The Electron Cyclotron Resonance Light Source Assembly of PTB - ELISA

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Introduction

In the radiometry laboratory of the Physikalisch-Technische Bundesanstalt (PTB) at the Berlin electron storage ring BESSY I, radiation sources for radiometric applications in industry and basic research in the vacuum-ultraviolet (VUV) spectral range are developed, characterized and calibrated. Established sources such as deuterium lamps, Penning and hollow cathode discharge sources have limited spectral ranges and in particular their stability and life time suffers from the erosion of the cathode material [1,2]. To overcome these limitations we have developed a radiation source based on the principle of the Electron Cyclotron Resonance (ECR) ion source [3-5]. The novel design of our source using a tunable cavity system and an adjustable magnet structure allows to produce rare gas line spectra of highly ionized species by very low power consumption in comparison to other radiation sources.

Source setup

The schematic setup of ELISA is shown in Fig. 1. The design realizes an efficient, compact radiation source by optimizing the power transfer from the microwave source to the plasma. A tunable resonant structure (cavity) is used to increase the electric field in the gas. Furthermore a movable magnetic structure allows to bring the resonance surface (i.e. the region where the cyclotron frequency of the electrons matches the microwave frequency) to a maximum of the electric field in the cavity. Both adjustments are necessary to obtain an efficient operation of the source over a wide range of discharge conditions.

The cavity inside the magnetic structure is formed by a copper hollow cylinder with an inner diameter of 25 mm. ELISA is a monomode source, since the coupling of the rectangular x-band waveguide to the cavity by a rectangular to circular waveguide transition allows only the propagation of the H_{11} microwave mode in the cylinder. The tuning of the cavity is achieved by a positionable spectroscopic aperture, which has a good, uniform electrical connection to the cavity and works as a short circuit. The quality of the tuning can be detected with two power meters measuring the forward (P_{for}) and the reverse microwave power (P_{rev}) in the rectangular waveguide section.

The magnet configuration is based on a design for a 10 GHz ECR ion source of the Universität Gießen [6]. The minimum of the magnetic field is about 0.35 T and sets the lower limit of the resonance frequency to 9.8 GHz (Fig. 2). The upper level of the resonance

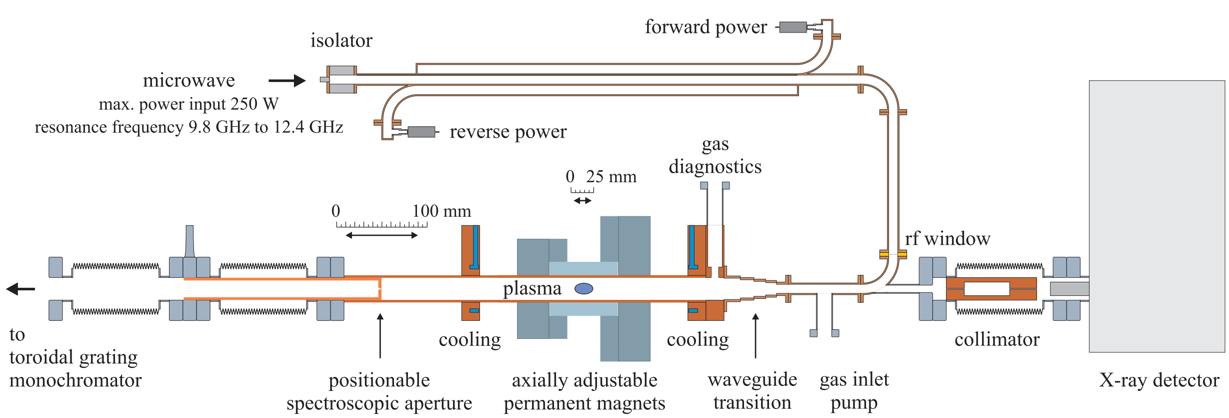

Fig. 1: Schematic of the setup of the Electron Cyclotron Resonance Light Source Assembly (ELISA). The radiation of the source can be detected simultaneously in the VUV and X-ray spectral range via a toroidal grating monochromator and a Si(Li)-detector.

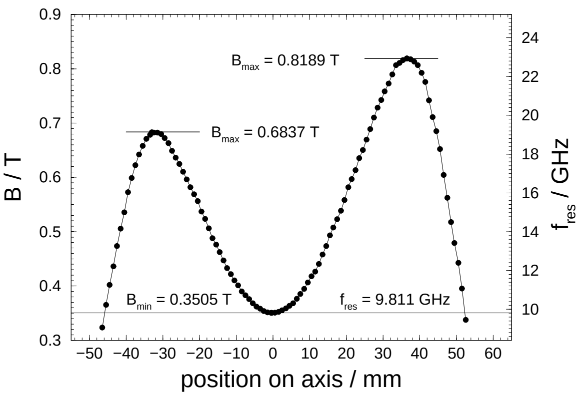

Fig. 2: The axial component of the magnetic field on the axes of the cavity.

