MODERNIZED TECHNOLOGICAL ACCELERATOR WITH ANODE LAYER FOR ION CLEANING

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INTRODUCTION

At present time the technology for new functional coatings possessing complex composition and layered structure is developed intensively. Usually for that purpose plasma sputtering sources of magnetron, vacuum arc, electron beam and other types [1] are used. Quality of the coating essentially depends on preliminary preparation of the surface – its cleaning and activation. This treatment should be done immediately before deposition of the coating in the single technological cycle. In microelectronics this task is usually solved by means of Kaufmann source use [2]. However, this type of the source has incandescent cathode in it, which limits its technological abilities.

Another possibility consists in the use of plasma accelerators with confined electron drift (for example, accelerator with anode layer, AAL). These systems allow obtaining the beams of ions of various substances with energy ranging from tens electron-volts up to several kiloelectron-volts and different densities (from milliamperes up to several amperes). Simplicity and reliability of the design, and also operational characteristics extend possible use of AAL for various applications [3].

In spite of external attractiveness of the system, accelerators with anode layer were previously used mostly as ion injectors and electric propulsions. Their abilities, as the tools for surface cleaning and activation, were described very incompletely [2]. On the other side, their application in the single technological cycle, particularly, in combination with continuously operating magnetron, imposes a number of extra requirements for AAL.

We have developed and tested compact technological accelerator with confined electron drift in crossed ExH fields, as the tool for substrate cleaning and activation immediately before deposition of functional coatings [4]. It has been shown that the device provides surface cleaning rate at a level of ~ 1 nm/s, which is close to the best values for Kaufmann source [2]. Special attention was paid to compatibility of the accelerator by pressure of working gases with magnetron operation. This problem was solved by the use of gas supply immediately in vacuum volume instead of common scheme of the supply through the system electrodes. At the expense of that we succeeded in raising operation pressure up to ~ 10^{-3} Torr. It enables placement of the accelerator in the same vacuum chamber with magnetron and their simultaneous use, thus making possible creation of continuously operating technological couples, which is especially important for treatment of the surfaces with large square.

The present proceeding is devoted to optimization of the accelerator design with an aims of increasing etching rate and lowering operation voltages. The reasons leading to non-monotonous dependence of etching rate on pressure in the system are studied experimentally.

EXPERIMENTAL SETUP

The experiments were carried out with ring accelerator with anode layer, similarly to those described in [4]. In that work also description of the setup is given. Argon and its mixtures with nitrogen and oxygen were used as working gases.

In experiments performed earlier in [4] it was shown that it is reasonable to supply working gas not through accelerator cathode or anode (classic option), but immediately to vacuum chamber. At that cleaning rate grows up approximately twice, and working pressure shifts toward higher values. That's why exactly this system of gas supply was used in modernized configuration of the accelerator.

In initial experiments [4] wide polepieces were used for the accelerator. In that case anode was situated in practically uniform magnetic field with about 1000 Oersted strength. At the same time it is known [3,5] that at AAL use for the propulsion it is recommended to place the anode in region with increasing magnetic field. The anode itself is elaborated at that, as hollow electrode. In present work we checked, whether these recommendations are valid at AAL use for ion cleaning. For that purpose polepieces were narrowed down to 5 mm. The field strength in the gap remained practically unchanged (1100 Oe), and at anode surface it decreased down to 600 Oe.

Initially we used plane anode. Dielectric target (usually glass) was placed at 7 cm distance from the accelerator.

For determining the surface cleaning rate photometry method described in [4] was used.

RESULTS OF MEASUREMENTS

Fig.1 exhibits dependencies of the target surface cleaning rate on pressure in working volume at constant voltage on the anode. Curves 1 and $1'$ correspond to uniform magnetic field in the accelerator gap. Dependencies 2 and $2'$ are taken when the anode is in region of increasing magnetic field. One can see that the curves are bell-shaped and reach their maxima at pressures about $8\text{-}9\cdot 10^{-4}$ Torr. At pressure decrease cleaning rate diminishes quickly, however, it retains positive values right down to zero. At pressure higher than 10^{-3} Torr cleaning is replaced by deposition. It is easy to see that the new magnetic field configuration provides higher values of the surface cleaning rate. At the anode voltage of 1200 V this increase is not critical, although it is visible. At 900 V voltage observed growth of cleaning rates exceeds factor of two. This fact is very remarkable from technological viewpoint. Whereas earlier the voltage increase from 900 to 1200 V resulted in more than triple increase of cleaning rate, now this difference became essentially smaller. It justifies the use of voltages in accelerator less than 1000 V, which surely influences its operational characteristics.

