Features of DC magnetron sputtering of mosaic copper-graphite targets

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At present materials researchers are tailoring desired properties and composition to receive new material with unique properties. Multi-element or composite materials form the cornerstone of present research activities [1, 2]. Most of multicomponent materials are fabricated as thin films by pulsed laser or magnetron sputter deposition techniques. Magnetron sputtering provides broader possibilities for complex materials engineering due to the spatial extent of the source and consequently greater area that can be homogeneously deposited. There are several possibilities to create the magnetron sputtered multicomponent coatings. First of all, a multi-source approach is widely used to deposit multi-element thin films [3]. Another way to create multicomponent thin films involves making changes at the target level. For this aim targets from an alloys [4, 5] or sintered powders [6] can be used. However, such targets have the disadvantage: their composition cannot be changed in a flexible way. Unlike them, segmented targets could easily create the necessary composition [7-10]. An alternative approach is the use of inserts. In this case, the holes drilled in the racetrack are filled with small cylindrical pieces. However the metal flux from the target can hardly be uniform. There are reasons for which sputtering of mosaic targets is problematic in reproducing the stoichiometry of a multi-element target material in the film. That is because removing a material is a ballistic process that considerably depends on many coupled processing parameters, such as the materials of target elements, the discharge power density, the target-substrate distance, the biasing voltage, the sputtering gas and the gas pressure, the electrode geometry [1]. The nonuniformity of target erosion due to the different sputter yield of the different segments should be taken into account for controlling a films composition by means of, for example, the Monte Carlo simulations [7].

It was meanwhile observed, that magnetron sputtering of metal-graphite mosaic targets after some initial transitional period resulted in an operational mode with equal erosion rates of metal and graphite elements [11]. The cause for equalization of sputtering rates of materials with highly different sputtering yields remains unclear. To clarify the problem we investigated the magnetron sputtering of the mosaic targets containing the materials with a considerably different sputtering yield, namely copper and carbon.

The Cu-C composite was chosen as a promising material. These two elements are immiscible, and therefore the composite can combine the high electrical conductivity of copper with the high characteristics of carbon, namely, a low coefficient of thermal expansion and good tribological properties. These alloys may be used in various applications from electrical contacts with friction to materials for confining plasma in nuclear fusion reactors.

The mosaic targets consisted of copper disks with cylindrical graphite inserts, placed in the racetrack region (Fig. 1). The relative area of the inserts S_{gr}/S was varied (S is the area of sputtering surface; S_{gr} is the area of the graphitic inserts). Single-component targets made with pure graphite and copper were used as well. The sputtering was performed at the discharge power density of P = 90 W/cm^2, the argon pressure of 4 mTorr, the target-substrate distance 60 mm. The time-average velocities of sputtering surface displacement of copper G_{cop} and graphite G_{gr} in the racetrack region were measured, as well as the volumes of sputtered copper V_{cop} and graphite V_{gr} and the corresponding values of discharge current I and voltage U. The structure and composition of the target after sputtering was examined with SEM having an EDX analyzer.

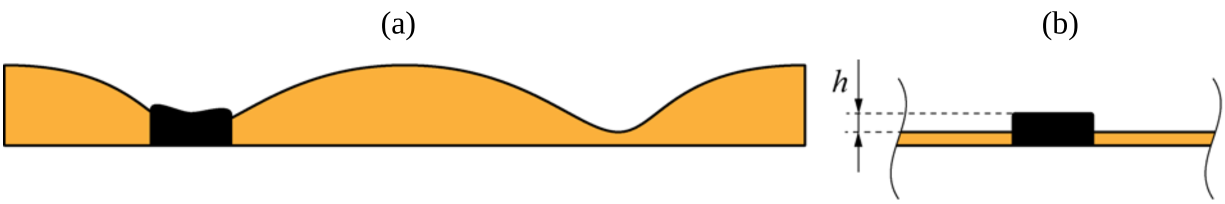

Fig. 1. Profiles of mosaic Cu-C target: radial profile (a), part of azimuth profile (b)

During about the first 60 min the values of G_{cop} and G_{gr} differed significantly, as a result the height drop h of about 1 mm between the graphite and copper surfaces was established. In the further sputtering these velocities equalized $G_{\mathrm{cop}} = G_{\mathrm{gr}} = G$ and the height h of the graphitic protrusion did not change during the process. The increase in the area of the graphite inserts resulted in the velocity G decrease at the same discharge power density.

