High Voltage Plane Cathode-Comb Anode Discharge

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Investigations on the characteristics of a plane cathode-comb anode discharge are presented. This discharge arrangement consists of a plane cathode with a series of anodes, resembling a comb, above it. A significant increase of the discharge voltage was obtained by increasing the number of comb-teeth. Voltage-current characteristics, the intensity and the spatial distribution of He, Al, and Ar spectral lines were investigated as functions of the number of comb-teeth, He pressure and discharge current. Due to the increase of discharge voltage, the spectral line intensities increased significantly in the negative glow region. In case of the Al-I 396.1 nm and the He-I 318.7 nm lines an intensity peak was observed also in the cathode glow region. This peak was pronounced in the case of high voltage anode arrangements and is attributed to excitation by positive ions.

Introduction

High voltage discharges are of great interest because of their application in plasma processing and lasers operating in the uv and vuv region [1–3]. Hollow cathode discharges are used for these purposes since they contain a relatively large number of high energy electrons.

In general, the discharge voltage can be increased by increasing the loss of charge carriers in the discharge. This aim can be reached by a suitable choice of the electrode geometry.

There are two basic solutions. In the case of the HAC (hollow-anode-cathode) arrangement, the loss of the charge carriers is caused in the cathode dark space by placing the anode rods there. This leads to a significant loss of electrons, which can be controlled by the number of the anode rods [1]. The other possibility is a helical device, where a metal wire constitutes the hollow cathode and the anode is placed outside the cathode coil. Here the loss is produced by the sideways diffusion of the charge carriers from the negative glow between the windings of the coil. The discharge voltage can be increased by increasing the distance between the windings [4, 5].

Originally the plane cathode + comb anode arrangement was chosen because its realization is easier than that of the two devices mentioned above. Since a relatively large distance between the plane cathode and the comb anode can be chosen, the excitation processes near the cathode surface can be studied. Endoergic charge transfer collisions have been investigated in this region. This process may be a promising excitation mechanism for lasers operating in the vuv region [6, 7].

A significant increase of the discharge voltage was obtained by increasing the number of comb-teeth. With five teeths, voltages up to 2.4 kV were reached. The intensity distribution of the He, Al and Ar spectral lines was investigated. A significant enhancement of spectral line intensities was observed in the negative glow region. Furthermore, in case of the He-I 318.7 nm and Al-I 396.1 nm lines an intensity peak occurred also in the cathode glow region near the cathode surface. This peak was pronounced in case of high voltage anode arrangements, and was attributed to the excitation by positive ions [8].

Experimental

Cross-sectional views of the electrode arrangement are shown in Figure 1. The electrodes were made of Al and were placed in a Pyrex tube. The teeth forming the comb structure of the anode were 0.5 mm thick and were placed above the plane cathode at a distance of 1 mm. This relatively large distance gives a good possibility to study the region near the cathode surface. The anode structure was machined from one piece. In this way accurate positioning of the teeth was obtained. The number of teeth was changed by placing different compact anode systems above the cathode.

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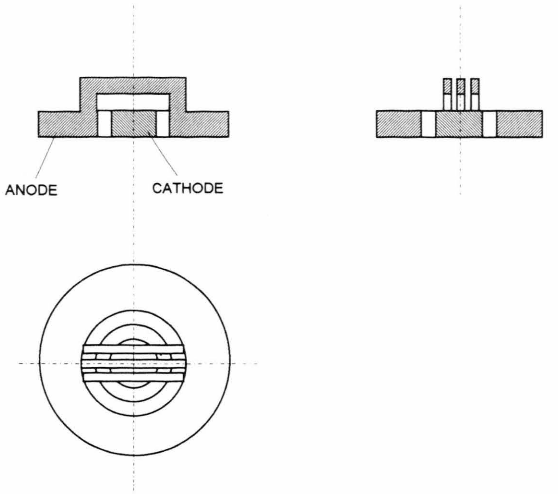

Fig. 1. Cross-sectional view of the electrode arrangement.

