An ECR ion source with integrated sputter magnetron for metal ion beam generation and large area implantation

Martin Kreller, Günter Zschornack, Alexandra Silze, Christine Baumgart, Tim Weichsel, Torsten Kopte, Ralf Blüthner, Ulrich Hartung

August, 26th 2014

Motivation

High current metal ion sources are utilized for surface irradiation and implantation in

- semiconductor industry,
- optical industry,
- medical industry,
- photovoltaic industry

Surface modification by ion implantation

- conductivity and charge carrier mobility of semiconductors,
- optical properties,
- surface hardness,
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Main focus: photovoltaic industry

- semiconductor industry: ion implantation is standard technique
- photovoltaic industry: almost no implantation facility
- new solar cell generation based on n-type silicon wafers utilizes p-type emitter layers usually generated by thermal diffusion of boron from gaseous compounds

Alternative: aluminum ion implantation

- well defined and reproducible doping level and profile
- high homogeneity and high purity
- reduced number of process steps
- replacement of toxic boron

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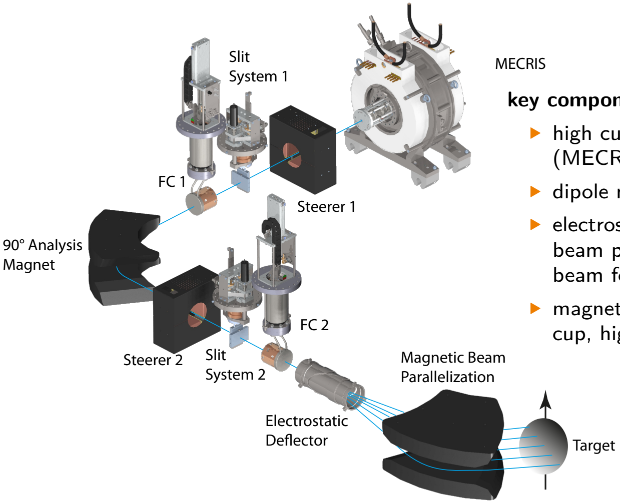
Goals of the project

- development of a high-current ECR metal ion source loaded by an inverted cylindrical sputter magnetron
- installation of a broad beam implanter for a target width up to 200mm
- characterization of the extracted ion beam
- aluminum ion implantation and characterization of the doping profile as proof of principle experiment

Alternativ…

- well d…
- high h…
- reduce…
- replacement of toxic boron

Ion beam facility

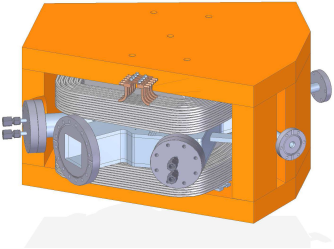


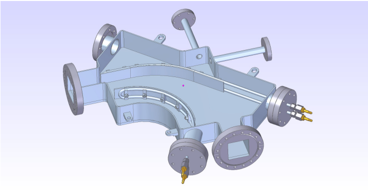
key components

- high current ECR metal ion source (MECRIS) with extraction system
- dipole magnet for charge separation
- electrostatic deflector and magnetic beam parallelization for the broad beam formation
- magnetic steerer, high power Faraday cup, high power Pepperpot

Dipole magnet for charge separation

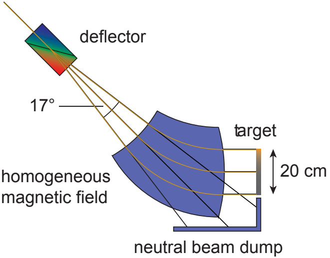
- a sputter gas is needed for metal production with the magnetron
- extracted ion beam contains a high amount of ionized sputter gas
- dipole magnet with cooled and replaceable chamber walls is required





Broad beam optics

- ion beam width of 200 mm is needed for the production of photovoltaic wafers
- ion beam scanning with an electrostatic deflector
- to achieve a homogeneous implantation profile a parallel ion beam is required
- static magnetic field parallelizes the beam for vertical surface impact
- pole shoes shaped for parallelization with static homogenous magnetic field



