Development Work at JYFL: Plasma Potential Measurements, Electron Heating Simulations, JYFL-MMPS, High Temperature Ovens

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Abstract Extensive plasma potential measurements have been carried out using a device developed at JYFL. In this article the main results of the measurements will be summarized. A new simulation code to study the electron heating is being developed. One objective of the code is to determine the change of the electron loss cone when the magnetic field component of the electromagnetic wave is taken into account along with the permittivity of the plasma. As a part of the work, accurate X-ray measurements have been initiated. A new plasma chamber based on the MMPS-concept (Modified MultiPole Structure) has successfully been constructed and tested with the JYFL 6.4GHz ECRIS. The results and conclusions will be presented elsewhere in these proceedings. In the same article, a new concept of ECRIS and first results will be presented. The active development work of evaporation ovens has been carried out in a joint European collaboration (ISIBHI). The objective of the task is to make the operation of the oven reliable at 2000°C for several days. Both resistively and inductively heated ovens have been studied and further developed. The status of this work will be presented.

Key words plasma potential, evaporation ovens

1 Plasma potential measurements

In order to understand the different plasma processes causing, for example, the beneficial effect of gas mixing, a series of plasma potential and emittance measurements have been carried out. An instrument which can be used to measure the plasma potential in a measurement without disturbing the plasma was developed[1]. The experiments performed have revealed clear dependencies of the plasma potential on certain source parameters such as the microwave power and frequency, gas pressure, biased disk voltage and drain current[1]. The plasma potential has been observed to increase with increasing microwave power or neutral gas pressure and, on the contrary, to decrease with increasing biased disk voltage or drain current. The plasma potential has been observed to increase also in increasing ion mass[2]. The observations indicate that the plasma potential is related to ambipolar diffusion i.e. the diffusion rate of the ions, having lower mobility than electrons, determines the particle loss rate from ECRIS plasma and the value of the (plasma) potential needed to maintain equilibrium conditions. The plasma potential has been observed to depend strongly on the level of carbon contamination accumulated on the walls of the

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plasma chamber during a MIVOC-run[2]. This is not only an example of the fact that the plasma potential reflects the performance of an ECR ion source but also emphasizes the importance of secondary electron emission from the plasma chamber walls. The plasma potential measurements have also given information about the momentum (energy) spread of the extracted ion beams, which is partly due to the plasma potential profile in the plasma sheath region. This information has been utilized to show that the plasma potential of an ECRIS affects the measured beam emittance values due to the afore-mentioned momentum spread and dispersive ion optical components used to direct and focus the beam during transport[3]. An important observation is also that double frequency heating does not affect the plasma potential and more importantly emittance of ion beams[4]. This result confirms that this technique can be used to improve the extracted beam currents of highly charged ions without a detrimental effect on the beam quality.

2 JYFL-MMPS: modified multiPole structure and new ECRIS concept

The JYFL-MMPS[5—7] is based on the idea that the multipole field can be increased at the magnetic pole by using a high permeability material like iron. A new plasma chamber for the JYFL 6.4GHz ECRIS has been designed[8] and constructed[9] to test the feasibility of the MMPS. In addition, a new ECRIS concept[10], where a closed resonance can be reached with specially shaped solenoids but without a multipole has been designed, constructed and preliminarily tested at JYFL. The successful tests of both concepts will be presented elsewhere in these proceedings[11].

3 Electron heating and X-Rays

Accurate Bremsstrahlung measurements have been initiated to improve the understanding of plasma-related parameters. The results shown in Figs. 1 and 2 have been measured with the JYFL 6.4GHz ECRIS in the radial direction at the magnetic pole using careful collimation and shielding of the detector. The plasma chamber wall strongly affects the intensity of low energy photons and also causes Compton scattering. No corrections have been done to eliminate the afore-mentioned effects. As a next step the measurements will be carried out with a wall thickness of 1.5mm of aluminum.

