Design of the evaporation source for Au-Ge alloy

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Abstract. The new design of the evaporator is developed in which the material is heated by heat transfer from a plate heated in glow discharge plasma above the surface of a magnetron sputtering source. The evaporator makes it possible to obtain pure films with deposition rates around 1 μm / min, 100% material productions, and from 1.5 to 3 times higher material consumption efficiency. The design of the source is very simple and the new one could be made without great cost. This solution can be useful in prototype and small-scale production for the implementation of evaporation process in vacuum coating machines equipped with only magnetron sputtering sources without the use of additional power supplies and without any changes to the control system.

1. Introduction

For devices of microelectronics, such as thermoelectric coolers (TEC), silicon crystals, etc., which after their assembly are exposed to high temperatures, or are subject to further installation at high temperatures because of the features of the technological process, it is necessary to use solders with a higher temperature melting in comparison with solders on the basis of tin. One of these high-temperature solders used in modern microelectronics is an Au-Ge alloy with a melting point of 356 °C [1, 2, 4]. This temperature is comfortable for the assembly process on the described solder, and is also sufficient for further temperature effects, which are usually carried out with further installation [3–9]. This solder is used in the assembly of thermoelectric coolers, which are subject to further installation in devices with high heat dissipation. In order for the TEC to withstand such a mounting, the temperature of its soldering should not be less, so they are also mounted on the Au-Ge solder [3, 4].

It was experimentally determined that the thickness of the Au-Ge layer for soldering the TEC should be from 15 to 20 μm. The deposition of such layers can be realized by the following methods: galvanic deposition, resistive, electron beam or arc evaporation, magnetron sputtering with solid target as well as with liquid-phase target. The solder paste cannot be used in this case, because when soldering the branches from the thermoelectric material to the ceramic base, menisci appear, and the solder material diffuses into the thermoelectric material, which negatively affects the quality of the thermoelectric material and the characteristics of the TEC as a whole.

In prototype or small-scale production, the number of equipment is usually limited. In our case, it is possible to obtain thick-film coatings either galvanically or by magnetron sputtering from solid or liquid-phase target.

There is no proven technology of Au-Ge alloy deposition by galvanic method to date. In addition, the method itself has a number of unacceptable shortcomings. The non-uniformity of the galvanic
coating during the good-quality process is not less than 15%. The deposition time of the layer of such thickness is about 3 hours. The deposited films contain impurities of materials released from complexes added to the electrolyte. Pollution of the solder layer can lead to a shift in its melting point, as well as an increase in brittleness after soldering due to the formation of intermetallic inclusions in it \[5, 6\].

When a layer is formed by classical magnetron sputtering from a magnetron source with a target diameter of 100 mm, it takes about 8 hours to produce a film with a thickness of around 20 µm. A good solution successfully used in the technological process for the deposition of thick-film coatings would be the use of the ion sputtering method in magnetron systems in target vapors (liquid-phase magnetron sputtering) \[10, 11\]. This method provides all the requirements in this case: film unevenness is not more than 5%, high productivity (deposition rates on a standing substrate are tens of micrometers per minute), the purity of the coatings obtained (the possibility of working in a deep vacuum). However, this method has a drawback – a very low effective material consumption of the order of 10%, which in the case of deposition of an extremely expensive Au-Ge alloy is unacceptable.

Equipping already available magnetron sputtering vacuum coating machine with other technological sources – thermal, electron beam or arc evaporators is not possible due to its design features, as well as economic inexpediency.

As a result, it became necessary to develop a new device for depositing Au-Ge alloy films with a high effective material flow rate and compatibility with the design of the existing coating machine. In this paper we present a design of a new evaporation source based on the existing 4" magnetron source, as well as the results of evaporation regimes during the deposition of a copper coating which has similar properties to Au-Ge alloy.

2. Design of the evaporation source
As it was said above, on the existing vacuum coating machine the method of liquid-phase magnetron sputtering (LPMS) is realized which will allow forming films of various materials with high speed and uniformity, but at the same time possesses a low material consumption coefficient.