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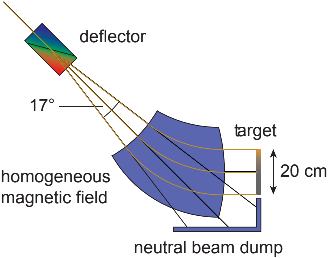
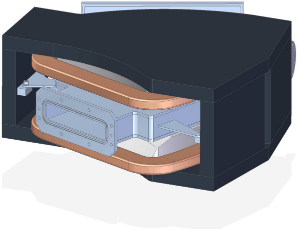
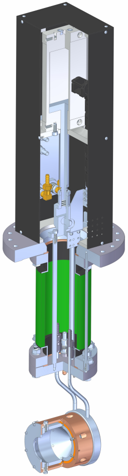


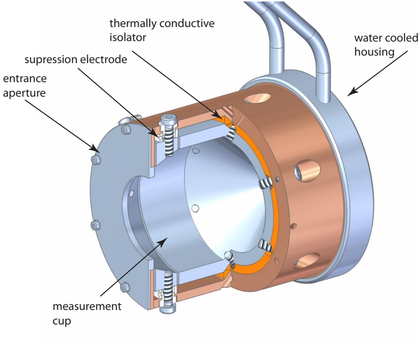


Ion detection with a water cooled Faraday cup



- ion beam facility is designed to achieve ion currents in the range of 30 mA with an energy of 30 keV
- high power Faraday cup is designed with water cooled housing
- Faraday cup system is based on a DN160CF flange and pneumatically movable
- measurement cup mounted by a insulator (potoveel) to the water cooled housing
- electrode for secondary electron suppression up to 500 V is included

Ion detection with a water cooled Faraday cup



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ECR ion source with integrated sputter magnetron

MECRIS development steps

1. development of an inverted cylindrical sputter magnetron by the Fraunhofer Institute of Electron Beam and Plasma Technique in Dresden
2. design of the magnetic field of the ECRIS with respect to the magnetic field of the included sputter magnetron
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Fraunhofer FEP

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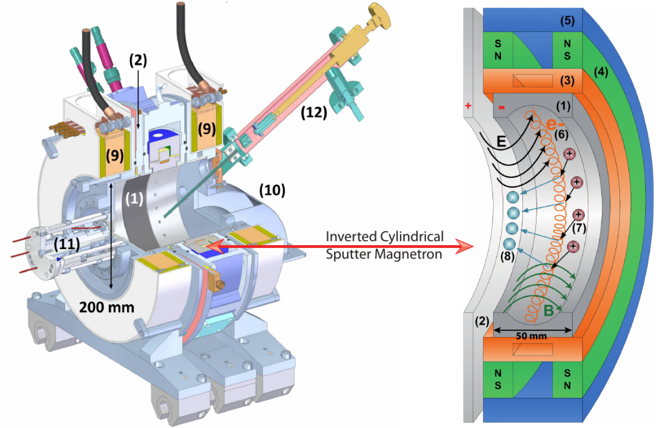
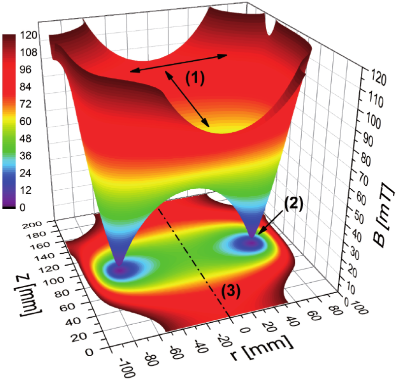
Electron & Ion Beam Technologies



(1) cathode (Al target)
(2) anode
(3) cooling plate (Cu)
(4) NdFeB permanent magnet rings
(5) soft iron yoke
(6) electron gyro-motion
(7) positive ions of process gas
(8) sputtered neutral atoms (Al)
(9) solenoid coils
(10) waveguide & mw port
(11) extraction system
(12) double Langmuir probe

Fraunhofer FEP

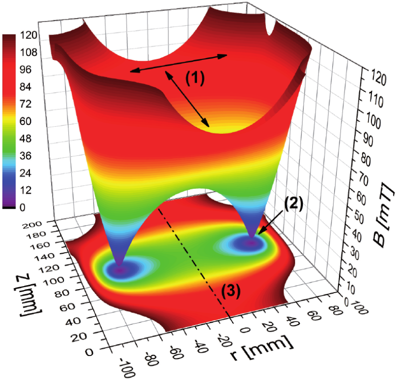
Magnetic field simulation with Comsol Multiphysics