Fig. 1. Dependencies of the cleaning rate on pressure. Curves 1 and $1'$ correspond to uniform magnetic field in the accelerator gap. Dependencies 2 and $2'$ correspond to anode is in region of increasing magnetic field.

Plasma column with practically unchanged cross section propagated from the accelerator for the distance not less than 50 cm. In the column cross section cylindrical zone situated under the anode (about 5 mm width) occurred, inside of which cleaning rate reached maximum and was almost homogeneous. Outside that ring zone cleaning rate decreased sharply, however, it retained positive sign (that is, was not replaced by deposition). Thus, cleaning profile was close to step-shaped one.

Use of hollow anode instead of plane one resulted in formation of the plasma flux with crossover. However, etching rate decreased at that, and edges of cleaning zone became essentially fuzzy, which is undesirable from technological viewpoint. It served as a base for the conclusion that hollow anode use is unreasonable at AAL use for technological applications.

Fig. 2. Dependencies of the ion beam current and current density on pressure.

For determining ion beam current onto the surface, metal collector separated from the plasma by grid under floating potential was installed in place of glass target. Negative potential of 200-400 V value, at which ion current reached saturation, was applied to the collector. Dependencies of the ion beam current on pressure are presented in Fig.2. As well as in case of uniform magnetic field, the curves represent monotonously growing characteristics. The ion beam current comprises about 10% of the discharge current.

Fig. 3. The floating target potential under the beam on dielectric.

For determining the reasons of etching rate decrease the target potential was measured under the beam (Fig.3). One can see that exactly in region of etching rate decrease the target potential sharply increases. Measurements accomplished by means of multi-grid analyzer have shown that energy of ions coming out of the anode layer is typical for the sources of such kind [3]. In this case floating potential growth from 300 to 600 V (see Fig.3) will strongly retard the ions, however, the portion of those will still retain energy sufficient for sputtering the target atoms.

One can mention ion-plasma flux defocusing in high pressure range, as one more factor, leading to the decrease of cleaning rate. The beam profiles measured at pressures of $7\cdot10^{-4}$ and $2\cdot10^{-3}$ Torr are shown in Fig.4. It is easy to see that the beam defocusing really takes place. However, use of the compensator at the second pressure value practically completely restores the flux profile (Fig.4). In other words, the beam defocusing is a consequence of the target floating potential change.

Fig. 4. The beam profiles at different pressures, with and without compensation. U_d = 900 V, Ar.

In consideration of the problem regarding AAL compatibility with magnetron one should take into account one more factor. In a process of depositing complex coatings multi-component gas mixtures are often used as plasma generating media. Most often in those cases small (~ 10%) addings of nitrogen or oxygen are used. That's why we tested the influence of such addings on the target cleaning rate. The experiments have shown that nitrogen adding to argon does not provide essential influence on the accelerator operation at nitrogen partial pressure up to 30%. Adding the same quantity of oxygen may lead to essential cleaning rate decrease (up to 3 times). The most probable reason of mentioned decrease of the rate may consist in formation of copper oxides at the surface to be cleaned.

CONCLUSIONS

Thus, in the proceeding it is shown that at use of single-step accelerator with anode layer for surface cleaning:

1 It is reasonable to place the anode in a region with rising up magnetic field. In this case cleaning rate increases, and usage of low voltages in the accelerator power supply system becomes much more efficient.

2 Unlike the case of AAL use for propulsion, in studied case the use of hollow anode is unreasonable and leads to both decrease of cleaning rate, and spread of the beam profile.

3 The beam defocusing observed at high pressures is a consequence of the target floating potential growth and resulted changes of ion-optical parameters of the system.

4 Nitrogen adding (up to 30%) to plasma generating gas does not provide significant changes in the accelerator operation. However, adding of similar amount of oxygen may lead to essential (up to 3 times) decrease of cleaning rate.

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