HTML ABSTRACT + LINKS

Rotating Cylindrical Magnetrons and Accelerators with Anode Layer for Large – Area Film Deposition Technologies

S.P. Bugaev, A.N. Zakharov, K.V. Oskomov, N.S. Sochugov, and A.A. Solovjev.

High Current Electronics Institute, Siberian Division of the Russian Academy of Sciences, Russia

Abstract. DC magnetrons with a rotating cylindrical cathode and length up to 2.5 m were designed. Results of the experiments for the sputtered film uniformity and target utilization degree increasing are presented. Depending on technological requirements, a magnet system of the magnetron forms either one sputtered particle flow or two flows in diametrically opposite directions. Linear accelerators with an anode layer designed for cleaning the substrate surfaces prior to the coating deposition and for hard carbon films deposition are described as well.

INTRODUCTION

The principal parts of a vacuum setup intended for thin film technologies are the devices creating particle flows from which a coating is formed. Depending on a realized technology, different devices can be used to create flows of this kind. To deposit coatings on large-area substrates, these devices should be extensive at least in one direction. By now, different variants of magnetron sputtering systems (MSS) are widely used to deposit coatings on large-area substrates using PVD methods [1-3]. The main demands made of these MSS are providing with high uniformity of the deposited coating, and achieving high target utilization degree [4].

When developing most of the thin film technologies, we have to solve the problem of increasing the coating adhesion to a substrate. Different variants of devices for preliminary ion-plasma treatment of the substrate surface are used for this purpose. Some of devices are the accelerators with the anode layer [3, 5]. Their merits are the design simplicity and possibility to generate extended (up to 2-3 m) ion-plasma flows. Different CVD technologies can be realized on the basis of this kind of sources.

This paper presents the results of the works carried out at the Institute of High Current Electronics directed on perfection of designs of magnetron sputtering systems with cylindrical cathodes and ion-plasma sources based on the accelerators with anode layer as well as on creation of technologies developed on the basis of these devices.

EXPERIMENTAL

Efficiency increase of MSS with rotating cathode

Among the variants of extended magnetrons the most promising are the systems with cylindrical rotating cathode [4]. A distinctive feature of these systems is using a cathode made as a tube inside which a magnetic system (MS) is placed. The cathode can rotate relative to the immovable MS that provides its uniform wear. The main merit of these magnetrons is high target utilization – up to 80% instead of 20-30% with the planar magnetrons. However, there exist possibilities for further efficiency increase of rotating magnetrons. The shortcoming common for all MSS is the fact that even at high uniformity of magnetic field along the target length, the substrate parts disposed near the magnetron ends are sputtered with less grow rate than the central part of the substrate. The reason is the nonsymmetrical sputtering diagram. Therefore, in order to achieve high uniformity of the coating thickness on the whole substrate area we have to fabricate magnetrons with the target dimensions exceeding the dimensions of

CP669, *Plasma Physics: 11th International Congress on Plasma Physics: ICPP 2002*
edited by I. S. Falconer, R. L. Dewar, and J. Khachan
© 2003 American Institute of Physics 0-7354-0133-0/03/$20.00

Downloaded 24 Feb 2011 to 138.253.100.121. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions

the treated substrates by 20-30 cm that results in magnetron cost rise and increase of the vacuum chamber dimensions. The shortcoming of the MPC with a rotating cathode is the accelerated eroding of the end cathode parts owing to high specific power falling to these parts in comparison with the rest part of the target [6]. As a result, in reality the coefficient of the target utilization is far from the maximum possible one.

Target thickness increase at the parts with accelerated eroding or fabrication of these parts from a hard sputtering material [6] solve this problem incompletely as this results in decrease of the magnetic field holding the plasma at the target surface, change of the discharge existing conditions, and appearance of instabilities in plasma. We have carried out a series of experiments on the efficiency increase of a rotating magnetron owing to the expansion of the region of the uniform coating deposition and decrease of the accelerated erosion of the end cathode parts. A cylindrical magnetron with a rotating cathode made of aluminum was used in the experiments. The cathode had an external diameter of 80 mm and the length of the sputtered part of 520 mm. The deposited film thickness was measured with an interference microscope. Erosion uniformity of the target by its length was determined by calculation of the erosion zone cross-sectional area.

