Electrochemical metallization of molybdenum alloys

A A Tikhonov¹, S I Arendateleva¹ and T I Perepelitsa²

¹Yaroslav-the-Wise Novgorod State University, ul. B. St. Peterburgskaya, 41 173003, Veliky Novgorod, Russia
²GK Rosatom, JSC ATOMPROEKT, 197183, St.-Petersburg, ul. Savushkina 82

Abstract. The experimental data about influence of chemical and electrochemical operations of surface treatment of alloys of molybdenum on adhesion and solderability of electroplatings are provided. Influence of structures and the modes of electrolytes on quality of coverings, adhesion and solderability of the coverings applied on molybdenum alloys is studied. It is proved that use of combination in one electrolyte of two operations: electrochemical etching and at once the carried-out operation of copper plating, leads to increase in adhesion of coverings to molybdenum alloys. It occurs because the oxide layer is rather fully pitted during anodic dissolution, and the most important, it doesn't manage to be formed before deposition again as it occurs in many other known technological processes. The developed technology of galvanic metallization of molybdenic alloys allows: to reduce the number of technological operations, to increase efficiency of process, to use cheaper inventory, to increase adhesion of electroplatings to alloys of molybdenum and to improve their solderability.

1. Introduction

Molybdenum possesses a number of valuable properties: high melting temperature 2620°C; corrosion and chemical resistance in various environments, including sulfuric, hydrochloric and orthophosphoric acids; high modulus of rigidity (Young’s modulus); low coefficient of thermal linear expansion; density 10,2г/см³, i.e. it is almost two times lighter than tungsten. That is why molybdenum has higher specific strength at temperatures below 1370°C. Molybdenum has such limitation as low scale resistance, besides it forms brittle welding compounds and can hardly be wrought, soldered and metalized. Some limitations of molybdenum can be corrected by alloying [1]. Consideration should be given to relatively new, so-called pseudo-alloys of molybdenum with copper of brands MD40, MD50. In the given work, exactly these alloys were used for galvanic metallization; they are called like this, because they are made by method of powder metallurgy, not by alloying. Due to copper alloying of molybdenum, these alloys have higher heat and electrical conduction than pure molybdenum, they are more technological, and also have rather high heat resistance [2]. Thanks to its properties, molybdenum and its alloys can be used in electronics, instrument making, aerospace, atomic and other industries. However, molybdenum alloying does not improve much its poor ability to be soldered and metalized. First of all, this is associated with its great affinity to oxygen, as an oxide film interferes with above-mentioned processes. While soldering, it is recommended to remove an oxide film from the surface of molybdenum and molybdenum-base
alloys by means of dipping into the melt consisting of 70% caustic soda and 30% sodium carbonate at temperature not higher than 400°C, or with the help of electrolytic etching in 80% aqueous solution of sulfuric acid at temperature 50 – 60°C. However, this does not allow to solve completely the problem of performing high quality soldering of molybdenum and molybdenum alloys in the conditions of increased demands to this process [3]. To metalize molybdenum and its alloys, various ways have been suggested: galvanic method, chemical method, vacuum condensation, magnetron sputtering, and others. For example, there is a well known way including the following operations: anodic stripping of oxides in 10% solution of etching acid at current density 5 A/dm² for 5 minutes, thermal processing in vacuum at temperature 700 – 900°C. The next way consists of the operations: electrochemical degreasing in 10 – 20% solution of caustic soda at current density 5–8 A/dm², activation in hydrochloric acid, chrome plating in standard sulfuric electrolyte, etching in hydrochloric acid, nickel plating in acid electrolyte with pH less than 1, etching in hydrochloric acid, and nickel plating in standard sulfuric electrolyte.

Much consideration has been given to metalize molybdenum and molybdenum alloys; multi-operative technologies have been developed, in which ecologically harmful substances are often applied, and expensive equipment (vacuum furnaces, furnaces with hydrogen environment, etc.) is used. However, these technological processes have low productivity, and they do not solve to the end the problem of increasing adhesion of coatings and improving their solderability [4, 5].