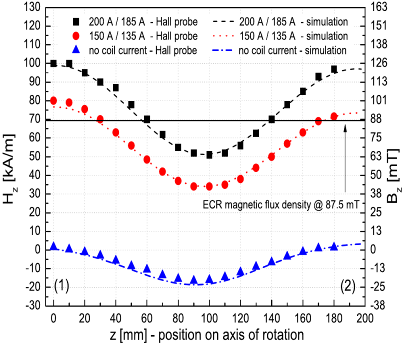


COMSOL-FEM-simulation of magnetic flux density of z-r cut plane of the MECRIS. (1) radial and axial magnetic mirror confinement of electrons, (2) magnetic sink - minimum B, (3) axis of rotation. (coil current combination 150 A/135 A)

Magnetic field simulation with Comsol Multiphysics

DREEBIT Electron & Ion Beam Technologies





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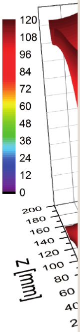

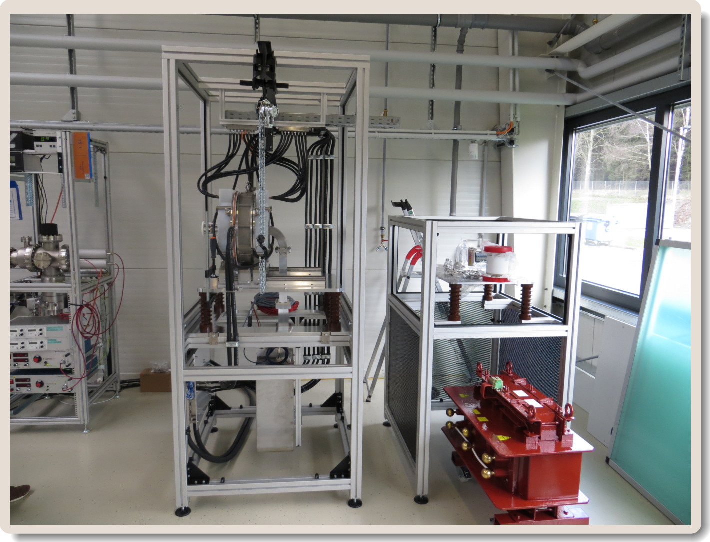

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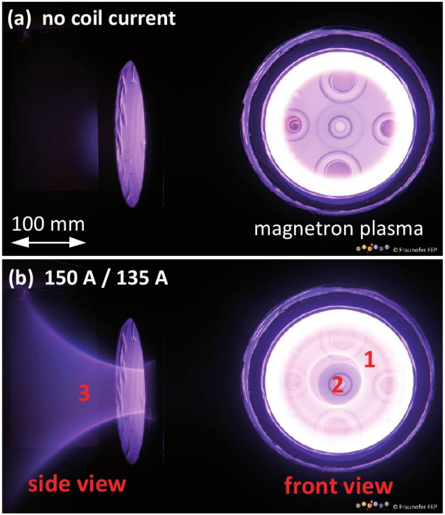
Optical measurement of the plasma confinement



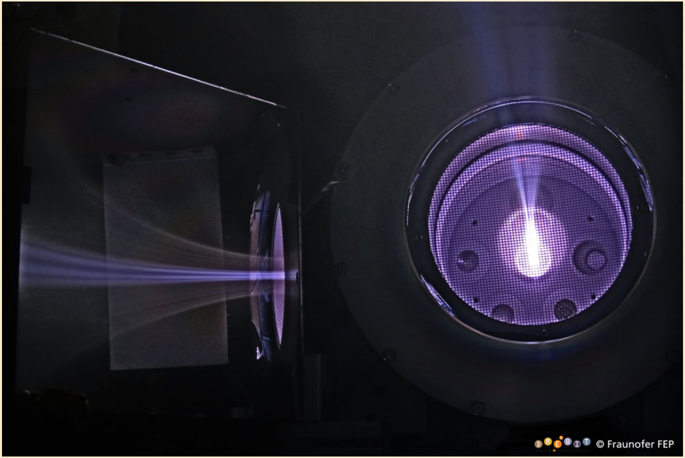
Plasma emission photography of magnetron plasma without (a) and with (b) magnetic mirror field. Side view of plasma emission in front of MECRIS was obtained by a mirror placed aside the source.

