Spectroscopic and Gas Kinetic Studies of Electron Beam Induced OH^*, Ne_2^*, He_2^*, and N_2^* Light Emission ◇

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Particle beam induced emission of ultraviolet (UV, 200-400nm), vacuum ultraviolet (VUV, 100-200nm), and extreme vacuum ultraviolet (XUV, 60-100nm) light is used to develop novel ultraviolet light sources. A project in which 10-20 keV electron beams are used for that purpose is described in a separate contribution to this annual report. Here, we describe basic spectroscopic and gas kinetic studies which have been performed in the context of this project.

The experimental setup can be briefly described as follows: A typically 13 keV electron beam is sent through a thin (300nm) ceramic membrane into a dense gas target which can contain gases from 0 pressure up to several atmospheres. About 90% of the beam power can be coupled into the target gas and leads to collisional excitation and ionization. Optical transitions of the excited species lead to light emission. Excited species are either formed in the primary collisons of the beam electrons with the target species or via a chain of gas kinetic reactions. The concept has been described in more detail in previous publications [1]- [3].

A fast pulsing mode for the electron beam has been added to the experimental setup in the year 2003 as an important improvement. The electron beams are formed by simple electron guns as normally used in cathode ray tubes. In these electron guns one grid is used to control the beam current by applying a voltage with respect to cathode potential. In the fast pulsing mode, the grid is biased at about -70V which sets the electron current to zero. Then, using a cable pulser, a short, 5ns electrical pulse of about +120V amplitude is added to the grid voltage, thus activating the electron beam for that short periode of time. The pulsed excitation can now be used for performing time resolved optical spectroscopy. The light detection technique is the same as described for experiments using the ion beam from the tandem accelerator for excitation [4], [5]. The typical electronic time resolution of the setup is 0.3ns. The characteristic excitation time scale, however, is on the order of 10ns due to the finite slowing down time of the electrons in the target gas.

Various studies on ultraviolet light emitting gases and gas mixtures were performed. Spectra emitted from Ne-Ar-F mixtures (193nm ArF^* emission) are presented in the contribution to this report about the technical developments mentioned above. Another well known rare gas halide emission is the 308nm light produed by $XeCl^*$ lasers. This wavelength is of particular interest for medical applications. There is interest in efficient light sources emitting in this wavelength region. To avoide the technical problems related with the use of chemically reactive halides (Cl_2) we have started to study the $\sim$ 310nm emission from OH^*. Intense emission in this band is observed from particle beam excited dense argon gas with water vapor as trace impurity, desorbed from the target cell walls. Normally, this emission had to be supressed with great effort using rare gas purifiers. Now this emission is optimized for practical applications. An emission spectrum in which an argon water-vapor mixture has been optimized for the emission of the 310nm (A-X) OH^* band is shown in Fig. 1.

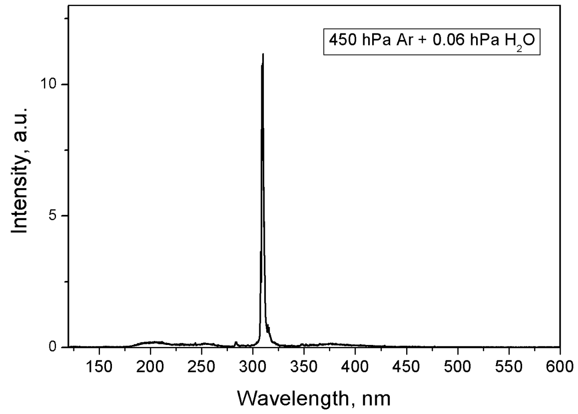

Fig. 1: Light emission from a argon water-vapor mixture. The spectrum is dominated by the A $\rightarrow$ X transition of the OH^* molecule.

A set of intensity data on the 310nm OH band versus H_2O concentration is shown in Fig. 2.

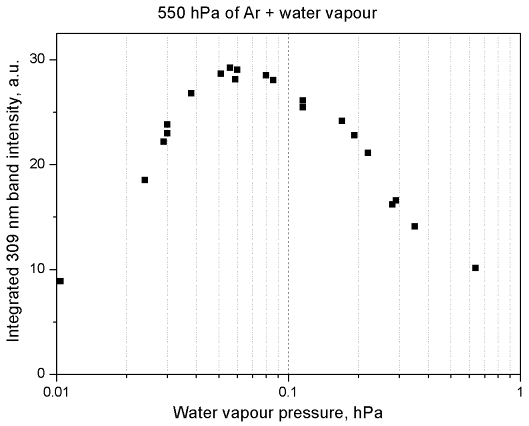

Fig. 2: Light output on the OH^* emission band is shown vs. water vapor partial pressure.