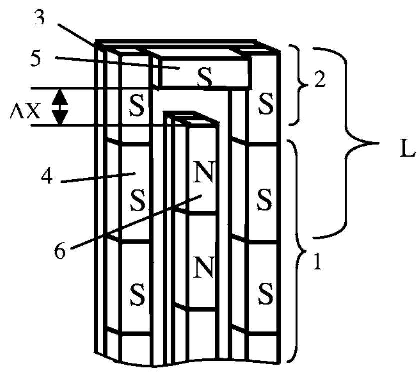

FIGURE 1. Magnetron magnetic system scheme. 1- linear part, 2- turn-around part, 3- core, 4- outer magnets, 5 – end magnets, 6- central magnets.

Figure 1 presents the scheme of the magnetron MS. It consists of a linear *1* and turn-around *2* parts forming a closed sputtering racetrack on the target surface. The linear part consists of three lines of permanent magnets placed at a core *3*. The lines of the outer magnets *4* are connected with each other by the end magnets *5*. Between the end magnets and the line of the central magnets *6* there is a gap ΔX; its value is chosen so that distributions of a longitudinal $B_{||}$ and normal $B_{\perp}$ components of the magnetic field along the gap ΔX should coincide with the distributions between the outer and central magnets at the linear part of the magnetic system (fig.2a, b) [7].

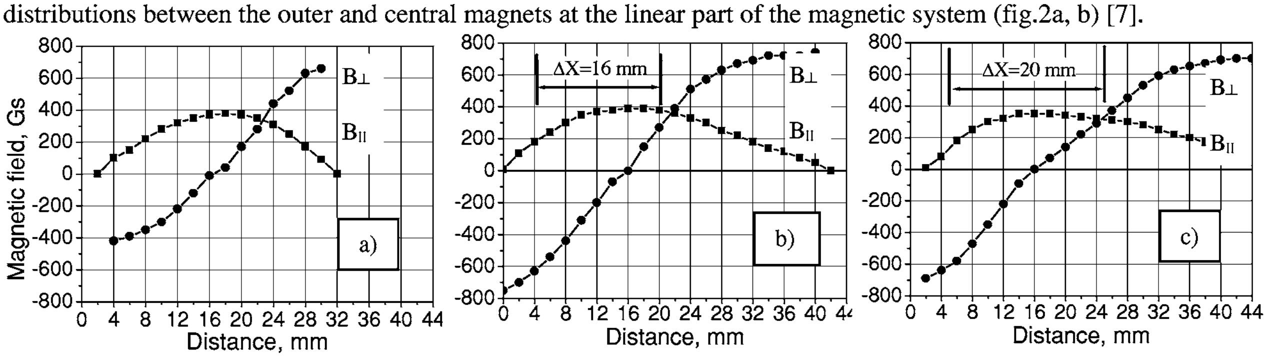

FIGURE 2. Distributions of a longitudinal $B_{||}$ and normal $B_{\perp}$ components of the magnetic field: a) between the outer and central magnets at the linear part of MS; b) along the gap ΔX =16 mm (initial MS design); c) along the gap ΔX =20 mm (modified MS).

Curves 1 in figs. 3a and 3b present the results of the experiments on measuring the coating thickness uniformity at a substrate and cathode erosion area uniformity. The experiments were carried out with the magnetron having the above-described magnetic system. As it is seen from the figures, the length of the deposition area with the uniformity being no worse than ±1% makes up 22 cm, i.e. at the overall length of the sputtering area equal to 52 cm at the magnetron ends there are areas with the dimensions of 15 cm each that are used ineffectively though they are subjected to sputtering. Obviously, these dimensions are enough large even for magnetrons with the target length of 2-3 meters. From fig. 3b one can see that at the curve 1 on the left there is a region with maximum erosion area that corresponds to the region of accelerated eroding at a turn-around part of the magnetic system. There is the analogous region at the opposite end of the target, but it is not shown in the figure. Sputtering velocity at the target ends is by 20% higher than on average along its length.

