*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, D-4.002 (2006)*

Electric Field Measurement using Stark Spectroscopy

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We report the development of a laser diagnostic technique based on Stark spectroscopy of xenon and krypton atoms. Stark shifts of highly excited atomic states, induced by the electric field were determined. This technique will be used to measure the space-resolved electric field in various types of discharges. Here it was tested in a DC glow discharge, because its electric field distribution is well-known. Measurements of Stark spectra from the sheath regions of glow discharges were performed, and experimental results were compared with theoretical calculations results by solving the Schrödinger equation for xenon and krypton atoms.

Stark shifts in a glow discharge were monitored using Laser optogalvanic (LOG) spectroscopy. This is based on laser-induced excitation of certain atomic/molecular levels, followed by monitoring the current through plasma. In this process, atoms/molecules are excited to the higher energy level, which is easily ionized by collisions with plasma electrons; this results in the increase of plasma current. By scanning the excitation wavelength, one can detect various excited states. The spectroscopic scheme used in this work is shown in Fig. 1. Laser excitation for xenon atom was performed from metastable level $6s'[1/2]_0$ to Rydberg levels. Because the lower level $6s'[1/2]_0$ is mixed with the $5d[1/2]_0$, it was possible to excite from this metastable state to *nf* Rydberg states. The similar structure in krypton enabled laser excitation from $5s[3/2]_2$ (mixed with $4d[3/2]_2$) to *nf* Rydberg states. In Fig. 1, thin arrows indicate the Stark coupling of energy levels because of the effect of the electric field. All these levels had to be included in theoretical calculations.

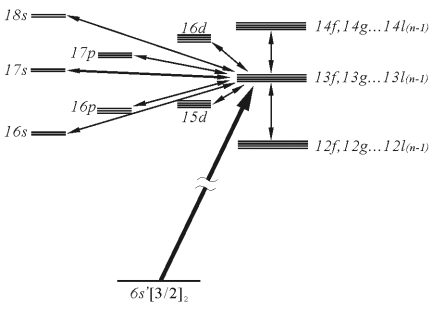

Fig. 1: The scheme of energy levels of a xenon atom.

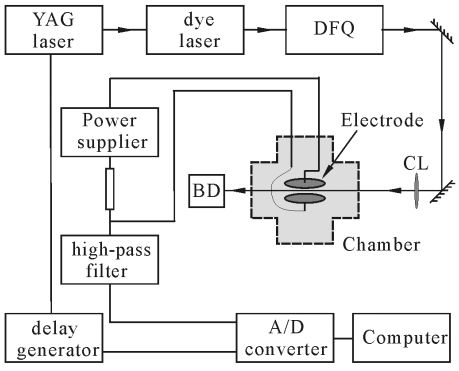

Fig.2: The scheme of the set-up.

A scheme of the experimental set-up is shown in Fig. 2. The laser source used for krypton measurement was a tuneable dye laser pumped by a Nd:YAG laser with second harmonic output (532 nm). The energy of each pulse of Nd:YAG laser was about 150 mJ, and frequency was 10 Hz. The tuneable dye laser was Lambda (L3002) and dye was Rhodamine 101, the output of dye laser was operated at $\lambda \sim$ from 611 to 662 nm. By using the crystal, the output was frequency doubled to generate radiation at $\lambda \sim$ 306 to330 nm which was used for exciting krypton atoms from *5s* states. For xenon measurement, the pumping laser was a excimer laser (pumping wavelength: 308 nm) and the output of dye laser was around 480 nm. A photodiode and a delay generator were used to trigger the A/D converter to acquire the LOG signal. A cylindrical lens was used to focus the laser beam into a sheet-like beam with a thickness of about 0.1 mm and a width of about 4 mm. The beam was directed through the sheath of plasma parallel to the electrode surfaces. The electrodes were round stainless steel plates with a diameter of 7 cm. Pure krypton gas filled the vacuum chamber, to attain the pressure of 7 mbar. For Xe measurements, pure xenon gas at 24 mbar pressure was used. A dc voltage was applied between the electrodes. The data acquisition system sampled the voltage signal as a function of time. Measurements were performed by scanning the dye laser wavelength and measuring the plasma current (LOG signal).

Fig. 3 contains typical Stark spectra taken in krypton and xenon at various positions with respect to the cathode. Stark splitting and shifts are very clear at short distances from the cathode, reflecting the strong electric field in the cathode fall. These spectra can be simulated by solving a perturbed Schrödinger equation for a hydrogen-like atom, with the perturbation induced by the electric field (Hamiltonian $H = H_0 + H_{Stark} = H_0 - eEz$). The method was adapted from [1-3]. Calculations for various electric field strengths yielded simulated shifts shown in Fig. 4. Finally, the comparison of calculated spectra and the measured ones at a given position in the plasma are shown in Fig. 5.

