Investigation of a high-frequency magnetron sputtering system operation modes during copper thin films deposition

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Abstract. The results of studying the radio frequency (RF) magnetron sputtering (MS) operation parameters during copper sputtering are presented. A comparison of the growth rate dependence on power during the operation of MS is made in RF and DC modes. The pressure dependences of the RFMS growth rate and bias target voltage are obtained. The prospect of using RFMS for deposition of smooth coatings is shown.

1. Introduction

The problem of creating high-quality thin-film coatings is one of the most urgent among the modern directions in the development of ion-plasma technology. Currently, protective, wear-resistant, reinforcing, decorative coatings and technologies for metallization of rolled materials, manufacturing elements of electronic and microelectronic products, as well as optical systems are in demand. One of the ways to form thin films is the magnetron sputtering (MS) method, which makes it possible to obtain coatings from almost any materials (metals and their alloys, dielectrics, semiconductors) with high performance and good adhesion. Recently, in many areas, there has been a tendency to increase the requirements for the quality of coatings, the production technologies of which are well known and debugged. In particular, for modern high-quality optical mirrors [1], neutron supermirrors [2] and substrates for graphene synthesis [3], multilayer coatings for erosion diagnostics [4], the requirements for coating roughness are continuously growing. The most common method for achieving the set goals is the method of molecular beam epitaxy [5]. This method allows obtaining the smoothest coatings, but it has low productivity and requires expensive equipment. A good alternative to molecular beam epitaxy can be radio frequency magnetron sputtering (RFMS) [1–3, 6]. Although the roughness of the films obtained by RFMS is somewhat higher than that of epitaxial films, this disadvantage is fully compensated by the performance of the method when using the technology on an industrial scale. At the same time, much less attention is paid to RFMS in the scientific literature compared to other types of MS, which indicates the prospects of research on this topic.

2. Experiment details

In the work, an industrial HF MRS with a copper target was studied. The deposition scheme and a photo of the stand are shown in Figure 1. The vacuum chamber was pumped down to a base pressure of 5⋅10⁻⁶ Torr using a vacuum system based on a spiral and turbomolecular pumps. A capacitive manometer MKS Instruments 627D was used for vacuum measurement. Deposition process was performed in the pressure range 5⋅10⁻³...5⋅10⁻⁴ Torr and powers 100…1000 W (reflected power is less than 1% in...
RF mode at 13.56 MHz) with preliminary substrate cleaning by an ion beam. Power was supplied by an Applied electronics APEL-M-5PDC-650-2 DC power supply and an Advanced Energy CESAR RF power generator with a Navio matching device. Power supplies switched manually. The coating growth rate was measured using an Inficon STM-2 thin film monitor. The deposition was performed on single-crystal (110) silicon wafers without additional heating at a power of 1 kW, a pressure of $7,5 \cdot 10^{-4}$ Torr and a distance of 130 mm between the substrate and the MS. The coating thickness was 500 nm at a growth rate of 2.26 nm/s in RF mode and 3.54 nm/s in DC mode. The surface was studied using a scanning electron microscope (SEM) Thermo Scientific Quattro S.

Figure 1. Deposition scheme and general stand view.

3. Results and discussion
Figure 2 shows the pressure dependences of the growth rate and bias voltage of the RFMS target at a constant power (1 kW).

Figure 2. Dependences of the growth rate and RFMS target bias voltage on pressure.

It has been established that there is an optimal pressure at which the maximum growth rate is achieved. With a power of 1 kW, this pressure is $7,5 \cdot 10^{-4}$ Torr. In this case, no explicit dependence of
the growth rate on the self-bias voltage of the MPC target is observed. At the optimum pressure, the dependence of the coating growth rate on power was measured (Figure 3). In the entire power range, the coating growth rates in the RFMS mode were approximately 1.5 times lower than in the direct current mode under the same other conditions.

Figure 3. Dependence of the growth rate on the RFMS and DCMS power.

Figure 3 shows SEM images of two coatings 500 nm thick, obtained using RFMS and DCMS under the same conditions.

The coating obtained with RFMS is much smoother than the coating applied with DCMS. It can be concluded that the use of high-frequency magnetron sputtering systems is promising for obtaining coatings with the lower roughness.

Figure 4. Copper coatings obtained by the RFMS (a) and DCMS (b).
4. Conclusion
In conclusion, operation modes of RFMS during sputtering of copper films were considered. The most optimal pressure at which the maximum growth rate is achieved is determined. In this mode, coatings were obtained using RFMS and DCM. Further study of the coatings using a scanning electron microscope showed that the films obtained by RFMS are smoother. This indicates that the use of RFMS is promising for obtaining coatings with the lower roughness.

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