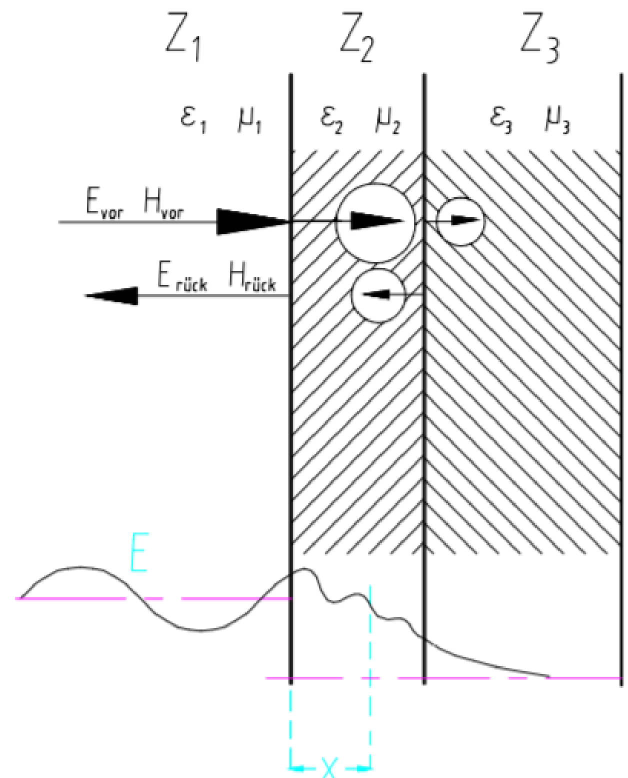
$$P_{Д} = 2\pi f\varepsilon_0\varepsilon' tg\delta \int_{V_{Д}} \left|E_{Д}^2\right| dV$$ Power absorbed in a dielectric placed in a microwave field



Semi-infinite slab analysis (b) the direction of the E-field along the waveguide face and (c) the electric field and power density distribution



Frequency dependence of ε_r' and ε_r'' in water influenced by temperature



Propagation of an electromagnetic wave in a multilayered dielectric. Below: Orientation of the electric field.

Incident, reflected and transmitted waves

Microwave power engineering installation of continuous mode

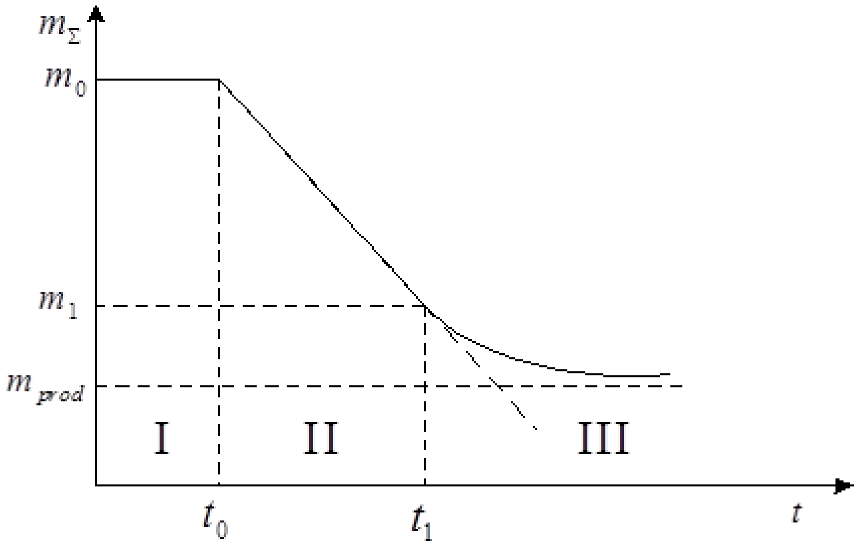
Microwave installation:

- Resonator type (single and multi mode);
- Waveguide type (waveguide load and waveguide insert);
- Irradiation type (slotted and horn antennas)

