Ions neutralization by reflection from solid target surface

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Abstract. The paper focuses on the one of the ion neutralization processes – process of ion neutralization by reflection from solid target surface. The three-electrode system of the fast neutrals source is considered as well as the main factors determining the parameters of neutrals beam. Moreover, the loss of energy during neutralization was obtained and the graphs of energy loss versus incident angle of the ion to the target for some target materials were built.

1. Introduction

Formation of submicron size structures is the essential part of the micro- and nanoelectronics products creation. Currently the most common method for this is plasma-chemical or ion-beam etching. But there is number of problems appearing when using this technology for etching of dielectrics or high-resistance semiconductors. Firstly the target acquires surface charge causing etching speed decreasing or even termination of etching. Secondly the UV radiation presented in the plasma spectrum may have negative effect on the target.

To prevent surface charging slow electrons insertion (current compensation) or high-frequency power supply can be used. Ultraviolet irradiation of the target can be reduced via appropriate design of the device.

However, all of these lead to significant rise of technological equipment price. Moreover the paths of ions in beam distorted due to target's surface charge and beam's space charge that hinders uniform etching and thus do not allow further reduction the size of formed structure parts.

These problems can be resolved through using broad beam sours of fast neutrals. Neutral beam do not distorted due to any charges or magnet fields that may be present in technological equipment. Moreover plasma source of fast neutrals can use direct current power supply.

2. Ion beam neutralization

2.1. Neutralization efficiency

There are two main processes than can be used to effectively neutralize ion beam: the resonant recharge on the gas target and neutralization by reflection from solid target surface.

In this paper the process of ion neutralization by reflection from solid target surface is considered. The main advantage over the resonant recharge is its independence of the pressure in the region of the neutralization. While the efficiency of the resonant recharge depends on the gas pressure the pressure in the sources of fast neutrals using ion neutralization by reflection from solid target surface is limited only by the pressure at which the discharge is maintained in plasma generation region and can be lowered down to 10^{-4} Torr using discharge with electrostatic confinement of electrons.

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The process of neutralization by reflection from solid target surface is effective at low angles between the incident ion and the target. In [1] was simulated the passage of ion beam through the channel width of 0.1 cm, consisting of two plates, inclined at the certain angle to the transmitted beam and the dependence of the neutralization efficiency of the channel length and incident angel was obtained. (figure 1)

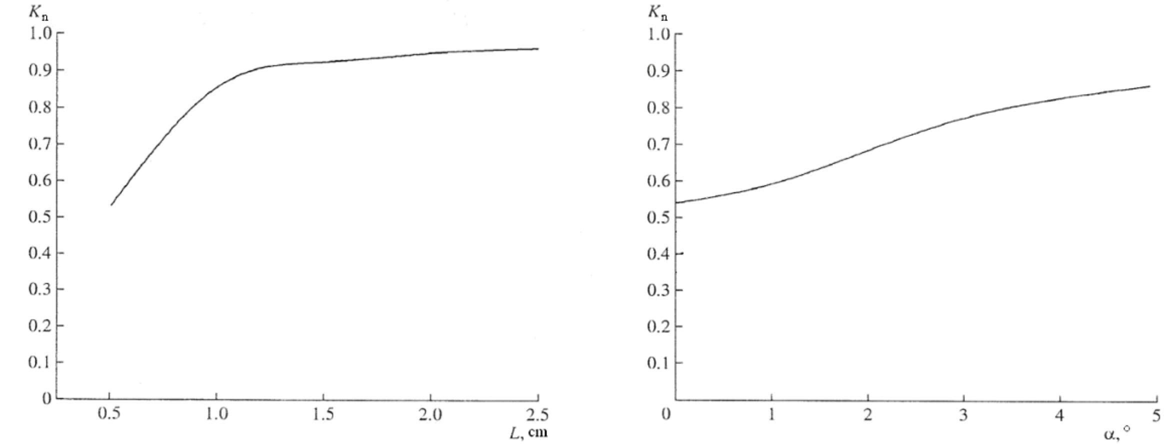

Figure 1. Dependence of the neutralization efficiency.

With sufficient length of the channel and low angle (angles everywhere reports from the tangent to the surface of the target) to the target surface coefficient of neutralization is close to unity and thus such a system effectively performs neutralization. But part of the ions in the beam still is passing through the channel without charge neutralization and fall onto the target surface. It leads to charge accumulation on the target surface and thus to charging of the surface. To avoid it the three-electrode system can be used (figure 2).