1. electron confinement area by axial magnetic mirror,
2. loss-cone-area,
3. plasma emission zone in front of MECRIS, generated by electrons escaping from 2

(2KW magnetron power, source pressure: 1 Pa, working gas: argon)

Optical measurement of the plasma confinement

Magnetron ECR plasma



parameter: $p = 0.2\,\mathrm{Pa}$, $P_{magnetron} = 500\,\mathrm{W}$, $P_{microwave} = 100\,\mathrm{W}$, argon

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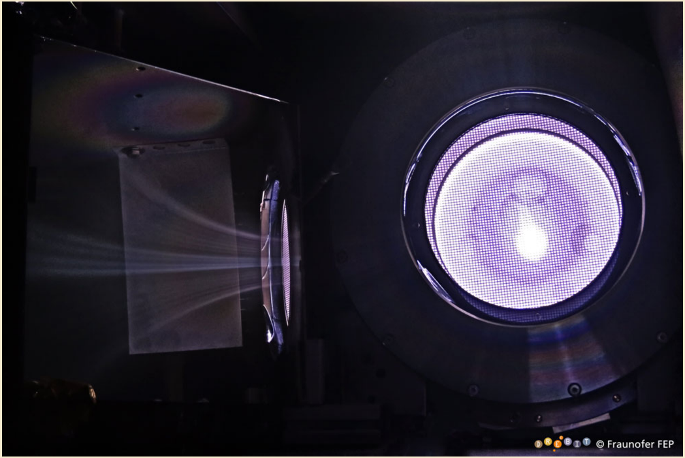

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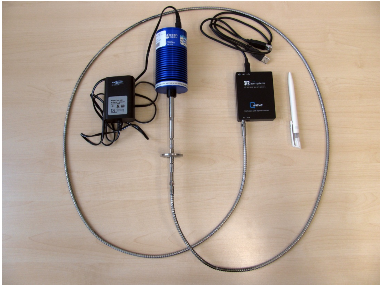
Plasma characterization

Optical emission spectroscopy (OES)



- Qwave VIS spectrometer (resolution: 0.5 nm between 350 nm - 880 nm)
- calibration of the relative sensitivity by using a tungsten-halogen light source (HL-2000 CAL, Ocean Optics)
- measurement of the atom and ion density of aluminum and argon as well as the electron density

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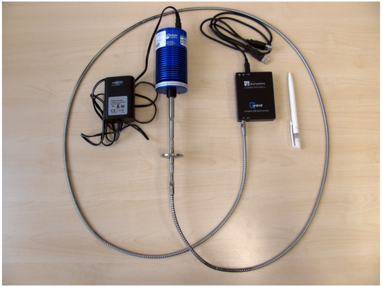

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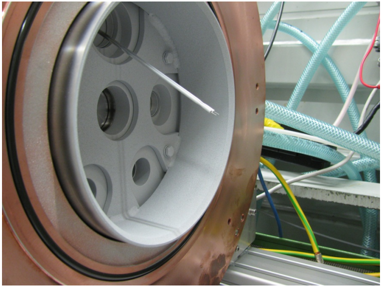
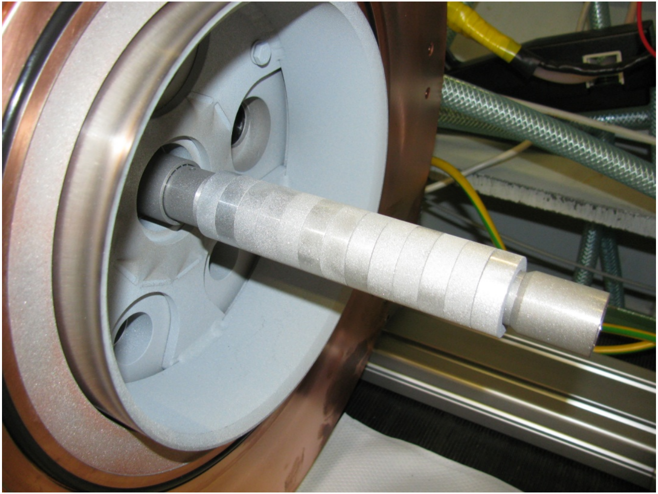
Double-Langmuir probe measurement



- double-Langmuir probe designed
- spatially resolved measurement of the electron temperature and electron density

