CONTROL OF PLANAR MAGNETRON SPUTTERING SYSTEM OPERATING MODES BY ADDITIONAL ANODE MAGNETIC FIELD

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The control of planar magnetron sputtering system operating modes by additional anode magnetic field was investigated. It was shown that additional anode magnetic field substantially affects to planar magnetron-sputtering system (MSS) balancing and allows adjusting the electron fluxes intensity to the operating surface. It was experimentally shown that the magnetic field intensity increasing stabilizes the low-current discharge. The magnetic field intensity increasing prevents the discharge extinction by the ignition of semi-self-maintained magnetron-type discharge in transverse anode magnetic field.
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1. INTRODUCTION

Rapid development of the solid surface treatment technologies forces the improvement of the vacuum-plasma processing equipment. Magnetron sputtering method is one of wide spread occurrence methods among the variety of film deposition methods [1].

Magnetic field configuration under the sputtering target is the major factor causing MSS working parameters. Magnetic field configuration defines potential distribution in the main particle generation discharge region where current-carrying electrons are magnetized and also it defines sputtering target erosion zone. Besides, the magnetic field configuration defines the neutral and charged particles fluxes to the operating surface direction as well as temperature load to the operating surface and coating homogeneity. It is necessary to consider a lot of parameters and carefully choose the operating conditions to realize specific film deposition problem by MSS.

2. FORMULATION OF THE PROBLEM

The maximum efficiency of magnetron-sputtering films deposition method is proportional to magnetron discharge current. The transformation from DC magnetron discharge to the arc discharge occurs in the case of current excess and target erosion processes changes[2].

The increasing of discharge gap resistance by transverse anode magnetic field is one of the limit current enhancement methods. But this method substantially changes the discharge gap properties and conventional power supply units usage may be prohibitive [3].

The additional anode magnetic field creation by the outer magnets and magnetic circuits application allows providing any required magnetron sputtering system operating conditions without additional power supplies and basic construction conventional equipment engineering change.

3. EXPERIMENTAL RESULTS

The experiments were carried out with the use of planar MSS and *45×180 mm* copper sputtering target.

The cross-section and magnetic field configuration of MSS are calculated with the use of FEMM 4 freeware (Fig. 1).

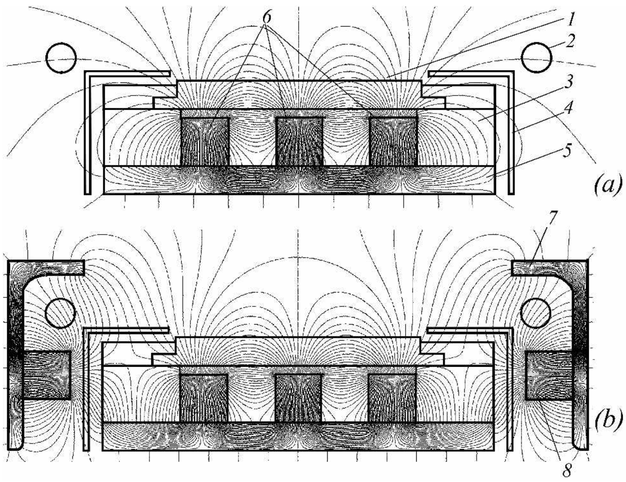

Fig. 1. The cross-section and magnetic field configuration of MSS. (a) without additional external magnetic field; (b) with external anode magnetic system. 1 – sputtering target, 2 – anode, 3 – MSS case, 4 – floating potential shield, 5 – magnetic conducting circuit, 6 – permanent magnets, 7 – external anode magnetic conducting circuit, 8– permanent magnets of the external magnetic circuit

The body and the details of the MSS are rounded with floating potential shield, behind which the water cooling anode is placed. The design of the MSS allows installation of the external anode magnetic conducting circuit, at which one can place permanent magnets. The polarity of the magnets has been chosen to align the vectors of the magnetic field generated by the anode circuit and the magnets under the cathode of MSS.

Fig. 2 shows the spatial distribution of the magnetic field strength along the anode plane. It has been calculated by the standard software FEMM 4.0.

The calculation of spatial distribution of the magnetic field in the MSS show that installation of the anode magnetic field circuit with permanent magnets generate additional near-anode transversal magnetic field.

