Light Emission from Rare Gases using Combined Electron-Beam and Radio-Frequency Excitation

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Light emission from rare gases, argon in particular, has been studied using both electron-beam and radio frequency (rf) excitation. Characteristic features of the emission spectra have been measured for a broad wavelength range from ~50 nm to 1000 nm. Strong variations of the intensities of these features have been observed with varying rf-power applied to an electron beam induced plasma. The effects are tentatively attributed to an independent variation of electron density and electron temperature with electron beam and rf power, respectively.

1. Background

A low energy electron beam with a particle energy of about 12keV is sent into gas targets. The technique has been used to build vacuum ultraviolet (VUV) light sources [1] in which rare gases and their mixtures are used as the light emitting media. In order to enhance the intensity and to modify the spectral shape of the light emission, radio frequency power was coupled into the target gas in addition to the electron beam. Besides useful effects for the light sources [2] this combination of two different excitation methods opens an interesting way to study low temperature plasmas, because it allows for the first time to realize "electron beam sustained discharges" (and vice versa “rf-enhanced electron-beam induced plasmas”) in a table top setup.

2. Results

The observed emission spectra show the characteristic features of excited rare gases. The VUV range is dominated by the continuum radiation originating from optical transitions from excited rare gas molecules (excimers) to the repulsive ground state. Excited and ionized rare gas atoms and molecules lead to a further continuum radiation in the deep UV (“third continuum”). Atomic and ionic line radiation appears in the visible and near infrared.

All these structures appear both in sole electron-beam and combined electron-beam rf-excitation, but in modified ways. Increasing the electron-beam current only leads to a rising intensity of the continua as well as the line radiation, proportional to beam current. This is mainly attributed to a higher electron density. Applying additional rf-power increases both the electron and gas temperature. This leads to an enhanced population of higher lying vibrational levels of the excimer molecules, which in turn leads to a strong shift in intensity in the VUV [2]. The so called second excimer continuum originating from vibrationally relaxed molecules is decreased and the so called first excimer continuum increased in intensity. The latter originates from high lying vibrational levels and is emitted on the short wavelength side of the second continuum. As the electron density is assumed to be rather constant for a fixed electron-beam current, the production rate of excimer molecules and therefore the integrated intensity of both continua does not change much.

Rising electron temperature with rising rf-power causes the intensity of atomic lines to increase. This is interpreted by collisional excitation of atoms in excited (metastable) levels.

The continuum emission in the deep UV range, the so-called 3rd excimer continuum, extends from about 170 nm to 250 nm in argon and has been assigned to a combination of optical transitions of various molecular species [3]. With rising rf-power the parts of this structure, belonging to singly ionized molecules, disappear, whereas the parts, belonging to doubly ionized molecules, are enhanced. This effect may also be explained by a higher electron temperature reducing the recombination rate.

Finally, a new feature appears in the emission spectra in the form of a broad continuum extending from the UV to the IR range. As its spectral shape is very similar for all rare gases and its intensity is rising with electron temperature, we assign this emission to Bremsstrahlung.

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References

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