MAGNETICALLY FILTERED VACUUM-ARC PLASMA DEPOSITION SYSTEMS

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This article is a brief historical review of R&D carried out by the KIPT scientists in the field of magnetic filtering of vacuum-arc plasma flows to be applied in thin film deposition technology.

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In spite of that fact, that vacuum-arc coating deposition method is known from 1870's [1,2] the process of its industrialization started one century later, namely since 1970's. At that time the group of Ukrainian researchers began its regular investigation in d.c. vacuum arc discharge: in Kharkov Institute of Physics and Technology (KIPT) there was developed vacuum-arc method of wear resistant coating deposition based on nitrides of such metals as Ti, Mo, Zr. There were created also the first industrial installations [3]. For a comparatively short time the method have gained wide recognition in tool production. However the presence of macroparticles (MPs) of cathode material in vacuum-arc plasmas retards a wider application of the method in such fields as optics, microelectronics, precision mechanics, medicine.

The most effective approach to reduce the MPs concentration in erosion plasma flows is based on spatial separation of trajectories of MPs and ion species. This can be most easily realized in the plasma source with magnetic focusing of the plasma flow [4]. However, the MPs problem is most effectively solved with use of magnetic plasma filters. The first magnetic filter was developed at the KIPT in the mid 1970's. In 1976 the application was registered for the invention of a plasma filter with a curvilinear plasma duct bent as a quarter of torus, as well as with S- and Ω-shaped plasma duct [5] (Fig.1). Having used that filter the Kharkov group obtained the results that stimulated the wide-scale researches in the field of vacuum-arc synthesis of amorphous carbon (or DLC) films and other high-quality films in many countries of the world.

In general terms, the mechanism of filtering plasma in magnetic filters can be described as follows. Between the substrate and the cathode there is a certain barrier installed (Fig.2) [6-8]. Baffles or the walls of the bent tube (plasma duct) can serve as the barrier mentioned. In their motion in straight lines the MPs are confronted by this barrier and fail to arrive at the substrate, while the ion and electron components of the plasma flow, owing to the magnetic field of particular configuration, go round the barrier and reach the substrate.

Due to rebound of MPs from the walls many of them reach the filter exit and arrive at the substrate. So, the efficiency of filtering is the higher, the longer is the plasma guiding channel, the narrower is it, the greater is the angle of the bend. However, in this case the losses of the plasma flow transported increase, the productivity of the system drops, its complexity and its cost is raised.

All attempts to simplify the systems enter in contradiction with requirements, the fulfillment of which is necessary for an efficient filtering of plasma. Considerable efforts were undertaken in many research centers to solve this inconsistent problem. In the KIPT there were developed some versions of magnetic plasma filter over and above those mentioned. The most of them were not published due to confidentiality of their application in defense industries. So, e. g., the filter with curved plasma duct of so called opened architecture described in ref. [9] had been developed in the mid 1980's as the unite of the high power set-up intended for high rate coating deposition by the method of electron beam and cathodic vacuum-arc evaporation of metals. But the short communication about this device has been published by its authors just in 2001 [10]. The filters with S- and Ω-shaped plasma duct [5] and the filtering plasma source comprising a cathode with cylindrical lateral working surface (Fig.3) [11] were developed much earlier than their analogues described in ref. [12] and [13] respectively.

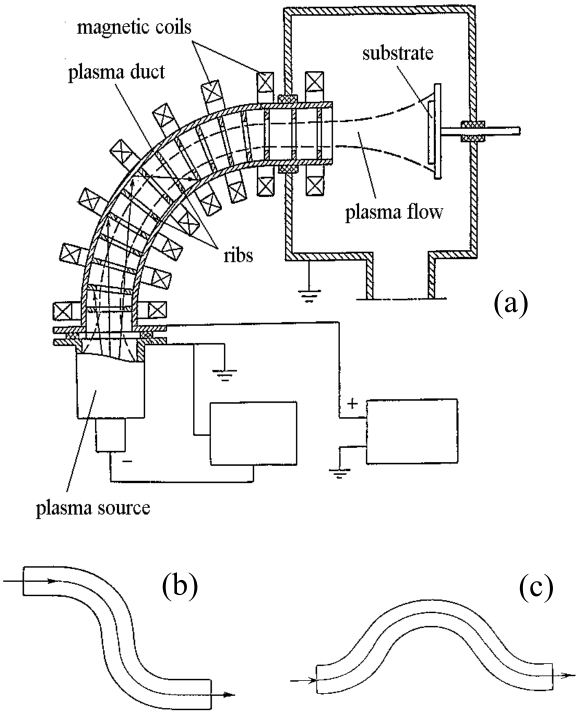

Fig.1. Curvilinear-filter. Toroidal 90^0 (a), S-shaped (b) and Ω-shaped plasma ducts

An attempt to solve the problem of large square surfaces treatment by macroparticles-free plasmas was undertaken by Sablev et al. [14,15]. But they were failed using the systems in industrial application due to their complexity and low degree of plasma filtering.

