*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-4.101 (2006)*

Pellet Injection Experiments at GOL-3 Facility for Plasma Fueling and ITER ELM Simulation

V.V.Postupaev[1], V.T.Astrelin[1], A.V.Burdakov[1], I.A.Ivanov[1], V.G.Kapralov[2], K.N.Kuklin[3], K.I.Mekler[1], S.V.Polosatkin[1], A.F.Rovenskikh[1], S.V.Sergeev[2], Yu.S.Sulyaev[1], E.R.Zubairov[1]

[1] *Budker Institute of Nuclear Physics, Novosibirsk, Russia*

[2] *St.Petersburg State Polytechnical University, St.Petersburg, Russia*

[3] *Novosibirsk State University, Novosibirsk, Russia*

A pellet injection technique is used at GOL-3 multimirror trap for the solution of several physical problems. Earlier use of small impurity pellets (CH_2, LiD) for the purposes of plasma diagnostics and for formation of dense plasma bunch inside the main plasma column was already discussed (see, e.g. [1]). Here two other topics of the pellet injection activity are presented.

The first topic is connected with continuing reactor-relevant studies of influence of a high-power pulsed stream of electron-hot plasma on solids (see, e.g., [2]). The new problem of expansion of dense target plasma along the magnetic field through a distance of several meters was investigated. A carbon pellet of 2-mm diameter was injected into the plasma for this purpose. The pellet was large enough that no full evaporation of graphite occured. Specific energy load was ~50 MJ/m^2. Parameters of the carbon plasma during its expansion were studied. Similar behaviour of surface plasma can be in reactor-class tokamaks at fast dump of energy during ELM events.

Other physical problem for pellet injection is the increase in plasma density near the axis of GOL-3. The status of works on cryogenic pellet injector, which is developed jointly by BINP and SPbSPU is presented.

GOL-3 EXPERIMENT AND IMPURITY PELLET INJECTION

The main aim of experiments carried out at the GOL-3 facility is the development of a multimirror confinement scheme for fusion. In present configuration of the device [3], a plasma of $10^{20}\div10^{22}$ m^{-3} density is confined in a 12-meter-long solenoid, which comprises 55 elementary mirror cells with mirror ratio B_{max}/B_{min}=4.8/3.2 T. The plasma in the solenoid is heated up to 2-4 keV temperature by a high power relativistic electron beam (~1 MeV, ~30 kA, ~8 μs, ~120 kJ) injected through one of the ends.

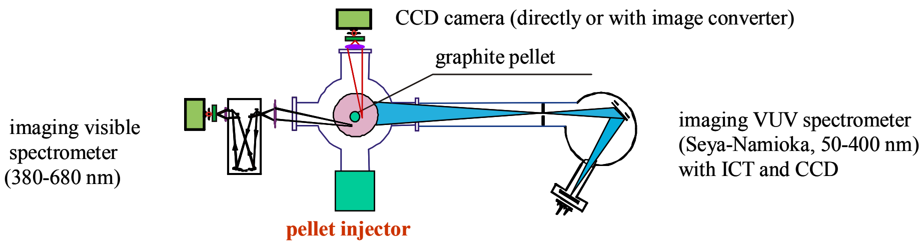

Fig.1. Layout of the pellet injection experiment (cross-section at pellet location).

Specific energy density in the beam-plasma system is very high, up to ~100 MJ/m^2 in high-field area. This value exceeds the expected energy load of divertor plates of reactor-class tokamaks during the ELM event. Creation and following expansion of a carbon target plasma was studied in the following scenario. The graphite pellet of 2 mm in diameter is injected upwards to the axis with the initial velocity ~20 m/s at the midplane of the solenoid (at ~6.6 m from the input mirror). When the pellet arrives to the axis the preliminary plasma is created by a discharge. Then, 30 μs later the beam injection begins and the plasma is heated up to 1-2 keV. Most energy is deposited in the surface layer of the target by the beam electrons during ~8 μs, so only ~0.3 mm layer from the beam side evaporates. Then graphite vapour expands spherically during ~2 μs up to ~2 cm radius. At this moment post-heating of the target plasma by the surrounding main plasma becomes significant, the carbon plasma magnetizes and then expands along the magnetic field only.