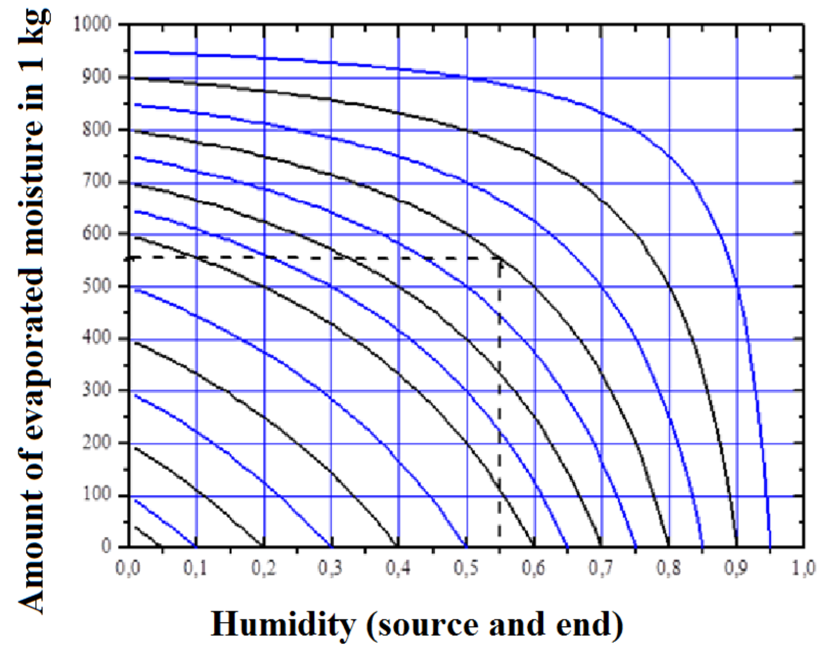
Problems of microwave heating:

- Microwave energy transfer efficiency
- Microwave heating uniformity
- Heating efficiency
- Heating process speed

Microwave energy for drying various substances



Drying curve. Typical time-dependent product weight for dehydration. I-heating, II- period of constant evaporation rate, III-evaporation of bound moisture.



Advantages of vacuum microwave drying:

Drying at low temperatures (less than 40 - 50 degrees Celsius);

Preservation of nutritional properties;

Low residual humidity (less than 1%);

High efficiency;

New product features.

Drying through processes:

surface evaporation;

sublimation;

barodiffusion.

Types of microwave drying:

Freeze-drying: 1-600 Pa;

Vacuum microwave drying: 1000-10000 Pa;

Convective drying at atmospheric pressure.

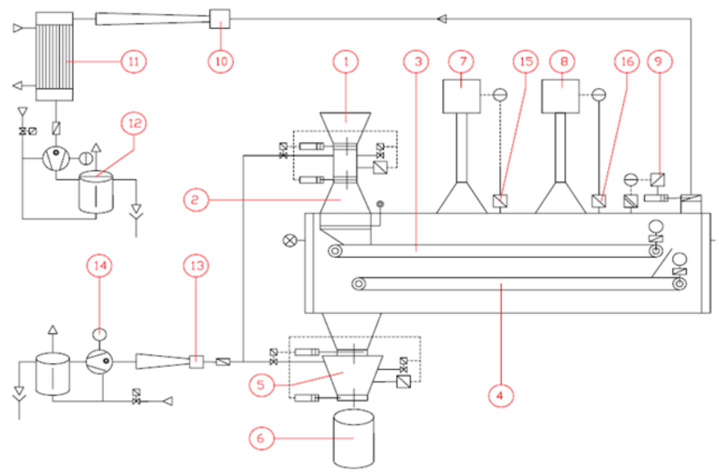
Industrial many magnetron and single-magnetron installations

$$P_m \cdot \Delta t = C_{prod} m_{prod} \Delta T_{prod} - r \cdot \Delta m$$

Installation for drying wood «SVCH-LES", Russia

Microwave vacuum dry
Gigatherm AG
http://gigatherm.ch

Pushner microwave conveyor-type vacuum drying



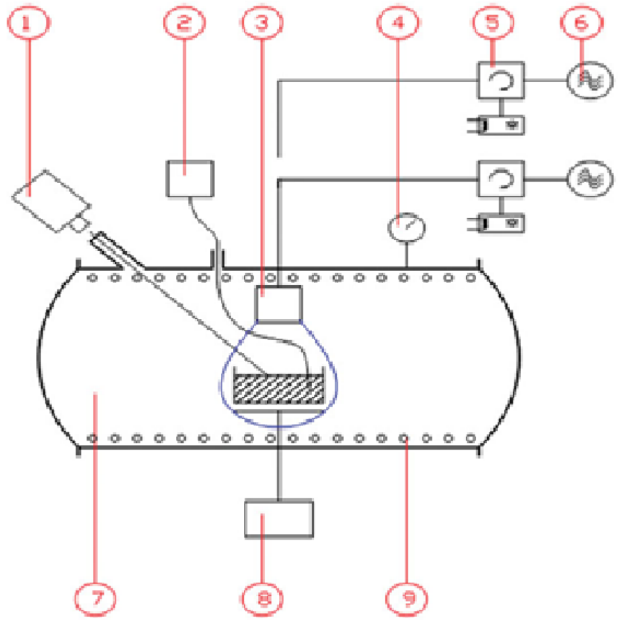
Legende:

1	Granular product inlet
2	Distribution system
3	Microwave Belt Drying Zones
4	PTFE coated conveyor belt
5	Product outlet
6	Hopper with dried product
7,8	Microwave system (2x)
9	Vacuum control
10	Steam injector
11	Condenser
12	Water ring vacuum pump
13	Gas steam injector
14	Water ring pump in- / outlet
15, 16	IR-camera (2x)

Figure 4. Process Flow Diagram ***µWaveVac1290***

μWaveVac0150

Dimensions Vacuum Chamber / Operation Mode	Ø 0,5 x 1m Batch
Microwave Power	1,2 - 6 kW / 2450 MHz
Total Dimensions	1.5 x 2.2 x 1,5 m



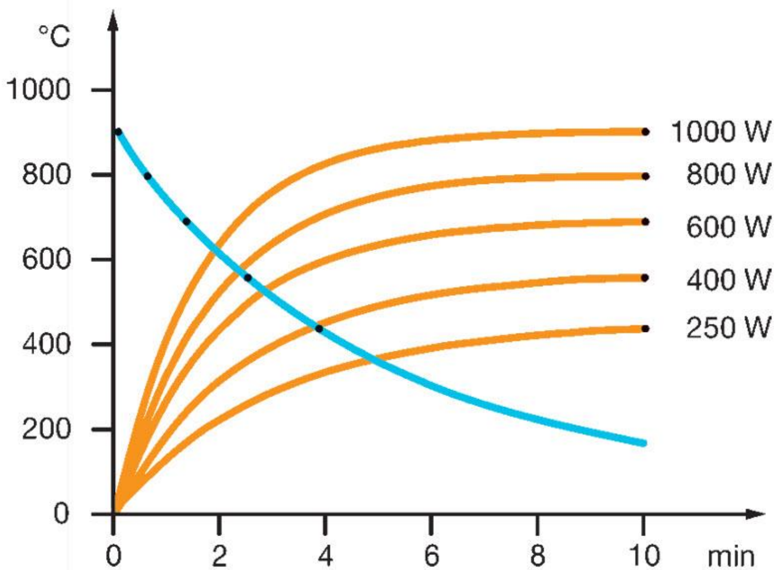
Block Diagram of Microwave Vacuum Trial Plant μWaveVac0150

1) Pyrometer (0..1000°C)
2) Fibre-optical temperature measurement system
3) Microwave antenna
4) Pressure measurement
5) Circulator (magnetron protection) incl. Measurement of the reflected power
6) 1.2kW/2450MHz Magnetron incl. DC high-voltage power supply
7) Vacuum vessel ca. 200l
8) 10kg load cell, 10.ooo digits
9) wall heating

Convective microwave conveyor-type dryers

High-temperature microwave power engineering

After temperatures of 600 degrees Celsius, losses due to thermal radiation in the infrared range make a significant contribution. The working chamber in a microwave installation can serve as a reflector, which redirects infrared radiation again to a heated object. Thus, it is possible to reduce heat loss and increase the speed and temperature of heating.



$$W = \sigma S T^4$$

$\sigma = 5{,}66\ 10^{-8}\ J/(K^4 \cdot m^2)$

Stefan Boltzmann's constant

Fields of application of high temperature heating:

- ceramic sintering,
- tempering products
- obtaining new materials,
- obtaining nanopowders.