Al-atom load rate - OES and substrate coating



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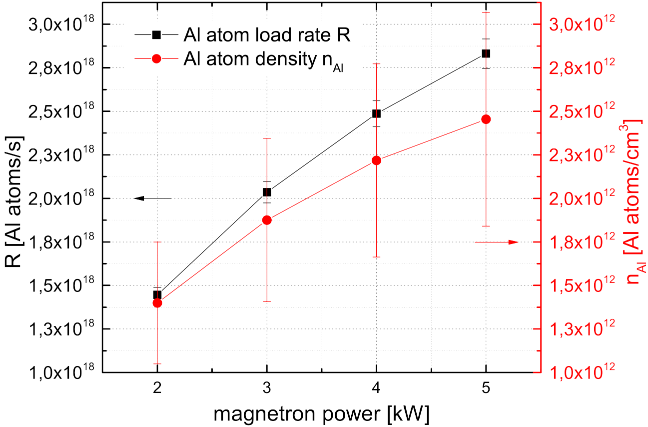
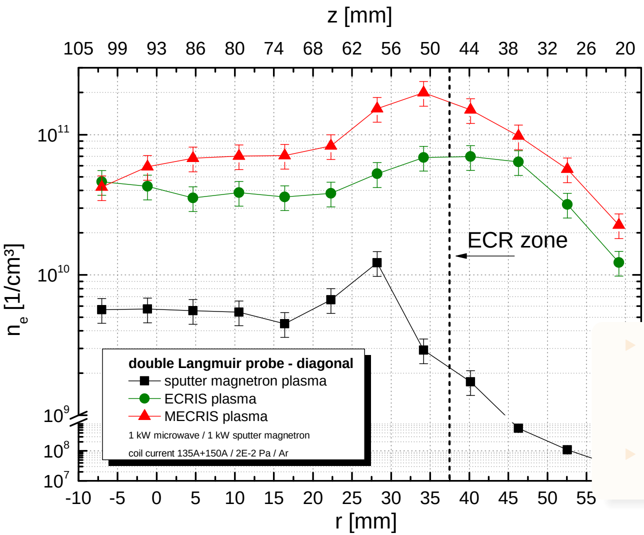


- magnetron provides an Al-atom load rate at least 1.5×10^{18} atoms/s which is supposed to be adequate to produce a milliampere Al^{1+} beam

Electron density in dependence on the position



- highest electron density for MECRIS plasma (microwave and suptter magnetron switched on)
- rising electron density with increasing magnetic field

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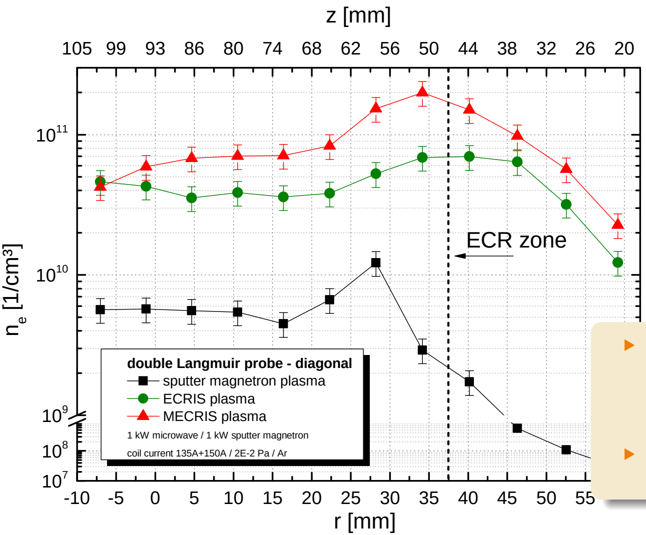

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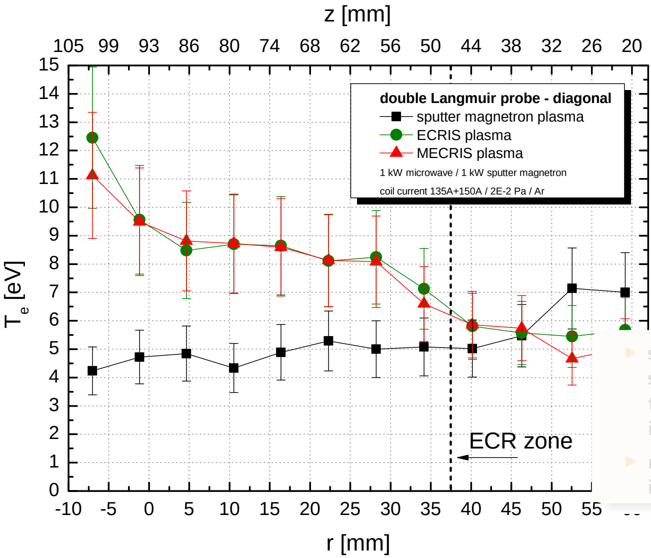