Main diagnostics at the pellet injection point are shown in Fig.1. All visible and VUV imaging diagnostics were absolutely calibrated. Spectrum of visible plasma emission was measured at different distances from the injection point with a flexible-fiber-optics-coupled high resolution double-grating spectrometer.

STUDY OF LONG-DISTANCE PROPAGATION OF A CARBON TARGET PLASMA

Figure 2 shows the carbon plasma image, taken with exposure 1 μs. Residue of the pellet is still clearly seen. The target plasma is optically transparent. If we assume that brightness of the carbon bunch is proportional to the line-integrated plasma density, then total amount of evaporated graphite can be calculated. The coefficient of proportionality was found from high-resolution spectroscopy of Stark wings of spectral lines. Such estimate gives N_C~4·10^{19} atoms, that agrees with the expected value from

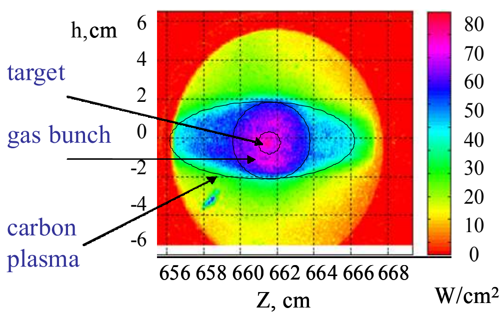

Fig.2. Target plasma at t = 10 μs.

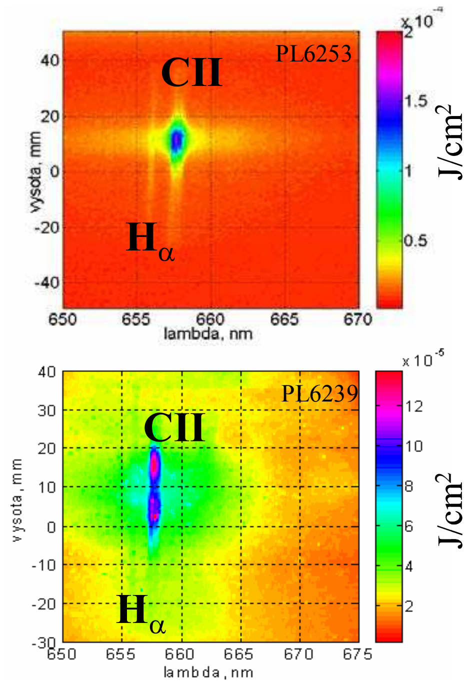

Fig.3. Spatially-resolved spectra: top – directly from the pellet surface, bottom – at some distance from the pellet. Pellets were positioned at +10 mm.

the beam range. Imaging spectroscopy shows (Fig.3) that H_α radiates from the main plasma, while CII doublet radiates by the carbon plasma. This allows to process mentioned lines independently. At the discussed conditions the line profile is mostly determined by a Stark broadening (see Fig.4). Fit shows that near the pellet the carbon plasma density reaches $\sim 10^{23}$ m^{-3}, and the main plasma density is $\sim 3 \cdot 10^{21}$ m^{-3}.

The carbon plasma loses energy mainly due to emission of VUV spectral lines. Figure 5 shows spectra for three cases: cold preliminary plasma, beam-heated plasma (impurity ions radiate from the periphery) and plasma with the pellet. Carbon plasma radiates mainly CII and CIII lines in 80-140 nm range. Integration of radiated power over time and space shows that pellet plasma loses 3 mJ/cm^2 (recalculated to diameter of the carbon bunch). This value is in a reasonable agreement with the wall calorimeter data, which gives additional 4 mJ/cm^2 at the wall.

A long-distance propagation of the carbon plasma was traced at both sides from the injection point at distances up to 5 m. At 4.5 m from the pellet injector the carbon density is $\sim 0.6 \cdot 10^{21}$ m^{-3}. Several diagnostics were used for time-of-flight measurements, which give average carbon expansion rate of $(1\div 2) \cdot 10^6$ cm/s that corresponds to $10\div 50$ eV energy of carbon ions. Transverse temperature in the carbon cloud is low. At 250 μs after the beam injection the carbon plasma reaches ends of GOL-3. Simple 1-D model of expansion of the pellet plasma combined with a spectroscopy data gives an estimate for amount of carbon in the plasma as $\sim 2 \cdot 10^{19}$ atoms. This means that all the evaporated carbon is still in the plasma. At that time molecular features dominate in visible spectrum.