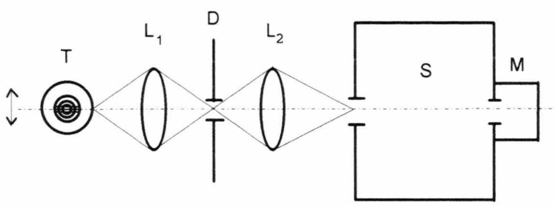

Fig. 2. Experimental set-up. T discharge tube; L_1, L_2 lenses, D diaphragm; S spectrograph; M photomultiplier.

The accurate machining and positioning of this anode system was found to be simpler and easier than in the case of HAC and coil cathode electrode arrangements. Anodes having one, three and five teeth were used.

The discharge was excited by a d.c. power supply capable of delivering 3 kV voltage. The discharge current was kept below 15 mA in order to prevent damage of the tube by the dissipating heat.

The discharge tubes were filled with He or a He–Ar gas mixture. The lower limit of the applied pressure was determined by the voltage of the power supply, the upper limit was found to be 15 mbar, where the discharge contracted into the form of a thin layer.

The optical arrangement is shown in Figure 2. A 4 times magnified real image of the cathode region was obtained using a lens L_1 of $f = 7.6$ cm. Small regions of the discharge were selected by using a 2 mm slit. The motion of the lens, perpendicular to the optical axis, was produced by a micrometer screw. Thus different parts of the discharge could be studied. The light passing the slit was collected by a second lens L_2 ($f = 16$ cm) which imaged it into the entrance slit of a ZEISS-PGS 2 spectrograph. For light detection a Pacific Photometric Inst. 62/3A14 type photomultiplier was used. The spatial distribution of spectral lines was investigated between the oblong anode teeth in the direction perpendicular to the cathode surface.

Results

Voltage-current characteristics measured for different teeth numbers are shown in Figure 3. As expected, a significant increase of discharge voltage was obtained by increasing the number of teeth. This voltage increase is attributed to the higher loss of electrons in the cathode dark space caused by the anode teeth placed there.

The voltage-current characteristic of the tube with a single anode is relatively flat and similar to that of a hollow cathode discharge.

The discharge voltage decreased with increasing pressure. In the tube with a single tooth, however, a slight increase of the discharge voltage could be observed, as can be seen in Figure 4.

The spatial distribution of the spectral lines was investigated in the direction perpendicular to the cathode surface. These measurements give information on

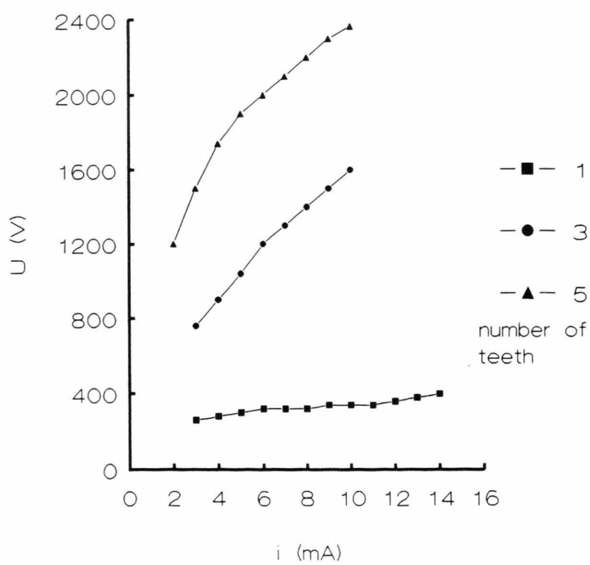

Fig. 3. Discharge voltage as a function of discharge current in case of 1, 3 and 5 anode teeth; He pressure 10 mbar.