Downloaded 24 Feb 2011 to 138.253.100.121. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions

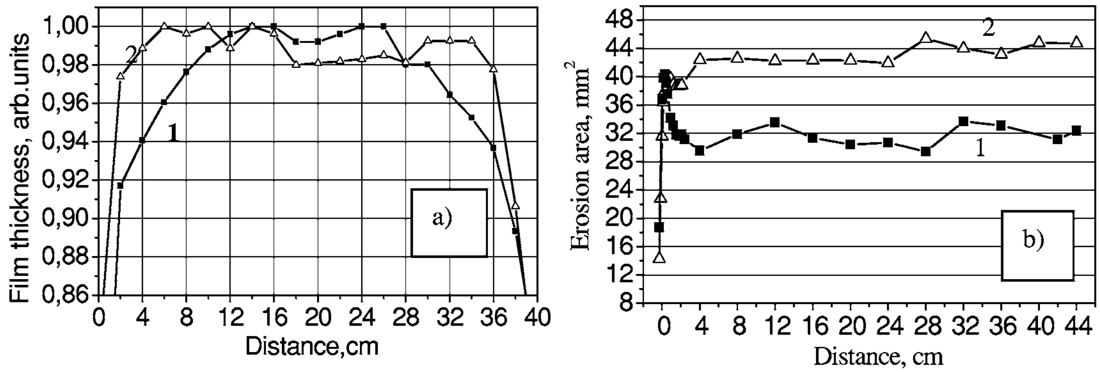

Figure 3. Results of the experiments on measuring the coating thickness uniformity at a substrate (a); and erosion area along the target length (b). 1- initial MS; 2- modified MS.

In order to overcome these shortcomings we've made changes in the MS design. Firstly, magnetic field induction at the parts of the magnetic system adjacent to the turn around parts was increased. This was achieved by means of replacement of the outer magnets (fig. 1) by the magnets having 5-15% higher residual induction of magnetic field. Varying the number of these magnets in the magnetic system we can change the length of the region with the increased magnetic field L (fig.1.). Secondly, by introduction of additional magnets into the gap ΔX the erosion area in the turning region was expanded that allowed decreasing the sputtering power density in these areas. Fig. 2c presents distribution of the magnetic field components corresponding to this case. Curves 2 in figs. 3a and 3b present the results of measurements of the coating thickness uniformity and cathode erosion uniformity. One can see that the length of the deposition area with the uniformity of ±1% expanded by 12 cm and made up 34 cm (fig. 3a). We have also managed to eliminate completely the accelerated wear effect of the rotational cathode part (fig. 3b).

Using the obtained results, we develop and fabricate rotating magnetrons with the target length up to 2.5 m for application in high-production technological setups. Depending on the type and production of a setup, we use either magnetrons with a continuously rotating target or magnetrons with a periodically turned target. A magnetron with a continuously rotating target is more efficient for application at conveyor type technological setups. A magnetron with a periodically turned target can be used at the batch type setups with movable technological sources.

Depending on technological requirements, we use magnetrons with magnetic systems forming either one flow of a sputtered material or two flows in diametrically opposite directions (two-sided magnetron) that allows making coating deposition on two substrates simultaneously. Magnetic system of a two-sided magnetron consists of two extended linear sections forming two sputtering tracks at diametrically opposite parts of the tube and two end sections providing the closure of the racetrack. We use magnetrons having this construction at the technological setups VNUK intended to deposit low- E coatings on architectural glasses having dimensions up to 1.6x2.5 m^2.

Sources of extended ion-plasma flows based on the accelerator with anode layer

We have developed extended ion-plasma sources based on the accelerator with anode layer intended for precleaning of large-area substrates (in particular, architectural glasses) prior to the coating deposition, and realization of CVD technologies. The source operation is characterized by simultaneous existence of the hollow cathode discharge plasma and ion beam in the vacuum chamber. The ion-plasma source has a high uniformity degree of the ion current linear density (current per unit of length of the source) that is achieved by the choice of the electrode system configuration, magnetic field strength, and operating pressure range. Fig. 4 presents measurement results of linear density of the source ion current for different operating parameters. This source has the full length of 350 mm and forms an extended ion beam with the linear part length of 236 mm. Nonuniformity of the ion current linear density doesn't exceed ± 4% at 90% of the source linear part. Ion sources with high uniformity of the ion current with the length up to 2 m have been designed on the basis of the obtained results.

High uniformity of the current linear density at the full extent of the ion source with closed electron drift makes possible to solve the problem of the diamond-like film deposition on large-area substrates. An important feature of the source that we have developed is possibility of simultaneous generation at definite conditions of a directed beam and uniform plasma. This allows realizing combined ion-plasma deposition of a-C:H films differing from ion deposition (ion beam only) by the high grow rate. It is necessary to note that it is not required to supply negative bias potential to the substrate that is important from the technological point of view.

