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ONE-BEAM DYNAMIC ION MIXING APPLIED TO COAT ELEMENTS ONTO SOPHISTICALLY SHAPED OBJECTS

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Recently suggested single-ion-beam setup for ion-beam assisted deposition (IBAD) of layers with various composition including the sputter target in a form of hollow truncated cone made of the material to be deposited allows the use of a single ion beam (e.g., noble gas) for simultaneous layer deposition and ion-beam mixing. Such a setup can also be applied for coating deposition on the surfaces having sophisticated geometric shape. In the present work single-beam IBAD was used for deposition of Ni and Mo coatings onto the surface of ball fingers. The Rutherford backscattering was used for evaluating the coating thickness distributions along the spherical surface of the aluminium ball fingers. It is shown that the results can be explained in terms of space distribution of the sputtered atoms inside the conical target.

INTRODUCTION

IBAD techniques are used for deposition of metals and other kinds of materials, e.g., integrated circuits metallization, dielectric layers, corrosion resistant and hardening coatings [1, 2]. These techniques provide such advantages as high adhesion and non-porous structure of the deposited coatings due to interfusion of the deposited and substrate materials in the intermediate layer. In its turn, ion sputtering makes it possible to deposit metals and alloys with the highest melting temperatures. In [3, 4] we have suggested the new type source for the substance to be deposited, making use of ion-beam sputtering of the inner surface of the truncated cone made of the desired material with the cone wide part perpendicular to the ion beam axis. The samples to be coated were placed inside the conical target. Such a setup allowed us to realize IBAD process using single ion beam of noble gas. This approach allows as to essentially simplify the technology and make the associated equipment less expensive, while retaining the advantage of the IBAD process. To improve the adhesion behavior of deposited layers and introduce an additional flexibility in the discussed processing's, a special sample holder has been designed [5]. This holder provides the cooling of the sample with running water during the implantation procedure, cleaning the sample surface under low-energy ion bombardment and repetitive (cycling) layer deposition with subsequent IBAD and ion beam mixing [6] of the layers. Recently it has been shown that produced in such a way multicomponent coatings on the surface of copper contacts of the key-type electric switches can substantially improve their properties in long-term operation [7]. One more potentially attractive application of single – beam IBAD technique is deposition of coatings onto three – dimensional objects [8, 9]. Our previous experiments also demonstrate that the deposition rate and the mixing efficiency are strongly dependent on the position and orientation of the flat sample surface inside the conical target. So, more detailed study of the spatial distribution of sputtered atoms inside the conical sputter seems to be essential especially for coatings of more geometrically sophisticated objects.

In this paper we present the results of the experimental measurements by RBS technique of the spatial distribution of sputtered target atoms inside the cone during implantation, together with the results of the experiments on the Mo and Ni coatings deposition onto the surface of three – dimensional objects having a form of ball fingers using single – beam IBAD setup.

EXPERIMENTAL

The schematic diagram in fig. 1 illustrates the essential features of the experiments on spatial distributions of the sputtered atoms measurements. Polished silicon 25×60 mm plate was placed parallel to the sputtering ion beam axis. The specimens of sputtered materials, 3×3 mm in size, were mounted at a distance of 15 mm from the silicon plate at an angle of 15° to the Si surface, thus playing a role of a small part of the conical surface. Specimens of W, Mo and Ni were irradiated with 75 keV Xe^+ ions up to a fluence of 4.5×10^{17} cm^{-2} in the vacuum environment of 3×10^{-6} Torr, sputtered atoms were collected at the Si surface. Then the deposited films were examined by RBS. RBS spectra were sequentially measured along the long side axis of Si plates with a step of 2 – 3 mm.

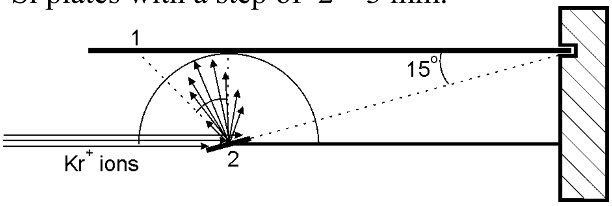


Fig. 1. Scheme of the experimental arrangement for the spatial distribution of the sputtered atoms measurement

The ball fingers for IBAD experiments were made of industrial aluminium alloy, containing about 1 per cent of copper. The surface of the samples was mechanically polished till the mirror finish. After cleaning in organic solvent the samples were placed into conical sputter (fig. 2.) made of Mo or Ni, which then was irradiated with 80 keV Kr^+ ions up to a fluence of 3.0×10^{17} cm^{-2}.