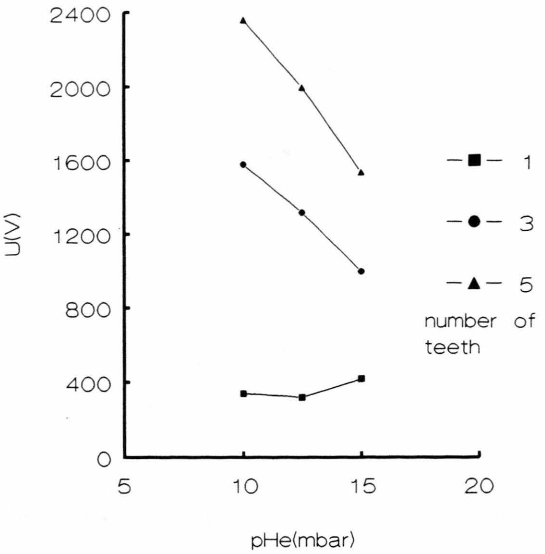

Fig. 4. Discharge voltage as a function of He pressure in case of 1, 3 and 5 anode teeth; discharge current 10 mA.

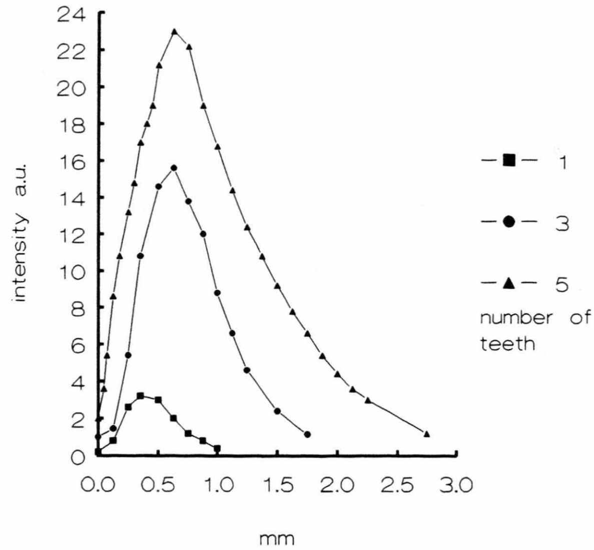

Fig. 5. The spatial intensity distribution of the He-I 492.2 nm line in case of 1, 3 and 5 anode teeth measured at 5 mA discharge current and 15 mbar He pressure.

the discharge distribution and also on the excitation mechanisms taking place in the negative glow and near the cathode surface. The strong He-I 492.2 nm spectral line was used to adjust the optical system. Its spatial distribution is shown in Figure 5. The intensity increased with increasing number of teeth, in accordance with an enhanced electron impact excitation rate due to the higher discharge voltage. The intensity maximum, moving away from the cathode surface by increasing number of teeth, can be explained by the following: an optimum electron impact excitation rate (an optimum electron energy distribution) belongs to each intensity maximum. The higher discharge voltage (in case of increasing number of teeth) changes this distribution so that the density of higher energy electrons increases in it compared to the optimum case. To reach again the optimum energy distribution, the electrons should take part in further collisions to loose energy, which results in moving the intensity maximum away from the cathode surface.

A similar spatial intensity distribution was observed for the He-II 468.6 nm and the Ar-II 476.5 nm ionic lines. Figure 6 and Fig. 7 show their maximum intensities and the discharge voltage as a function of the number of teeth. The intensity of both ionic lines increased considerably with increasing number of teeth. Since the upper level of the He-II 468.6 nm line is excited by electron impact, its intensity curve follows closely that of the discharge voltage. A difference occurs, however, between the curves of the intensity of the Ar-II 476.5 nm line and the discharge voltage. Since the ionization potential of Ar is lower than that of He, Ar ions can be produced also by Penning-ionization via collisions with metastable He atoms. Therefore a lower voltage is needed to maintain the discharge, and thus a flat curve of discharge voltage vs. number of teeth occurs. However, the intensity of the Ar-II 476.5 nm line increases strongly with increasing number of teeth, since many He 2^3S metastable atoms and ground state Ar ions are present in the discharge, and this transition is excited by energy transfer collisions between metastable He 2^3S atoms and ground state Ar ions.