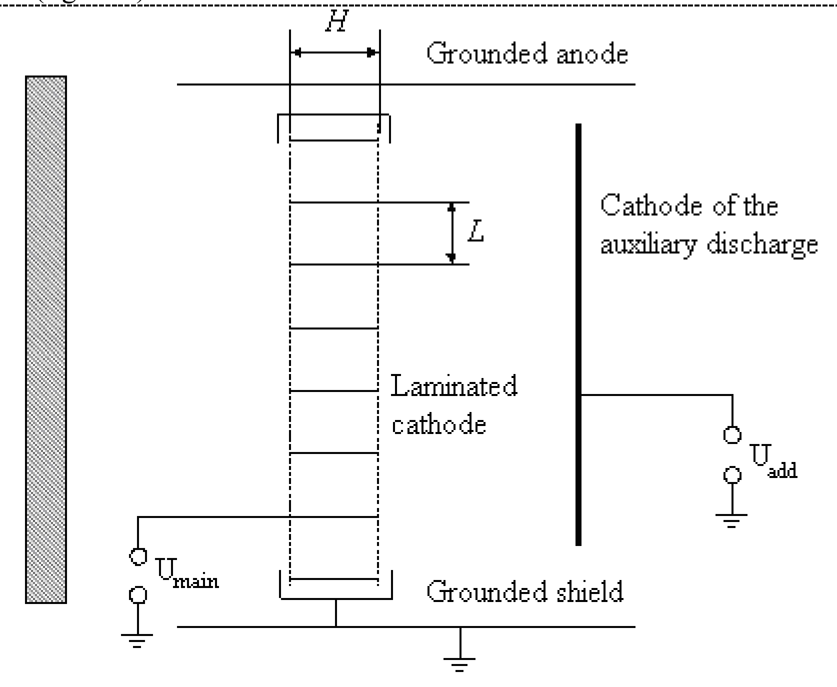

Figure 2. Three-electrode system.

Ions accelerated in the cathode potential drop are neutralized by reflection from the laminated cathode surface. At the same time not-recharged ions from the beam cannot leave potential well in the cathode region with sufficient energy and fall onto the target surface.

In such a system the distance between the plates is largely determines the characteristics of the system and cannot be less than two width of the cathode layer. Otherwise the plasma will enter into the gap between the plates and laminated cathode will function as the hollow cathode.

If the distance between the cathode plates is significantly less that its thickness we can ignore the hit of the ions on the end surface of the plates. In this case, we can approximately assume that the plasma forms a cylindrical surface around the end of the each plate with the radius of curvature equal to the width of the cathode layer (figure 3).

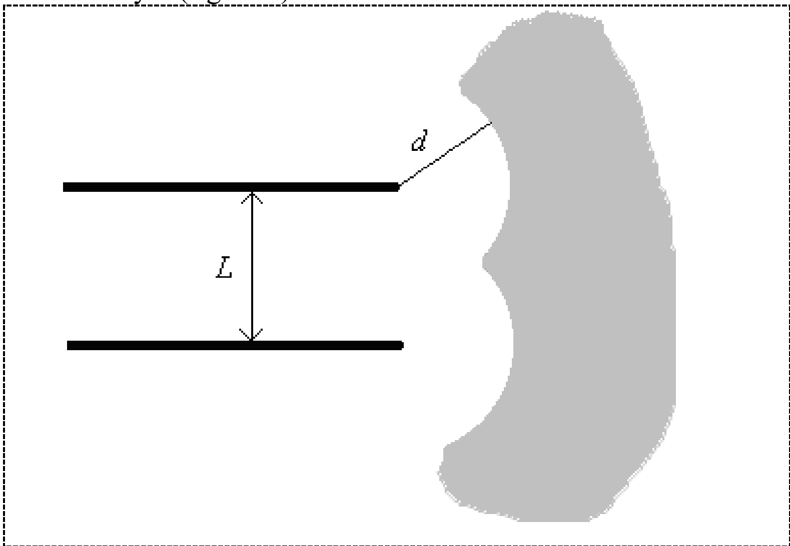

Figure 3. The location of the cathode plasma.

If we assume that ions are emitted normal to the surface of the plasma the maximum angle at which they fall onto the surface of the cathode equal to the $\arctan(\frac{L}{2d})$, where L is the distance between the plates of the cathode and d is the width of cathode layer. If we assume that ions neutralized by reflection when they fall to the surface at angles less than 10° then the ratio of L to d should not be less than 0.35.

But if L is small enough then we cannot ignore ions falling on the end surface of the plates as well as difference of the plasma surface from cylindrical. Since the thinness of the plates is limited by structure durability the distance between the plates is limited as well. Thus this system will work well at low pressure when the width of the cathode layer is high enough.

