

## The methods of decrease operating pressure of fast neutrals source

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**Abstract.** The fast neutral particles sources are more and more widely used in technologies of surface processing and coatings deposition, especially in the case of dielectric surfaces processing. However for substantial expansion of the sources applications scope it is necessary to decrease the pressure in the vacuum chamber at which they can operate. This article describes the methods to reduce the operating pressure of the fast neutral particles source with combined ions acceleration and its neutralization regions. This combination provide a total absence of the high-energy ions in the particles beam. The main discussed methods are creation of pressure drop between internal and external volumes of the source and working gas preionization which is provided by combustion of auxiliary gas discharge.

### 1. Introduction

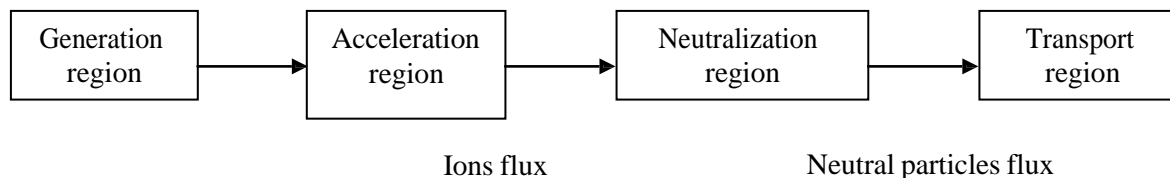
Several decades ago sources of fast neutral particles were poorly studied and its applications were very limited. First of all, this is due to the greater complexity of the fast neutral particles sources compared with ions sources. Moreover there was no significant need for a fast neutral particles processing back at that time.

Active developments of fast neutral particles sources take place in the last decade. These developments occur under influence of two factors: increase of processing quality requirements and increasing demand for high-quality processing of dielectric surfaces. The second factor caused by the fact that compared with ions beam processing the fast neutral particles processing has a significantly high quality especially for dielectric surfaces [1–4]. Thereby at the present time extensive theoretical work is performed and a large number of different designs of fast neutral particles sources are developed.

The difficulty of the fast neutral particles beams generating is the inability of particles acceleration by applied electric field as it is widely performed in ion sources. Nonetheless there are devices in which the direct acceleration of neutral particles is performed [5, 6]. However the fast neutral particles sources that use those principles have very low particles flux and thus low processing performance which lead to low practical value of these sources. Therefore at the present time the sources that use direct acceleration of fast particles are in the stage of laboratory tests and despite certain positive sides of these sources prospects of their future wide uses are not clear.



Due to these most of the developed fast neutral particles sources use the following principle of operation: gas ionization in the plasma volume, acceleration of generated ions by electric field and then its neutralization [7, 8]. A schematic diagram of these sources is shown in figure 1.



**Figure 1.** The scheme of fast neutral particles source operation

A significant disadvantage of this operating principle is that due to the non-ideal neutralizer a part of the accelerated ions remains non-neutralized. Since the neutralization occurs in an equipotential space this leads to the fact that some of the ions reach the processed surface while have a high energy. This causes a generation of charge-induced defects on the surface and in some cases is unacceptable.

To remove the high-energy ions out of the beam a magnetic or electrostatic deflection of charged particles can be used. However these methods lead to the considerable complication of the source and increased cost.

Another method to ensure the absence of fast ions in a particles beam is a combination of acceleration and neutralization regions of the source.

## 2. The fast neutral particles source with combination of acceleration and neutralization regions.

In the work [9] authors describes a fast neutral particles source, its scheme is shown in figure 2. The fast neutral particles source is consists of three electrodes – anode, main and additional cathodes. The main cathode is a set of parallel plates fixed at a certain distance from each other, the anode is a frame wrapped around the cathode. The additional cathode is a hollow electrode, the main and additional cathodes are arranged in a way that they form a quasi-closed volume.

The anode is grounded and the negative voltage of power supply is applied to the main cathode.

The additional cathode is electrically isolated from other electrodes and is under a floating potential.

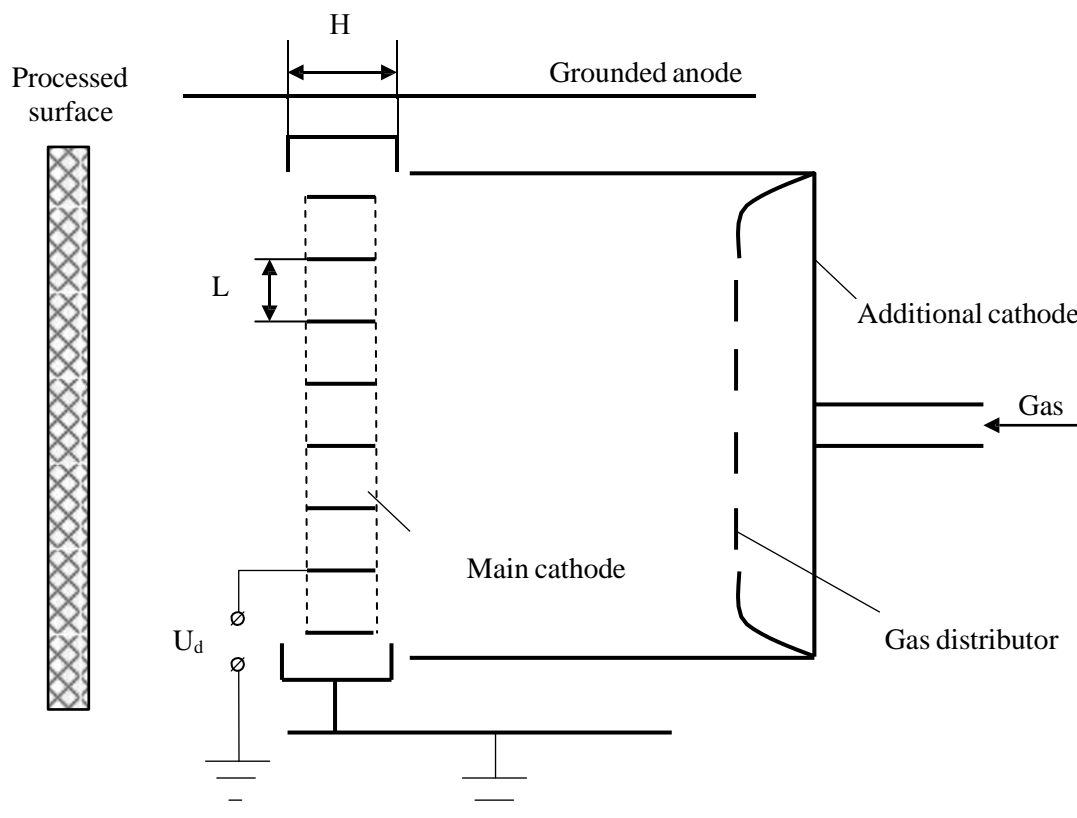
When the power supply voltage is applied between cathode and anode and the gas discharge is ignited in the quasi-closed volume of the source, the additional cathode potential is determined by equating the ion and electron currents from the plasma surface.