LINN HIGH THERM GmbH high temperature systems

Recycling carbon fibers (left and right) and hybrid microwave conveyor ovens

Plasma microwave power engineering

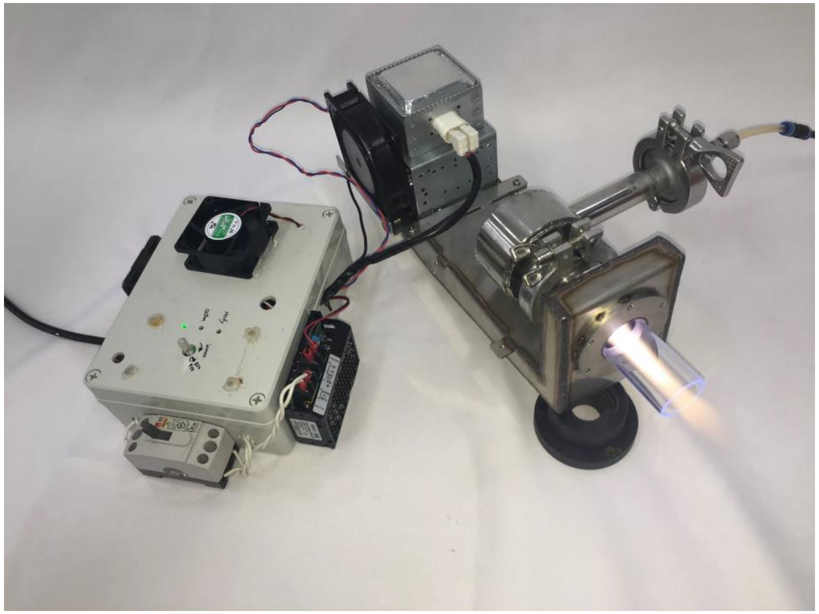
Microwave energy can be effectively converted to plasma. The main advantages of microwave plasma: inertia-free, clean electrodeless plasma, high degree of ionization, high electron temperature, chemical activity of ions.

Applications of microwave plasma:
plasma-chemical reactions;
EM and light radiation sources;
surface cleaning;
surface etching;
obtaining nanomaterials;
space exploration.

Sources of microwave plasma waveguide and resonant plasmatrons.

The working pressure of the plasma-forming gas is from 0,001 Pa to 10^6 Pa.