- sputter magnetron has only small influence on electron temperature when microwave is switched on
- minimal electron temperature in the center of the ion source

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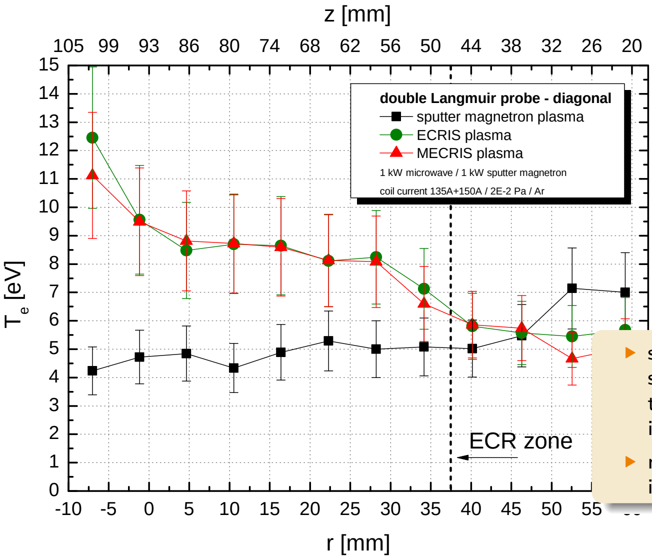

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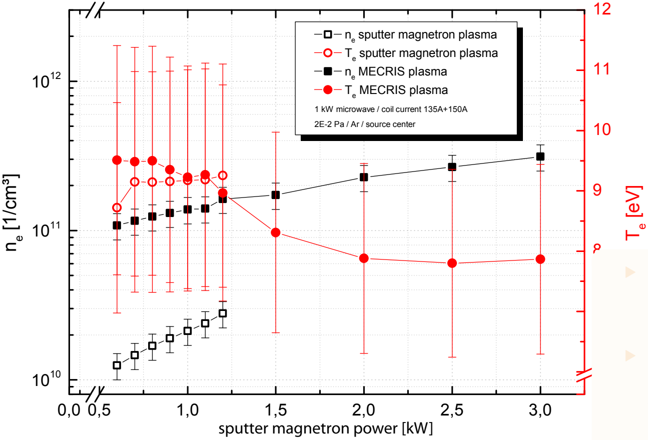
Variation of the magnetron power



- increasing electron temperature and electron density with increasing magnetron power
- measured electron temperature of MECRIS plasma decreases with increasing magnetron power
- higher amount of particles - cooling effect?

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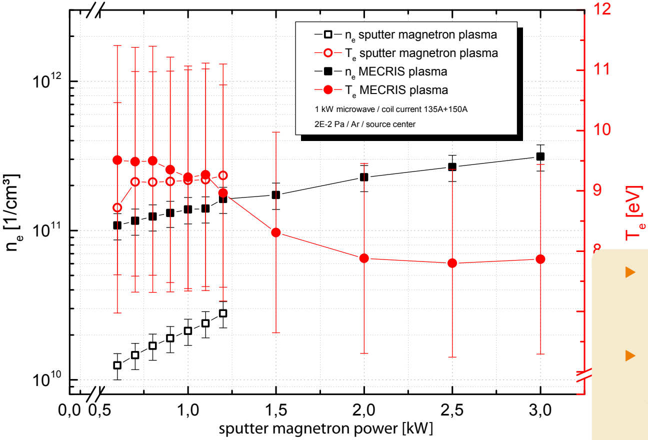