The spatial intensity distribution of the presented He and Ar spectral lines exhibited a single peak in the negative glow region.

In the spatial intensity distribution of the Al-I 396.1 nm and the He-I 318.7 nm lines two peaks occurred, however, one near the cathode surface and the other in the negative glow region (Figures 8–11). The first peak corresponds to excitation in the cathode glow region. As can be seen in Fig. 8, the cathode glow

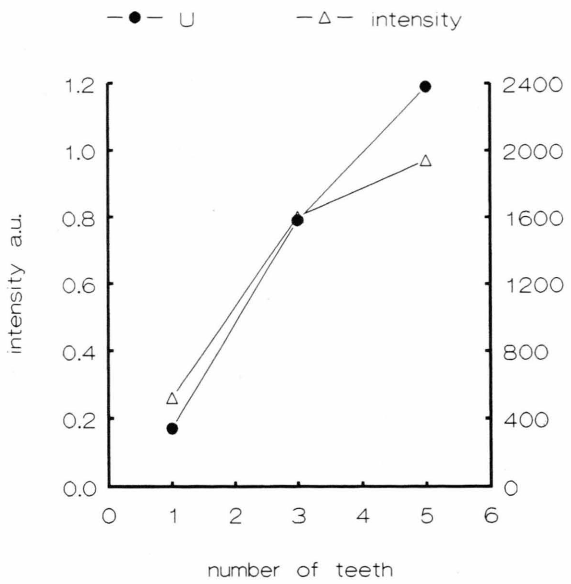

Fig. 6. The intensity maximum of the spatial distribution and discharge voltage as a function of the number of teeth in case of the He-II 468.6 nm line. He pressure 10 mbar; discharge current 10 mA.

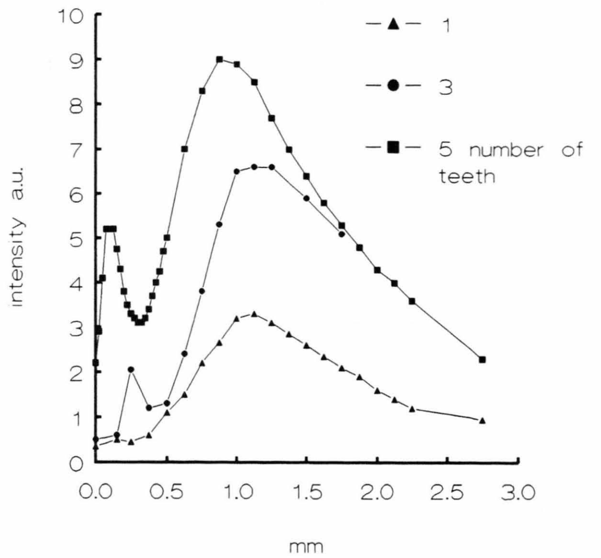

Fig. 8. The spatial intensity distribution of the He-I 318.7 nm line in case of 1, 3 and 5 anode teeth measured at 10 mbar He pressure and 10 mA discharge current.

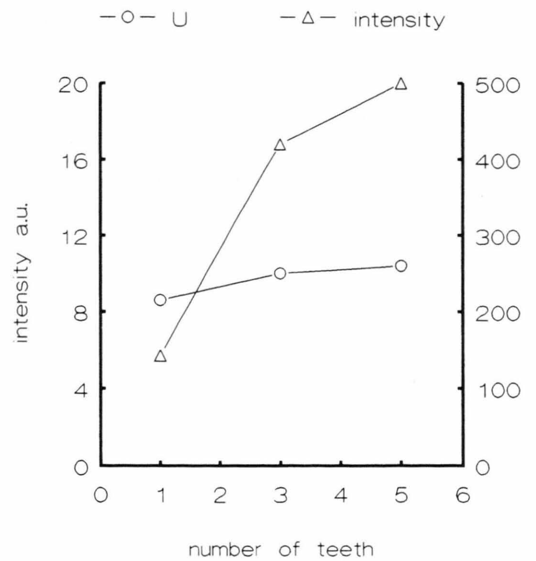

Fig. 7. The intensity maximum of the spatial distribution and discharge voltage as a function of the number of teeth in case of the Ar-II 476.5 nm line. Partial pressure of He 10 mbar, that of Ar 2.5 mbar; discharge current 10 mA.

