Calculation and design of a technological module for formation of island thin films and nanostructures in vacuum

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Abstract. The application areas of island thin films are considered, and the relevance of their application is presented. The choice of the method for formation island thin films and nanostructures is justified. A design of the thermal evaporation module is proposed and its documentation is developed. The use of it will allow to form continuous and island coatings. Variants for placing the module in the laboratory equipment - MVTU-11-1MS are considered. The analysis of the evaporator configurations was carried out and the type of evaporator – «tape» evaporator, was selected. The necessary calculations are presented: evaporator resistance (2.31 mOhm) and thermal calculation (1200 K, 20), – this contributed the design of the module and the materials selection of its components.

1. Introduction
Island thin films (ITF) and nanostructures (INS) are coatings that were completed at the island formation stage [1]. These films are attracted by features that allow implementing such phenomena, for example, as tunneling.

The INS application area is steadily increasing. ITF are in demand in such industries as laser technology, solar energy, micro- and nanoelectronics, optics, photonics, medicine. Insular thin films can also be used in quantum computers [1–4].

There are several possible methods for INS formation, the main ones are magnetron sputtering, thermal evaporation, and vacuum-arc evaporation. For further implementation, the resistive thermal evaporation method was chosen, since it has good reproducibility, the method is easy to implement, and the resulting coatings have good adhesion to the substrate [3]. It is possible to observe both the thin films growth mechanism of vapor–crystal and the mechanism of vapor–liquid-crystal, when formation thin film coatings by thermal evaporation (TE) in a vacuum. It is particularly important in the island thin films and nanostructures formation at the early stages of coating formation.

To obtain ITF and INS, the MVTU-11-1MS equipment, located in the laboratory of "Elion technologies" of the Electronic engineering Department of The Bauman Moscow State Technical University, was selected. This equipment is used to control the initial stages of thin-film coatings growth and the island nanostructures formation [5].

2. Analysis and selection of variants for placing the technological module
The vessel of MVTU-11-1MS is equipped with five connectors for connecting coating formation sources (figure 1). However, only three of them are available for placing new technological module – one on the right at the vessel bottom (figure 1, A) and two – on the left side wall (figure 1, B and C). The upper connector on the wall (location C) is not suitable for placing the TE source, since the source
will be close to the substrate and the range of distance variation will be small, which reduces the ability to vary the film growth rate.

Thus, three placing variants were identified. The first variant is to use the connector at the vessel bottom – location A. This variant is more common than the others. The thermal evaporation module is equipped with an individual shutter. But this variant will be inconvenient due to the fact, that this connector is already used by the other technological source. Additional time will be spent for changing sources, which is not advisable in laboratory conditions when several research cycles are carried out on the same equipment. At the same time, due to the presence of a shutter, it becomes necessary to design the rotating feedthrough. This means that the design becomes more complex and its cost increases.

In the second variant, the TE module is located on the wall of the camera – location B. Since the source is located in the connector that is not used in current projects, it is possible not to remove the module after using it. The source is also equipped with an individual shutter. However, the design will be complicated again.

The third variant of the TE module solves the problems of the second variant. We will also use the location B, but this time we will not design an individual shutter. We will transfer it to the existing shaft of the general rotating feedthrough. Choosing this variant will simplify the design of the module and reduce its cost.

![Figure 1. The vessel of MVTU-11-1MS with the final placement of the TE: 1 – substrate holder; 2 – shutter; 3 – TE module; A, B, C – connectors available for placing the module.](image)

Thus, the third variant is the most appropriate (figure 1, B), since the TE module will be located in the connector that is not used yet and there is also no individual shutter, which makes the design easier and reduces its cost.

3. **Design work**

3.1. **The calculation of the evaporator resistance**

As a result of the analysis of the types and configurations of the evaporator, a step-shaped tape evaporator was selected (figure 2). The main advantage of this form are the greatest resistance in the area of evaporation and the ability to evaporate a large amount of material.

The evaporator resistance is summed of the resistances of each section:

\[ R = 2R_1 + 2R_3 + R_2, \]  

where \( R \) – the total evaporator resistance, \( R_1 \) – resistance of the 7x8 mm evaporator section (area I), \( R_2 \) – resistance of the 6x6 mm evaporator section (area II), \( R_3 \) – resistance of the 6x10 mm evaporator section (area III).
The resistance sections of the evaporator were calculated by the formula:

\[ R = \frac{\rho l}{h b'} \]  

(2)

where \( \rho = 0.135 \text{ Ohm} \cdot \frac{\text{mm}^2}{\text{m}} \) – the tantalum resistivity, the evaporator material, \( l \) – the length of the considered evaporator section, \( h = 0.25 \text{ mm} \) – the evaporator thickness, \( b' \) – width of the considered evaporator section, mm.

After calculating using the formula (3), we obtained the following values: \( R_1 = 472.5 \text{ mkOm}, R_2 = 720.0 \text{ mkOm}, R_3 = 324.0 \text{ mkOm}. \)

Using the formula (2), the total evaporator resistance is calculated: \( R = 2.31 \text{ mOm}. \)

Among the laboratory equipment, there is a power supply that can provide the following output parameters: the current is 400 A and the voltage is 1 V, which in turn provides full power with a resistance of 2.5 mOm. Since the calculated resistance is close to the required one, we accept the dimensions of the tape evaporator used in the calculation.

3.2. 3D-model development of the TE module

3D modeling was performed in the Autodesk Inventor 2020 environment. The TE module (figures 3, 4) is a KF 50 flange 2 with two holes \( \Theta 15 \text{ mm}. \) Current leads \( 4 \Theta 6 \text{ mm} \) are placed in the holes of the flange.

Copper is chosen as the material of current leads, since it is able to conduct current with the highest density \( j = 3 \text{ A/mm}^2. \) The current leads are provided with grooves for locking rings for fixing the bushings 1. The material of the bushings is caprolon, which has an excellent dielectricity and a relatively low price. The outer diameter of the bushings inside the flange holes is 14 mm, which provides a gap that allows gas to escape from the structure and quickly assemble the module. Outside the flange holes, the diameter of the bushings is 20 mm. The bushing is also provided with a step \( \Theta 19 \text{ mm}. \) This step allows to avoid a short circuit between the module and the vessel.

Between the bushings there is a rubber o-ring 3. The outer diameter of the o-ring is 14 mm, when tightening the nuts 6, the ring diameter will increase, and the thickness will decrease from 6 mm to about 3.5 mm. Due to the fact that the o-ring thickness will decrease, the length of the bushings is increased by 1.5 mm over the flange width. The evaporator 5 is located on the current leads and is held...
by copper bars using a bolted connection. The evaporator material is tantalum, which allows it to heat up faster. Current is supplied to the current leads by terminals held by nuts 7.

3.3. Thermal calculations
The problems of thermal conductivity and heating of the developed module design were solved, using the software for multiphysical modeling – COMSOL Multiphysics (figures 5, 6).

It is determined that the geometric parameters of the elements are selected correctly, since the highest temperature (1200 K) is reached in the evaporator center, and the temperature of the current leads is very close to 300 K almost throughout their entire length.

The heating time calculation showed that it takes about 20 sec to heat the tape evaporator to almost 1200 K.

![Figure 5. Thermal modeling results of the TE module in COMSOL.](image1)

![Figure 6. Results of modeling the non-stationary heating process of the TE module in COMSOL MPh.](image2)

4. Conclusions
The components of the TE module were sent to production and fabricated. The technological module will be assembled in the near future. It is expected that this module will become an integral part of the laboratory equipment.

References
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