Report on Visit to Ruhr-University Bochum by International Training Program

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I stayed at Prof. Czarnetzki's laboratory in Ruhr University Bochum in Germany. The duration of the visit was from May 29 to July 28. The laboratory is famous for optical diagnostics of plasma using laser induced fluorescence (LFI) spectroscopy, LIF-dip spectroscopy, Thomson scattering, optical emission spectroscopy and so on. During former visit (February 13 to March 13 in 2009), I developed a plasma diagnostic system using an extended cavity diode laser (ECDL), and a preliminary experiment was performed. This time, laser induced fluorescent spectroscopy and laser absorption spectroscopy of metastable argon atoms have been performed. The summary of the visit is reported below.

Introduction of Bochum and Ruhr University

Bochum is an industrial city, which prospered as a town of coal mines and iron manufacturing industry, in North Rhine-Westphalia, Germany. Although all coal mines were closed by the 1970s, some of them are renovated as a museum and a situation of those days can be known there. Figure 1 shows the German mining museum, which is in the distance of 10-minute walk from the downtown area of Bochum. The museum is a famous mining museum in Germany, and visitors can see an underground coal mine shaft. The Zollverein coal mine in Essen, which is a neighboring town of Bochum, was registered as a world heritage in 2001. Visitors can walk around the huge coal mine. In recent years, the main industry of this region is changing from mining and manufacturing to the automobile industry, etc.

Since it was a very good season, many festivals and concerts were held during the stay. Figure 2 is a photo of the main site of a downtown concert which was held in Bochum. During the period of the music festival, many tourists and local peoples came, and the downtown area was like a huge concert hall. In addition, many events, such as an industrial culture event "ExtraSchicht" which was cosponsored by the towns of Ruhr industrial area, were held in almost every week.

Fig. 1 the German mining museum

Fig. 2 Downtown concert in Bochum

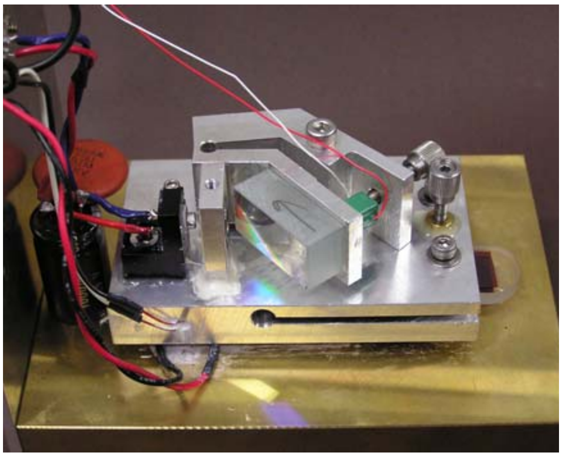

Fig. 3 696.7 nm ECDL

Bochum central station is located at the center of the downtown. Ruhr University station adjoins Ruhr University which is in the distance for 10 minutes by subway from Bochum central station. The number of students of Ruhr University is about 34,000 people, and the number of staffs is about 5000 persons. Approximately 10 % of students are international students from 130 countries. Since Ruhr University has separated a few from the downtown, it is very suitable for concentrating on research in a quiet environment

Measurement of Argon metastable atoms in a high density plasma

In recent years, an understanding of spatial structure formation of plasma and neutral gas in consideration of the interaction of plasma and neutral gas is beginning to attract attention. In condition of low gas pressure and high degrees of ionization, electron pressure can exceeds neutral gas pressure. In such case, the modification of the spatial distribution of neutral gas by electron pressure has been reported. Therefore, in order to realize uniform plasma processing in large area, an understanding the interaction of plasma and neutral gas is needed. In order to evaluate the local pressure of neutral gas, it is necessary to measure the density and temperature of neutral gas. Although the density and temperature of neutral gas are acquired by observing the Doppler spectrum of neutral gas, a tunable laser with narrow line width is needed for the observation of the low-temperature neutral gas. Since the line width of pulsed laser is relatively wide, it is not suitable for the LIF Doppler spectroscopy of low-temperature neutral gas.

