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Commissioning of a powerful electron gun for electron–ion crossed-beams experiments

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ABSTRACT

The sensitivity of an electron–ion crossed-beams experiment is mainly determined by the densities of both beams in the interaction region. Aiming at the extension of the available range of accessible electron energies and densities, a new high-power electron gun has been developed and fabricated. It delivers a ribbon-shaped beam with currents of up to 1 A at variable energies reaching 3500 eV at the maximum. The design goals of the gun are being met by using a configuration of electrodes, which allows for a variety of operation modes. Here, we report on the results of the ongoing tests of the new electron gun. In particular, electron-impact ionization cross sections of He^{+} and Xe^{5+} ions were measured employing the animated crossed-beams technique. The results are in excellent agreement with literature data.

1. Introduction

In electron–ion collision studies, it is highly desirable to have an electron beam available with high intensity over a wide energy range as these two parameters define the experimental accessibility of the cross sections to be investigated. Moreover, a well-defined energy in the interacton region is desirable for the investigation of, e.g., resonant ionization processes with high resolution.

An electron gun producing an electron beam between 10 and 1000 eV with currents of up to 450 mA at 1000 eV has been built and successfully operated at our institute for about three decades [1]. However, as techniques for the production of highly charged ions have improved and the focus of interest has shifted to more highly charged ions (see, e.g., [2,3]), access to higher collision energies became necessary. Thus, a project for the development of a new electron gun with wider accessible electron-energy range was started [4]. The envisaged capabilities of the new electron gun included the energy range between 10 and 3500 eV as well as the ability to deliver high electron currents at low energies. With these parameters a continuation of projects for the determination of electron-impact ionization cross sections of, e.g., xenon and tungsten ions and the extension to higher charge states than the formerly accessible Xe^{24+} [2] and W^{19+} [3] will be possible. The determination of these data is highly desirable for plasma-modeling purposes and the validation of theoretical calculations that have already been carried out for charge states not experimentally accessible yet (e.g., W^{25+} [5]).

After thorough simulations [4] and the fabrication of the first prototype, further developments and improvements were carried out addressing, e.g., thermal loads, high-voltage operation, the cooling of the electron collector as well as prevention of the ion beam from being influenced by the fields of focusing electrodes outside the electron gun [6]. Meanwhile, the gun is integrated into the electron–ion crossed-beams setup in Giessen (see [3] and references therein). The commissioning of the gun is currently underway. This report aims at giving an overview of the experimentally observed characteristics and capabilities of the present version of the new electron gun and its current commissioning status.

2. Characteristics of the electron gun

The present electron gun comprises ten different electrodes which are electrically insulated from each other and can be controlled and monitored independently (Fig. 1). Electrons are emitted by a rectangular cuboid-like tungsten dispenser cathode with a curved emitting surface (60×5 mm) mounted into the Pierce-type focusing electrode. Thus, the produced electron beam has the shape of a ribbon. The first electrodes (focusing electrode, controlling electrode 1 and 2) focus the electron beam into the interaction region where it has a height of approximately 1–2 mm. Subsequently, the beam is defocused (by the controlling electrodes 3 and 4 as well as

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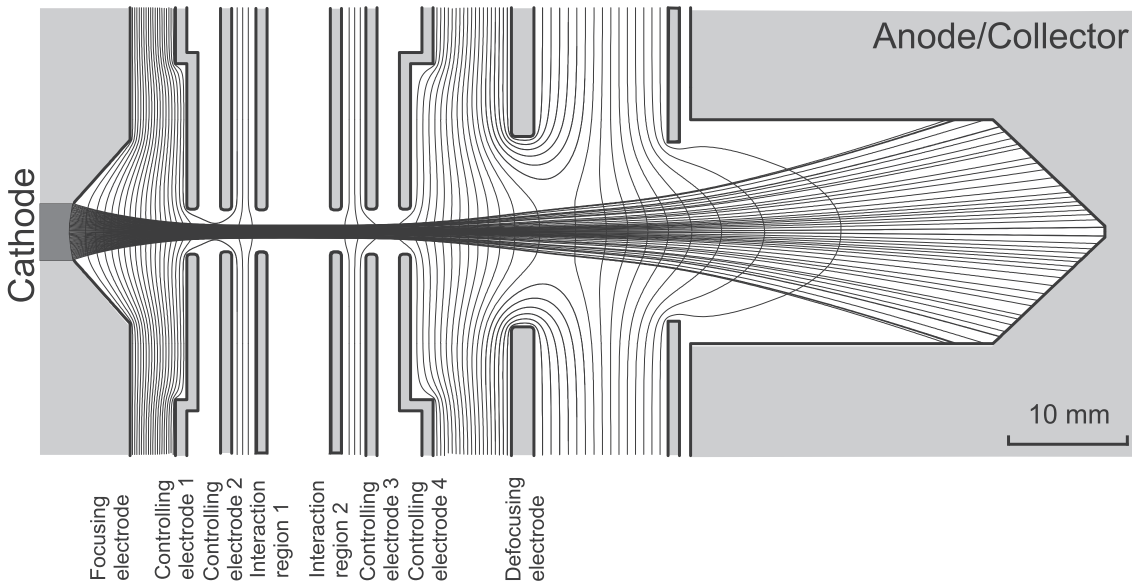

