*36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-1.187 (2009)*

Light Profile Measurement on the 35keV Lithium Beam on TEXTOR

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Diagnostic alkali beams are standard diagnostics in many devices to measure plasma electron density profile in the edge and SOL plasma [1]. The intensity of light emission by collisionally excited atoms of the beam is primarily determined by the local electron density of the plasma and the attenuation of the beam so far. The density distribution can be reconstructed from the measured intensity distribution (the light profile) of the Doppler shifted Li *2p-2s* line emission. Two calculation methods are used: the 'IPP' technique [2] and the recently developed probabilistic data analysis [3].

The 35 keV atomic Lithium Beam Emission Spectroscopy diagnostics has been reinstalled on TEXTOR tokamak with an upgraded observation system [4]. A CCD camera monitors the light profile from the beam with typically 100ms time resolution and a 16 channel APD camera – recently developed at KFKI-RMKI – measures transient events with up to 1MHz frequency. Periodic beam chopping – when the beam is completely removed from the plasma – gives the possibility to continuously monitor the background light. The statistical density reconstruction method [5] has been recently implemented for which the measurement error of the light profile is crucial input information. In the present study we attempt to calculate all factors that influence and estimate the systematic error of the light profile measurement by the CCD camera.

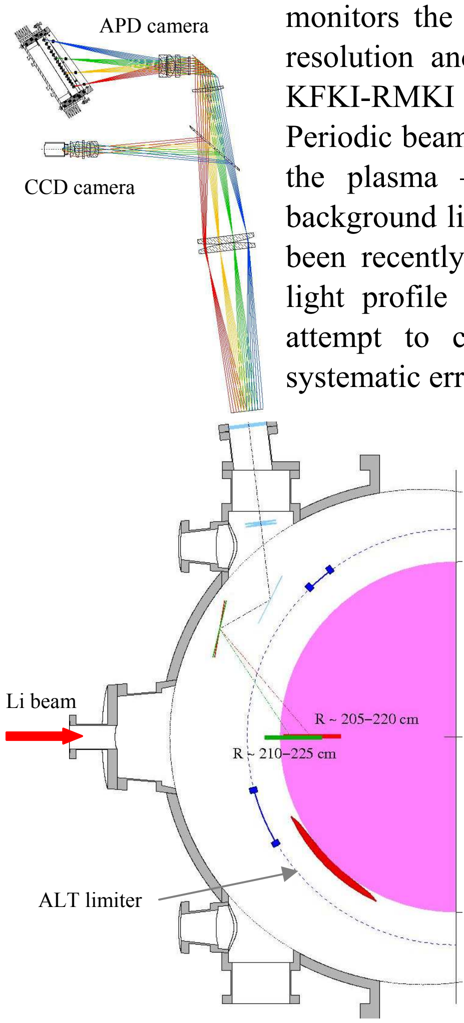

Fig. 1 Schematic of the Li BES observation system on TEXTOR

Experimental set-up

The Li beam comes into the tokamak in the midplane and has a toroidal angle of 10º with the radial direction in 9/10 section of TEXTOR. Schematic of the observation system is shown on Fig. 1. The optics consists of two parts: the ‘periscope’ built into the tokamak and the outside optical system built up on a vertical plate. The axis of the optics lies in a vertical plane that is determined by the centerline of the atomic beam. The periscope contains the first focusing element and two mirrors; the first mirror can be set to two angles which allows an ~5cm shifting of the observation region. The collected light goes out through a vacuum window and an about 1:1 image of a 150mm long section of the beam is formed outside. The outside optics – built up on a vertical plate – contains the field lens (placed at the image of the beam), a beam-splitter, a mirror, the focusing elements with interference filters and the detectors for the two branches of observation. The beam-splitter directs ~20% of the beam light to a PCO Pixelfly CCD camera (640x480 pixels of 10x10µm size, used with 2x2 binning).

Beam image on the CCD

The optics sees the beam from behind; the two settings of the first mirror correspond to α_0 = 50.0° (inner) and α_0 = 56.6° (outer), respectively. Fig. 2 shows a simplified optical