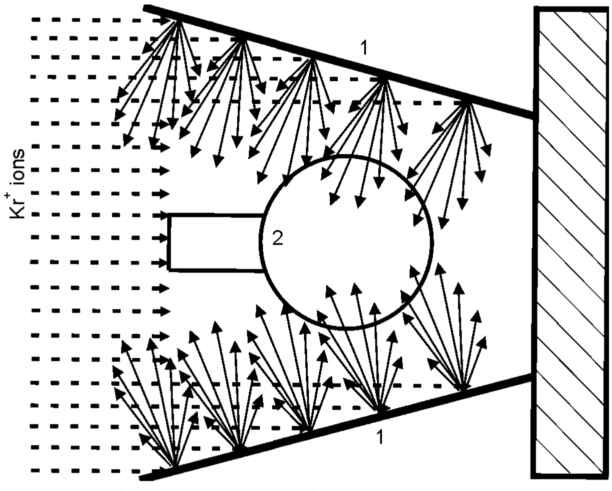


Fig. 2. Scheme of the coating deposition experiment: 1 – truncated cone of material to be deposited, 2 – ball finger.

The thickness of the deposited Mo and Ni films on the spherical parts of the ball fingers was measured by RBS. He^+ ion beam with $E_0 = 1.5$ MeV was used in experiments. The backscattered at 170° He particles were detected by the RBS spectrometer with overall energy resolution of 17 keV. The samples were mounted on the three-axis goniometer in a specially designed sample holder in such a way that the center of the spherical part coincided with the inter-section point of the goniometer rotation axes and the axis passing through the cylindrical part of the sample coincided with the analyzing ion beam axis. Previously goniometer position was adjusted so that the ion beam hit the center of the sample holder. Therefore, after the sample tilt with respect to the ion beam axis the beam spot displacement along the sample sphere was directly proportional to the tilt angle. The diameter of the sphere was 15.8 mm and the beam diameter – 1.5 mm so the angle step of 15° was chosen since analysis regions for the neighbouring points did not overlap. RBS spectra were measured for the tilt angle interval 0 – 135°, where zero point is situated at the sphere pole opposite the cylindrical part of the sample. To estimate the film thickness homogeneity in azimuthal direction two sets of measurements in mutually perpendicular planes was accomplished for each sample.

RESULTS AND DISCUSSION

Fig. 3 shows the dependencies of Ni and W layer thickness (in atoms per square cm) on the distance from the right end of silicon plate, according to fig. 1. The measured profiles have

