Recent developments and electron density simulations at the ATOMKI 14.5 GHz ECRIS

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Summary

1. Magnetic trap upgrade and other developments
   - Hexapole change
   - New iron plugs
   - Ions from solids
   - New control system

2. Simulation of the ECRIS electron cloud
   - TrapCAD summary and upgrades
   - Initial conditions
   - General results
   - Filtering by energy and position: specific results
Main features:

- 14.5 GHz (1000 W)
- 8…12 GHz (20 W)
- Room-temperature coils
- NdFeB hexapole
- Platform voltage: 50 V – 30 KV
- No post-acceleration

Applications / research topics:

- Plasma diagnostics
- Atomic physics (ion guiding)
- Industrial application (surface mod)
- Medical applications (surface mods)
- New materials (X@C60)
• 1996: first hexapole: **0.95 Tesla** in the chamber (R=29 mm)
• 1996-2007: about **2%** decrease year by year.
• 2008: un-understandable sudden decrease: **0.7 Tesla** only! (R=29 mm)
• 2008-2012: the ECRIS mainly operated at lower frequencies (8…12 GHz).
• 2012: new hexapole: **1.2 Tesla** in the chamber
## Table ECRIS hexapole

<table>
<thead>
<tr>
<th></th>
<th>Material</th>
<th>Segments</th>
<th>Length (mm)</th>
<th>ID (mm)</th>
<th>OD (mm)</th>
<th>B-field at R=29 mm (Tesla)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old hexapole</td>
<td>NdFeB (490i/400i)</td>
<td>24</td>
<td>200</td>
<td>65</td>
<td>135</td>
<td>0.95 (0.7)</td>
</tr>
<tr>
<td>New hexapole</td>
<td>NdFeB (N45H)</td>
<td>24</td>
<td>200</td>
<td>65</td>
<td>155</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Magnetic system upgrade 2: new iron plugs

- the soft iron magnetic plugs at the injection side were re-designed, manufactured and installed.
- to increase the peak magnetic field at the injection side inside the plasma chamber as high as possible.
- to minimize the force to the plugs and thus to minimize the opposite direction force to the basic structure of the ion source.
- now the peak axial magnetic field at the injection side is almost 1.3 Tesla
New beams from solids

Challenge:

Some of our users (materials physicists, dentists) require „unusual” beams, like:

- Fullerene: routinely used
- Gold: sputtering, first result are promising
- Calcium: sputtering, argon mass difficulty
- Silicon: grinded, mixed with carbon powder (SiH₄ better?)
Old control system (1996-2012)

- P1 computer
- GPIB card
- RS232 card
- Windows 95
- VEE software

New Control system (2012-)

- NI PXI chassis
- Built-in controller with GPIB
- A/D I/O cards
- RS232 card
- High voltage platform extension
- Windows7
- Labview 2011
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ECRIS plasma electrons simulation

- TrapCAD code: since 1994...
- More than 20 users
- „Multiple-one-particle” code
- Realistic magnetic field (2D-3D)
- Stochastic ECR heating
- Magnetic field: PoissonSuperfish
- Only electrons
- Plasma potential not included
- Collisions not included
TrapCAD: cloud from 50000 elektrons
ECRIS electrons simulation

- Improved magnetic trap = time to re-calculate
- Magnetic field: PoissonSuperfish

- TrapCAD recent upgrades:
  - the initial electron density on the surface of the resonance zone is much more equal than before
  - the surface may have a thickness
  - faster running

\[ B = B_{ECR} + 100 \text{ gauss} \]

\[ B = B_{ECR} - 100 \text{ gauss} \]

\[ B = B_{ECR} \]

\[ D = 0.6 \text{mm} \]
Initial conditions

**Geometry.** Cylindrical plasma chamber of the ATOMKI-ECRIS, D=58 mm, L=210 mm.

**Magnetic field.** New hexapole, new plugs, PoissonSuperfish. Mesh size 1 mm.

**Electrons.**
- 3 million electrons, resonance surface (B=5200 gauss, f=14.5 GHz)
- Thin layer: 100 gauss difference from Becr: B=5100...5300 gauss
- D=0.6 mm thickness
- Energy: random between 1-100 eV, both components

**Microwave.** 14.5 GHz, 1000 watt, circularly polarized plane wave

**Simulation time.** 200 nanoseconds, CPU time 127 hours
General results

Non-lost (plasma) electrons: 49% (1.46E6)
Lost (on walls) electrons: 51%
Average energy of plasma electrons: increased from 100 eV upto 3330 eV.
By comparing the simulation results with X-ray photos of the argon ions there is a correlation between the spatial position of these two particle clouds.

Based on this result, any spatial information obtained for the warm electrons can be used for the plasma ions.

Results 1.

Starting positions of the non-lost and lost electrons

At the middle plane more electrons lost than from other positions. (Six lost arms are here, wall is closer, etc.)
Electron density distribution along the plasma chamber axes (z-axes).

Normalized electron density distribution along the plasma chamber axes (z-axes).

- the final energy and positions of all the electrons are saved
- non-lost electrons are filtered by their energies
- significant difference between the 4 electron populations
- cold electrons are found all along the plasma chamber
- warm (ionizing) electrons concentrate much more around the RZ
- even much less hot electrons outside the RZ

For all energy components: electrons separate into a high density inner plasma surrounded by a lower density halo (same observation also by others)
Plasma slices

- To get 3D-impression about the main component of the plasma
- one centimeter thick plasma-slices
- intermediate, warm, hot electrons
- Z=11-12 cm middle plane of the plasma chamber
- 8-9 and 14-15 cm positions: two ends of the RZ
- right column: the superposition of all the plasma slices
The extraction “third” of the plasma chamber ... 

Z-positions: 13-21 cm, 3-10 KeV warm electrons

1. Individual ions can be started from the appropriate x-y-z coordinates where the ion density (warm electron density) is the highest.

2. Or: to construct a 3D density matrix by the TrapCAD output files (number of electrons in each cubic mm) and to use the position-dependent density values for the ions extraction simulations.
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Thank you for your attention!