Fig. 1. Geometrical sketch of the electron gun with its various electrodes as well as the equipotential lines and electron trajectories for operation in the high-energy mode with w = 0.25 as defined in Table 1.

the defocusing electrode) as it moves further towards the water-cooled collector. No magnetic field is involved. The properties of the tungsten dispenser cathode set strict requirements for the vacuum conditions. Stable gun operation can only be assured at residual-gas pressures not exceeding the lower 10^{-9} mbar range. Considering substantial gas emission from the collector surfaces as a result of the bombardment by energetic electrons, the task to maintain the required pressure is challenging, despite the availability of high-speed pumping (around 2400 l/s for N_2). For this reason, the electron beam can be decelerated immediately before entering the collector thus reducing the deposited power and the corresponding gas emission. This feature is very useful at high electron energies, where deposited powers may easily exceed 1 kW.

Compared to the prototype version of this electron gun described in [4], some minor changes to the design have been realized. Most notably, a formerly existing interaction box has been replaced by two separate, electrically insulated electrodes named interaction region 1 and 2. This change allows for an independent monitoring of the loss of electron current before and after the interaction with the ion beam and, thus, a more accurate determination of the electron current that is available for the ionization process. However, when the electron gun is in operation, both electrodes are set to the same potential resulting in a uniform potential in the whole interaction region and, thus, no change in the calculated electron trajectories. Moreover, separate insulated plates at the entrance and the exit of the electron–ion interaction region, as seen from the perspective of the ion beam, were installed in order to shield the primary ion beam from the electrode potentials outside of the electron gun (see Fig. 2).

The given configuration of electrodes allows for a variety of different operation modes, which can be classified into four groups (Table 1): High-energy modes, high-current modes, modes without a potential trap for positive ions and modes with the electron beam decelerated at the collector to reduce the deposited power and, correspondingly, the heat load on and gas emission from the collector surfaces. The high-energy modes are suitable for higher electron energies, where intense currents can be reached straightforwardly. To obtain sufficient currents at low energies, the high-current modes can be used. Here, the potential on the first controlling electrode (also termed extraction electrode) is increased resulting in a higher electron current drawn from the cathode. Before entering the interaction region, electrons are decelerated thus achieving the desired electron energy. In both types of modes, the intense electron beam induces a potential trap in the interaction region, which may influence the energy resolution and trap positive ions of the residual gas leading to distortions of the measured absolute cross sections. This can be avoided by applying negative potentials on the controlling electrodes 2 and 3 with respect to the interaction region (modes without a potential trap). Finally, the power deposited on the collector surfaces can be reduced by applying a lower potential to the collector such that the strict vacuum conditions described above can be satisfied also at high electron energies.

For a better understanding of the rather theoretical paragraph above and to supply specific values, a complete set of potentials for the different operation modes at an electron energy of 500 eV is given here. In order to achieve the desired electron energy of 500 eV, the cathode together with the focusing and the defocusing electrode is set to −500 V, while the interaction region 1 and 2 are set to the ground potential for all modes. When using the high-energy mode with w = 0.25, the controlling electrodes 1, 2, 3 and 4 are set to 125 V and the collector is on the ground potential. However, for the corresponding high-current mode with, e.g., x = 1.5, the potential on the controlling electrodes 1 and 4 is raised to 750 V thus achieving a raise of the extracted electron current from ≈65 mA to ≈160 mA. To eliminate the potential trap in the interaction region in this particular case, a value of y = −0.55 with the resulting potential on the controlling electrodes 2 and 3 of −275 V is needed. Finally, to reduce the power deposited on the collector, a value of, e.g., z = −0.5 results in an applied potential of −250 V and the decrease of power from ≈80 W to ≈40 W.

For the investigations described here, the potentials are set symmetrically with respect to the interaction region, which means that the potentials on the controlling electrodes 1 and 4 as well as on the controlling electrodes 2 and 3 are the same.

3. Experimental technique

The cross-section measurements are performed with the new electron gun integrated into the Giessen electron–ion crossed-beams setup. This apparatus has already been described in detail elsewhere (see, e.g., [3] and references therein) and, thus, will only be briefly described here. In the setup, ions are produced by