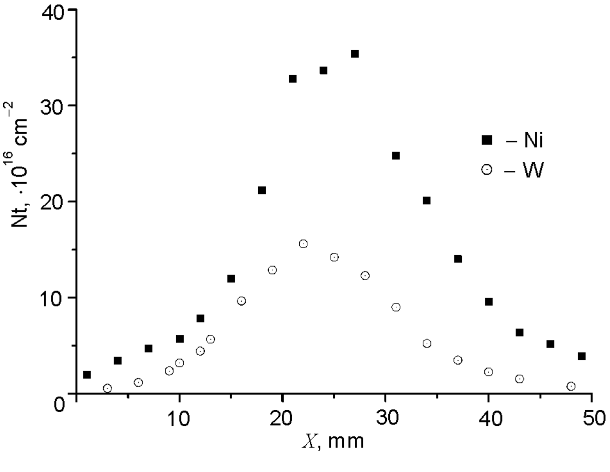
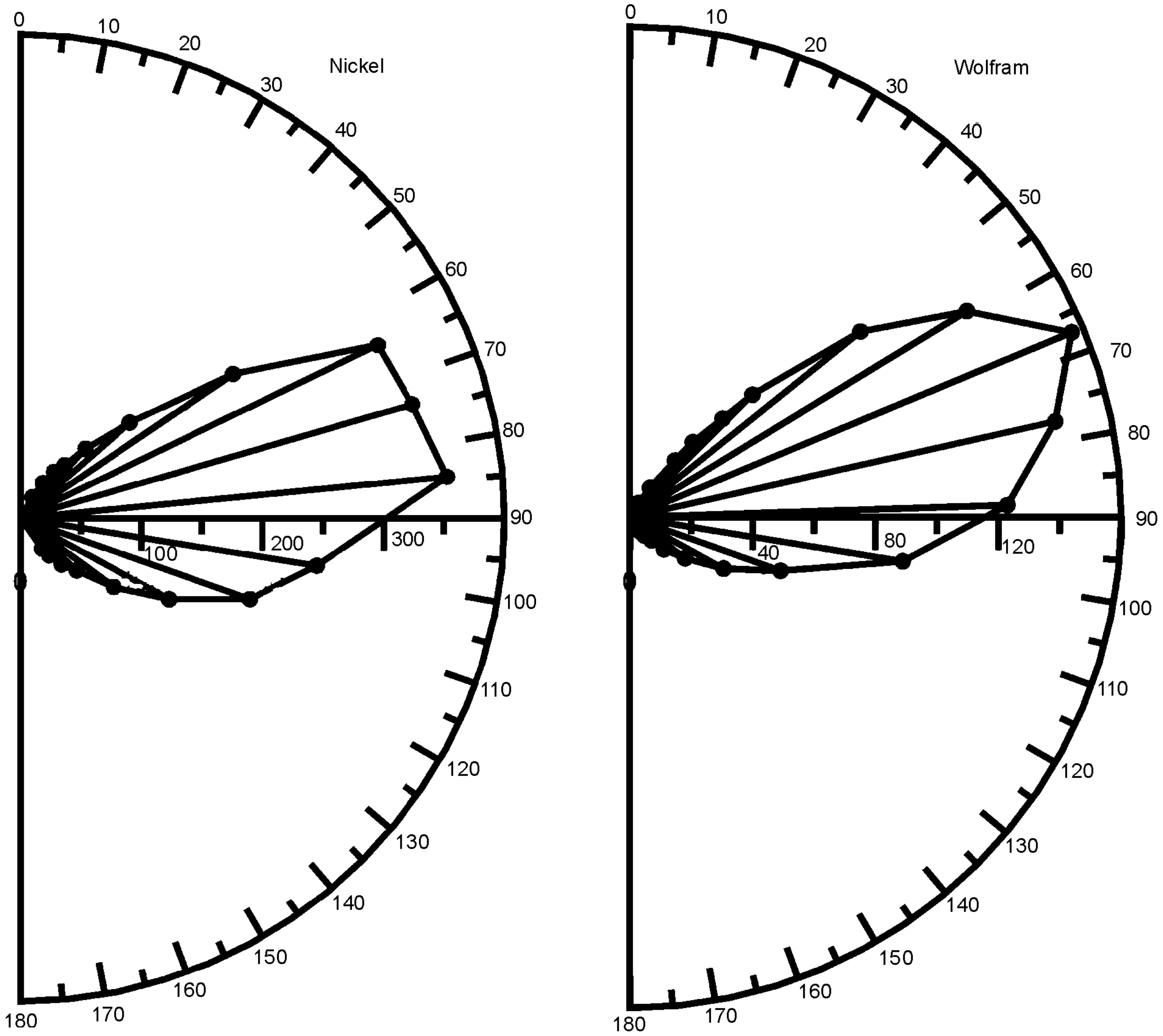


Fig. 3. Thickness of the deposited Ni and W layers vs. distance along the cone axis.



a)　b)

Fig. 4. Angular distributions of the sputtering yield for Ni – a) and W – b).

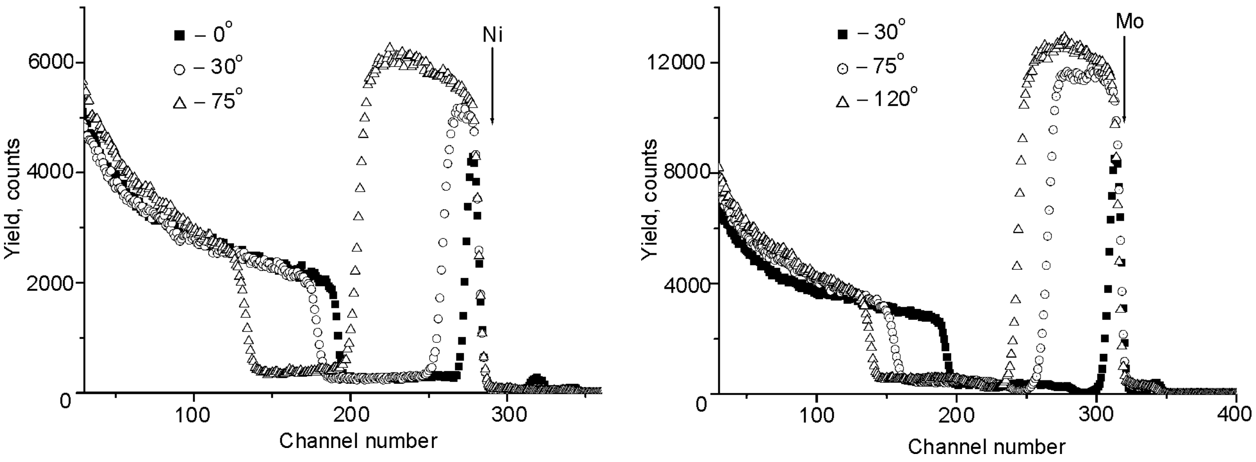
very similar shape, close to that of Gauss distribution.