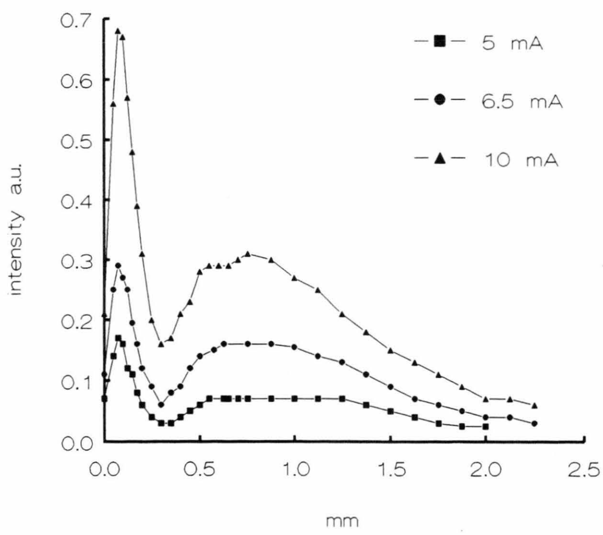

Fig. 9. The spatial intensity distribution of the Al-I 396.1 nm line in case of different discharge currents at 10 mbar He pressure.

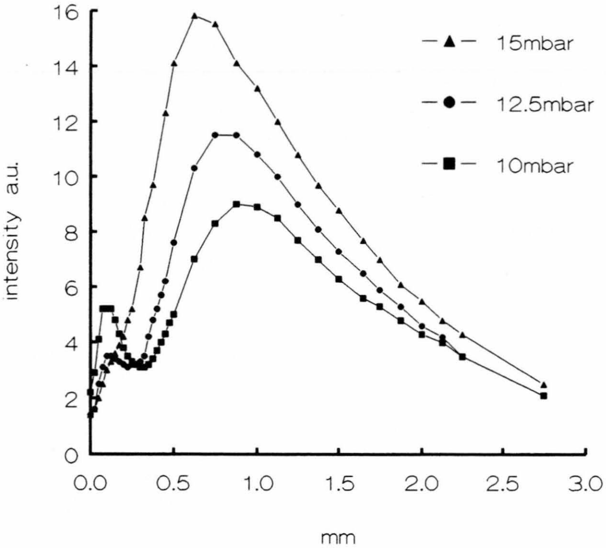

Fig. 10. The spatial intensity distribution of the He-I 318.7 nm line in case of different He pressures at 10 mA discharge current.

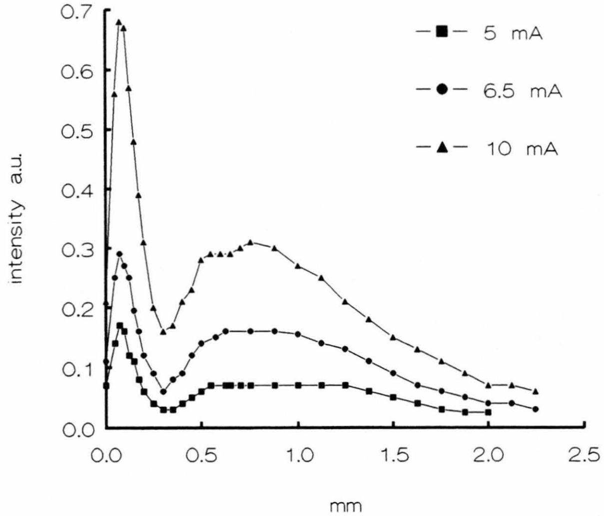

Fig. 11. The spatial intensity distribution of the He-I 318.7 nm line in case of different discharge currents at 10 mbar He pressure.

peak at the He-I 318.7 nm line is hardly observable in the one anode tube and it becomes pronounced in the tubes of higher number of teeth, where the voltage is increased. This result shows the important role of high voltage in the occurrence of this peak. Cathode glow peaks are usually excited by positive ions originating from the negative glow and the cathode dark space [8]. These ions are accelerated by the electric field of the cathode dark space and become capable to produce a significant excitation. Intensity peaks in the cathode glow have been observed for ionic lines, where excitation is due to the endoergic charge transfer collisions [6, 7].