This work is devoted to further improvement of electroplating technology of molybdenum alloys, increased adhesion of applied coatings, and improvement of their solderability.

2. Materials and Methods

Plates of copper-containing molybdenum pseudo-alloys MD40 and MD50 with 40% – 50% of copper, depending on the brand, were used as samples. Percentages in these alloys of molybdenum are given by weight as all other percentages given in this work. The samples had size 61x42x1mm. The samples of alloy MD40 were used in all experiments. The samples of alloy MD50 were used only in the last series of experiments (III -5). Distilled water and chemicals of brand "сhp" (chemically pure) were used to prepare electrolytes. Electrochemical operations were performed in 1 liter bath equipped with thermostating system, a propeller blade mixer, and rectifier VTKG-3 with current stabilization system. Adhesion strength of coatings with molybdenum alloys was checked by methods of scratch-brushing, filing, undercutting, detachment. Solderability of the coating was checked by solder flowing area POS61 (tin-lead solder containing about 61% tin) on the tin-bismuth coating and by contact angle determination with the help of a unit for programmable heating and welding VSU200. Samples with dosed test charge 0.5 g of solder POS61 were placed in the unit VSU200, vacuumized and preserved in nitrogen. Vapors of formic acid derived at gas bubbling through liquid formic acid were used as a fluxing agent. Fluxing was performed at temperature 170°C during 6 minutes. Soldering was performed at temperature of isothermal hold time 220°C during 1.5 minutes.

3. Examination of impact of preparing molybdenum alloy surfaces on adhesion and soldering of galvanic coatings

Adhesive strength of coatings on molybdenum alloys is much less, if compared with that of galvanic coatings with copper, brasses, plain steels, and other well-metalized metals and alloys. This is associated with the fact that a molybdenum surface is coated with an oxide film which is badly etched, and, after removing, it can be formed again very soon. Due to this, much consideration has been given to composition selection and etching regimes of molybdenum alloys.

The first variant of technological scheme consisted of the operations: degreasing at temperature 60 – 80°C, washing in hot tap water at the same temperature, chemical etching, washing in cold tap water, washing in cold distilled water, electrolyte 1 tin-bismuth galvanic alloying (presented in table 2), washing in reclaim rinse, washing in hot water 60 – 70°C, drying, and quality control. The first variant has been presented by experiments denoted with I-1, I-2, I-3, I-4, where Roman numeral denotes the variant number, and Arabic numeral matches the number of chemical etching solution presented in table 1. The second variant of technological scheme differs from the first one in that, before tin-bismuth
alloying, the so-called “flash” nickel plating in electrolyte 2 presented in table 2 was used, and chemical etching was performed in solution 3 (table 1), correspondingly, the experiment is denoted as II-3. In the third variant of technological scheme, electrochemical etching was used instead chemical one, with electrolytes given in table 4 (experiments III-1, III-2, III-3, III-4), and, before tin-bismuth alloying, the operation of galvanic coppering was performed in sulfuric acid electrolyte 3 (table 2).

Samples for all experiments were degreased in the following solution (g/l): caustic soda 10–20, sodium carbonate 40–50, tri-sodium phosphate 40–50, sodium metasilicate 3–5, synthanol (ДС-10) 1–2. Temperature of this electrolyte was maintained from 60 to 80°C. At first, in this solution chemical degreasing has been performed for 5 min, then cathode degreasing has been done at current density 5–10 А/dm² for 3 min, and then anode degreasing has been done at current density 3–8 A/dm² for half a minute. Degreasing quality was controlled by sample surface wettability with water.