We have developed an ECDL for measurement of argon

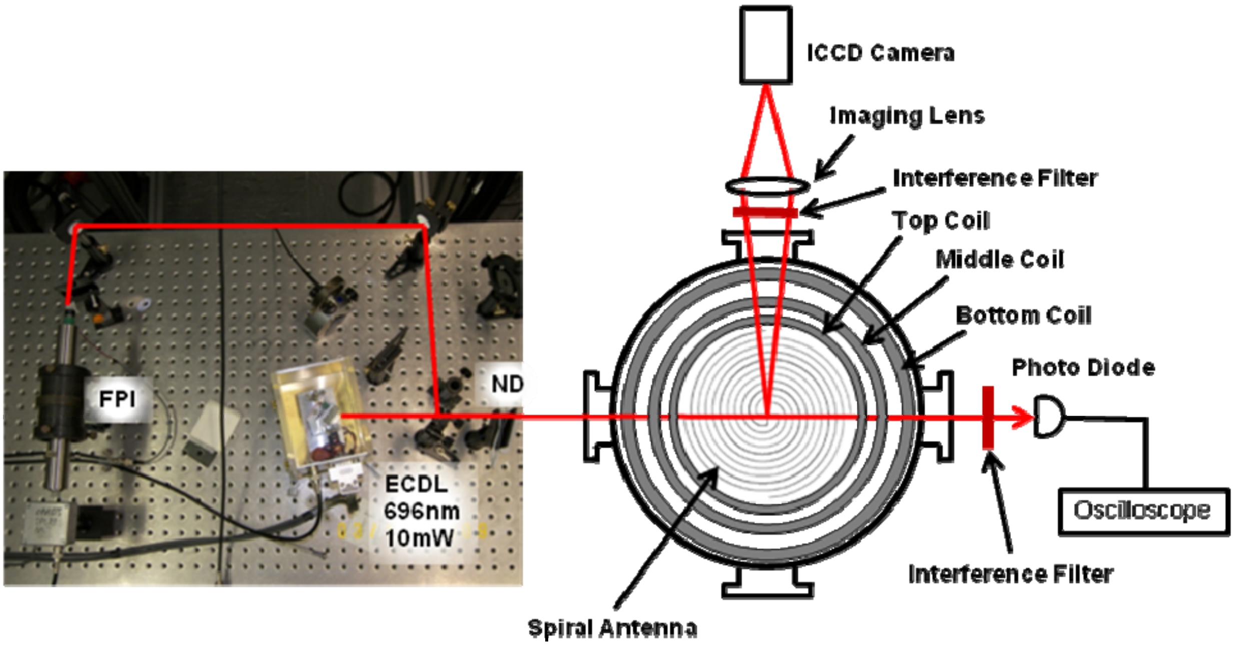

Fig.4 Experimental setup

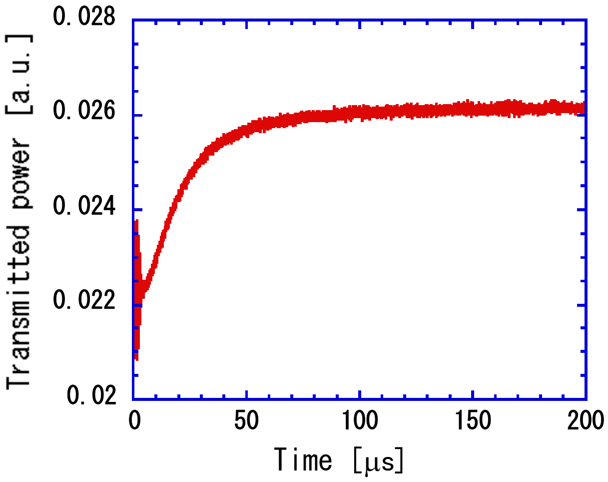

Fig. 5 Temporal variation of transmitted laser power.