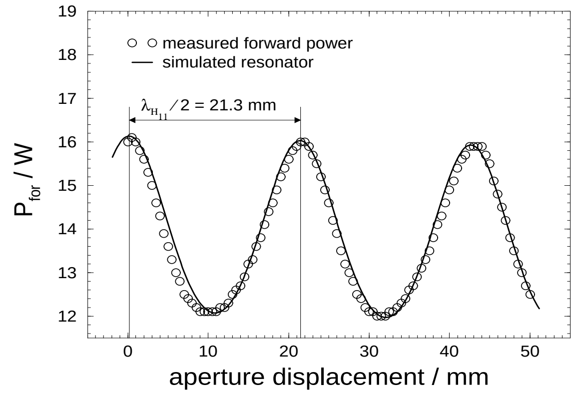

Fig. 3: Measured and calculated forward microwave power as a function of aperture displacement.

frequency is limited by the dimensions of the applied rectangular waveguide to 12.4 GHz. The complete magnetic structure can be precisely moved along the axis of the cavity over a range of 25 mm, which covers half the wavelength of the H_{11} mode.

Experimental

To optimize the performance of ELISA the cavity is tuned and the magnets are adjusted to a maximum of absorbed microwave power in an iterative process. For a stable and reproducible source operation the cavity characteristics under certain discharge conditions have to be measured. The resonator properties were investigated for the plasma-free case and when producing a plasma by filling the cavity with the working gas.

Figure 3 shows that the microwave power in the plasma-free cavity can be well described by a resonator with 100% reflectance at the aperture and 7% reflectance on the other side. The observed periodicity corresponds to half the wavelength of the H_{11} mode at 9.94 GHz.

The left hand side of Fig. 4 illustrates that with no plasma only little microwave power is absorbed in the source (P_{abs} = P_{for} - P_{rev}). The right hand side of Fig. 4 shows the tuning dependence of P_{for} and P_{abs} with a krypton plasma in the cavity. The obtained structure also has a period of $\lambda_{H11}/2$, but the absorbed power now shows sharp resonances.

The increase in the absorbed microwave power leads to a pronounced increase of the VUV and X-ray radiation from the plasma (left hand side Fig. 5). The radiant intensity shows a steep cut off when the aperture is moved beyond the position of optimized cavity tuning.

Moving the magnetic structure along the axis of the cavity a $\lambda_{H11}/2$ periodicity is found again for the absorbed microwave power, since the resonance surface is now moved along the electric field distribution in the cavity (right hand side Fig. 5). The dip at 18 mm which is superimposed on the sinus like periodicity may be explained by the fact, that a frequency of 9.94 GHz leads to two separate regions where an optimized overlap of the resonance surface and the maxi-

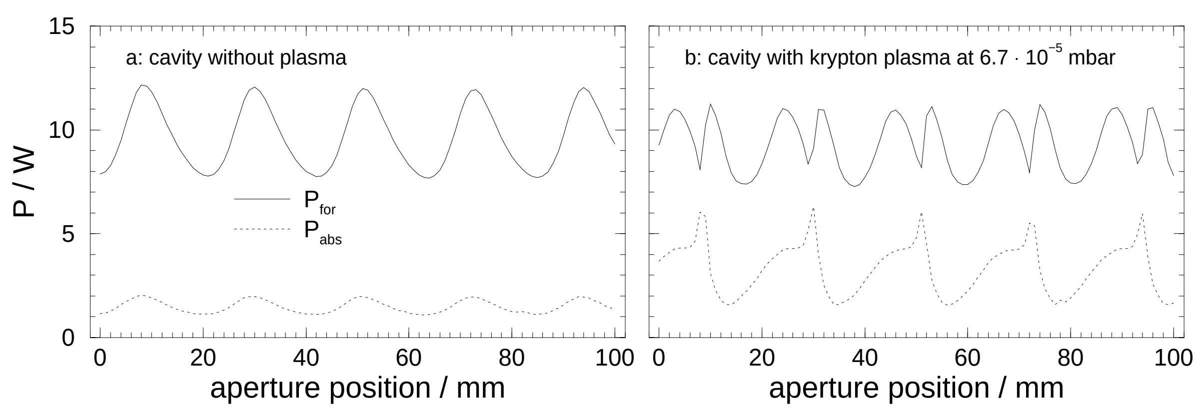

Fig. 4: Comparison of the microwave behaviour in the cavity without plasma and with a krypton plasma. The observed periodicity corresponds to half the wavelength of the H_{11} mode at 9.94 GHz. With a krypton plasma in the cavity the absorbed microwave power shows sharp resonances.