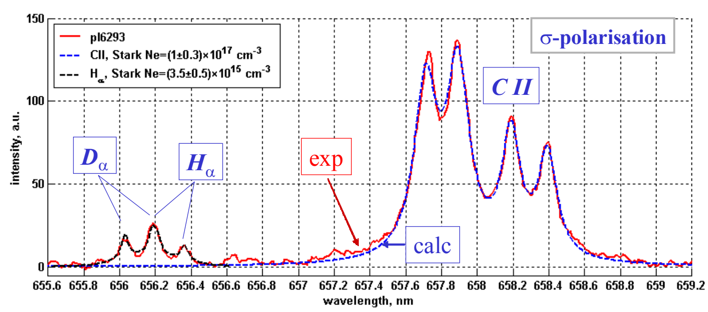

Fig.4. Example of a fit of observed spectrum.

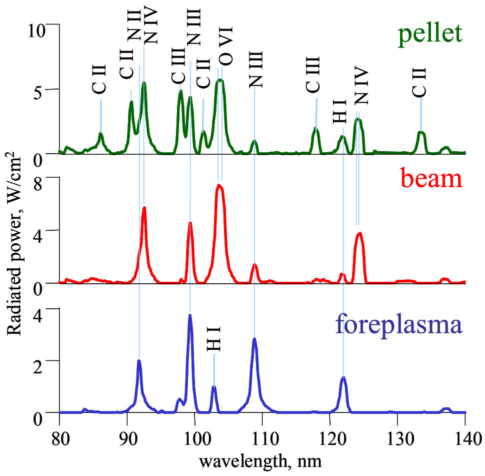

Fig.5. VUV spectra for different plasmas.

PELLET INJECTION FOR PLASMA FUELING

Now achievable density is limited by decrease of conductivity of preliminary (start) plasma and respective deterioration of compensation of a current of heating relativistic electron beam with a plasma return current that leads to disruption. A possible experiment scenario to avoid this instability is use of cryogenic pellet injection for fueling. It is checked up, that parameters of the preliminary discharge do not degrade because of a pellet injection by the moment of the beam start.

Operation scenario of the GOL-3 facility requires positioning of the pellet at the axis at the moment of the beam injection with good reproducibility and accuracy. Pellet injector ITV-7 was designed by SPbGPU for 1 mm pellets with initial velocity within 10-100 m/s range (Fig.6). Now assembly and tests of different subsystems of the injector are in progress.

SUMMARY

Expansion of carbon target plasma at ~50 MJ/m^2 energy load in 4.8/3.2 T magnetic field was studied in the ELM simulation experiments at GOL-3. The carbon plasma with n_C~(2÷10)·10^{20} m^{-3} propagates without significant particle loss at ~5 m distance with ~(1÷2)·10^6 cm velocity that corresponds to 10÷50 eV energy of carbon ions. Carbon ions in the stream are mainly single- or double-ionized. Molecular emission was observed near the solid surface. Preparation of cryogenic pellet injector for near-the-axis plasma fueling is in progress.

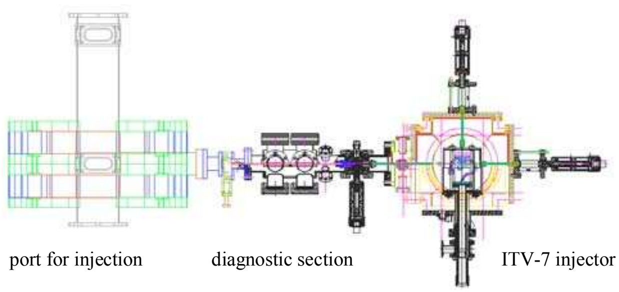

Fig.6. Layout of ITV-7 pellet injector at GOL-3 (top view).

ACKNOWLEDGMENTS

This work is partially supported by RFBR projects 05-02-17160a and 05-08-65387a, and CRDF Y3-EP-08-02.

REFERENCES

1. R. Yu. Akent'ev, et al. // Plasma Physics Reports, 30, 9 (2004).
2. V. T. Astrelin, et al. // Nuclear Fusion, 37, 1541 (1997).
3. A. V. Burdakov, et al. // this Conference, paper P4.179.