The first measurements confirmed the well-known results, which show for example that only a weak dependence can be seen between the microwave power and the energy of the peak intensity of the spectrum. This indicates that the higher power density inside the resonance volume mainly increases the electron density of plasma – not the energy of electrons. However, it should be noted that Bremsstrahlung does not give information about the energies of confined electrons. Fig. 1 shows that average energy increases about 10% while the power increases from 100W to 600W. All X-ray counts of the spectrum measured by the detector were integrated to obtain the value shown in the graph. Fig. 2 shows that the X-ray yield increases vigorously as a function of microwave power. An increase of about 200% in total X-ray count was obtained when the power was increased by 100%. One possible explanation is that the low energy photons were strongly attenuated by the plasma chamber wall. The future experiments will reveal more information concerning this. The figure also shows a comparison between the MMPS-scheme and the normal multipole scheme. The X-ray yield is practically identical at the low microwave power when at high power the MMPS-structure produces less X-rays. Here the normal multipole scheme corresponds to the radial multipole field without the use of iron rods ($Brad = 0.55$T). With the rods a value of 0.85T is achieved at the magnetic poles (see Refs. [5—9] for further information).

The behavior shown in Fig. 1 and Fig. 2 motivated the development of our simulation code. Our intentions are to improve the understanding of permittivity behavior, Bremsstrahlung and the energy gain of electrons. This work will partly be carried out in collaboration with the Los Alamos Neutron Science Center (LANSCE) ion source group. The heating of electrons by the microwaves has been simulated earlier, for example, by Biri et al.[12], by Girard[13] and by Koivisto[14].

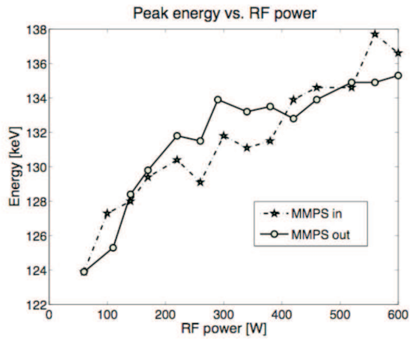

Fig. 1. The intensity distribution peak as a function of microwave power.

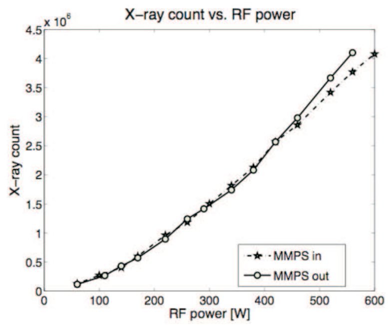

Fig. 2. Total X-ray count as a function of microwave power.

4 Development of beam diagnostics

In some nuclear physics experiments a very low beam intensity is needed. The original measurement system used at the JYFL accelerator beam line was not capable of detecting these beams. The dashed line shown in Fig. 3 shows the noise of original current measurement system. The disruptive noise was caused mainly by the noisy ground of electronics. An integrating circuit was designed in order to solve the problem. In this approach the increase of the voltage over the capacitor and relating time is measured ($V = It/C$, where I is current, t is time and C is capacitance), which makes it possible to calculate the ion beam current. The solid line in Fig. 3 shows the current of about 15pA measured using the first version of the "homemade" current measurement system. The same ground was used in both measurements. Due to the integrating measurement system a remarkable improvement in diagnostics has been achieved compared to the original set-up.

As a next step a low-noise ground for the electronics was provided by the PXI rack-mount. As the lower picture of Fig. 3 shows a remarkable improvement was again obtained. The noise is approximately ±5fA. Further improvement of the system can be done by cooling the operational amplifier of the integrating circuit, which is the most important logic module (IVC102: Burr-Brown Products from Texas Instruments) in the design of the measurement card. The input bias current of operational amplifier increases approximately by a factor of two when the temperature of the amplifier increases by 10K. At room temperature its input bias current is about 30fA, which is practically the lowest measurable current at room temperature (RT). Further improvement can be done also by using an amplifier, which has a lower input bias current (down to 1—5fA at RT).