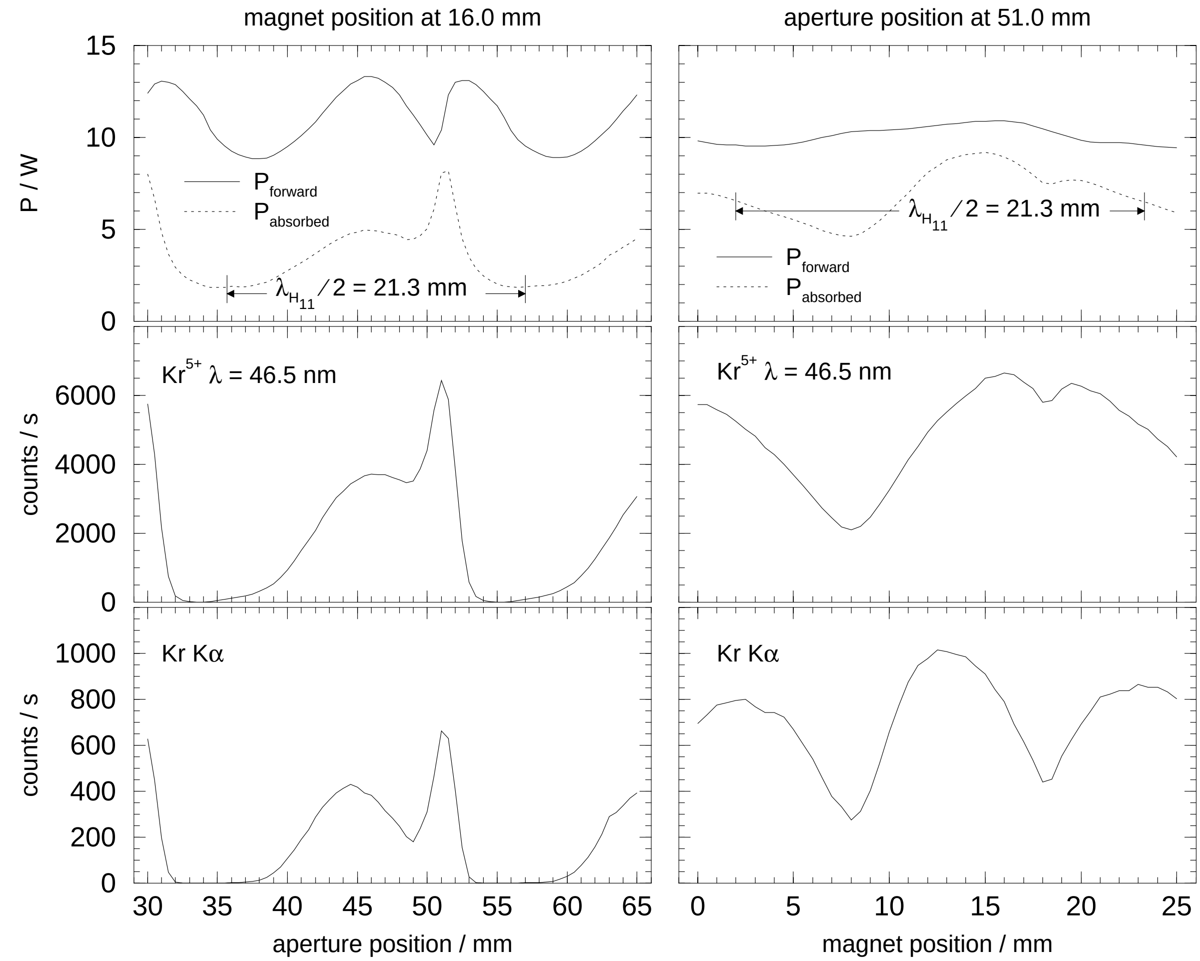

Fig. 5: The absorbed microwave power and the corresponding radiant intensity of a VUV emission line and the krypton Kα emission line as a function of aperture and magnet position.

mum of the electric field is possible. Again the increase of the absorbed microwave power corresponds with a strong increase of the radiant intensity of the source. However, the position of the maximum of the intensity is different for VUV emission lines and X-ray transition lines.

To maximize the radiant intensity of a specific emission line an individual iterative process of cavity tuning, magnetic field positioning and optimizing of pressure has to be realized. The VUV spectrum of a krypton plasma shown in Fig. 6 was measured with optimized conditions for a group of transition lines of the charge state Kr^{9+} at 10.3 nm. Due to the optimization potential of the source a microwave power of only 13 W is sufficient to produce emission lines corresponding to charge states of Kr^{1+} to Kr^{9+} (examples are marked in the spectrum).