| Components and regimes | Solution 1 | Solution 2 | Solution 3 | Solution 4 |
|------------------------|------------|------------|------------|------------|
| Potassium ferricyanide, g/l | -          | -          | -          | 200        |
| Caustic soda, g/l     | -          | -          | -          | 50         |
| Hydrofluoric acid, %   | -          | -          | 6          | -          |
| Sulfuric acid, %       | -          | 80         | 18         | -          |
| Hydrochloric acid, %   | 39         | -          | -          | -          |
| Temperature, °C        | 20–25      | 20–25      | 20–25      | 58–60      |
| Time, minutes          | 5          | 5          | 5          | 5          |

| Components and regimes | Electrolyte 1 | Electrolyte 2 | Electrolyte 3 |
|------------------------|---------------|---------------|---------------|
| Stannous sulphate, g/l | 40–60         | -             | -             |
| Bismuth sulphate, g/l  | 0.8–1.5       | -             | -             |
| Nickelous chloride, g/l | -            | 100–150       | -             |
| Cuprous sulphate, g/l  | -             | -             | 200–250       |
| Sulfuric acid, g/l     | 100–110       | -             | 50–70         |
| Hydrochloric acid, g/l | -             | 100–150       | -             |
| Sodium chloride, g/l   | 0.3–0.8       | -             | -             |
| Preparation OS-20, g/l | 4–5           | -             | -             |
| Cathodic current density, A/dm² | 1          | 10          | 2             |
| Time, minutes          | 15–30         | 3–5          | 15–30         |
| Temperature, °C        | 18–30         | 25–40        | 18–30         |

In experiments I-1, I-2, I-3, I-4, II-3 with samples of alloy MD40, smooth 6 to 8 mcm thick tin-bismuth coatings without visible defects were obtained. However, as table 3 shows, adhesion of these coatings is very low, especially of those obtained in experiments I-1, I-2, I-3. These samples withstood scratch-brushing trials only, the rest did not withstand the trial. Potassium ferricyanide-base solution recommended to etch molybdenum copper-containing alloys was tried [6]. At etching in this solution (experiments I-4), selective etching took place. Molybdenum was etched off faster than copper. The alloy surface became dark-red due to formation of copper matt layer on the MD40 alloy surface. However, as table 3 shows, adhesion of tin-bismuth coatings on samples in experiments I-4 did not become better, if compared with that of similar coatings on samples obtained in other experiments I-1, I-2, I-3. Thus, chemical etching only is not enough to prepare the surface of molybdenum alloys. In relation to this, experiments II-3 were carried out, in which, to increase adhesion, the sublayer of fine nickel of acid flash electrolyte with pH less than 1 was used, before alloying with tin-bismuth coatings. Such technology also did not solve completely the problem of low adhesion. Though the adhesion...
became a little better, as the samples could withstand the scratch-brushing and scratching trials, and other samples obtained in experiments I-1, I-2, I-3, I-4 could withstand scratch-brushing only. Nevertheless, such adhesion is not enough to practice metalized MD40 alloys.

Table 3. Adhesion of galvanic coatings of tin-bismuth alloys on MD40 alloy treated in chemical etching agents.

| Experiment number | Adhesion measurement methods |
|-------------------|-----------------------------|
|                   | 1 | 2 | 3 | 4 |
| I-1               | + | - | - | - |
| I-2               | + | - | - | - |
| I-3               | + | - | - | - |
| I-4               | + | - | - | - |
| II-3              | + | + | - | - |

In tables 3 and 5 the following adhesion measurement methods are given: 1 – the manual scratch-brushing method with a brass brush, 2 – the method of gridding with a scalpel (a scratch mark method), 3 – the method of filing the coated sample edge with a file, 4 – the method of tearing off a wire soldered (by POS61) to the coating. When tearing off, the samples have been considered to stand the trial, if the breakage occurred along the solder, i.e. the adhesion exceeded the solder strength, and, accordingly, the samples have been considered to not stand the trial, if the coating came off the surface of the molybdenum alloy.