There is a maximum at 0.06hPa of water vapor pressure which corresponds to a concentration of 0.01%. Water vapor concentration was determined in the experiments by filling the cell to a certain partial pressure and then adding argon gas. The mixture was controlled using a calibrated hygrometer. The walls of the cell were covered with a gold

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layer to minimize absorption and desorption of water from the walls, in particular those walls which are irradiated by the UV photons emitted in the light source. A time spectrum of the light emission from an electron beam excited 50hPa/0.05hPa Ar/H_2O mixture recorded on the 310nm OH^* band is shown in Fig. 3.

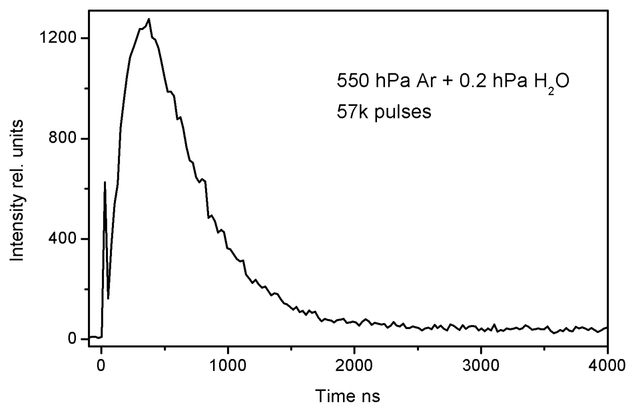

Fig. 3: Time structure of the OH^* emission from an Ar water-vapor mixture

Another system which has been revisited in the year 2003 is the XUV emission from the pure rare gases helium and neon. A XUV monochromator which has been borrowed from the Max Planck Institut für Plasmaphysik has been made operational in a student's project (S. Schoop) and measurements similar to those presented in ref. [6] were performed systematically, mainly by a visiting scientist (A. Fedenev) from the High Current Electronics Institute in Tomsk, Russia funded as a PiZ (Projekt zur internationalen Zusammenarbeit) project by the Bayerische Forschungsstiftung. The helium and neon excimer emissions which cover the spectral region from 60 to 120nm were used to measure transmission spectra of lithium fluoride. Note that LiF has the shortest cut-off wavelength of all optical window materials. This cut-off can therefore not be measured with regular excimer lamps which always need high gas density and in which LiF would be the best window material possible. As described in [6] this problem can be avoided if no optical windows are used at all. The experimental setup is completely filled with purified dense rare gases He or Ne and XUV light is produced by electron beam excitation of this gas filling. Inserting a LiF sample into the light path and recording reference data with the sample removed lead to the sample transmission spectrum of LiF shown in Fig. 4. An improvement was implemented for the spectral region from 100 to 120nm where the helium excimer emission is already rather weak. Here a mixture of neon with 1..2% of argon was used as the light emitting gas. Adding argon to neon leads to an energy transfer process from neon to argon. At this concentration argon aquires nearly all the excitation energy gained by neon. The absolute pressure of argon, however, is low enough to allow emission on the so called first continuum which is otherwise strongly self absorbed.

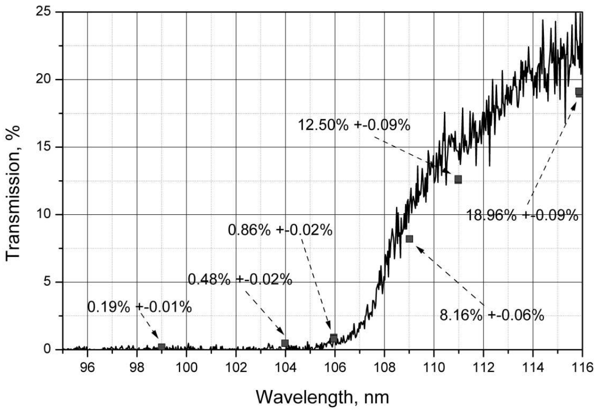

Fig. 4: Transmission spectrum of LiF near it's absorption edge. Data, shown as a continuous line were obtained from two scans, with and without sample. The other data points indicated are precision measurments at selected wavelengths.

Another study of electron beam induced gases was stimulated from the high energy particle astrophysics community. High energy cosmic ray particles induce so called air showers in the atmosphere. In this context it is interesting to study the particle beam induced light emission from air. The emission is dominated by the C-B bands of N_2 in the 300 to 400nm wavelength region. An emission spectrum from 250 mbar pure nitrogen in this region is shown in Fig. 5.