Fig. 2 presents the dependencies of velocity G and of effective sputtering yield coefficients of copper Y(Cu) and graphite Y(C) sections on relative graphite surface area are presented. Effective sputtering yield coefficients Y(Cu) and Y(C) were obtained from experimental values of V_{cop} and V_{gr} and time- average ion currents on copper (I_{cop}) and graphitic (I_{gr}) parts of the sputtered target. The ion currents were corrected with allowance of ion-electron emission. When estimating the I_{cop} and I_{gr} it should to be taken into account that the ions are focussed to the nearest protruding surface by the electric fields in presheath and cathode layer. The ion path in the cathode layer is colissionless. With the cilindrical stub arised, the plasma potential distribution changes [12] and some part of the ion flow is redirected to graphite protrusion. As a result the effective ion collection area S_{gr}^{eff} (and I_{gr} accordingly) can increase by 50% and more as compared with the geometrical area of the top of inserts, increasing the value of I_{gr}/I_{ion}. In deriving the ion current on I_{cop} and I_{gr} we took into account that centers of the graphite inserts were in the region of the maximal racetrack erosion, so the ion current density on the inserts was higher than the average one $j \approx I_{ion}/S$. The obtained values of Y(Cu) and Y(C) for various insert areas and discharge voltages are shown in Fig. 2. The value of Y(C), calculated from measured values of V_{gr} decreased significantly taking into account the ion flow redistribution. On the contrary, value of Y(Cu) increased and gave the growing dependence of Y(Cu) on the discharge voltage. But Y(C) is still remained 2.5–3 times larger than the measured effective sputtering yield of the pure graphite target.

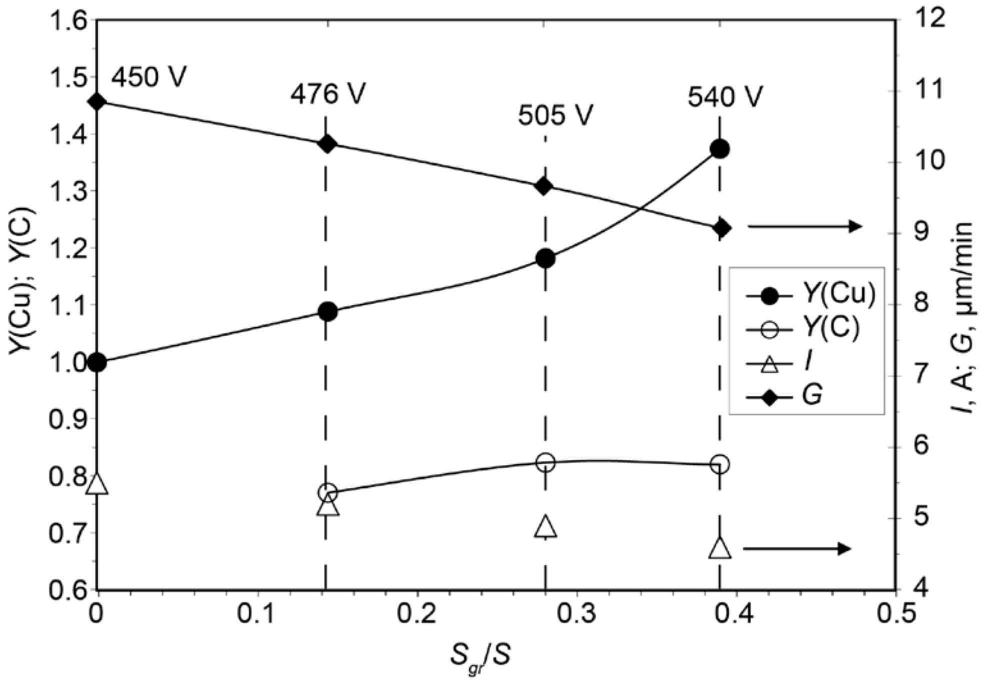

Fig. 2. The dependencies of velocity of sputtered mosaic target surface movement G and of effective sputtering yield coefficients Y (Cu) and Y(C) on relative graphite surface area.

SEM analysis of the sputtered target showed that sputtering surface of the inserts had an intricate micro relief. EDX analysis showed the presence of C, Cu and Ar in the sputtered graphite insert. In the regions without caverns the content of Cu was in the range of 5–12 at.%, Ar was 1–7 at.%. In the caverns the content of Cu was up to 100 at. % and Ar was up to 10 at.%. Thus during the high power sputtering the significant structure modification and composition change of target surface layer occurred. The estimation of a Cu ion fraction in the plasma n_{Cu} for our conditions and the calculation of the ion range in carbon with allowance the experimentally measured G value gave the relative concentration value of several percent for implanted Cu and

Ar near the surface of the carbon insert. These results give the reason to believe that during the sputtering an implantation of bombarding ions into the carbon insert and capture of the atoms (Ar and Cu) occurred. The change in the surface composition, produced by the implanted heavy inert gas atoms, has minor effects on sputtering yield because of relatively large size of these atoms. It is known that heavy atoms of high density impurities significantly increase the sputtering yield of light component by increasing the fraction of energy loss in the surface layers of the lattice [13,14]. According to our SRIM calculation, addition of 4–6 % of Cu atoms increases Y(C) by 60–90 %, and only by 15 % in case of Ar atoms impurities.

Obviously the content of copper in graphite inserts should increase with the growth of n_{Cu} and the Cu ion energy. This explains the observed relationship of the equalization of sputtering rates with the discharge power enhancement.

Thus the reasons described above are as follows: the ion flow redistribution due to graphitic insets protruding above the copper surface and the graphite sputtering yield increase due to Cu and Ar implantation can explain the effect of sputtering rate equalization for mosaic copper-graphite targets. The equalization of velocities because of ion flow redistributions should occur at sputtering of mosaic targets with small inserts of any composition.

The work was supported by RFBR grant #12-02-01177.

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