Electric field strength was determined by matching the peaks position of spectra in the experiment and in the calculation. A quite good accuracy, with less than ±25V/cm for excitation to 13f, was achieved for the high field (≥2000V/cm). The error increased to ±50-100V/cm for the middle field (1300-2000V/cm); below 500 V the method was not reliable. Fig. 6 shows the spatial distribution of the electric field, measured in the vicinity of the cathode in xenon. That the electric field in sheath is almost linear, as expected, and the thickness of the sheath in our case is about 2.1 ± 0.2mm. By integrating the electric field over the sheath, we obtain the potential drop over sheath of 325 V; this is about 90% of the voltage of 345±10 V that was applied across the discharge gap.

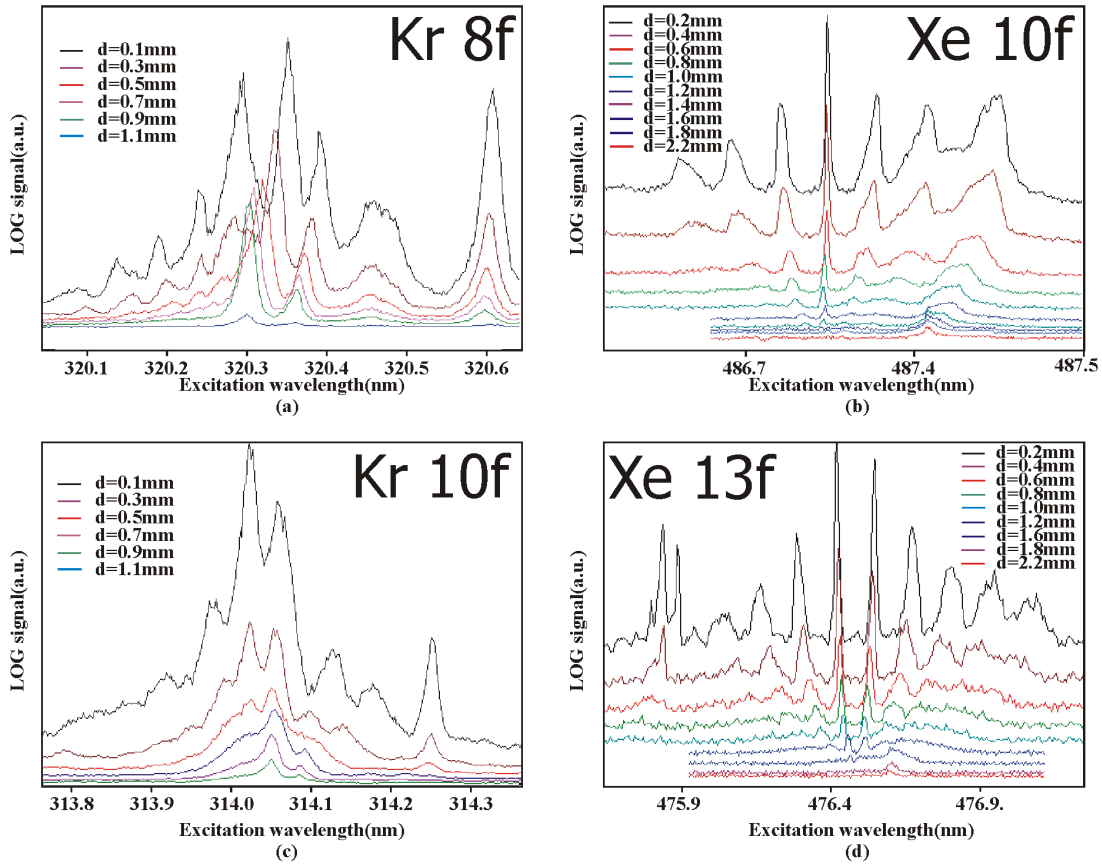

Fig. 3: Stark spectra in Kr and Xe, showing splitting in various f states of these atoms.

