BEAM INDUCED FLUORESCENCE MONITORS FOR FAIR

F. Becker[*], C. Andre, C. Dorn, P. Forck, R. Haseitl, B. Walasek-Hoehne, GSI, Darmstadt, Germany
T. Dandl, T. Heindl, A. Ulrich, Physik Department E12 TU-München, Garching, Germany

Abstract

Online profile diagnostic is preferred to monitor intense hadron beams at the Facility of Antiproton and Ion Research (FAIR). One instrument for beam profile measurement is the gas based Beam Induced Fluorescence (BIF)-monitor. It relies on the optical fluorescence of residual gas, excited by beam particles. Depending on the beam parameters and vacuum constraints, BIF monitors can be operated at base pressure or in dedicated local pressure bumps. Spectroscopic data in nitrogen and rare gases confirms an exploitable dynamic range from UHV to atmospheric pressure. Optical transitions and corresponding beam profiles are discussed for gas pressures from $1 \cdot 10^{-3}$ to 30 mbar. Fundamental limitations for some application scenarios will be addressed as well.

MOTIVATION

Compared to synchrotrons with typical vacuum pressures p_{SYN} of $1 \cdot 10^{-12}$ to $1 \cdot 10^{-9}$ mbar, beam transport sections are usually operated in the range p_{TS} of $1 \cdot 10^{-9}$ to $1 \cdot 10^{-6}$ mbar. This fact increases the set of possible instrumentation in the FAIR HEBT sections, since the expected signal strength for gas based profile monitors scales $\propto p$, see [1, 2]. Beside Ionization Profile Monitors (IPMs) for high sensitivity or high rate applications, compact BIF installations are foreseen. At low duty cycles, temporarily triggered gas puffs beyond $1 \cdot 10^{-4}$ mbar could be provided with pulsed gas valves. In front of production targets for radioactive ion beams or in plasma physics applications, vacuum requirements are less restrictive or even protective gases are used with typical pressures p_{TAR} from $1 \cdot 10^{-4}$ mbar to atmospheric pressure. In order to characterize the BIF monitor at gas pressures $\geq 1 \cdot 10^{-4}$ mbar, imaging spectroscopy was performed in a separated gas cell at the Munich Tandem van de Graaff accelerator. With a DC 200 nA S^{8+} beam at 3.75 MeV/u former results [3] for gas pressures $\leq 1 \cdot 10^{-3}$ mbar could be confirmed. This data-basis was now extended to gas pressures up to 30 mbar.

EXPERIMENTAL SETUP

Figure 1 illustrates the gas cell with a 1.1 mg/cm^2 and ⌀ 5 mm Ti-window (A) to separate the vacuum system of the transport section. Two equally spaced (20 mm) steel plates (B) and (C) with ⌀ 10 mm core holes, have been isolated from the chamber grounding. For the right potential, the plates worked as repeller anode for secondary electrons from (U_A= -1000V, U_B= 0V). However, no significant in-
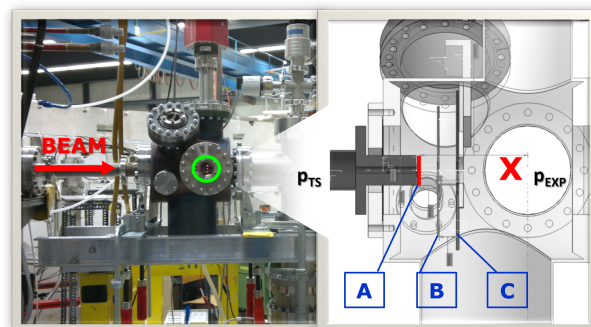
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[*] Frank.Becker@gsi.de

Figure 1: Photograph of the installations (left) and zoomed technical drawing of the chamber setup (right). The red cross indicates the optical sweet spot of the imaging spectrograph. The experimental cell with a gas pressure of p_{EXP} is separated by a Ti-window (A) from the vacuum system of the transport section at p_{TS}. The HV-plates (B) and (C) could be set to dedicated potentials.

fluence on the actual imaging spectroscopy data was observed.

