Module for dielectric surfaces modification by fast neutral particles beams.

V T Barchenko$^{1,2}$, A A Lisenkov$^{1,2}$, N A Babinov$^1$

$^1$ Saint Petersburg Electrotechnical University “LETI”, Saint Petersburg, Russia
$^2$ Institute of Problems of Mechanical Engineering, Saint Petersburg, Russia

E-mail: VTBarchenko@yandex.ru

Abstract. In this paper, we describe the module for dielectric and wide-gap semiconductor surfaces modification by fast neutral beam. The module can be used for cleaning, etching or assisting of films deposition. The surface proceeding by neutral beam can prevent an accumulation of surface charge without using current compensation by inserting electrons to the beam or RF power supply. The module beside cathode and anode contains an electrode with floating potential. Insertion of the additional electrode causes electron retention in an electrostatic trap resulting the reducing of the module operating pressure. Moreover, the electrode with floating potential allows increasing the current efficient of the module. An important feature of the module is that neutralization of the ions extracted from the plasma occurs in the cathode potential well. Thereby ions that have not neutralized cannot leave near-cathode region and there are no fast ions in the output beam. Module does not contain sources of the magnetic fields or elements heated by external sources. Module operates with free cooling. Thus, the module does not need water cooling and can be freely moved in the vacuum chamber.

1. Introduction
The processing of dielectric and semiconductor surfaces has special difficulties related to charging of the surfaces if the ion beams are used. The surface charge causes defect formation as well as reduces efficiency of the further processing. To eliminate the surface charge the following methods are used: current compensation of the ion beam, combination of ion and electron beams or using RF-plasma.

The other method of surface modification is using fast neutral particles beam. In this case there is no need to neutralize the surface charge and moreover charge-induced surface defects do not formed. Charging of the surface occurs only due to secondary electron emission. However in this case surface potential does not become too large because of returning emitted electron to the surface. Thus the maximal surface potential is determined by maximal energy of secondary emitted electrons and usually less than 100 volts.

Processing of dielectric and semiconductor surfaces using fast neutral particles beam significantly reduces processing damage compared with using ion beams or direct inductively-coupled plasma processing [1–4]. It is caused by lack of charge-induced or UV-induced defects formation.

In this regards, development of module for dielectric and semiconductor surfaces modification by fast neutral particles beam is of practical interest.
2. Module description

The module scheme is shown in figure 1. The module consists of three electrodes: cathode, anode and additional electrode. The cathode of this system is a set of parallel plates fixed at a certain distance from each other and additional electrode is hollow. An output aperture of additional electrode matches laminated cathode, the two electrodes are arranged so that they form a quasiclosed volume.

When the module installed in the vacuum chamber, the anode is grounded, negative voltage from DC power supply submitted to the cathode. Additional electrode is isolated and has a floating potential.

![Figure 1. Module scheme](image)

When power supply is submitted to the module, potential at the additional electrode is determined by the condition of equal electron and ion currents to the electrode. Since in the low pressure gas discharge electron temperature is significantly higher than ion temperature, there will negative potential at the additional electrode which limits electron current. As was measured the value of the additional electrode potential relative to the anode approximately is a half of discharge voltage.

The quasiclosed volume formed by cathode and additional electrode creates an electrostatic trap for fast electrons. Due to multiply reflections of electrons from the electrodes a length passed by electrons in the plasma volume before leaving it is greatly increases. At low pressure it causes reducing of the proportion of an energy carried away from the discharge by fast electrons and thus reducing of the discharge voltage. Using of the electrostatic trap allows reducing the minimal operating pressure of the module to a value of 1–2 Pa. Moreover the localization of the gas discharge plasma in the quasiclosed volume between electrodes is occurs. It allows increasing of the neutral beam flux.

Ions generated in the plasma volume are accelerated in the cathode voltage drop region. Its neutralization performed by two processes: resonant recharge on gas target and low angle reflection from cathode plates with neutralization. The percentage of the ions neutralized by each of the two
processes is determined by a gas pressure in the near-cathode region and configuration of cathode plates.

Since the module is designed for operating at low pressure, the neutralization of ions by low angle reflection from metallic surface is the most important. Due to the independence of this process from the gas pressure in the neutralization region the operating pressure of the module is determined only by pressure of gas discharge maintaining.

Since the ions neutralization is occurs in the cathode voltage drop region, not-neutralized ions cannot leave the cathode potential well and thus cannot reach the processed surface with high energy. The highest possible energy of ions is determined by anode voltage drop and less than 10–20 eV. In the most cases this value of ions energy is too small to induce a defects forming. Thus, the module design provides absence of ions with high energy in the generated beam without using special devices such as separator extracting not-neutralized particles from the beam.

An electrical isolation of the additional electrode provides the zero current at this electrode. Thus, the entire discharge current flows through the cathode which plays the role of an emission grid as well. Due to this the current efficiency (the ratio of equivalent current of the beam to the discharge current) of the module is close to the 100 % and determined only by imperfect passage of the particles through the cathode. Moreover, the ion current density to the cathode and additional electrode is equal while the area of the additional electrode is significantly higher than the area of the cathode and the total ion current to the additional electrode is higher than to the cathode. Therefore there is significant secondary electron current from the additional electrode. These electrons due to the high voltage on the additional electrode have energy high enough for gas ionization. The secondary electron emission from the additional electrode noticeably reduces the discharge voltage and minimal gas pressure at which the maintaining of discharge is possible.

For additional reducing of the minimal operating pressure of the module a pressure difference between internal volume of the module and vacuum chamber is created. For this the working gas is inserted directly in the quasiclosed volume of the module through an inlet at the bottom side of the additional electrode. There is a gas distribution system between the inlet and gas discharge volume, it is required for the uniform distribution of the working gas in the internal volume of the module. Gas distributor is a plate with a plurality of holes in it. The creation of gas pressure difference under condition of constant gas flow through the module is possible due to the significant resistance of the cathode to the gas flow.

The figures 2 and 3 show photos of the module. The cathode plates is made of molybdenum to decrease energy loss on ions reflection with neutralization. All other metallic parts of the module are made of nonmagnetic stainless steel.
Since there are no magnetic field sources in the module it is capable to operate while in vacuum chamber with free radiation cooling. Thus there is no need in forced water cooling and the module can be moved freely in the vacuum chamber.

The figure 3 shows $I$-$V$ characteristics of the module at two pressures in the vacuum chamber: 3.5 Pa (black circles) and 2 Pa (white circles). The characteristics show that the module is able to operate at the gas pressure of 2 Pa and discharge current of 150–200 mA.

References
[1] Low angle forward reflected neutral beam source and its applications / B. J. Park, S. W. Kim, S. K. Kang and oth. // J. Phys. D: Appl. Phys. 2008. 41 024005
[2] Damage-free surface treatment of carbon nanotubes and self-assembled monolayer devices using a neutral beam process for fusing top–down and bottom–up processes / Samukawa S., Ishikawa Y., Okumura K and oth. // J. Phys. D: Appl. Phys. 2008. 41 024006
[3] Removal of Aspect-Ratio-Dependent Etching by Low-Angle Forward Reflected Neutral-Beam Etching / D. H. Lee, B. J. Park, G. Y. Yeom and oth. // J. of the Korean Ph. Soc. 2005. Vol. 46, № 4, pp. 867–871
[4] Effect of neutral beam etching of p-GaN on the GaN device characteristics / B. J. Park, K. S. Min, H. C. Lee and oth. // J. Vac. Sci. Technol. B. 2007. Vol. 25, № 2. pp. 295–298