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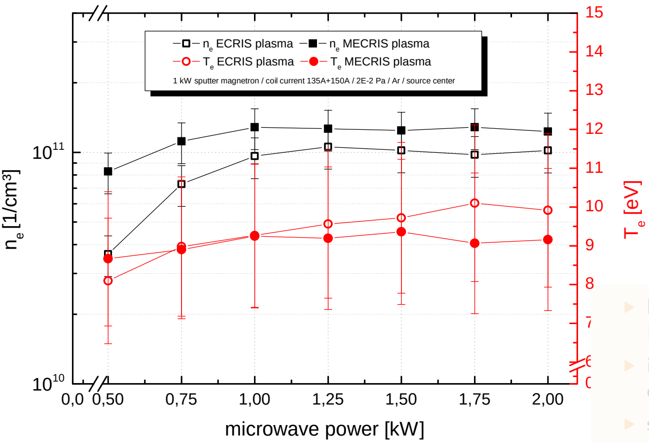

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- increasing temperature and density up to 1 kW
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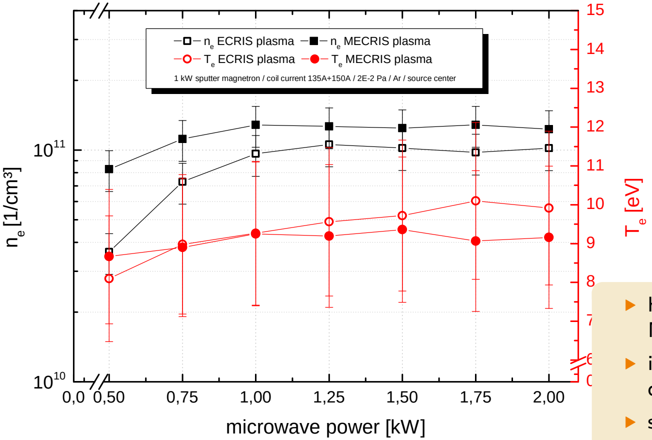

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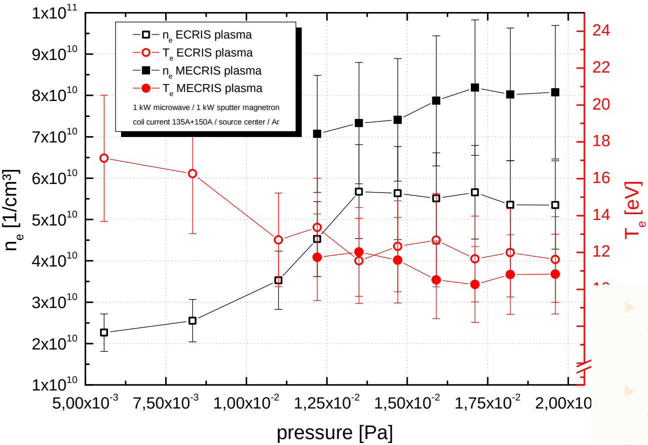
Variation of the sputter gas pressure



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- increasing electron density up to a pressure of 1.3 Pa
- electron density in the range of the cut of density

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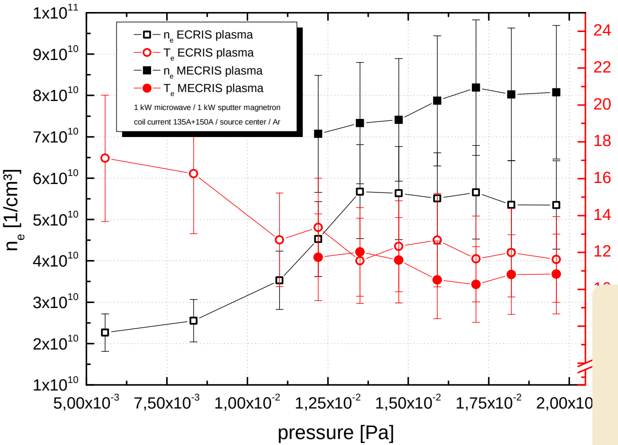

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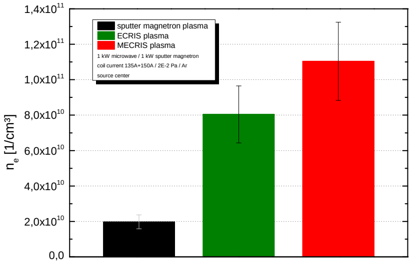
Outlook

Key parameters of the different operation modes

Electron density



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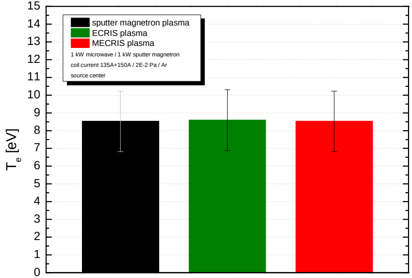

