Vacuum coating system for deposition of superconducting W$_x$Si$_{(1-x)}$ ultrathin films used in single photon detectors

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Abstract. VUP-11M coating system for thin films deposition in vacuum is described in this article. Technological features which appear at laboratory vacuum system modernization for implementation of dual-components W$_x$Si$_{(1-x)}$ films forming process by means of magnetron co-sputtering from two sources are shown. Totals of the system modernization and research results of obtained W$_x$Si$_{(1-x)}$ films are reported.

1. Introduction

In recent years development and manufacturing of single photon detectors is one of the most actual direction in microelectronics. Single photon detectors are indispensable in such areas as infrared wave length research, quantum cryptography, at weak laser radiation detecting, at LIC (large integrated circuit) testing, in radio astronomy observing, fluorescence radiation measurements with high time resolution and others [1]. Along with existing types of single photon detectors (photomultipliers, avalanche photodiodes, etc.) which differ by photon detecting principle, during last decade the new type of detectors has appeared. It is superconducting single photon detectors (SSPD) [1]. This type of detectors is oriented on the spectral range from 0.6 to 2.3 μm. SSPD is characterized by low jitter (less 40 ps), low dark count rate (less 10 GHz) and has quantum efficiency more 85 % [2]. In contrast of avalanche photodiodes and photomultipliers SSPDs have higher performance wherein its working temperature isn’t ultra-low as transition edge sensors working temperature and is around 4.2 K.

At present time SSPDs are produced on the base of ultrathin NbN film which thickness is about 4 nm [1]. Due to such small thickness radiation absorption of film itself is limited and that decrease detecting quantum efficiency. However coating thickness increasing, i.e. conductor cross-section increasing, also reduce this parameter because hot spot which arises after photon absorption can't guaranteed to cause the junction to normal state on the whole cross-section of conductor. One of material which could replace NbN in SSPD is W$_x$Si$_{(1-x)}$ [3]. Using this material it is possible to achieve quantum efficiency close to 100 %.

2. Features of W$_x$Si$_{(1-x)}$ coatings forming

As it was founded earlier content percentage of tungsten in these films has been determined as 71 ± 10 % [4]. At such quantity of tungsten W$_x$Si$_{(1-x)}$ coating which thickness is 500 nm goes over to superconducting state at the temperature ~5 K [4]. Precise components’ ratio for achievement of higher critical temperature can be found only by means of empirical path. Wherein required coating thickness depends on SSPDs operation features and shouldn’t exceed 10 nm.
To achieve the high output parameters at the technology development the following requirements for the vacuum coating system appear. This requirements are the result of the features of \( W_xSi_{(1-x)} \) thin films forming and they are:

- necessity to vary components ratio to find the best ratio value;
- possibility to change of process parameters (power source capacity and distance to technological source) for obtaining of controlled and reproducible coatings deposition rates;
- ultimate pressure not more than \( 3 \times 10^{-5} \) mbar to ensure the suitable purity of residual environment in vacuum chamber;
- accuracy of the beginning and ending of the deposition process because films’ thickness is several nanometers.

3. Purpose and tasks

The purpose of this work is realization of ultrathin superconducting \( W_xSi_{(1-x)} \) coating forming process on VUP-11M vacuum coating system [5] with reproducible results. VUP-11M vacuum coating system was developed in the “Elion processes and nanotechnologies” laboratory of “Electronic technologies in machine building” department of the Bauman Moscow State Technical University. The basic version of this system include 4” planar cylindrical magnetron sputtering source, arc evaporator and grid ion source for surface ion treatment. The tasks within the framework of this theme are:

1) to realize \( W_xSi_{(1-x)} \) thin films deposition on VUP-11M system by magnetron sputtering;
2) to modernize the vacuum chamber with heat and cooling system;
3) to design and produce special shutters for the reproducibility improving of the coating forming process.

4. Modernization of the technological system

Deposition of the two-component thin films by magnetron sputtering can be realized with using of two ways. The first one is sputtering of the two-component alloy target or a mosaic target (figure 1(a)) using just one sputtering source. The second one is to sputter homogeneous targets using two separate sputtering sources located at the same plane or at an angle to each other (figure 1(b)).

![Figure 1](image1.png)

**Figure 1.** Two-component coatings deposition: (a) – using alloy or mosaic target and single magnetron source; (b) – using two magnetron source and homogeneous targets.

Using of the alloy or composite targets doesn’t allow controlling components ratio in the coating at working out of its forming technology. Besides in process of magnetron operation for a long time the components composition in the erosion zone and on the substrate surface become different [6]. Using of two magnetron sources located at the same plane doesn’t allow reaching the high coating uniformity both in thickness and components content in the film. Therefore it is expediently to realize the coating forming by means of simultaneous magnetron sputtering from two sources located at an angle to each other. This will allow to control the components ratio with maximize precision.

