Vacuum system “MAGNA TM 150-01K” for magnetron sputtering deposition of multilayer functional coatings

V V Odinokov, R A Karakulov, V V Panin and A V Shubnikov

JSC Research Institute of Precision Machine Manufacturing (NIITM), 124460, Moscow, Zelenograd, Russia

E-mail: vodinokov@niitm.ru

Abstract. The new vacuum system “MAGNA TM 150-01K” developed at Research Institute of Precision Machine Manufacturing is described. Its structure and principle of operation are considered. This system was used for magnetron sputtering deposition of multilayer coatings on 100 – 150 mm circular silicon wafers. Coatings were deposited in common vacuum cycle from three targets with use of cassette holder in load-lock built-in “clean room”. Titanium (Ti) and titanium nitride (TiN) layers were deposited consequently from common titanium target, aluminum (Al) layer was deposited from two aluminum targets.

1. Introduction
All layers must be deposited on the substrates in a common vacuum cycle to obtain high-quality multilayer coatings when creating various semiconductor devices based on thin-film technologies. This technology provides not only a growth of productivity, but also an increase of the adhesion between the substrate and the adhesive layer, as well as between individual layers of coating [1].

An important task is creation of the domestic special process equipment (SPE) with cassette holder in load-lock built-in “clean room”. This could provide good quality of coatings and allow to operate in automatic mode with control of all parameters at all stages of the deposition process [2].

2. Description and principle of operation of the system
Figure 1 shows the appearance of the system. The system consists of load-lock with cassette, transport chamber with vacuum robot, process chamber and control rack.

The system operates as follows. Loading and unloading of cassette 12 with wafers occurs manually by means of load-lock 1 (figure 2). Then high-vacuum gate valve 2 is opened and vacuum robot 10 conveys wafers individually from cassette to substrate holder 8 which heats substrate 6 up to 300 °C when the required ultimate pressure is achieved. The individual gas channel with a mass-flow controller of argon under the substrate provides an even warming up of its surface.

After that, the wafer is undergone ion cleaning in the plasma of the high-frequency (HF) gas discharge due to the supply of the HF potential to the substrate holder. Multicathode sputtering device (MSD) with three 100 mm circular targets 3 and 4 is used to produce material of coatings (third target is not shown on figure 2). Shutter 5 rotates and opens the targets sequentially when the process technology is executed. The substrate holder ensures a smooth rotation of the wafers around the vertical axis at a frequency of up to 20 rpm. At the end of the process, the manipulator conveys the processed wafer into its cell in the cassette and takes the next untreated wafer.
Figure 1. The appearance of the «MAGNA TM 150-01K» system.

Figure 2. The principal scheme of the «MAGNA TM 150-01K» system.

3. Results and discussion
The «MAGNA TM 150-01K» system was used for deposition of multilayer metallization on 100 mm circular silicon wafers. Titanium (Ti), titanium nitride (TiN) and aluminum (Al) layers were deposited consequently in common vacuum cycle in a co-sputtering mode. Such multilayer functional structures are used to create thin-film circuits in microwave devices.

The modes of HF cleaning of the wafers, presented in table 1, were selected. The 600 W power HF generator was used.
Table 1. The modes of HF cleaning.

| Argon flow, l/h | Process pressure, Pa | Power, W | Time, min |
|----------------|----------------------|----------|-----------|
| 1.4            | 1.8                  | 100      | 10        |

The efficiency of this operation was evaluated by measuring the thickness of the silicon dioxide layer (SiO$_2$) before and after purification. Thickness was controlled on the wafer at 5 points in its various sections (figure 3). Thus, information about the uneven etching of the material was received. The average cleaning rate was 1.511 nm / min. The results of the measurements are shown in table 2.