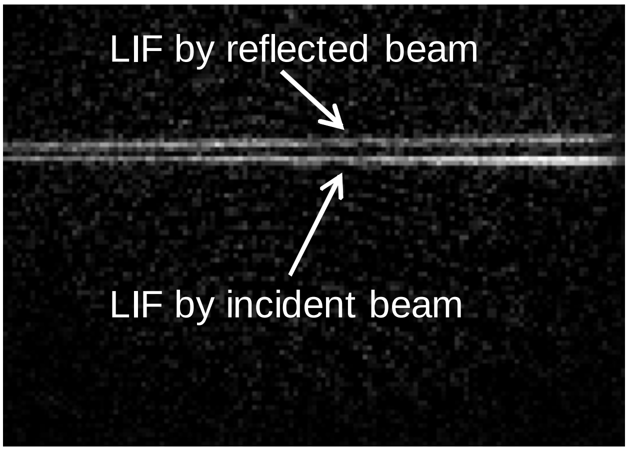

Fig. 6 LIF image taken by an ICCD camera.

metastable atoms in a high density plasma. The line width of the ECDL is narrow enough for the diagnostics of neutral atoms, and the wavelength is tuned at 696.735 nm to excite the $4s[3/2]^o_2$ state argon atoms to $4p'[1/2]_1$ state.

Figure 3 shows the ECDL which was developed during the former visit. The output of the laser diode is collimated by a lens and reflected by the diffraction grating. A laser wavelength is stabilized by returning the first order diffraction light to the laser diode. The laser wavelength is controlled by adjusting the angle of the diffraction grating, operating current, and temperature of the laser diode. Although the feed-forward control of operating current was not applied, the wavelength of the ECDL could be swept in the range of about 5 GHz without mode hop. The laser power was about 10 mW.

Figure 4 shows the experimental setup. Plasmas are produced by an inductively coupling discharge or Helicon wave discharge excited by a spiral planar antenna. The rf input power and the pressure of argon gas were 1 kW (13.56 MHz) and 0.1 Pa, respectively. When performing an laser absorption spectroscopy, in order to avoid the saturation of absorption, the laser power was attenuated to about 0.1% using a neutral density (ND) filter before entering the vacuum vessel. The transmitted laser light is separated from optical emission of plasma by an interference filter, and is detected by a photo-diode. On the other hand, when performing LIF measurement, the laser light is focused at the centre of the vacuum vessel without decreasing power by ND filter. The 826.68 nm fluorescence emitted by the deexcitation of the $4p'[1/2]_1$ state atoms into the $4s[1/2]^o_1$ state. The LIF signal is separated from optical emission of plasma by an interference filter, and is detected by an ICCD camera. During the measurements, the spectrum shape of the ECDL is monitored by a Fabry-Perot interferometer to check single mode operation.

Results

Temporal variation of transmitted laser power is shown in Fig. 5. RF power is turned off at time = 0 s. The wavelength of ECDL is fixed at the centre of the resonance. Since high energy electrons which generate argon metastable atoms decrease immediately after the discharge is stopped, the density of metastable atoms decrease and transmitted laser intensity increases with time. We are developing a method which calculates plasma parameters using the temporal variation of the laser absorption. It will be reported as a paper elsewhere, soon.

Figure 6 shows the radial distribution of the LIF signal which was observed by the ICCD camera. Here, the laser wavelength was fixed at the centre of the resonance. The two LIF signal lines were generated by the incident and reflected beam, respectively. The reflected beam is a part of the incident beam reflected on the output viewing window. By taking LIF images with various laser wavelength, the spatial variation of Doppler spectrum can be reconstructed; however we could not achieve enough S/N to do it. It will be the next task of the collaboration.

Progress of the collaboration after the program

Taking advantage of the ITP program, we have started the collaboration with Prof. Czarnetzki. Using Doc 2 Doc International Invitation Program of Ruhr University, Mr. K. Ogiwara, who is a member of our collaboration group, was invited to Prof. Czarnetzki's laboratory by Mr. Y. Celik in October, 2009. He performed plasma diagnosis using a directional Langmuir probe. Moreover, Mr. Celik, who performed the experiment with me during the stay in Germany, came to our laboratory in order to learn how to assemble and tune the ECDL in January, 2010. The results of our collaboration were reported at the meeting of the German Physical Society in March, 2010.