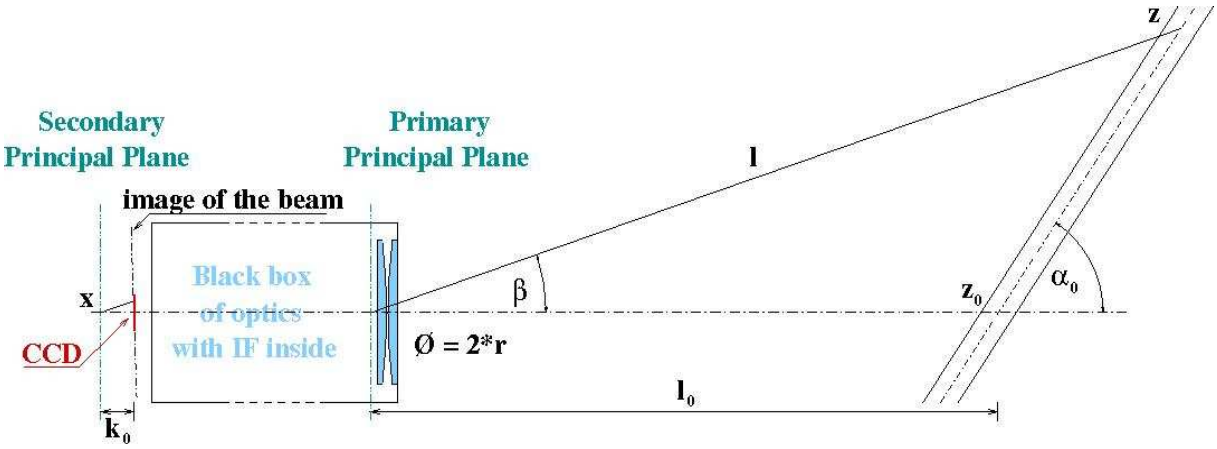

Fig. 2 Simplified optical set-up. Beam trajectory is along the 'z' axis.

arrangement. The beam is a tilted object so its image is tilted as well:

$$x_{im} = \frac{\Delta k}{N_0} \cdot tg\alpha_{obj} \Rightarrow tg\alpha_{im} = \frac{tg\alpha_{obj}}{N_0}, \text{ where } N_0 = k_0/l_0.$$

The image is not in the perpendicular plane of the CCD sensor which causes an enlargement of the spot size and thus contributes to geometric 'smearing' in x ↔ z (distance along the beam) mapping:

$$x(z) = k_0 \cdot \frac{(z - z_0) \cdot \sin(\alpha_0)}{l_0 + (z - z_0) \cdot \cos(\alpha_0)} \Rightarrow z(x) = z_0 + \frac{x \cdot l_0}{k_0 \cdot \sin(\alpha_0) - x \cdot \cos(\alpha_0)}$$

Our design values were: α_0 = 50.0°, N_0 = 0.0496 $\Rightarrow tg\alpha_{im} = 24.0$ and α_0 = 56.6°, N_0 = 0.0516 $\Rightarrow tg\alpha_{im} = 29.4$, respectively. A calibration tool was used to check the x ↔ z mapping and to

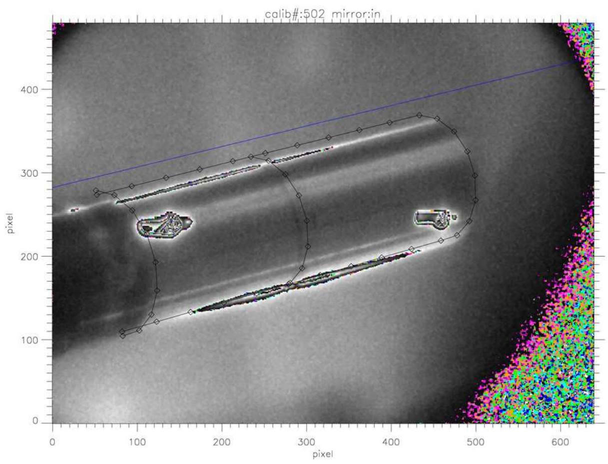

Fig. 3 Calibration tool on the CCD picture. The two illuminated slits indicate the beam position.

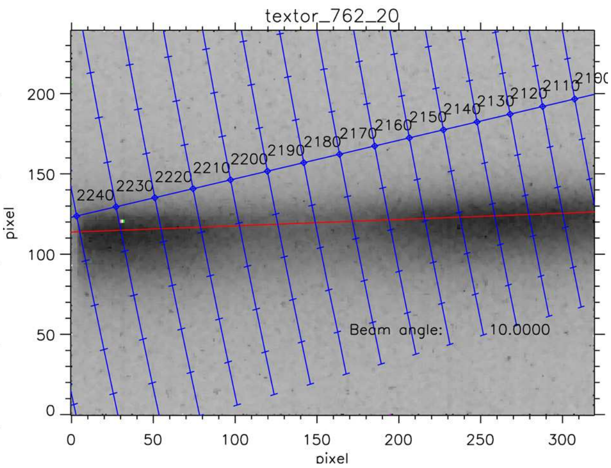

Fig. 4 Beam in gas on the CCD picture with grid (major radius) in the midplane plotted over.

assign midplane tokamak coordinates to the points on the CCD image (see Fig. 3). The results for the two settings are: α_0 = 48.0°, N_0 = 0.0517 and α_0 = 54.7°, N_0 = 0.0542.