Moreover, most part of the of the magnetic field lines, which were previously open (i.e. lines, which lead way beyond the body of the MSS), become locked to external magnetic circuit. This prevents irradiation of the processed surface with intensive electron flux and preserve the shape of the arc magnetic field over sputtered target.

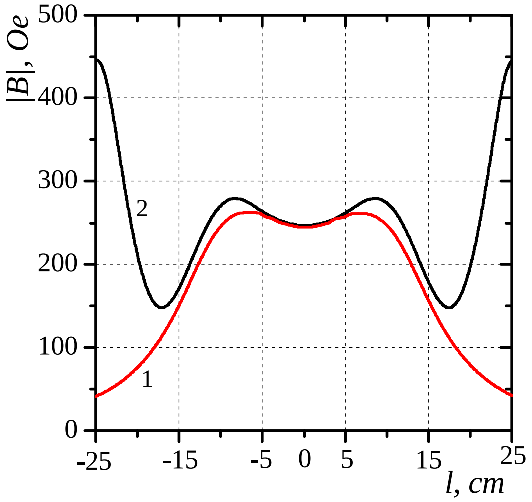

Fig. 2. The calculated spatial distribution of the magnetic field strength along the anode plane.
1– without anode magnetic field;
2– with anode magnetic field

Power feed of the MSS has been provided by magnetron power supply with off-load voltage of 1200 A, which allows the regulation of the discharge current. The current-voltage characteristics has been measured in the following way: the voltage has been measured at the power supply and the discharge current has been measured in anode part of the electric circuit. This approach has provided the reliability of the measurements.

MSS has been installed inside the vacuum chamber pumped down to residual pressure of $p=1\times10^{-5}$ Torr. The working pressure has been regulated by inlet of the Ar flow through the gas distribution system; the gas has been let in directly over the surface of the sputtered target. The pressure gauge has been located in the proximity of the discharge gap.

Fig. 3 and Fig. 4 show voltage-current characteristics of MSS without influence of additional external anode magnetic conducting circuit and with it. The figures show the characteristics measured at different working pressures.

One can see that the discharge is capable to glow in a wide range of pressure $p=(1..10)\times10^{-3}$ Torr, when there is no additional external anode magnetic conducting circuit used. However, when the external magnetic conducting circuit generates the field, the discharge is unable to ignite due to presence of the additional transversal magnetic field in the near anode region. This magnetic field provides additional resistance for the current of the discharge. The effect is present in the pressure range of $p<3\times10^{-3}$ Torr.

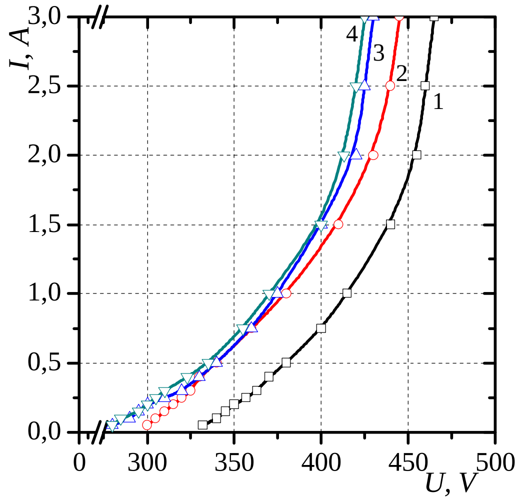

Fig. 3.Current-voltage characteristics of the magnetron sputtering system without anode magnetic field (Fig. 1, a): 1– $p=1\times10^{-3}$ Torr, 2– $p=3\times10^{-3}$ Torr, 3– $p=5\times10^{-3}$ Torr, 4– $p=7\times10^{-3}$ Torr

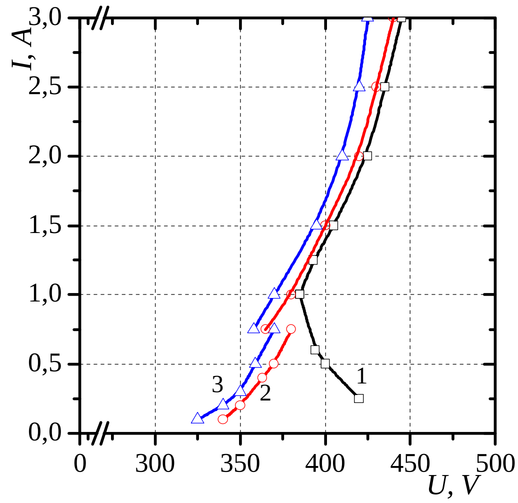

Fig. 4. Current-voltage characteristics of the magnetron sputtering system with anode magnetic field (Fig. 1, b): 1– $p=3\times10^{-3}$ Torr; 2– $p=5\times10^{-3}$ Torr; 3– $p=7\times10^{-3}$ Torr