Since the electrons in the glow discharge plasma have much greater mobility than the ions, there is negative potential at the additional cathode that cuts off a part of electron current. Thereby the reflection of the electrons from the additional cathode is possible.

The electrodes design provides an electrostatic confinement of electrons in the quasi-closed volume formed by main and additional cathodes. This leads to the substantial reduction of the discharge voltage and allows the source to operate at the pressure down to about 5 Pa. Moreover, the gas discharge plasma is localized in the source quasi-closed volume and plasma concentration increases.

The fact that additional cathode has floating potential provides a zero current to it, despite the fact that the area of plasma which borders the additional cathode substantially exceed the area of plasma which borders the main cathode. Due to this all the discharge current flows through the main cathode which plays a role of emission grid as well. Thus the current efficiency (the ratio of the equivalent beam current to the discharge current) of the source is close to 100 %. Not 100 % current efficiency is caused only by non-ideal passing of the particles through the cathode.

The ions generated in gas discharge plasma are extracted from the plasma surface and accelerated in the cathode potential drop. Neutralization of the accelerated ions is performed by reflection from the surface of the cathode plates.



**Figure 2.** The scheme of fast neutral particles source with combination of acceleration and neutralization regions

Due to the fact that ions neutralization occurs in the region of the cathode potential well, non-neutralized ions cannot leave the near-cathode region and reach processed surface with energy greater than 10...20 eV. The maximum energy of the ions in the beam is determined by plasma potential relative to the anode ("ground") potential. Thus, this source design provides complete absence of fast ions in the particles beam without using additional sources of electric or magnetic fields for deflecting non-neutralized particles from the beam.

However the described source has significant disadvantage – high minimal operating pressure not lower than 5 Pa. Thereby some steps were made to reduce the source operating pressure.

### 3. The source operating pressure decrease

To reduce the operating pressure of the fast neutral particles source a few methods were used.

One of them was the replacement of the cathode in the form of set of the plates fixed at the rather great distance from each other to the cathode in the form of a thick plate with a plurality of the small diameter holes. The holes in the cathode are angled 10 degrees to the surface thus achieving the conditions for ions entering on the cathode surface at small angles that ensures the highest efficiency of the neutralization and lowest energy losses.

The cathode in the form of a thick plate with holes has substantially greater resistance to gas flow than the cathode plate. This allows creating significant pressure difference between internal and external volumes of the source. Due to this the pressure in the vacuum chamber may be reduced while the pressure in the internal volume of the fast neutral particles source is high enough for gas discharge maintaining.

Moreover, the cathode plate thickness, angle of the holes inclination and its diameter are chosen thus that the plasma is not visible from the processed surface. Thus, the processed surface is isolated from the plasma UV-radiation that is capable to cause a significant damage to the processed surface.

The second method that was used is the separation the source internal volume into two parts with a plate that has approximately ten holes with diameter of 1 mm. The small number of the holes and its small diameter provide a very high pressure drop whereby a gas pressure in one part of the source is high enough and the gas discharge voltage does not exceed a few hundred volts.

Due to this, there is an auxiliary gas discharge that combust at the area with higher pressure (from the gas inlet). The cathode of this discharge is the source additional cathode and the anode is the main discharge plasma surface. The auxiliary gas discharge current flows through the small holes in the plate that indicates that there is a double electrostatic layer near the holes. Maintaining of this layer is possible due to the high gas pressure on the one side of the plate (from the gas inlet) while on the other side of the plate (from the cathode) the pressure is not high enough for double electrostatic layer maintaining.

The auxiliary gas discharge combustion provides preionization of the operating gas, which then enters the main discharge combustion area. Thereby the main gas discharge voltage is reduced and the gas discharge can be maintained at the lower pressure. This leads to the additional decreasing of the source minimal operating pressure.

In addition we assume that creation of a magnetic field to provide a closed electron drift will allow maintaining the gas discharge at a pressure of down to  $10^{-2}$  Pa. Given that the main method of the ions neutralization in the source is the neutralization by reflection from the metal surface that is not influenced by gas pressure this will reduce the operating pressure source to the same value.

Reducing the source operating pressure to that point will significantly expand the scope of the source applications. In particular it makes possible to use the source for film deposition assistance.

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