2.2. Energy loss in neutralization

The energy of the neutrals will be determined by the difference of the potential energy of the particles between points of birth and neutralization. Ideally, if there was no resonant recharge and the reflection of the ions from the target surface would occur without loss, the beam of fast neutrals would be monoenergetic with the energy of particles determined by cathode voltage drop.

But the energy spectrum of the beam is influenced by two effects. Firstly, there is some loss of the energy in ion reflection from the target surface and this loss depends on of the incident angle of the ion to the target. Secondly due to the presence of the neutral molecules in the cathode potential drop region some of the ions may recharge on the gas target before reaching the cathode. Thus, besides the primary ions emitted from the plasma surface there will be some secondary ions formed by resonant recharge. As well as primary, secondary ions in the electric field of cathode potential drop will move to the cathode but their energy will be less. Moreover during the resonant recharge the neutrals are formed with energy determined by the potential difference between the plasma and point of recharge that is less than the energy of the neutrals formed by neutralization of the primary ions at the cathode.

Due to these processes, the energy spectrum of the neutrals beam spreads into the region of the low energies. This distortion depends on the neutral gas concentration in the cathode voltage drop region, the length between the plasma and the cathode and the energy loss by reflection from the cathode surface.

For the mathematical description of the process of ion neutralization by reflection from the solid target surface there are models of single and double binary collision [2]. Using the model of single binary collision the expression $E_i / E_n = (1+\mu^{-1})^{-2}(\cos(2\theta) - \sqrt{\mu^{-2} - \sin^2(2\theta)})^2$ for loss of energy was obtained, where μ - ration of the masses of the incident particle and atom of the target and θ - the angle of incidence related to the normal to the surface. Figure 4 shows graphs of energy loss on incident angle on the surface for the argon ions and few target materials. According to the obtained results the loss of energy increase with increasing angle of incidence of the ion to the target surface and the rate of the increase of the loss is greater the smaller the atomic mass of the target material. These suggest that the surface of the cathode-target should be made of a conductive material with high atomic number and the design of the cathode should be such that the ion incident angles to the cathode surface are small as possible.

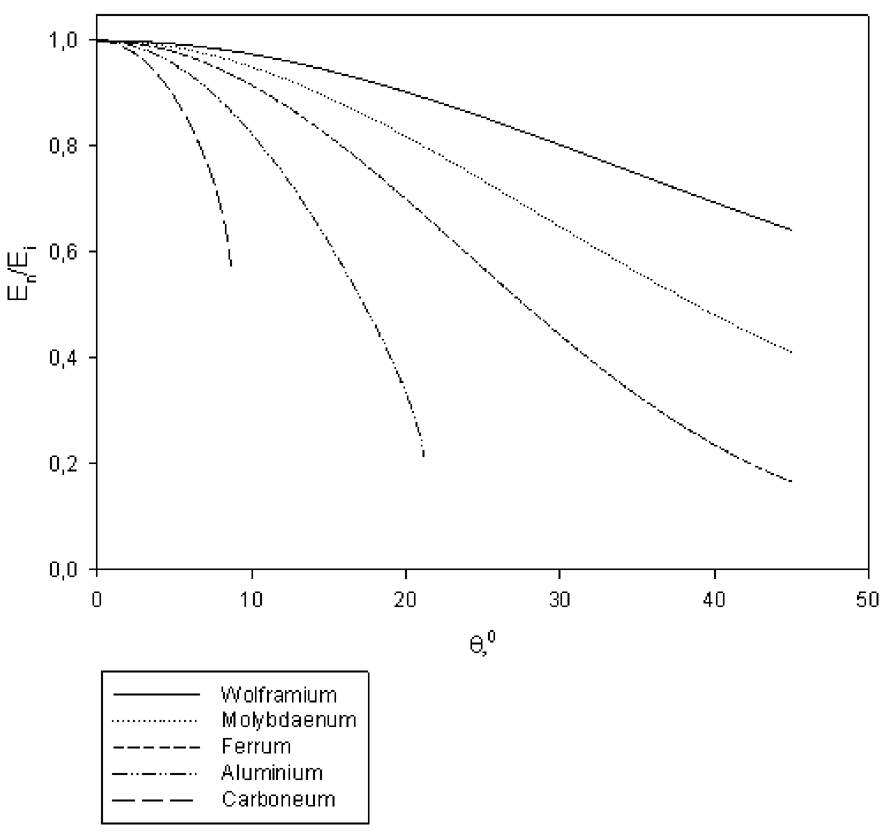

Figure 1. Energy loss in reflection

References

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[2] Koppers W R, Tsumori K, Beijersbergen J H M, Weeding T L, Kistemaker P G and Kleyn A W 1998 *Int. J. Mass Spectrum. Ion Physics.* **174**. 11