The measurements confirm that the additional magnetic field influences the discharge parameters of MSS, when discharge current $I < 0.75$ A. At elevated working gas pressure $p=(5\ldots10)\times10^{-3}$ Torr, the presence of the additional external magnetic field helps to ignite the non-self-sustained discharge of the magnetron type. It glows in the near-anode region of the transversal magnetic field. The magnetized electrons in this region and in the region of the near-cathode arc magnetic field drift in the same direction. However, at lower pressure of the working gas $p=(4\ldots5)\times10^{-3}$ Torr, the magnetron discharge begins its dissipation, because the resistance of the discharge gap has been increased due to presence of the transversal magnetic field.

At higher discharge current, i.e. $I > (0.75\ldots1)$ A, the presence of the transversal magnetic field does not sufficiently change the parameters of the discharge glow characteristics of MSS

4. CONCLUSIONS

This work presents the expewrimental and theoretical study of the spatial magnetic distribution on discharge characteristics of the MSS. It has been shown that additional external anode magnetic conducting circuit may change sufficiently the balance of the planar MSS and allows regulation the intensity of the electron flows on the surface of the processed wafer.

The experimental findings show that the increase of the magnetic field strength in the near-anode region helps to stabilize the glow of the discharge, when the working pressure is low. It prevents also the discharge dissipation in the near-cathode region of the magnetic arc at lower pressure. This is possible due to ignition of the additional non-self-sustained discharge of the magnetron type in the magnetic field located in the near-anode region. This field provides the flow of the drifting magnetized electrons, which is directed similarly to the electrons in the near-cathode region.

However, the presence of the transversal magnetic field does not influence the discharge significantly, when the discharge current is high enough. This helps to increase the maximum discharge current due to increase the resistance of the discharge gap elevating the strength of the transversal magnetic field with the use of the standard power supplies..

Therefore, the application of the external magnetic field circuit allows to provide practically any required regime of the discharge glow, avoiding the usage of additional power supplies and re-design of the MSS

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УПРАВЛЕНИЕ РЕЖИМАМИ РАБОТЫ ПЛАНАРНОЙ МАГНЕТРОННОЙ РАСПЫЛИТЕЛЬНОЙ СИСТЕМЫ ДОПОЛНИТЕЛЬНЫМ ПРИАНОДНЫМ МАГНИТНЫМ ПОЛЕМ

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Исследовано управление режимами работы планарной магнетронной распылительной системы (МРС) дополнительным прианодным магнитным полем. Показано, что дополнительное прианодное магнитное поле существенным образом влияет на балансировку планарной МРС и позволяет регулировать интенсивность электронных потоков на обрабатываемую поверхность. Увеличение напряженности прианодного магнитного поля стабилизирует горение разряда в диапазоне малых разрядных токов за счет зажигания несамостоятельного разряда магнетронного типа в прианодном поперечном магнитном поле.

КЕРУВАННЯ РЕЖИМАМИ РОБОТИ ПЛАНАРНОЇ МАГНЕТРОННОЇ РОЗПИЛЮВАЛЬНОЇ СИСТЕМИ ДОДАТКОВИМ ПРИАНОДНИМ МАГНІТНИМ ПОЛЕМ

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Досліджено керування режимами роботи планарної магнетронної розпилювальної системи (МРС) додатковим прианодним магнітним полем. Показано, що додаткове прианодне магнітне поле істотно впливає на балансування планарної МРС і дозволяє регулювати інтенсивність електронних потоків на поверхню, що оброблюється. Підвищення напруженості прианодного магнітного поля стабілізує горіння розряду в діапазоні малих розрядних струмів за рахунок запалювання несамостійного розряду магнетронного типу в прианодному поперечному магнітному полі.