On the basis of the data from fig. 3 angle distributions of sputtered atoms yield was calculated. The results of these calculations are graphically presented in fig. 4. Here the mark "90°" indicates direction perpendicular to the cone axis. It is seen that the maximum flux of the sputtered atoms is formed above the normal to the cone axis and is situated close to the perpendicular to the center of the sputtered specimen.

So, each point of the inner surface of the cone behaves as the source of sputtered atoms with the angular distribution like shown in fig. 4.

Fig. 5 represents RBS energy spectra taken at different tilt angles from the ball fingers with deposited Ni and Mo, respectively. It is clearly seen that the deposited coatings possess strong thickness inhomogeneity in latitudal direction.

Calculated from the RBS data tilt angle – film thickness dependencies are shown in fig. 6. The presence of two sets of points for each element reflects the fact that two sequences of measurements were done for mutually perpendicular planes. The difference in thickness for minimum and maximum values reaches an order of magnitude for Ni and even exceeds this value for Mo coating. Such a result can be explained as follows. Our measurements of the spatial distributions of sputtered atoms showed that the maximum of the flux is directed perpendicular to the cone surface, hence, their highest density is created inside the upper (wide) part of the cone. Besides, the sputtered area of the conical target also increases when moving from its narrow to



a) b)

Fig. 5. RBS spectra from the IBAD treated samples taken at different tilt angles, a) – Ni, b) – Mo.

the wide part whereas the ion beam density of noble gas remains constant. One more important participating factor is the spherical shape of the treated samples. In the pole zone of the sphere the angles of incidence of the sputtered atoms on the sphere surface take the maximum values, thus increasing the probability of re-sputtering of the deposited film and decreasing the probability for incident atoms to be captured at the sample surface. These factors should be taking into account for depositing the uniform thickness coating onto sophistically shaped objects including spherical ones.

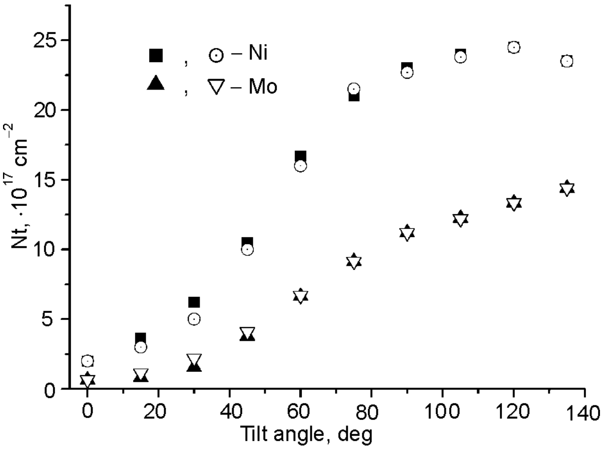


Fig. 6. Dependencies of the deposited film thickness on the tilt angle value.

CONCLUSION

The single – beam IBAD can be efficiently used to coat different layers onto sophistically shaped objects. To deposit the uniform coatings onto such substrates the realistic spatial distributions of sputtered atoms as well as a special form of the treated samples should be taken into account in such prospective processing.

Moreover, the presented results are of a great importance to predict progressive and rotational motions of treated objects in order to provide the uniform coatings onto such substrates.