Investigated gases (N$_2$, Xe, Ar, Ne, He) with a purity better 99,998 % have been applied in a dynamic equilibrium at permanent flow against a 700 l/s turbomolecular pump for p $\leq 5 \cdot 10^{-3}$ mbar and against a 12 m^3/h scroll compressor in a bypass mode for higher pressures. Between two different gas species, the chamber was evacuated to $2 \cdot 10^{-7}$ mbar base pressure for cleaning purpose. Measurements with a residual gas analyzer confirm impurities ≤ 1 ‰.

The imaging spectrograph with ~1.5 nm spectral resolution, described in [3] was mounted in front of the CF-40 view port (optical grade, fused silica), see Fig. 1 (green). According to the calibration, the reproduction scale was measured to be 492 pixel per 15 mm in the spatial dimension and 656 pixel per 533 nm (within 260 and 793 nm) in the spectral dimension. Spatial calibration and focusing was realized with a row of four ⌀ 0.2 mm LEDs with 5 mm interspacing, that were pneumatically moved to the beam axis. For spectral calibration, a Hg-Ar lamp, coupled to a UV-grade fiber was fed into the vacuum chamber and mounted on the movable calibration holder. Measurements in this publication were recorded with 5 μm entrance slit opening. The spectral efficiency of the optical system is shown in Fig. 2. Depth of field was calculated to be 2, 4 and 16 mm for f-stop 2.8, 5.6 and 22, focal distance f=50 mm, blurring diameter z=30 μm and g=200 mm object distance [2].

For data acquisition, an image intensified digital camera (ICCD), equipped with a Bialkali photocathode and a two stage MCP configuration was used [3].
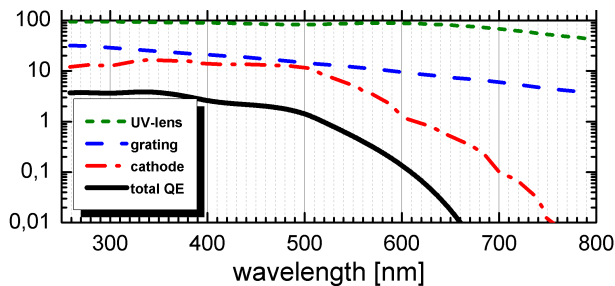
Figure 2: Spectral efficiencies of the relevant optical components and their product (black). Viewport and photocathode substrate show flat response within 250 - 800 nm.

DATA ANALYSIS - RESULTS

In order to cover the full dynamic range of 5.3 orders of magnitude (∼55 dB) for increased gas pressure from $1 \cdot 10^{-4}$ to 30 mbar, the ICCD camera was operated in a photon counting mode. Assuming 2 % of the 322 kpixel are counted during a full scale integration, about 38 dB dynamic range are available. Another 18 dB were obtained by fading down the iris from f-stop 2.8 to 22. Each set of parameters was recorded as sequence of 1000 images with 170 ms integration time and 5 Hz rep rate, for constant accelerator settings (DC 200 nA S^{8+} @ 3.75 MeV/u). The images were analyzed with an ImageJ algorithm, assigning local grayscale maxima to corresponding pixels [2]. Typical image blurring due to intensifier blobs could be avoided this way. Electronic noise from the CCD was suppressed by a 3 bit threshold. Furthermore hot pixel were identified and excluded.

Depending on the experimental purpose, either spectral or spatial (profile) information was obtained from the fluorescence images. By choosing confined Regions Of Interest (ROI), even profiles of single atomic transitions, or spectra of a certain beam region can be displayed [2].

Spectral Study

Fluorescence spectra were obtained from a 30 by 656 pixel core-ROI of the excited gas volume, which corresponds to 0.9 mm in the spatial dimension and 533 nm in the spectral dimension. In Fig. 3, fluorescence spectra of different working gases are plotted for three different pressures of the respective gas species.

Spectra of the particularly lowest gas pressure at $1 \cdot 10^{-3}$ mbar (solid lines) confirm former experimental data [3]. For intermediate pressures (dashed lines) a spectral conversion was observed, with different transitions appearing. For the particularly highest gas pressure (dotted lines) the spectral intensity of Xe, Ar and Ne is concentrated in a few or even a single transition. In He and N_2 there is no concentration, but totally different transitions were observed, compared to the low pressure case.