Electric field strength from 10^{-2} to 10^3 kV / cm

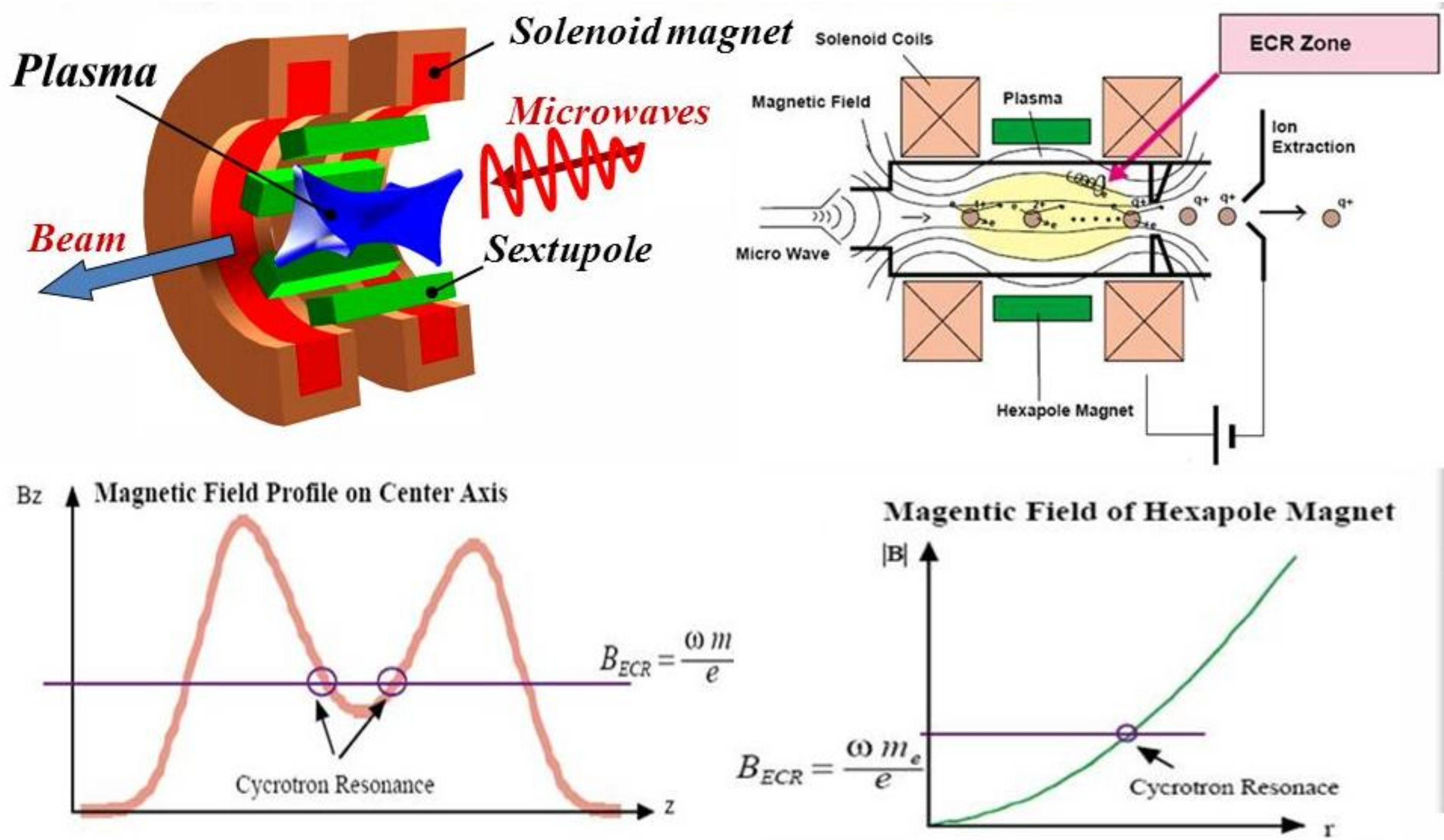


Microwave torch plasma torch

Microwave plasma etching system

PLS Plasma Lighting System (supher) by LG

Ion sources based on electron cyclotron resonance



Hitachi and Chalk River National Laboratory began to develop such ESR ion sources.

The main advantages of microwave sources:

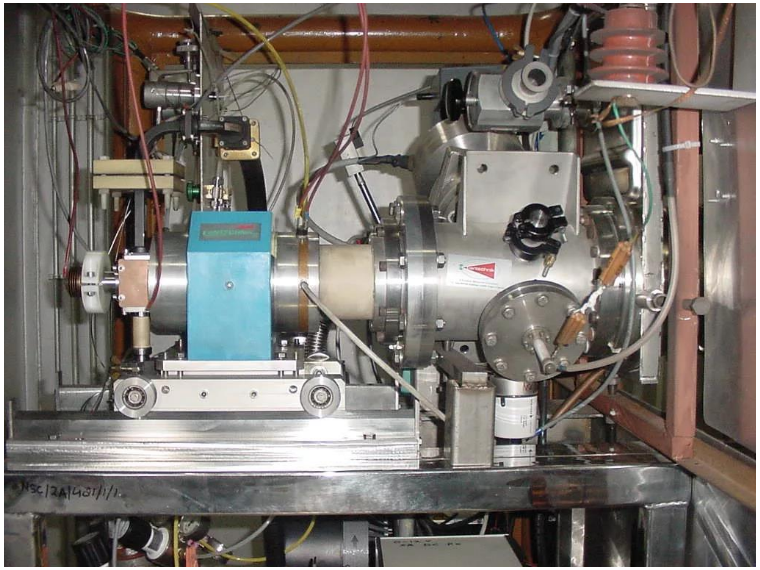
• Lack of consumable components, resulting in extreme reliability and stability
• Life time up to a year
• Possibility of obtaining a small emittance
• Compactness
• Easy operation

The best absorption of energy occurs when the frequency of collisions of electrons with atoms and the field frequency are close

