Introduction

Atomic powerful sources will be used as a source of heating of the plasma in future fusion reactors. To achieve high effectiveness of neutral injection the target with high neutralization efficiency is necessary in such systems. Currently, the main approach to neutralize the ion beams is to use a gas target, the efficiency of which at high energies (1 MeV) does not exceed 60% [1]. In addition, these approaches significantly affect the vacuum conditions and the appearance of impurities in the beam. A possible solution to the problem of the negative ion beam to atomize, one high with high efficiency without flares is a "photon trap", as the basic process of this method is based on the photoabsorption of an electron from a negative ion. The use of the mechanism allows neutral atoms yield close to 100% [2].

Quasi-stationary photonneutralization based on the adiabatic photon trap

The trap consists of a system of two complex surfaces composed of individual cylindrical and spherical mirrors with a typical size of 50 mm and a radius of curvature of 250 mm, that multiple reflections of beams and their adiabatic retention (Fig. 1) [2]. Input laser radiation takes place through the aperture (d = 300 mm) in one of the mirrors.

In the work applied dielectric mirror segments with a reflection coefficient 0.997, which allows radiation to accumulate several hundred times. The radiation pumping employs industrial ytterbium fiber laser with an output power up to 2kW and long wave 1064nm.

Fig. 1. Scheme of nonresonance photon trap (a) and its action (b).

Confinement of photons in such a trap is based on the adiabatic conservation Fc (x) = const at stability condition [3]

F (x) = −(cos β(x) − 1)]

Numerical simulation

To evaluate the applying of nonresonant converter, was carried out numerical calculation for the laser injection capacity of 2 kW and an energy Hi ions - 10 keV. Coefficient reflectance is selected not the maximum - 0.995. Simulation of the neutralization process shows an encouraging result for the experiment on a real beam (Fig. 2).

Fig. 2. Modeling photon neutralization of negative ions.

Scheme for the neutralization experiment H and D in an adiabatic optical trap

For carry out the experiment at measuring the coefficient of neutralization in the quasi-stationary photon exchange target, was made a special installation the stand is shown in Fig. 3.

Concept for big ITER-like NBI system

For large ITER like NBI system the following parameters can be elected (see fig.2). The distance between mirrors is 6 meters.

The neutralization zone width is 0.4 m. The cylinder mirror radius of curvature is 5 m. The curvature radii of toroidal ends are 5 m and 20 m. The laser injection through small holes in mirrors is divided into three groups. First group is located in 19 cm on the mirror end from middle vertical plane. Their laser beams have angular spread about 0.2 degree. The second group is located in 17 cm, has 1 degree spread. The third is respectively 8 cm and 3 degrees. The power is distributed on groups in proportion 0.2:0.4:0.3. The mirror reflectance is taken 0.9995. The averaged along Z-axis intensity profile obtained with using ZEMAX code is shown doted line in Fig. 4. As can be seen the confinement region has sufficiently sharp boundaries.

The degree of neutralization is determined by the ratio of signal current to the signal enabled without laser in target. The experiments were conducted at an energy of particles 6.5 - 12 keV, working gas of hydrogen and deuterium.

Fig. 7. Oscillograms in experiments neutralization D beam (a). The same waveforms averaged on 100 shots and scaled (b).

Fig. 8. Layout of big photon neutralizer.

Technological problems

1. Large mirror area. Manufacturing such single mirror is impossible. It have to be combined from sufficiently small elements. The main problem is creation of the multiple adiabatic films with high requirements of uniformity. At present the several manufacturers are ready to consider dimensions about 50x50 cm.

2. Mirror stability toward neutron or other particle flux. As for neutron load the tests [5] have demonstrated that mirrors with titanium and zirconium dioxide films can withstand fluence of 10^{16} n/cm². Taking into a account the neutron flux at outside NBI ducts order 10^{14} n/cm² [8] the mirrors can be used at least several years. Other particle flow will produce due to scattering high energy particles (neutrons, ions) on residual vacuum particles (of order 10^{14} Pa)[7]. A Simple estimation gives load ~10^{15} cm².

Although this is significantly lower than possible neutron flux, it is probably the defects and vacancies in dielectric film and substrate will become more rapid created. This issue and also effect of electrons detached from negative ions needs research experiments. Probably significant improve the vacuum conditions will be the needed. Note that the calorimeter will be possible only at shielded mirrors i.e. without neutralization.

3. Cooling system for mirrors. The average heat flow does not exceed 10 W/cm². It does not seem an insurmountable problem despite large total radiation power.

Advantages

1. Radiation sources availability. The source of radiation with extremely high requirements to radiation quality is not needed.

2. Very complicated system of resonator elements stabilization is not needed.

3. A substantial modification of the negative ion beam generator to drastically reduce the width (a few cm) of the stream is not needed.

4. The possibility of such approach with comparable accumulation coefficients in the target experimentally confirmed.

Conclusion

Carried out experiments confirm high potential of nonresonance photon target method for effective neutralization of negative ion beams. This photon accumulator can be pumped by the commercial fiber laser. However for creation large neutralizer for example ITER neutral heating system [1] or TRISTAN [2,3] it is required manufacturing big mirrors of complicated shape. A mirror stability under high energy ion, atom, electron flows is an important issue. But on the other hand we get simplifying and reduction in cost of radiation source, positioning and stabilization system for optic elements.

References