Next steps

- installation of the beamline up to Faraday cup 2 until October 2014
- measurement of the integral and mass-to-charge ratio separated ion current
- optimization of the aluminum output and the Al/Ar ratio
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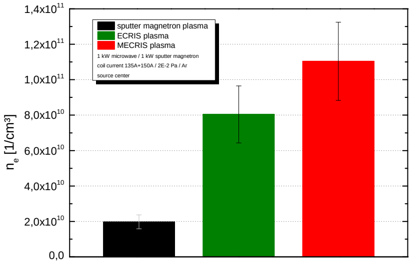

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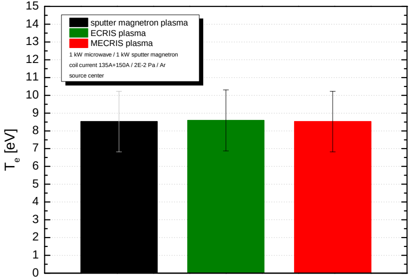

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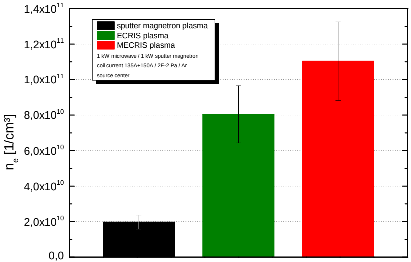

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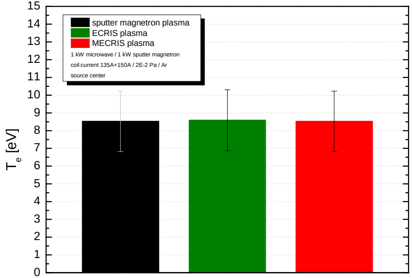

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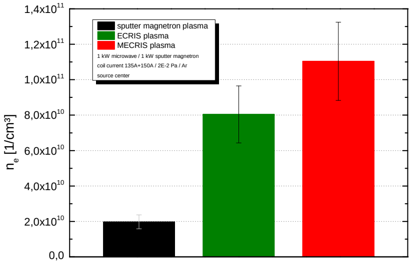

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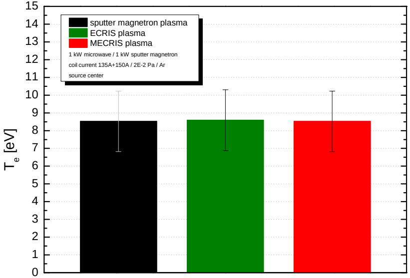

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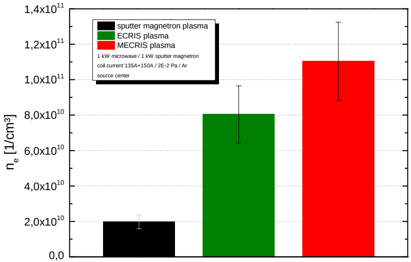

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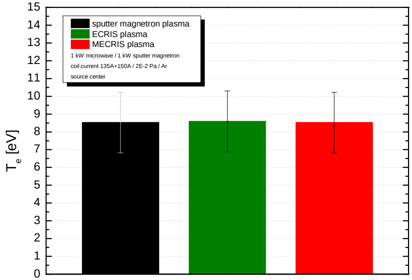

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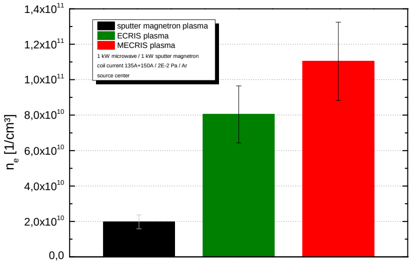

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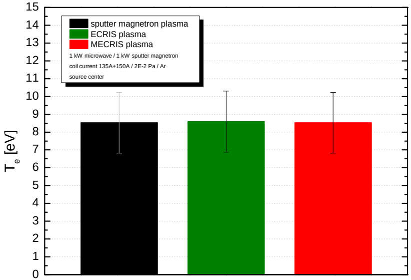

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Fraunhofer FEP

- and the Dreebit GmbH (G. Zschornack, F. Großmann, A. Silze, M. Kreller, C. Baumgart)

DREEBIT Electron & Ion Beam Technologies

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