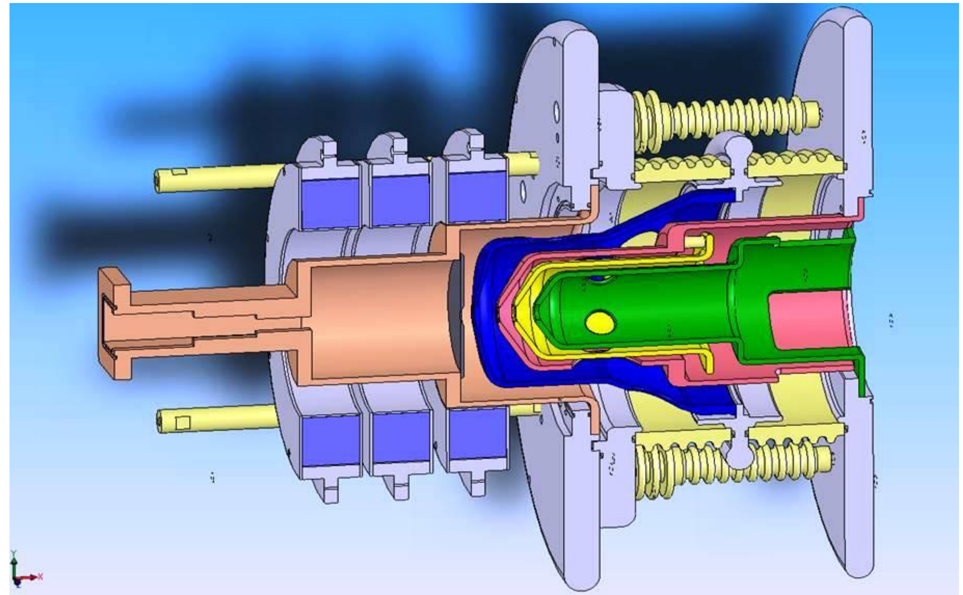
$$P = \frac{ne^2}{2m\nu} E^2 \frac{\nu^2}{\nu^2 + \omega^2}$$

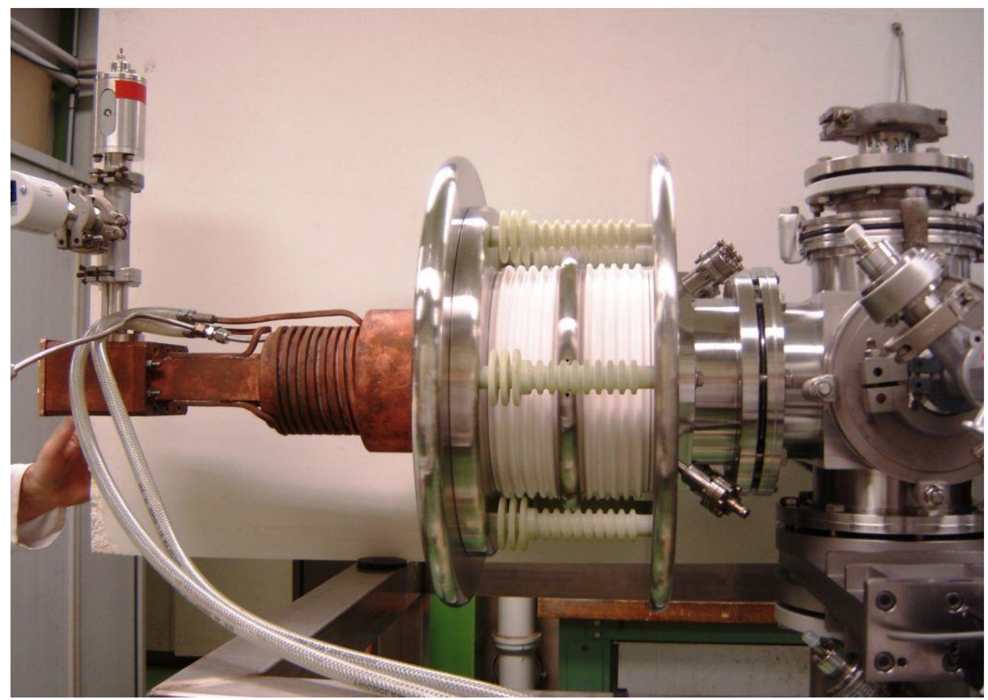
where ν- and ω-, accordingly, the frequency of collisions of electrons with atoms and the field frequency, E - are the electric field strengths, n - is the electron concentration.

Sources on a microwave discharge are most suitable for producing singly charged ions with a current of up to 100 mA and low emittance in both pulsed and continuous operation modes. To increase the ion density, not high pressure is used, but large magnetic fields in the ionization region.



Type of ion	Range of charge states (q)	Range of energy (E)	Range of beam current (euA)
Oxygen (O)	1+ to 6+	50keV to 0.9MeV	0.1 to 100
Argon (Ar)	1+ to 10+	50keV to 1.5MeV	0.1 to 15
Xenon (Xe)	1+ to 20+	50keV to 3.0MeV	0.1 to 15
Lead (Pb)	1+ to 15+	50keV to 2.2MeV	0.1 to 8





Thanks for attention!