For low N_2 pressures, only transitions of the ionized molecule N_2^+ (B→X) were observed, whereas exclusively transitions of the neutral N_2 (C→B) appeared in 30 mbar. This strongly affects the profile reading, as transitions of
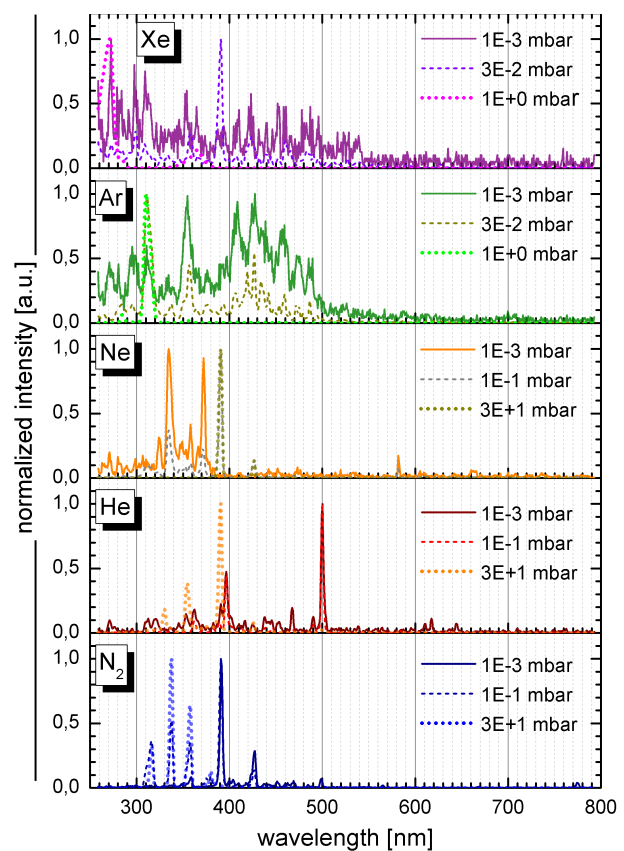

Figure 3: Normalized fluorescence spectra of a DC 200 nA S^{8+} beam @ 3.75 MeV/u in different working gases (Xe, Ar, Ne, He, N_2), measured at three different gas pressures each. Ar-spectra were recorded with 15 μm slit opening.

the neutral molecule are now more likely excited by secondary electrons [4] and thus tend to generate profile halos, according the additional mean free path of the electrons. In high He pressures beside two neutral transitions at 330 and 355 nm, a pronounced line appears exactly at at 391 nm, the N_2^+ (B→X) (0-0). The same line is observed for intermediate pressures in Ne and Xe and might be due to traces of nitrogen. Different transfer processes due to N_2 impurities can be observed in all rare gas species. In Ar a hydroxide transition (OH*) at 310 nm was observed, which originates from dissociated water vapor in the unbaked system.

Beam Profile Comparison

Beam profiles were obtained from full images in Fig. 4 or from 492 by 10 pixel spectral ROIs, that corresponds to 15 mm in the spatial dimension and ∼8 nm in the spectral dimension, in order to select profiles of specific transitions, see Fig. 5. The profile data in Fig. 4 was recorded for constant accelerator settings but it should only be compared among a pressure series of the respective gas species, since drifts during 72 hours of operation cannot be ruled out.