An interesting feature of the intensity distribution of the Al-I 396.1 nm line is shown in Figure 9. The peak in the cathode glow is higher than that occurring in the negative glow. In our case Al and He ions are present in the discharge with high densities. The excitation of the cathode glow peak in case of the Al-I 396.1 nm line is probably not due to collisions with Al ions. The density of the sputtered Al is low, thus Al ions participate in only few symmetric charge transfer collisions during their movement through the cathode dark space. Because of this, Al ions have a large mean free path and can gain a large kinetic energy [9, 10]. These ion energies, which can reach values in the order of several hundred eV [9, 11, 12], are considered to be too high for efficient excitation of the low lying upper level (3.14 eV) of the Al-I 396.1 nm line. Excitation of the peak in the cathode glow region is thus considered to be mainly due to collisions with He ions. The density of high kinetic energy He ions is low in this region [11, 12]. The average energy of He ions is in the order of 3–4 eV, the density of them is high, their energy is in the range of the upper level energy of the Al-I 396.1 nm line. These features support excitation of this line by He ions.

In case of the He-I 318.7 nm line the intensity distribution was measured as a function of He pressure and discharge current. In Fig. 10 it can be seen that the magnitude of the cathode glow peak decreases with increasing pressure. This supports excitation of the peak in the cathode glow due to positive ions. If it were electron impact excitation, it would not disappear with increasing pressure, but it would move towards the cathode. To see which ion may be responsible for excitation of this line, a similar consideration as in the case of the Al-I 396.1 nm line is made. The upper level energy of the He-I 318.7 nm transition is 23.71 eV. This energy is too high to be considerably excited by the 3–4 eV average energy He ions. Thus it is probable that high energy Al ions excite this line [11, 12]. As can be seen in Fig. 11, the magnitude of the cathode glow peak increases with increasing discharge current. This is due to the increasing density of exciting Al ions. In the five teeth tube, in which the data were measured, the voltage increase with increasing current plays also an imporant role in the production of Al ions (see voltage-current characteristics in Figure 3). The cathode glow peak at the He-I 318.7 nm line was observed to increase in a strongly non-linear manner with increasing number of teeth (Figure 8). This is explained by the fact that the density and energy of Al ions exciting the He-I 318.7 nm line in the cathode glow increases significantly when the voltage increases. The higher energy Al ions present at increased voltage sputter more Al atoms from the cathode, thus more can be ionised.

The first peak in the cathode glow was not observed in the spatial intensity distribution of the He-II 468.6 nm and the Ar-II 476.5 nm ionic lines. Since the upper level energy of these transitions is rather high (75.6 eV and 35.7 eV, respectively), the absence of the peak can be explained by the lack of high energy positive ions that are capable of exciting these levels.

Conclusions

A high voltage discharge tube was constructed with an anode arrangement resembling a comb. This plane cathode – comb anode arrangement is an easier practical realisation of increased voltage discharge tubes. Increasing the number of teeth, a significant enhancement of discharge voltage and spectral line intensity was observed. Using an five teeths tube, the voltage increased up to 2.4 kV. In the course of spatial distribution studies an intensity peak of the He-I 318.7 nm and the Al-I 396.1 nm atomic lines was observed in the cathode glow region. This peak was strong in case of three and five teeth tubes having increased voltages and is attributed to excitation by Al and He ions respectively, which are accelerated by the high electric field of the cathode dark space.

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