![Figure 3. Location of control points on the wafer.](image)

Table 2. Efficiency of HF cleaning

| Point number | SiO$_2$ before etching, nm | SiO$_2$ after etching, nm | Thickness changing (Δ), nm | Δ$_{av}$, nm |
|--------------|-----------------|----------------|------------------|-----------|
| 1            | 318             | 300,93         | 17,07            |           |
| 2            | 325,98          | 313,14         | 12,84            |           |
| 3            | 316,79          | 302,93         | 13,86            | 15,11     |
| 4            | 316,53          | 302,24         | 14,29            |           |
| 5            | 320,25          | 302,76         | 17,49            |           |

Optimum modes of deposition of Ti, TiN and Al layers, shown in table 3, were chosen on the basis of the following criteria: maximum productivity, magnetron discharge stability, composition and structure of the coating. Titanium and titanium nitride coatings were deposited using a single titanium target (Ti) and aluminum coating was deposited using two aluminum (Al) targets. Two 3 kW power direct current (DC) sources was used. A switching device was used to switch first power source between the titanium target and one aluminum target. The second power source has always been connected to another aluminum target.

A series of experiments was performed to obtain a stoichiometric coating of titanium nitride (Ti$_1$N$_1$). It is known that the best characteristics (specific electrical resistance) is the titanium compound with nitrogen in the ratio of atoms 1:1 [3]. At the initial stage, the primary evaluation of the
coating structure was its color: stoichiometric titanium nitride has a golden sheen, a purple hue indicates excess nitrogen and gray color indicates its lack. After this, the final optimization of the modes for the formation of the required structure was carried out after an analysis of the elemental composition. The result of the investigation of the coating obtained after the final adjustment of the deposition parameters showed the content (quantitative) of nitrogen at the level of 53.65 %, and the specific electrical resistance of the film was 216 μΩ·cm.

Table 3. Optimal modes of deposition

| Coating | Argon flow, l/h | Nitrogen flow, l/h | Process pressure, Pa | One target power, W | Temperature, °C |
|---------|----------------|-------------------|---------------------|-------------------|-----------------|
| Ti      | 1.0            | -                 | 0.45                | 1500              | 200             |
| TiN     | 0.4            | 0.34              | 0.33                | 1500              | 200             |
| Al      | 1.0            | -                 | 0.52                | 1500              | 150             |

In addition, for the «MAGNA TM 150-01K» system the character of the pressure recovery depending on the flow of nitrogen during the application of titanium nitride in the working chamber is established (figure 4). Because the nitrogen concentration in the plasma increases on path 1-2, the process of active nitriding of the titanium target begins. As a result, the titanium content in the working volume is sharply reduced and the pressure also increases spasmodically as titanium is a getter. The rate of nitriding gradually decreases with a decrease of nitrogen consumption (path 3-4) and becomes equal to the nitride sputtering rate. The pressure in the chamber becomes the same as soon as nitride is completely removed from surface and sputtering of pure titanium begins.

Figure 4. Hysteresis of working pressure during TiN deposition.

The performance of the "MAGNA TM 150-01K" system for metallizing of wafers with such metals can be judged by knowing the rates of their deposition. The results of measurements of the thickness of the coatings of each material are shown in table 4.

Table 4. Thickness of coatings.

| Coating | Time of deposition, min | Thickness, nm |
|---------|-------------------------|---------------|
| Ti      | 1                       | 70            |
| TiN     | 2                       | 120           |
| Al      | 5                       | 1270          |

Thus, the average deposition rate of titanium and titanium nitride using a single magnetron is 70 nm/min and 60 nm/min respectively. The average deposition rate of aluminum using two magnetrons is 254 nm/min.
4. Conclusions
The «MAGNA TM 150-01K» system allows deposit multilayer functional thin film coatings in common technological cycle by means of magnetron sputtering. In this case, high-quality multilayer thin films are formed having good adhesion strength between the substrate and the adhesive layer, as well as between the individual layers. The automatic control system monitors all process parameters and maintains their stability according to the set values. This ensures good reproducibility of the properties of the coatings. The placement of equipment of this type in clean industrial premises will significantly reduce the introduced defectiveness on the wafers and lead to an increase in the yield of suitable products.

References
[1] Odinokov V V, Pavlov G Ya, Panin V V, Putyrskiy V V, Rashchinskiy V P, Shpakov A N and Shubnikov A V 2014 Nanoindustry 9 8–11
[2] Karakulov R A, Odinokov V V, Panin V V, Shubnikov A V, Vladimirov D S, Vladimirov S V and Golubtsov A A 2017 Nanoindustry 2 80–6
[3] Grigoriev S N, Melnik Yu A, Metel A S, Panin V V and Prudnikov V V 2011 Japan. J. Appl. Phys. 50 08JG04