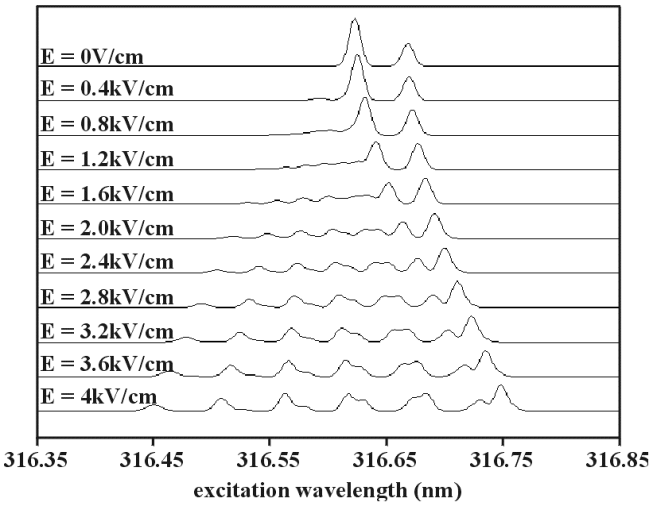

Fig. 4: Calculated Stark spectrum for Kr, excited from *5s* to *9f*.

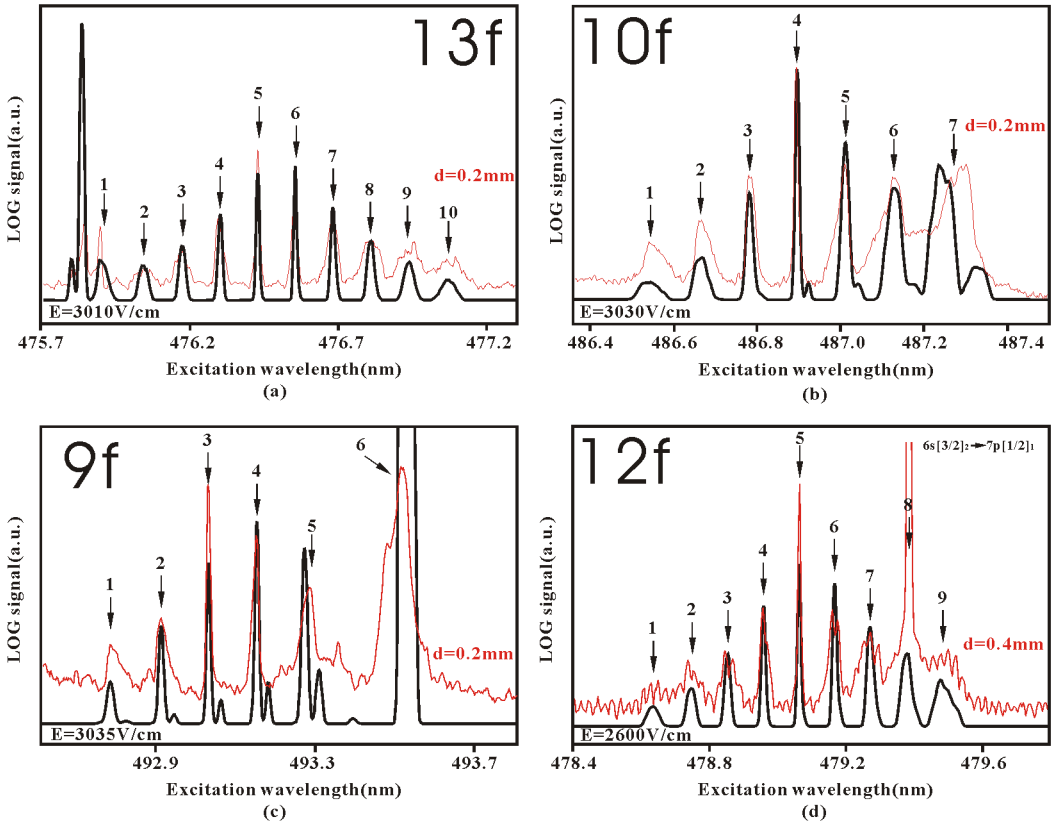

Fig. 5: Experimental Stark spectra compared with calculated spectra for xenon *9*, *10*, *12* and *13f* excitation from *6s*'$[1/2]_0$.

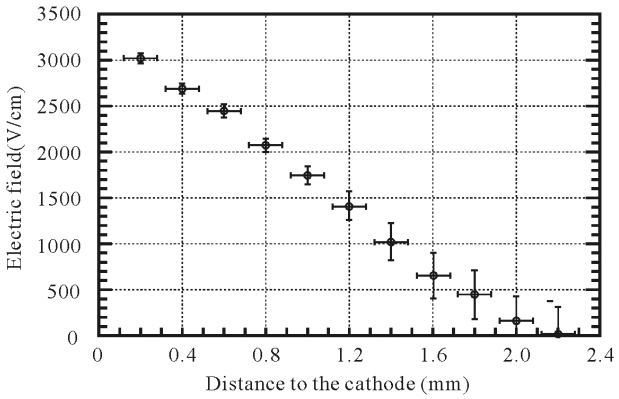

Fig.6: The spatial distribution of the electric field, measured in the vicinity of the cathode using xenon.

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