The measured intensity distribution from a narrow beam depends on geometric and optical factors varying along the beam. Their cumulative effect can be measured by shooting the beam into gas when the pressure is low enough to have negligible attenuation on the observed beam path. The image of a gas shot (mirror: out) is shown on Fig. 4. The 'intensity hole' around the middle of the beam image is rather strange; it most probable comes from the interference filter in the optics.

Narrow band interference filter is used to reduce background radiation. The doppler shifted beam light coming from the whole observation region in the wavelength range of 671.8nm < λ < 672.4nm reaches it in a cone of ~8-9º half-angle. When parameters of the IF were defined we had to keep in mind that large part of the background light from the limiter comes at the unshifted Li 2p-2s wavelength (670.8nm) as thermal Li sources operate at TEXTOR. Fig. 5 shows the transmission curve of the interference filter (Andover) used in the CCD optics.

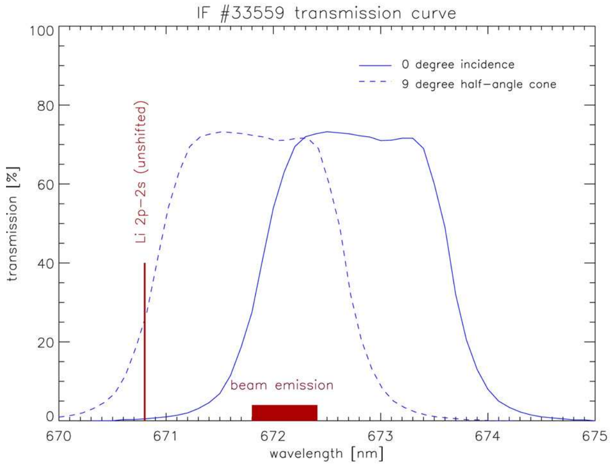

Fig. 5 CCD IF transmission curves for two cases: incidence at 0º and in a 9º half-angle cone

The wavelength dependent transfer function of the optics (with interference filter) was calculated to explain the intensity hole. This calculation takes into account that the collection solid angle and the Δx ↔ Δz relationship varies along the beam. The ZEMAX optical designer program was used to find the angle of incidence of rays at the interference filter which determine the shift of its central wavelength. The result is shown on Fig. 6. Though the calculated sensitivity (transfer) curve shows similar effect than the measured one, the calculation can only fully explain the extent of the dip if the original transmission curve (at 0º incidence) is shifted by 0.15 nm to higher wavelength. This calculation revealed that the reason for the reduced transmission is that rays from points close to the optical axis hit the IF with (in average) small incidence angle and its transmission curve is not shifted enough to lower wavelength. The dip is not in the middle of the CCD image because the wavelength of the Li2p photons grows with the distance along the beam (as the angle to first mirror becomes smaller).

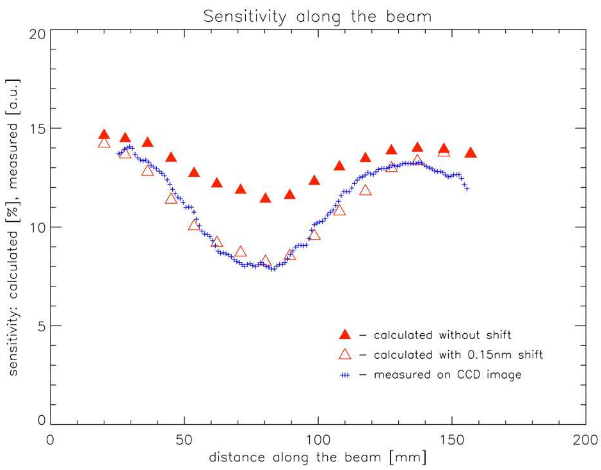

Fig. 6 The measured sensitivity and calculated transfer curves for the CCD optics.

Determination of the light profile from the CCD picture

The light profile measurement is always accompanied by background radiation which originates from the plasma and/or from plasma facing components (in our case the ALT limiter on TEXTOR) seen by the diagnostics. An example image of the beam in plasma is shown on Fig. 7. The beam goes from left to right; mirror setting: 'out'. Background light from the ALT limiter can be seen on the left of the image.