While soldering, the solder POS61 practically did not flow on the MD40 alloy samples coated with the tin-bismuth alloy (experiments I-1, I-2, I-3, I-4), and, accordingly, the samples had very poor or poor solderability (see table 7). As all copper samples coated with the tin-bismuth alloy were soldered excellently, the above-indicated solder flowed well. Taking this into consideration, technology of coating the MD40 alloy with a two-layer coating consisting of a copper sublayer and a galvanic tin-bismuth alloy has been worked out. To practice this technology, electrolytes for electrochemical treatment presented in table 4 were used.

Table 4. Electrolyte compositions and electrochemical treatment regimes.

| Components and regimes | 1 | 2 | 3 | 4 | 5 |
|------------------------|---|---|---|---|---|
| Sodium carbonate, %    | 20|   |   |   |   |
| Orthophosphoric acid, %|   | 90|   |   |   |
| Sulfuric acid, %       |   | 20| 80| 45–65|   |
| Cuprous sulphate, %    |   |   |   | 2–3|   |
| Anode current density, A/dm² | 2 | 3–6 | 1–10 | 3–30 | 10–30 |
| Cathode current density, A/dm² |   | 3–10 |   | 0.5–2 |   |
| Cathode treatment time, min. |   | 2 | 4–6 |   |   |
| Anode treatment time, min. | 5 | 4 | 5 | 5 | 2–4 |
| Temperature, °C.       | 20–30 | 20–30 | 20–30 | 78–80 | 70–80 |

Technology recommended for molybdenum metallization, and providing electrochemical anodic etching in 20% sodium carbonate solution has been tested. However, at anodic etching, primary dissolving of copper occurred in this electrolyte of the MD40 alloy (experiments III-1), this being testified by the electrolyte bluish color appearing during anodic treatment of the MD40 alloy. Then electrolysis in sulfuric mixed electrolyte of coppering (table 2, electrolyte 3) was performed at cathodic current density varying from 1 to 8 A/dm². Along margins of the sample of the MD40 alloy with dimensions 42x61x1mm, a copper coating grew up, but any copper coating was not formed in the sample center. This testifies that an oxide film from the surface of molybdenum included into the MD40 alloy was not etched off completely, or was formed again.
Before coppering and tinning, the samples of the MD40 alloy in experiments III-2 were etched in 90% orthophosphoric acid, at first on anode at current density from 3 to 10 A/dm² for 4 minutes, then on cathode at current density from 3 to 6 A/dm² for 2 minutes. Before coppering and tinning (experiments III-3), the MD40 alloy samples were etched on anode in 20% sulfuric acid, and to make experiments (III-4) – in 80% sulfuric acid, treatment regimes are indicated in table 4. Thickness of galvanic copper coatings and that of tin-bismuth alloy coatings were varied from 6 to 12 mcm, herewith the coating thickness did not impact on the adhesion.

| Experiment number | Adhesion measurement methods |
|-------------------|-----------------------------|
| III-2             | +                           |
| III-3             | +                           |
| III-4             | +                           |
| III-5             | + +                         |