Conclusion and Outlook

ELISA is a new radiation source for the VUV spectral range. The underlying principle of an ECR heated plasma avoids life time and stability problems arising from the erosion of the cathode material as known from present plasma discharge VUV sources standards. The special compact design of ELISA using axially positionable permanent magnets in combination with a tunable cavity allows to produce radiation from highly charged ions with very low power consumption in comparison to other VUV radiation sources.

Our first investigations of the tuning behaviour of ELISA with a krypton plasma exhibited a strong dependence of the VUV and X-ray radiant intensity on cavity tuning and magnetic field positioning. Both adjustments are pressure dependent.

In a next step detailed investigations of the long term stability and reproducibility of the source will be performed, to provide the basis for the radiometric calibration of ELISA. For the measurement of the absolute radiant intensity of ELISA the emission of the source will be compared to the synchrotron radiation of BESSY I, which is a primary radiometric standard source [7].

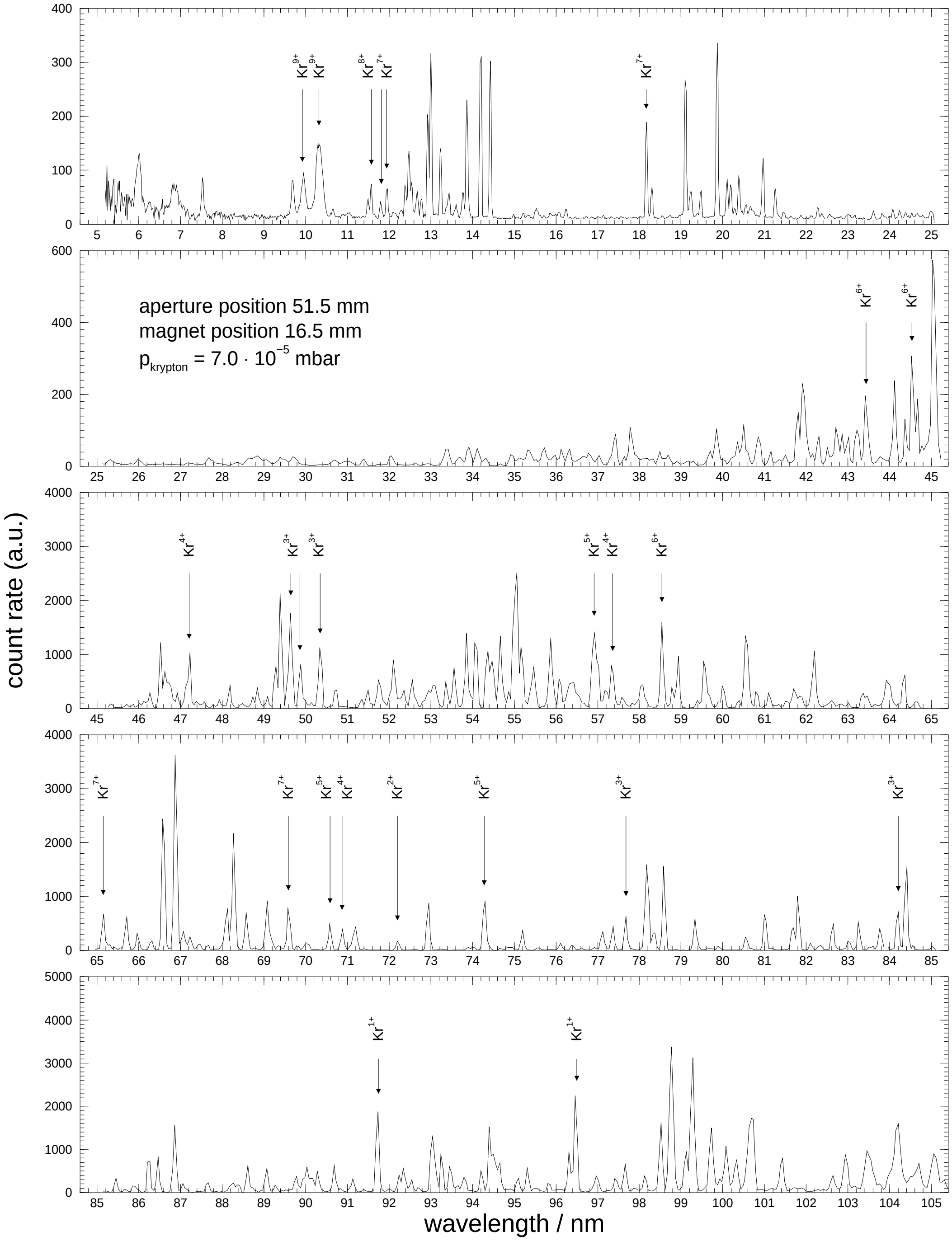

Fig. 6: Spectrum of a krypton plasma produced by ELISA in the range from 5 nm to 105 nm measured with the toroidal grating monochromator of PTB at BESSY I.

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