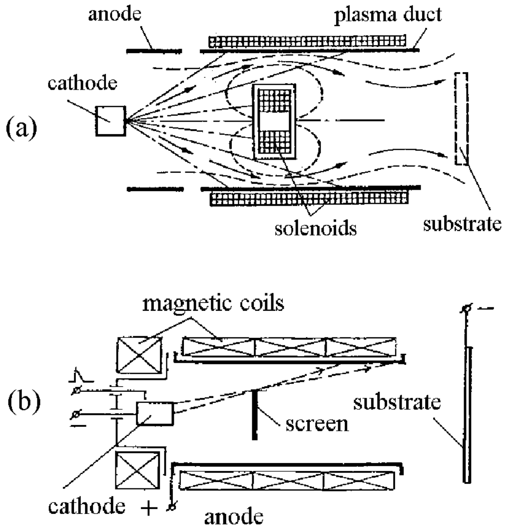

Fig. 2. Rectilinear plasma filters with magnetic "island" (a) and passive flat screen (b)

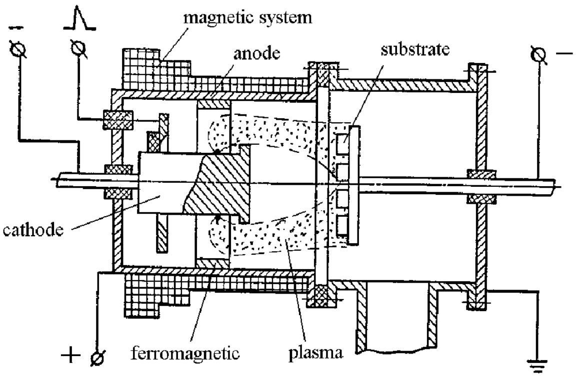

Fig. 3. Filtered plasma source with "dome" type of the magnetic system (prototype)

The existing methods of defining the plasma contamination with MPs are based on counting the number of MPs in coatings. So, the optimization of filters is rather complicated challenge. The problem is simplified by means of computation of MPs motion in a plasma duct of filters. We solved the problem in two-dimensional approximation for axisymmetric and plane-symmetric systems [16]. The method is rather useful for the comparative estimation of filtering properties of the system of different geometry. Besides, using this method it's quite easily to find out that the use of long and narrow plasma guiding ducts which have a lot of knees, is unadvisable approach if MPs are in solid state. The success can be achieved choosing appropriate systems of baffles (ribs) and their arrangement inside the duct of simple shape [17].

Another important characteristic of the filtering system is its capacity. Analysis of plasma motion along a toroidal magnetic field shows that for a successful plasma travel the field intensity must be above 1 T. At this field (i) it is impossible to provide a stable burning of the d.c. arc discharge in the system and (ii) the plasma injection into a field of such strength is practically impossible too. Thus, it was reasonable to consider plasma motion in condition of partly magnetized plasma [18]. In this case plasma has a very high resistivity across the magnetic field and very high conductivity along the field. Electrons move along the central lines of magnetic field, crossing the cathode. And ions follow the electrons to conserve plasma quazineutrality. This model is based on the Morozov's plasma optics principles [19]. Later it was investigated in details by Boercker et al. [20]. They showed that this model, which is known as the "flux-tube model" is quite useful for qualitative estimation of plasma motion in curved duct, but it is much less advisable to be used for quantitative calculation. There were developed more perfect theoretical models [21-23]. These models describe mechanism of plasma losses caused by plasma diffusion across magnetic fields. They predict displacements of plasma flow due to gradient and centrifugal drift. But these models are developed for ideal toroidal fields, so they are quite useless in cases of distorted systems. Here the drift shift of plasma flow may be directed toward the side, which is not predicted by the theory. On the contrary, the very first model developed [18] explains these phenomena quite simply: the plasma moves along the flux of magnetic lines crossing the cathode active surface where the plasma flow arises. So, one can direct the plasma in any run choosing an appropriate geometry of magnetic lines. Thus, we have rather effective means, which are very helpful and useful for optimizing and designing magnetic plasma filters.