Results of the trials for adhesion strength of coatings with the MD40 alloys obtained in experiments with the surface electrochemical treatment demonstrated that combination of anodic treatment and cathodic one (experiment III-2) gives better results, if compared with anodic treatment only (experiments III-3 and III-4). This is most likely to be associated with the fact that the sample surface during the cathodic treatment is being saturated with hydrogen which slows down formation of oxides on the surface of molybdenum. Nevertheless, in this case the adhesion is also insufficient to be used in production, as the samples did not stand all the tests. In experiments I-1, I-2, I-3, I-4, II-3, III-1, III-2, III-3, III-4 as well as in many well-known technologies of galvanic metallization of molybdenum alloys, the coating high adhesion was not obtained by means of different ways of preparing the surface. This is due to the fact that, after etching and before coating with a galvanic coating, details are being washed in water and transferred into another bath. While washing and transferring, an oxide film is partly formed again on the molybdenum surface, and this decreases adhesion strength of the coating on molybdenum alloys. In a new way suggested (experiment III-5), anodic etching of an oxide film off the molybdenum alloy surface and the following coppering were performed in one universal bath consisting of cuprous sulphate 2 – 3 % and sulfuric acid 45 – 65%, without extracting details from the electrolyte. Thus, the pause between the operation of anodic etching and that of coating is excluded practically completely. Copper plates of brand M0 were used as electrodes. In experiments III-5, anodic etching at current density 10–30 A/dm² had been performed for 2–4 min, then, without removing the sample from the electrolyte, the polarity was reversed at once, with electrolyte being mixed at the same time. Cathode electrodeposition of copper had been started by current rush with cathode current density 8-10 A/dm² with the exposure time 0,5–0,7 min, then the working cathode current density 0,5–2 A/dm² was set, and electrolysis was performed for 4–6 min. As a result, a fine copper coating was formed on the MD40 alloy samples. Further, copper was grown up in electrolyte 3 presented in table 2. The tin-bismuth coating from electrolyte 1 was placed on copper coating (table 2). Coatings obtained by this way (experiments III-5) had the highest adhesion to the MD40 and MD50 alloys. As table 5 shows, they could stand all tests, including tearing-off the copper wire soldered by POS61, the adhesion strength being higher than the strength of solder POS61. Besides, the technology developed allowed to improve solderability and flowability of solder POS61 on molybdenum alloys with a two-layer coating of copper and tin-bismuth. Solderability of the coating was checked by solder POS61 flowability area on the tin-bismuth coating and by contact angle determination according to formula (1) given in the work [7].

\[ \theta = 7,12(V / \sqrt{S^3}) \]                        (1),

where \( \theta \) – angle, \( V \) – solder volume, \( S \) – flowing area.
Herewith, solderability was evaluated like in the work [8], using the tables similar to table 6.

| Solderability    | Value of contact angle determined by flowing area |
|------------------|--------------------------------------------------|
| Very poor        | More than 50°                                    |
| Poor             | 50–34°                                           |
| Satisfactory     | 34–12°                                           |
| Good             | 12–3°                                            |
| Excellent        | Less than 3°                                     |

Table 6. Coating solderability evaluation.

| Number of sample (experiment) | Base-metal        | Solderability |
|-------------------------------|-------------------|---------------|
| I-1                           | Alloy MD40        | Very poor     |
| I-2                           | Alloy MD40        | Very poor     |
| I-3                           | Alloy MD40        | Very poor     |
| I-4                           | Alloy MD40        | Poor          |
| II-3                          | Nickel alloy MD40 | Good          |
| III-2                         | Copper alloy MD40 | Good          |
| III-3                         | Copper alloy MD40 | Satisfactory  |
| III-5                         | Copper alloy MD40 | Excellent    |
| IV-1                          | Copper            | Excellent     |

Table 7. Solderability of MD40 alloy and copper alloyed with tin-bismuth by POS61 solder.