REFERENCES

1. Ray R.A., Cuomo J.J., Yee D.S. Control of microstructure and properties of copper films using ion-assisted deposition//J. Vac. Sci. Technol. – 1988. – Vol. A6, No. 3. – P. 1621-1626.
2. Berkowitz A.E., Benenson R.E. Ion beam enhanced adhesion of Au films on Si and SiO_2//Nucl. Instrum. and Meth. in Phys. Res. – 1985. – Vol. B7-B8. – P. 877- 880.
3. Komarov F.F., Komarov A.F., Ïukowski P., Karwat Cz., Sielanko J., Kozak Cz.M., Kiszczak K. Ion beam assisted deposition of metal layers using a novel one beam system//Vacuum. – 2003. – Vol. 70. – P. 215-220.
4. Karwat Cz., Komarov F.F., Kozak Cz., Lozak M., Romaniuk F., Ïukowski P. Electrical and mechanical properties of surface layers deposited on copper by the novel IBAD method// Vacuum. – 2003. – Vol. 70. – P. 221-225.
5. Bojko E., Karwat Cz., Kiszczak K., Kolasik M., Koltunowicz T., Komarov F.F., Komarov A.F., Kozak Cz., Wdowiak A., Ïukowski P. Deposition of monoatomic and compound metal layers by the dynamic ion mixing//Vacuum. – 2005. – Vol. 78. – P. 241-245.
6. McNally J.J., Jungling K.C., Williams F.L. Optical coatings deposited using ion assisted deposition//J. Vac. Sci. Technol. – 1987. – Vol. A5, No. 4. – P. 2145-2149.
7. Bojko E., Karwat Cz., Kiszczak K., Kolasik M., Koltunowicz T., Komarov F.F., Kozak Cz., Romaniuk F.A., Wdowiak A., Ïukowski P. Elect-

rical properties of contacts covered with multicomponent coating by the dynamic ion mixing// Vacuum. – 2005. – Vol. 78. – P. 495-502.

8. Ensinger W. Ion sources for ion beam assisted thin-film deposition//Rev. Sci. Instrum.– 1992.– Vol. 12. – P. 5217-5233.
9. Harper J.M.E., Cuomo J.J. Modification of metals by low energy ions during thin film deposition//J. Vac. Sci. Technol. – 1985. – Vol. A3, No. 6. – P. 2693-2696.

ОДНОПУЧКОВЕ ДИНАМІЧНЕ ІОННЕ ПЕРЕМІШУВАННЯ ДЛЯ НАНЕСЕННЯ ПОКРИТТІВ НА ОБ'ЄКТИ СКЛАДНОЇ ФОРМИ

Е.Б. Бойко, Ф.Ф. Комаров, П. Жуковський, Ч. Карват, М. Коласик, Ч. Козак

Запропоновано систему з одним іонним пучком для іонно-асистуємого нанесення (ІАН) шарів різної композиції, яка включає мішень, що розпорошується, у формі усіченого порожнього конуса, виготовленого з матеріалу, що буде наноситися. У цій системі одночасно реалізується як нанесення шару, так і іонно-променеве перемішування його з підкладинкою. Така система може використовуватися і для нанесення покриттів на вироби довільної геометричної форми. У цій роботі однопучкове ІАН застосовувалося для осадження шарів Ni і Mo на поверхню алюмінієвих кульових пальців. За допомогою зворотного резерфордівського розсіювання іонів He^+ визначався розподіл товщини покриття уздовж сферичної поверхні кульових пальців. Показано, що отримані результати можна пояснити на основі даних по просторовому розподілі роспилених атомів усередині полою конічної мішені.

ОДНОПУЧКОВОЕ ДИНАМИЧЕСКОЕ ИОННОЕ ПЕРЕМЕШИВАНИЕ ДЛЯ НАНЕСЕНИЯ ПОКРЫТИЙ НА ОБЪЕКТЫ СЛОЖНОЙ ФОРМЫ

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Предложена система с одним ионным пучком для ионно-ассистируемого нанесения (ИАН) слоев различной композиции, которая включает распыляемую мишень в форме усеченного полого конуса, изготовленного из материала, который будет наноситься. В этой системе одновременно реализуется как нанесение слоя, так и ионно-лучевое перемешивание его с подложкой. Такая система может использоваться и для нанесения покрытий на изделия произвольной геометрической формы. В настоящей работе однопучковое ИАН применялось для осаждения слоев Ni и Mo на поверхность алюминиевых шаровых пальцев. С помощью обратного резерфордовского рассеяния ионов He^+ определялось распределение толщины покрытия вдоль сферической поверхности шаровых пальцев. Показано, что полученные результаты можно объяснить на основе данных по