5. Installation of the additional magnetron sputtering source at the coating system

Initially vacuum coating system VUP-11M was equipped with one 100 mm size magnetron sputtering source installed at the left flange of the chamber. To realize deposition of WSi additional 50 mm size
sputtering source need to be installed. The only possible place was at the top flange of the vacuum chamber (figure 2). For this purpose mechanical treatment of the flange has been carried out and special connector has been produced. This connector was designed so that it doesn’t require any additional adaptors for magnetron fixing. Sealing of the magnetron was provided between connector and magnetron’s tube so that allow to vary the distance between substrate and magnetron in the wide range from 75 to 135 mm and therefore to vary the deposition rate.

As a result of this modernization it became possible to obtain $W_xSi_{(1-x)}$ coatings with total deposition rate around $\sim 0.47$ nm/s [7]. Such deposition rate allows getting reproducible thin films which thickness of several nanometers. Magnetron sources are settled at the angle 90° between them. Silicon target is set up on Ø100 mm magnetron and the tungsten target is set up on Ø50 mm magnetron. Substrate is located on the substrate holder at the angle 45° to both of magnetrons targets (figure 2).

6. Modernization of heating and cooling system of the vacuum chamber
Heating and cooling system of the vacuum chamber has been modernized for improvement of residual vacuum. In addition to banded heater the flowing water heater has been installed. This heater provides water heating in copper tubes which are soldered to the vacuum chamber on all sides. Water circulation is carried out by water pump in a closed loop. Flowing heater allows to heat the vacuum chamber up to 60°C in a short time due to of tight contact between copper tubes and chamber walls. The banded heater provides temperature of the chamber walls at the level about 70–80°C. Cooling is realized at the same copper tubes by cool tap water supply. Chamber heating and cooling processes allow to obtain less pressure of residual gasses. This is confirmed by mass-spectrometry research (figure 3) [8].

7. Design of technological fixture
To ensure the reproducibility of $W_xSi_{(1-x)}$ thin films deposition suitable fixture has been designed. This fixture prevents deposition at the back side of substrate while operation of targets in idle mode and
provides accuracy beginning and ending of the deposition process. The fixture is a system of shutters between both magnetrons and substrate holder. There are two ways for this shutters realizing. The first construction is stationary substrate holder with movable shutters between magnetrons and substrate and between two magnetrons (figure 4(a)); the second one is movable substrate holder with movable shutter between two magnetrons and stationary shutter between magnetrons and substrate holder (figure 4(b)).

**Figure 4.** Variants of shutter fulfilment: (a) – with stationary substrate holder and mobile shutter; (b) – with mobile substrate holder and stationary shutter.

The first variant is easy in design and production but doesn’t allow turning the substrate holder to others radially located technological sources, e.g. to ion source for ion pretreatment in the single vacuum cycle. Therefore the second variant of fixture construction has been realized (figure 5).

While pumping the substrate is located at maximal distance from bypass pump line and during targets training the substrate is out of plasma area. Wherein coating deposition process begins by substrate holder turning and placement of sample in sputtering zone. Process stopping occurs by the same way: by turning of substrate holder out from the sputtering zone. Because of this there is no necessity to track simultaneous magnetrons switching-off. Forming of last coating layers with another components ratio is also excluded.

**Figure 5.** Shutter: (a) – appearance; (b) – inside VUP-11M system.

Due to dividing the space inside vacuum chamber into two zones there is no film deposition at the back side of the substrate during the targets training because of the hole in the shutter is closed by special plate. The cross-sputtering during targets training is excluded due to shutter between magnetron sources and the cross-sputtering during deposition is insignificantly enough due to very small time of it (~20 s).
8. Modernization results
1. Installation of the second magnetron source on the top flange of the chamber allows obtaining superconducting coatings by magnetron sputtering from two sources simultaneously at the VUP-11M coating system. There is opportunity to vary components ratio while the process. Wherein deposition rate is ~0.47 nm/s that allows to get thin films which thickness is in the range from 5 to 9 nm.

2. Improvement of the heating and cooling system provides decrease of ultimate pressure and obtaining more cleaner residual vacuum for coatings process. It has been confirmed by mass-spectrometry research.

3. Designed and produced system of shutters provides reproducible output coatings parameters what is confirmed by measurements of output parameters of W, Si(1-3) thin films [9] and SSPD based on this films [10].

9. Conclusion
Modernization of VUP-11M coating system has allowed to realize reproducible forming technology of ultrathin superconducting WSi coatings with critical temperature about 3.7 K. Produced on the base of this films detectors shows quantum efficiency on the level of 65 %. Moreover opportunity to vary components ratio and deposition rates allows carrying out further researches.

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