As table 7 shows, samples I-1, I-2, I-3 with one-layer tin-bismuth coatings, the surface of which had been etched chemically before coating with tin-bismuth alloy, had very poor solderability. When soldering these samples, the solder POS 61 practically did not flow on the tin-bismuth coating, but appeared to “fall” into the coating and was fused into it, practically without flowing. This was most likely to be conditioned by very low adhesion of the galvanic tin-bismuth alloy with the molybdenum MD40 alloy surface. In sample I-4, solderability was poor, i.e. it was improved insignificantly, if compared with that of samples I-1, I-2, I-3, this seems to be due to copper enrichment of the molybdenum MD40 alloy surface, which occurs in selective etching in solution 4, table 1. The use of two-layer coatings, a nickel one with the tin-bismuth alloy and a copper one with the tin-bismuth alloy, as well as the use of electrochemical etching methods, when preparing the surface of the molybdenum MD40 alloys, allowed to improve solderability from very poor to satisfactory (sample III-3) and even good (samples II-3 and III-2). Before coating with a galvanic tin-bismuth coating, samples III-2 and III-3 were coated with copper coatings of almost similar thickness from one electrolyte, using similar electrolysis regimes (see table 2). Similarity was also preserved, when coating with tin-bismuth coatings, however, their solderabilities were different. The main difference between samples III-2 and III-3 was in electrochemical preparation of the surface. At first, samples III-2 underwent anodic etching, then – cathodic one in the solution of orthophosphoric acid, and samples III-3 were etched only on anode in the solution of sulfuric acid (see table 4). As a result, the adhesion strength of galvanic coatings on samples III-2 became better than on samples III-3 (see table 5). This appears to have become the main cause of improving the solderability of samples III-2, if compared with that of samples III-3 (see table 7). The solderability of the molybdenum alloy samples coated with an electrochemical tin-bismuth alloy is influenced by the composition and structure of an underlying coating, their adhesion to the molybdenum alloy surface, and adhesion of the galvanic tin-bismuth alloy to these underlying coatings. Thus, at approximately similar adhesion of the coatings on samples II-3 and III-4, a nickel sublayer, as it appears to be more porousless and dense, allowed to achieve better results of soldering, other things being equal. The solderability of the samples with nickel and copper sublayers became almost similar.
(see table 7), when the adhesion of the copper sublayer in sample III-2 became slightly higher than that of the nickel sunlayer coating in sample II-3 (see tables 3 and 5). Attempts of further improving the solderability of samples II-3 and III-2 due to enlargement of tin-bismuth coating thickness from 6 mcm to 12 mcm, and variation of current density from 1 to 2 A/dm² practically did not change the ability of the samples of series II-3 and III-2 to be soldered.

The situation with solderability has been changed sharply, the solderability has significantly improved and become excellent, by using new technology implemented in experiment series III-5 (see table 4). As a new method suggests, anodic etching of an oxide film off the surface of the molybdenum alloys MD40 and MD50 followed by coating with copper is performed in one universal bath composed of cuprous sulphate 2–3 % and sulfuric acid 45–65%, without extracting details from the bath. This practically excludes a pause between the operations of anode etching and coating as well as formation of a new oxide film on the molybdenum alloy surface. Correspondingly, such technology increased significantly adhesion and solderability of the molybdenum alloys. Experimental data obtained allowed to determine the dependence between adhesion of galvanic coatings and their solderability. Despite the fact that solderability of galvanic coatings is influenced by many factors, adhesion of galvanic coatings with the surface of molybdenum alloys is one of the most significant factors to solder molybdenum alloys. The higher is adhesion strength of coatings with molybdenum alloys, the higher is solder quality, as a rule. Thus, it is possible to line up the molybdenum alloy samples coated with the tin-bismuth alloy as solderability increases, depending on adhesion. The samples of molybdenum alloys I-1, I-2, I-3, I-4 with the surfaces prepared by a chemical way of etching had very poor or poor solderability, as well as the lowest adhesion of coatings. Samples II-3, III-2, III-3 prepared by electrochemical ways of etching and coated with layers of the nickel and tin-bismuth alloy, or the copper and tin-bismuth alloy had solderability from satisfactory to good, depending mostly on adhesion as well. Among metalized samples of molybdenum alloys, samples III-5 obtained by new technology of combining anode etching and coating with copper in one universal bath possessed the best, excellent solderability. Flowing area of dosed test charge of solder POS 61 on samples III-5 was less not more than by 10%, if compared with flowing area of dosed test charge of solder POS 61 on tinned copper samples IV-1. Herewith, samples III-5 had excellent solderability by POS61 close to that of tin-bismuth coatings on copper samples IV-1 (see table 7).