Downloaded 24 Feb 2011 to 138.253.100.121. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions

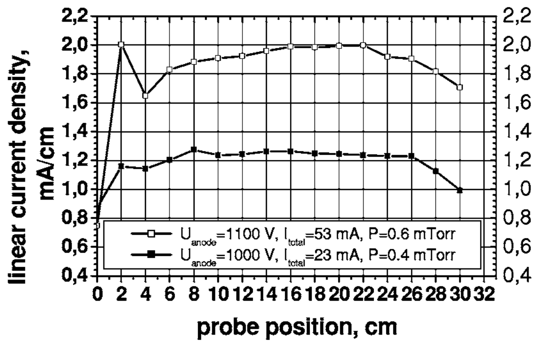

FIGURE 4. Measurement results of linear density of the source ion current for different operating parameters.

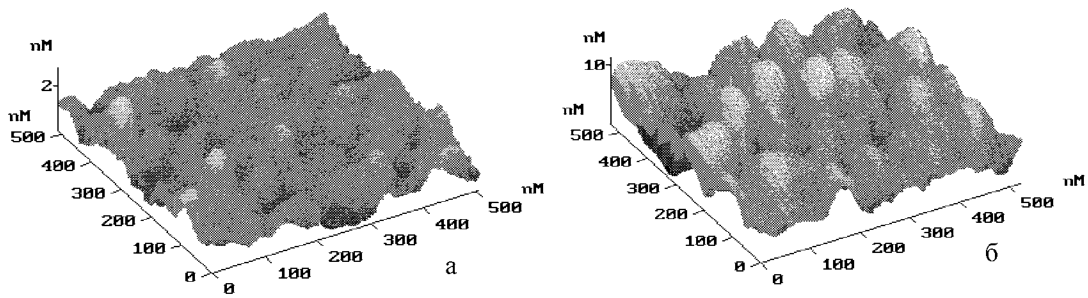

FIGURE 5. A picture of the surface of the diamond-like (a) and polymer-like (b) a-C:H-films obtained by means of an atomic-force microscope.

The experiments that were carried out have shown that the properties of the a-C:H-coatings deposited with the use of the ion-plasma source are determined by the relation of hydrocarbon ions from a beam and hydrocarbon radicals from plasma to the substrate surface in the process of deposition and by the ion energy proper. Optimum deposition parameters (gas pressure, current, discharge voltage) allowing obtaining a diamond-like a-C:H-coating differing by high hardness and adhesion to different substrates (silicon, glass, plastics, and polymers) were determined. Increase of the operating pressure and discharge current as well as voltage decrease at the accelerating gap resulted in deposition of a soft polymer-like film due to insufficient ion bombardment of the coating surface in the process of rising. One of the evidences of transition from the diamond-like to the polymer-like structure of the a-C:H-film can serve increase of the surface roughness from 2-3 to 10-12 nm that was observed by means of an atomic-force microscope (fig. 5).

CONCLUSION

Designs of high-performance cylindrical magnetron sputtering systems and ion – plasma sources allowing realizing the processes of depositing different coatings on large-area substrates have been developed. Use of a modified magnetic system at MSS with a rotating cathode allows widely using possibilities of the cylindrical target in achieving high target utilization degree. It is shown that hard diamond-like films can be obtained at the large area substrates using the chemical vapor deposition by means of an ion source with closed electron drift.

REFERENCES

1. Nadel S. J., and Greene P., Thin Solid Films 392, 174-183 (2001).
2. Safi I., Surf. Surf. Coat. Technol. 127, 203-219 (2000).
3. Bugaev S.P., and Sochugov N.S., Surf. Coat. Technol. 131, 474-480 (2000).
4. Kukla R., Surf. Coat. Technol. 93, 1-6 (1997).
5. Vershinin N., Straumal B, Filonov K., Dimitriou R., Gust W., and Benmalek M., Thin Solid Films 351, 190-193 (1999).
6. Vanderstraeten E., Norgan S., Vanderstraeten J., and Gobin G., patent of Canada, WO98/35070, (1998).
7. Shidoji E., Nemoto M., and Nomura T., J. Vac. Sci. Technol. A 18(6), 2858-2863 (2000).

Downloaded 24 Feb 2011 to 138.253.100.121. Redistribution subject to AIP license or copyright; see http://proceedings.aip.org/about/rights_permissions