When gas pressure is increased, the observed beam profile width grows in all gas species. Beyond about $1 \cdot 10^{-1}$ mbar, beam profile width starts decreasing again. In N_2, He, and Xe, the narrowest beam profiles were observed for
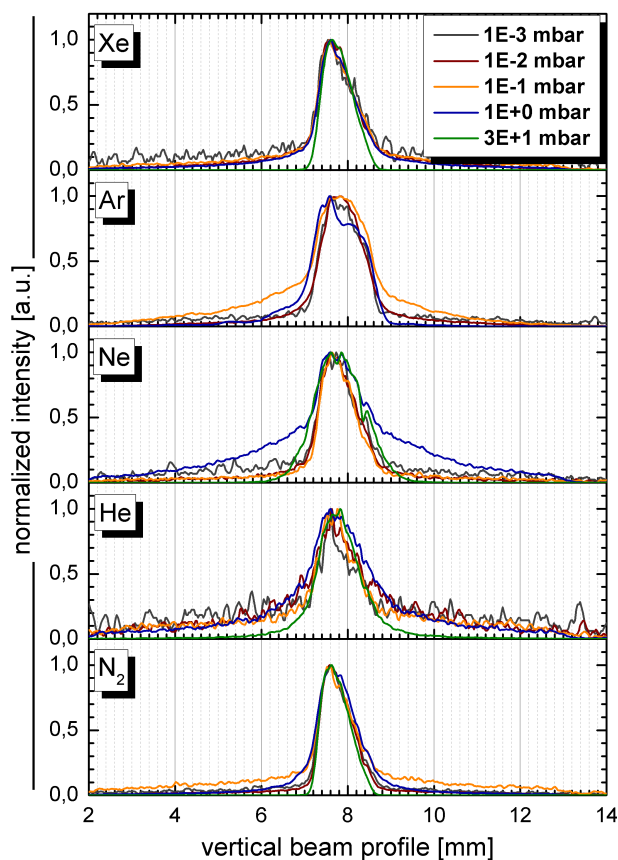
Figure 4: Normalized beam profiles in the working gases Xe, Ar, Ne, He and N_2, recorded at a set of different gas pressures each. Ar-profiles have been recorded with a different beam focusing.

Figure 5: Normalized beam profiles of two selected nitrogen transitions for a set of increasing gas pressures each.

the highest gas pressure. However, the smallest relative change in profile width is clearly observed for nitrogen.

Transition selective beam profiles provide a deeper insight in the relevant processes. Figure 5 shows profiles of the most prominent transitions at 337 and 391 nm for increasing gas pressure. While profiles of the N_2 (C→B) (0-0) appear with the unwanted profile growth and decrease, the N_2^+ (B→X) (0-0) transition remains almost constant. In the other investigated gas species, this beneficial effect was observed for different optical transitions as well.

CONCLUSION

The exploitable dynamic range of BIF monitors can easily be extended to tens of millibars or even atmospheric pressure, as long as suitable transitions are selected with an optical filter. In the case of nitrogen, the N_2^+ B→X (0-0) at 391 nm should be selected. Usually ionic transitions seem to be profile preserving. In He no prominent ionic transition was observed. In Ne, Ar and Xe, fluorescence light of ionic transitions was divided among several lines. Further investigation is planned to provide a guideline for rare gases as well. Moreover, the excellent correlation with competitive profile monitors [5] makes BIF monitors a versatile instrumentation for FAIR applications.
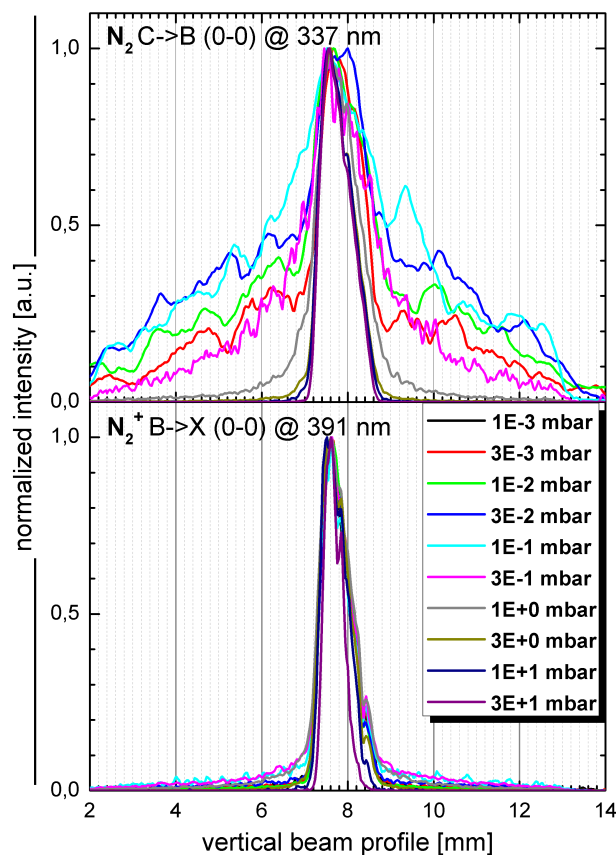
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