4. Conclusions
Use of chemical solutions of etching only is not enough in technology of preparing surfaces of molybdenum copper-containing alloys, to achieve necessary adhesion of galvanic coatings. Successive use of anode and cathode treatments in preparing the surface increases, though slightly, adhesion of galvanic coatings to molybdenum alloys. The highest adhesion of coatings, higher than the strength of solder POS61, was obtained by combining two operations in one electrolyte № 5 (table 4): electrochemical etching and coppering operation performed at once, practically instantly. Adhesion of coatings to molybdenum alloys increases, since an oxide film was sufficiently etched off during anode dissolving, and it had not enough time to be formed again, as it is common in many other known technological processes. Impact of adhesion strength of electrochemical coatings on solderability has been studied. It has been defined that two-layer copper-alloy and tin-bismuth galvanic coatings placed on copper-containing pseudo alloys of brands MD40 and MD50 with adhesion higher than the strength of solder POS61 possess excellent solderability. Technology of electrochemical metallization of molybdenum alloys which allows to achieve rather high adhesion and excellent solderability has been developed. Priority and originality of developed technology of galvanic metallization of molybdenum alloys was confirmed by the patent [9].

Acknowledgement
The author expresses his gratitude to engineer Vasilyev V A for help in conducting experiments on determining solderability on a programmable heat and welding installation VSU200.
References

[1] Nikonov N V 2014 *Molibden. Svojstva, primenenie, proizvodstvo, produkcija* [Molybdenum. Properties, application, production, products.] (M: OOO “Metotehnika” Publ) p 34 (in Russian)

[2] Makedonskij B K, Morozova I G and Skazkin V E 2012 Pseudosplavysistemy med’ – molibden [System pseudo-alloys copper – molybdenum] Modern problems and ways of their solution in science, transport, production and education Available at: [http://www.sworld.com.ua/konfer29/750.pdf](http://www.sworld.com.ua/konfer29/750.pdf) (accessed 18.03. 2019)

[3] Petrunin I E and al 2003 Soldering guide. Spravochnik popajke [Reference book on soldering.] (M.: Mashinostroenie) p 480 (in Russian)

[4] Nishhev K N, Martynenko V A, Beglov V I, Grishanin A V, Eliseev V V, Maligin M Ju, Novopol’cev M I and Judin V A 2013 Issledovanija svojstvmnogoslojnojmetallizaciistruktur “kremnijnamolibdene”, poluchennojmetodom magnetronnogoraspylenija [Researches of properties of the multilayered metallization of structures "silicon on a molybdenum" received by method of magnetron dispersion] Izvestijavysshih uchebnyhzavedenij (Povolzhskij region: Fiziko-matematicheskie nauki) 3 (27) p 248–260

[5] Azhogin F F and al 1986 *Gal’vanotehnika. Spravochnik* [Galvanotechnics. Reference book] (M: Metallurgija) p 736 (in Russian)

[6] Sekrety gal’vaniki ot GalinyKorol’yojov. Pokrytie molibdena pod pajku [Galvanics secrets from Galina Korolyovoy. A molybdenum covering under soldering] URL: Available at: [https://www.subscribe.ru/archive/socio.science.galvanika/201105](https://www.subscribe.ru/archive/socio.science.galvanika/201105) (accessed 21.03.2019)

[7] Lanin V L 2008 Evaluation of solderability of electronic components and details in electronics *Componenty i tekhnologii* 2 p 28–32

[8] Kireev S Yu and Perelygin Yu P 2011 Methods of determining solderability of coatings *Galvanotekhnika i obrabotka poverkhnosti* 2 Vol XIX p 52–57

[9] Tikhonov A A 2018 *Spособ gal’vanicheskoy metallizacii molibdenovyh splavov* [Way of galvanic metallization of molybdenic alloys.] Patent RF, no. 2653515 Bul 13 p 7