Production of permanent vacuum-tight connections: copper–aluminum, copper–titanium by diffusion welding for use in microwave electro-vacuum device nodes

V A Smirnov, A O Tsybert, A A Parmenov, K G Simonov, S A Vashin, A A Chistova, A V Tsybert, O V Fedotova, N A Klyuchnikov, D A Oselkov and A V Smirnov

Research and production corporation "Istok" n. a. Shokin
Vokzalnaya str. 2a, Fryazino, Moscow region, 141190, Russia

E-mail: info@istokmw.ru

Abstract. The aim of this work is obtaining vacuum-tight CuTi and CuAl connections used for the manufacture of components applied in microwave electro-vacuum devices, for example as electron beam output windows for soldered electron guns.

Currently, there is a great interest in soldered electronic guns, which are used in various fields of science and technology. The main task of such devices is to ensure that the electron beam is released into the atmosphere (or other interaction medium) with the least loss and distortion. The boundary node between the vacuum part of the gun and the atmosphere (or other medium) is the output window of the electron beam, i.e. the quality output of the electron beam largely depends on the properties of the output window. Therefore, special requirements are applied to this node.

The goal of our work is to meet these special requirements for electron beam output windows for soldered electron guns.

We have divided all the requirements into operational and design ones.

Operational requirements include:
• ensuring the output of the electron beam to the atmosphere (or other interaction medium) with the least losses and distortions, i.e. it is necessary to use a material that provides high permeability (transparency) for the electron beam. These materials are: beryl, titanium and aluminum foil with a thickness of 20 to 50 μm.
• ensuring vacuum density, i.e. the choice of materials and a range of these materials that provide pressure in the device during the storage and operation period of no more than 1.2·10^-4 Pa (recommended for use aluminum (AD1) and titanium (VT1-0) foil with a thickness of 20 μm, as well as a copper strip of the M0b brand meet the specified requirements).
• ensuring form stability (maintain geometric shapes and dimensions (within certain limits) when exposed to operational loads), i.e. have mechanical strength.

Design requirements include:
• obtaining a mechanically strong and vacuum-tight connection of the materials used.
• ensuring the assemblability (the possibility of further assembly) with other elements of the design.
To meet the above requirements, you must select the materials that are best suited to meet all the requirements at once.

Unfortunately, the listed materials do not have such properties as to clearly meet all the requirements.

Aluminum and titanium foil, which has good transparency for the electron beam and sufficient vacuum density, does not completely withstand the compression loads applied along the rolled axis, and the tension in the transverse direction of the rolled axis, that is, it does not provide form stability (mechanical strength). A strip of M0b grade copper that has sufficient vacuum density and has the necessary mechanical strength is absolutely not suitable for the transparency requirement for an electron beam. Therefore, the production of the output window node requires combined use of these materials.

A mesh is made of M0b copper strip, which should provide form stability and assemblability. To ensure the output of the electron beam, disks were made for the letter 1 node from titanium foil, and for the letter 2 node from aluminum foil. The only possible way to obtain a vacuum-tight connection of dissimilar copper–titanium (CuTi) and copper–aluminum (CuAl) materials is by diffusion welding.

Obtaining vacuum-tight connections due to the difference in coefficients of linear thermal expansion (CLTE) using a fitting (figure 1) CuTi and CuAl are described in the literature [1].

![Figure 1. Photo of the fitting for thermal diffusion welding.](image_url)

The disadvantages of thermal diffusion welding due to the difference of CLTE include: low repeatability of the results (low output rate of operational nodes), the inability to control grip force during execution of the operation (compression force during the welding process depends entirely on the temperature of heat treatment), large thermal inertia, low harmonization of the fittings in relation to the space and materials of the welded parts (fittings are designed for specific material and specific area). The advantage of this method is cheapness and ease of use (no special equipment is required, with the possibility of compressing parts during heat treatment). In our work, we tested two options for obtaining diffusion compounds, option #1 due to the difference in CLTE (in the fitting previously used for this purpose), option #2 using special equipment (installation UDSR-200/250-1150/100).

According to option #1, several nodes of the letter 1 (copper–titanium) were manufactured, all the resulting vacuum-tight units had large plastic deformations, that made them impossible to be used in products (a soldered electron gun). Therefore, the result for option #1 was considered negative and further work on this option was not carried out, including for the manufacture of nodes of the letter 2 (copper–aluminum). Minimal plastic deformations were obtained in the welding mode $T = 740 \, ^\circ\text{C}$,
exposure time 35 minutes, with a greater decrease in temperature it was not possible to obtain a vacuum-tight joint.

When performing work on option #2, the welding modes were selected taking into account the recommendations specified in the literature [1].

When manufacturing nodes for letter 1 and letter 2 using the UDSR-200/250-1150/100 installation, it was possible to determine the optimal welding modes that ensure vacuum density and minimal plastic deformations (up to 0.2 %) of the units. For nodes of letter 1, the optimal mode is: temperature \((T)\) 740 °C, exposure time \((t)\) 35 min, pressure in the working chamber \((B)\) no more than \(3 \cdot 10^{-3}\) Pa, pressure on the parts \((P)\) 0.5 kgf/mm². For nodes of letter 2, the optimal mode is: temperature \((T)\) 520 °C, exposure time \((t)\) 20 min, pressure in the working chamber \((B)\) no more than \(3 \cdot 10^{-3}\) Pa, pressure on the parts \((P)\) 0.2 kgf/mm².

CuTi and CuAl connections are characterized by the formation of brittle intermetallides and low-melting eutectic, which significantly affect the strength of these connections. To reduce the possibility of formation of brittle intermetallides and eutectic, the lowest temperature at which it was possible to obtain a vacuum-tight connection was selected, and the temperature influence from massive equipment elements was reduced by using ceramic fitting elements (see figure 2).

In addition to intermetallides and eutectic, the quality of the connection is affected by oxides. As technological methods for better cleaning of the surfaces of parts, we used: annealing of a copper part in vacuum at a temperature of 800 °C and holding for 20 minutes immediately before welding the units in the same installation (unloading of parts after annealing is combined with loading the units for welding), temperature rise depending on the pressure in the working chamber, additional holding at a temperature of 200 °C for 10 minutes and at a temperature of 300 °C for 20 minutes. The schedule of selection of welding modes for the nodes of the letter 2 is shown in figure 3.

![Figure 2. The loaded sample with junction through ceramics.](image)

Figure 4 shows photos of the results obtained for letters 1 (left) and 2 (right). To check the quality of the obtained connections of the letter 1 and letter 2 nodes, the method of metallographic research was
used. The results of the study obtained the following values: thickness of the diffusion layer at the nodes of the letters 1 – 7.4 µm (figure 5, left), in the nodes of the letter 2 – 4.7 µm (figure 5, right).

Figure 3. Modes of loading for the copper–aluminum connection.

Figure 4. Photos of electron output windows: left – letter 1; right – letter 2.

Figure 5. Photographs of metallographic section analysis: left – letter 1; right – letter 2.
The strength of the resulting connections during the tensile test was more than 6 kgf/mm². Given that this connection during the operation of the finished product works only for compression (does not experience tensile loads), the resulting strength fully meets the operational requirements.

As a result of our work, we have obtained and analyzed vacuum-tight CuTi and CuAl connections used for the manufacture of components applied in microwave electro-vacuum devices, in our particular case as "electron beam output windows" for soldered electron guns.

References
[1] Simonov K G 1985 Electronic soldered guns (Moscow, Radio and communication) 129 p
[2] Kazakov N F 1976 Diffusion welding of materials (Moscow, Mechanical engineering) 312 p