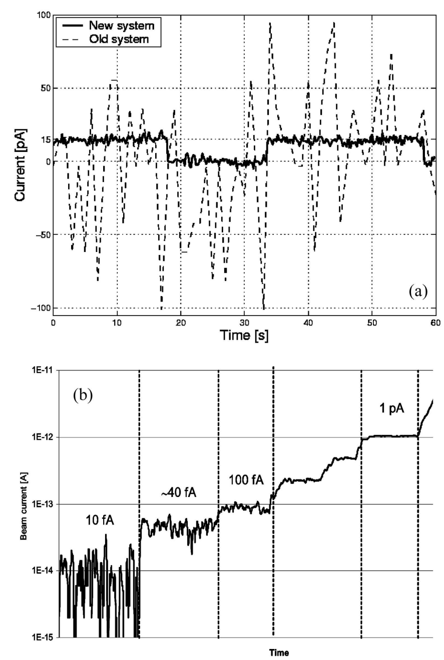

Fig. 3. The improvement of the beam intensity measurement system. The upper picture shows the noise of original configuration (with Keithley picoammeter) and the measured ion beam intensity with the first "homemade" system. The lower picture shows the measurement using the present measurement configuration.

5 Oven development

Oven development work has been carried out in a joint European collaboration (ISIBHI in EU-

RONS/FP6), which is dedicated to the 3rd generation ECRIS called MS-ECRIS[15]. The objective of the oven related work is to enable reliable operation of evaporation ovens up to 2000℃ for several days with the MS-ECRIS. One starting point is the further development of the HTO construction[16] and to make it operational in the MS-ECRIS. An inductively heated[17] and a resistively heated foil oven[18] are also being developed to meet the afore-mentioned requirements.

5.1 Inductively heated oven

A resonant circuit for the inductively heated oven was developed and tested for curiosity. The simple design made it possible to reach an oven temperature of over 2000℃. The approach is based on the use of a signal generator controlled transistor. The signal generator opens and closes the transistor causing the oscillation of current in LC-circuit. The resonance occurs at a frequency of 150—200kHz. The first version of resonance circuit gave a pronounced distortion to the signal, which strongly affected the lifetime of the transistor. This problem was solved with diodes, which unfortunately decreased the heating efficiency. So far, the oven has been tested only with the crucible being inside the coil (i.e. without the oven body or frames). Fig. 4 shows the setup of the resonance circuit.

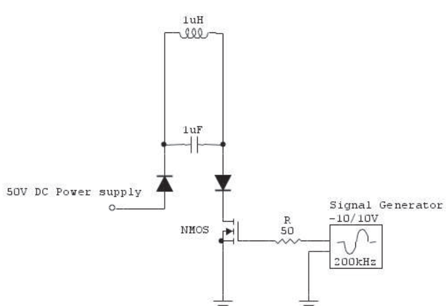

Fig. 4. Resonant circuit of the inductively heated oven.

5.2 Resistively heated foil oven

In this design (see Fig. 5) the current is conducted along the copper rod (1) and crucible stem (2) through a 25μm thick Ta foil (4). Due to high current density in the foil (up to 10kA/cm^2) its temperature easily exceeds 2000℃. The crucible (5) where the material to be evaporated is placed is mainly heated by the heat radiation from the foil.

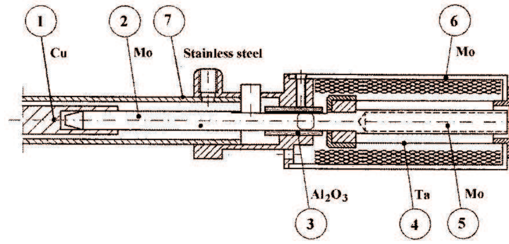

Fig. 5. The foil oven.

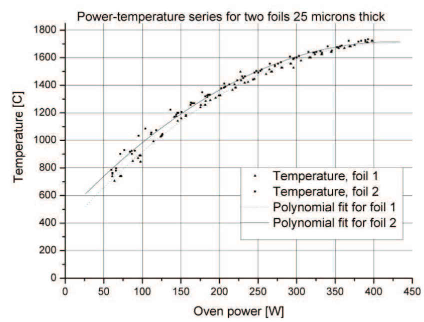

Fig. 6. Temperature of oven as a function of power.

In experiments, a temperature of about 2000℃ has been reached at a total power of 500W (≈70A, 7V). However, it has been noticed that the operation temperature decays slowly as a function of time. This can be seen in Fig. 6, where about 1750℃ was reached at 500W. The measurement was performed after durability tests, which included, for example, several heating cycles above 2000℃ (1—2 days) and several ventings of the chamber. The exact reason for the performance decay is still unknown. The oven has successfully been used for the production of Au and Y ion beams for several days. In the Yttrium run a strong reaction occurred between the Yttrium sample and Mo strongly affecting the life time of Mo crucible.

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