To increase the efficiency of material consumption, the only way is to reduce the diameter of the crucible. But this will lead to the fact that the discharge zone will be located outside the crucible, which will not allow the material to warm up in the crucible and will also lead to the sputtering of the crucible material. Therefore, we proposed the following construction (figure 1), which is an additional evaporation module placed directly on the existing 4" magnetron source. The distance between the cover plate 1 and the surface of the magnetron 2 is 50 mm, which is sufficient for the anomalously glow discharge between them.

The surface of the magnetron is a cathode, and the special cover is an anode. The special cover is made of molybdenum, since it has a low sputtering coefficient and is a refractory material. On the surface of the magnetron source molybdenum spacers 3 are installed. A molybdenum disk 4 with a groove is placed on the spacers. A crucible 5 with a diameter of 15 mm is placed in the groove on the disc. Between the molybdenum disk and the magnetron surface, there is a guaranteed gap of 0.5 mm in width, which insulates the disk from cooling. The protective screen 6 is mounted on the special cover. The special cover itself is mounted on a stainless-steel support 7, which in turn is mounted on an external screen 8.

The construction is assembled in such a way that the discharge burns exclusively between the special cover 1 and the disc 4. By bombardment with ions, the disc is heated to a high temperature. By thermal conductivity and radiation, the crucible having direct contact with the surface of the disk is heated to a temperature sufficient for the melting and evaporation of the material inside the crucible. The system of protective screens prevents the material of the disk and covers from getting onto the substrate. Since the discharge burns between the screens, there is a constant re-sputtering of the material of the disk and the cover, which is confirmed by the almost complete absence of the material of the disk in the erosion zone of the disk 4.
3. Pilot process of the evaporation and its results

To carry out the experiments we used 60×48 mm AlN substrates with a thickness of 0.25 mm and average roughness Ra 0.009. The distance from the substrates to the source was 115 mm. The regimes were tested using copper, since this material has similar values for saturated vapor pressure, but a higher melting point and a significantly lower cost than the Au-Ge alloy. The discharge power was 1.5 kW in direct current mode at an argon flow rate of 4 l/min. The deposition time was 12 min. The deposition was carried out on a substrate without rotation.

The weight of copper in the crucible was 2 grams and the weight of the deposited film, measured on UG Unigram microbalances, was 0.6 g. The efficiency of material consumption at these parameters was about 30 %. With similar parameters, the efficiency of material consumption for a liquid-phase magnetron is about 10 %, for a classical magnetron – about 20 %. The thickness of the copper film measured on the MarSurf PS1 profilometer was 12 μm and the calculated deposition rate was around 1 μm/min.

The resulting sample (figure 2) was studied using a Thermo Scientific X-ray microanalyzer for the presence of crucible materials or screens. The results of the study (figure 3, table 1) showed that these materials were not found. On the surface of the film, elements O and C are found, which indicates contamination of the surface in the atmosphere, and Al and N are found under the film, which are the main elements of the ceramic substrate.

Figure 1. Design of the source: 1 – special cover, 2 – existing magnetron source, 3 – spacers, 4 – disc with groove, 5 – crucible, 6 – protective screen, 7 – support, 8 – external screen, 9 – plasma zone, 10 – anode of the magnetron source.

Figure 2. Image of the substrate with a copper film.
Figure 3. Auger spectrograph of the elemental composition of the sample by volume.

Table 1. Percentage of elements by volume of the film.

| Element | Mass ratio, % | Atomic ratio, % |
|---------|--------------|----------------|
| C       | 0,97         | 4,63           |
| N       | 0,36         | 1,49           |
| O       | 0,82         | 2,95           |
| Al      | 2,14         | 4,55           |
| Cu      | 95,70        | 86,38          |
| Total   | 100,00       | 100,00         |

4. Conclusions
Developed new design of the evaporator allows to obtain clean films with high speed and the efficiency of material consumption, which exceeds by 1.5 times the classical magnetron sputtering and 3 times the liquid-phase magnetron sputtering. The presented solution may be useful if there is no evaporation system using existing magnetron sputtering coating machines, because it can be implemented very simply and cheaply. This circumstance is especially important for small production and research laboratories. An additional advantage is full integration with the existing control system of the vacuum coating machines, which is impossible with the installation of power supplies for additional standard evaporation sources.

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