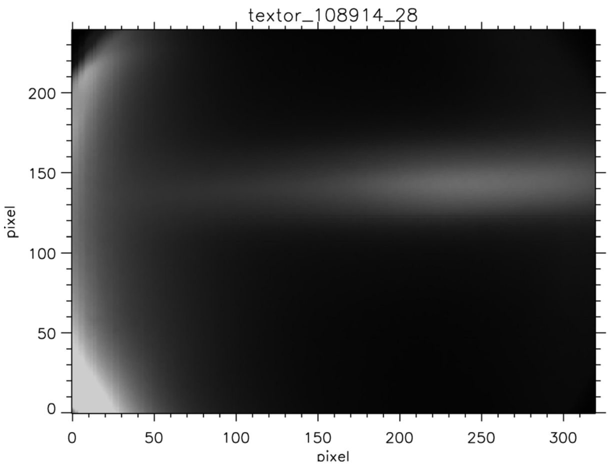

Fig. 7 Typical image of the beam in plasma with low background on the CCD. Mirror: 'out'.

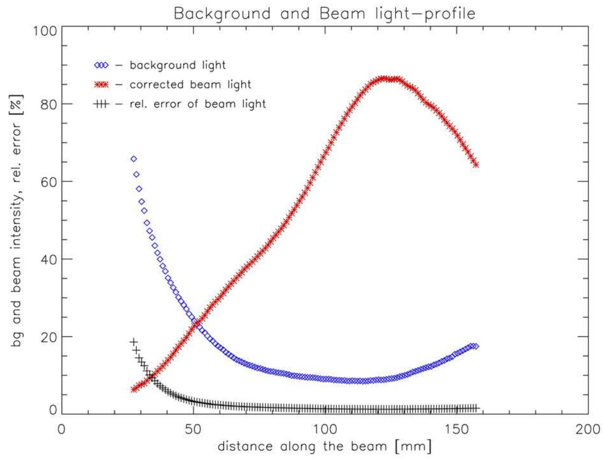

Fig. 8 Light profile and its error calculated from consecutive CCD images with beam chopping.

The background light level is usually much lower than the beam light level for Ohmic or moderately heated discharges in TEXTOR but it can be much higher for NBI heated plasmas. If the plasma evolves slowly the background light distribution on the CCD picture also changes slowly and the background picture for the 'beam on' phase can be calculated by interpolating between the two 'beam off' phases before and after it. The systematic error of such background picture can be estimated as ~10% of the difference between the two pictures in 'beam off' phases, i.e. a few percent relative error. The relative error of the light profile depends on the background to Li2p signal ratio; it can be high at low signal level. An example light profile with background correction and its estimated error is depicted on Fig. 8. This method is not applicable on those part of the CCD picture where the background level is comparable to the Li2p intensity and it varies strongly on the 10ms time scale. In such cases only part of the light profile can be determined (or it cannot be determined at all) from the CCD measurement.

The total number of photons in the beam image on the CCD pictures can be estimated from the APD measurement ($\Sigma\ I_{APD} \approx 5*10^{10}$ photon/sec). Taking into account the much smaller light collection efficiency of the CCD camera the result for 30ms integration time is $N_{tot} \approx 1*10^8$ photons which corresponds to a $5\text{-}10*10^6$ count in the (background corrected) beam image. From this a rough estimate for the sensitivity of the CCD to Li2p photons can be given: 10-20 photons needed for 1 count. These facts indicate that the relative error due to photon statistics is below 1% at the beginning and at the end while about 0.1% around the peak of the light profile (for ~2-3mm resolution along the beam).

The electronic background of the CCD camera varies slowly so it can be easily removed by choosing equal 'on' and 'off' times. The systematic error in the light profile determination due to the remaining electronic background can be estimated to be ≤ 0.5% around the peak of the light profile (for $\sigma_{e.n} \approx$ 3count/pixel and ~2-3mm resolution along the beam).

References:

[1] D. Thomas at all, *Fusion Science and Technology* **53,** p. 487 (2007)

[2] J. Schweinzer at all, *Plasma Physics and Controlled Fusion* **34**, p. 1173 (1992)

[3] R. Fischer, E. Wolfrum, J. Schweinzer and ASDEX Upgrade Team, *Plasma Physics and Controlled Fusion* **50**, 085009 (2008)

[4] G. Anda at all, 35th EPS ECA Vol. **32D** P-5.076 (2008)

[5] S. Kálvin at all, P4.211, presented at this conference