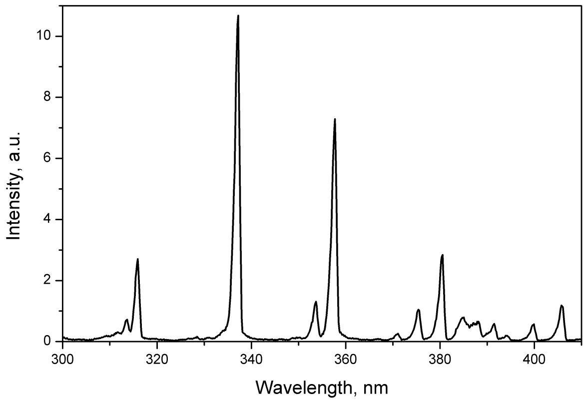

Fig. 5: Spectrum emitted from pure nitrogen in the wavelength range from 300 to 400nm.

A measurement of the absolute intensity of this air shower radiation shall provide information about the initial energy of the cosmic rays. All the information about the influence of the gas components of air such as oxigen, CO_2, water vapor etc. as well as parameters such as pressure and temperature will be required to model the light emission from these air showers. We have performed preliminary experiments on a number of issues in this field in a collaborative experiment with P. Privitera and V. Verzi from the University of Rome II at our laboratory. Measurements were already performed on the lifetimes and the self- quenching rates of the C ^3P_u (v=0) state of nitrogen. A sample time spectrum is shown in Fig. 6.

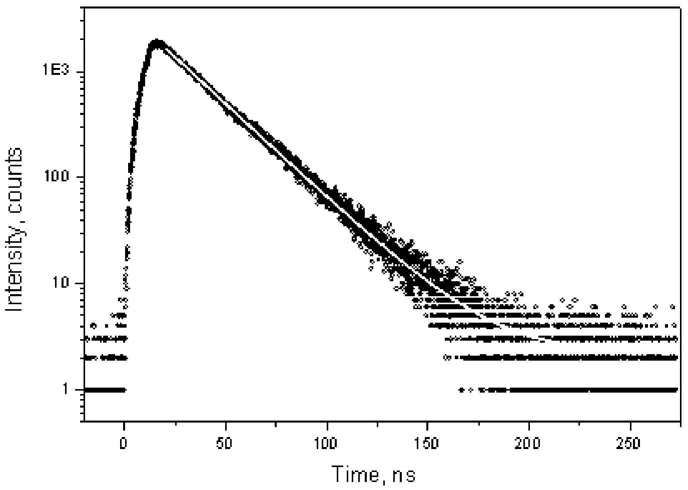

Fig. 6: Time spectrum on the 337nm C-B molecular nitrogen transition following 5ns pulsed electron beam excitation.

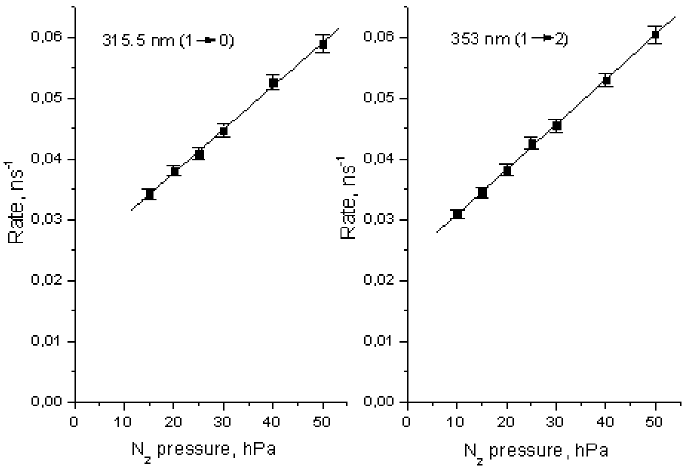

Fig. 7: Inverse lifetimes are shown for the 315.5 and 353nm nitrogen transitions vs. nitrogen pressure. Lifetimes and collisional quenching rate constants can be derived from the linear fit to the data.

analysis of several time spectra on the 337, 357, 315, and 353 nm transitions (B, v=0, and 1 respectively) and for various gas densities leads to the following results which can be obtained from data sets as those shown in Fig. 7: Lifetimes of 43.1 and 42.6 ns for the (B) v=0 and v=1 vibrational states, respectively with an error of 1.5ns and quenching rate constants of 1.7 and 2.9×10^{-11} cm^3/s, respectively with an error of 0.10×10^{-11} cm^3/s.

References

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