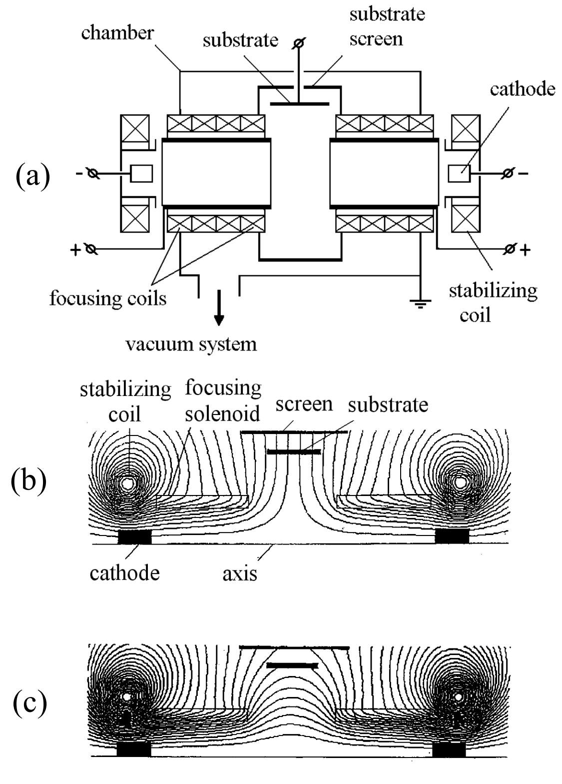

Fig. 4. Filtered plasma source with linear-to-radial transformation of plasma flows. Schematic (a), magnetic field configurations (b, c)

The development of high-efficiency plasma filter is the key task for opening the way to a wide-scale application of the vacuum-arc method for high technology practice. There are created a great number of original design structures for to solve this problem [24]. However, none of them so far has an appropriate efficiency. The plasma throughput is not more then 25…50%. From this viewpoint the recent developments of KIPT seam to be promising. One of them is the system with radial flow of filtered plasma [25] (Fig. 4). It comprises two similar vacuum-arc magnetic-focusing plasma sources. They arranged coaxially, facing each other. Axial flows of plasma here are transformed into radial flow moving through the annular gap between the anodes of the sources. The gap is wide compared to the length of the plasma path toward the exit. So, the diffusion to the walls across the magnetic field is not intensive. The gradient and centrifugal drifts in the annular gap are closed, so the plasma drift losses are negligible. As a result the total losses are very small. The transmittance is very high: plasma throughput is about 90%. The system coefficient is about 8,5%. None of other system has such a high characteristic. Besides, the system with radial flow has a very large area of filtered plasma flow cross section. It is very useful for rectangular variant of the system (Fig. 5). This version is supposed to be used for deposition of coatings on flat substrates of large area and also on web materials.

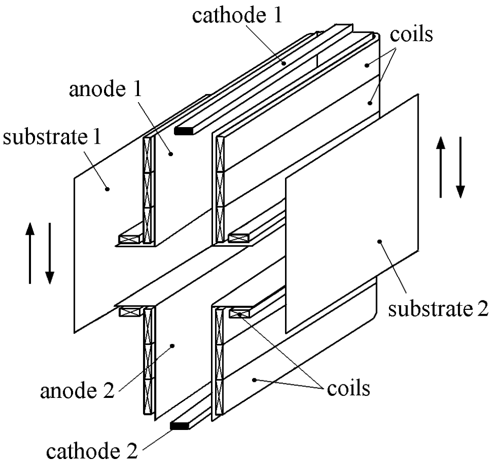

Fig. 5. Source of double filtered plasma flows

Another variant of plasma filtering system, which is developed in KIPT recently, is the filter with an L-shaped duct [26]. Its transportation efficiency is about 65%, i. e. less than for previous "radial" variant. It is likely due to the presence of gradient and centrifugal losses because of the system is asymmetric. But 65% is much higher as compared to convenient systems.

The L-shaped filter is used presently in industrial production of storage system elements for deposition of ultra-thin protecting DLC films. This is a promising step for vacuum-arc method of coating deposition in high technologies application.

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