# METAL-TO-SAPPHIRE BRAZED AND DIFFUSION BONDED WINDOWS FOR OPTICS, ULTRA-HIGH VACUUM TECHNICS AND ELECTRONICS FOR MAINTENANCE AT TEMPERATURES 77–800 K

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## ABSTRACT

Brazed and diffusion bonded titanium-to-sapphire windows for possible application as optical elements of ultra-high vacuum units in electronic instrumentation and high vacuum engineering are developed. As the base of a solder and the material of a deformable gasket aluminium is selected and as a material of the frame titanum alloys are selected.

Metal-to-sapphire windows were made by two ways:

1. brazing sapphire to a titanium by melts of aluminium alloys at temperature 983±20 K;
2. diffusion bonding of metal to sapphire using the aluminium gasket.

Designs and technological regimes of the brazing and diffusion bonding of titanium-to-sapphire windows are developed. Experimental samples of bulky (up to 100 mm) brazed and diffusion bonded titanium-to-sapphire windows are fabricated and long tests on thermocycling in a broad range of temperatures from 800 K up to 77 K were acomplished. All tested windows have remained vacuum-tight after 180 thermocycles and have kept the high optical and radio engineering characteristics.

## INTRODUCTION

Leucosapphire (artificial colourless sapphire) is widely used in many areas of modern engineering due to a combination of high dielectric, thermal and mechanical properties [1,2]. Frequently it is necessary to use hermetic units consisting of leucosapphire joint with metals capable not only to work at superlow temperatures (down to 4 K) for long duration but also to withstand one or more heatings up to 700-800 K. Till now metal-to-quartz and metal-to-ceramics units, to be maintained at superlow temperatures, are brazed using soft solders based on indium, lead or their alloys [3], which do not allow to heat such joints up to temperatures above 300-500 K.

In the practice of brazing the most popular metal solders which immediately wet nonmetallic materials, particularly leucosapphire, are solders based on silver alloyed with titanium (up to 5 mass %). They ensure obtaining brazed joints not agreed on the thermal expansion [4,5]. However, units brazed by silver-contaning solder have large residual stresses due to high rigidity of the latter and because of this reason it is extremely difficult to receive bulky units (diameter 80-100 mm) with such solders since

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sapphire disk damage is possible as the result of residual stresses increasing as diffusion bonded details contact surface increase.

## RESULTS AND DISCUSSION

We make attempt to use aluminium for development of bulky sapphire-to-metal units capable for long time work at temperatures 77-800 K in multiple thermocycling conditions. It is well known that aluminium retains high plasticity at temperatures down to 4 K [6]. Silver-containing solders are less preferable for this conditions becauce of their higher hardness and melting temperature which leads to large residual stresses in sapphire detail. For example, the microhardness of aluminium at 293 K is 195 MPa against that of silver which is 960 MPa [7] and that of the frequently used copper-silver eutectic type solder (PSr 72), which is even higher. As the metal titanium alloys VT 1-0 and VT6 were selected because they are successfully used in apparatus maintained at superlow temperatures [7]. Besides the, titanium is more compatible with aluminium in comparison with other structural materials (based on iron, nickel etc.) with which aluminium forms too fragile and rigid intermetallic compounds .

Titanium is a temperature coefficient of the linear thermal expansion rather close to this of leucosapphire, which is very important for obtaining metal-to-sapphire joints with a minimum level of thermomechanical stresses.

Titanium-to-sapphire windows were prepared by diffusion bonding using the aluminium deformable gasket and by brazing with aluminium [8, 9].

Fig. 1 shows the versions of the most universal diffusion bonded and brazed constructions of titanium-to-sapphire windows which were able both to serve as an optical element for usual light and to work effectively during passing high frequency radiation up to 150 GHz with power up to 0,5 MWt through them. The constructions given allow to cool the windows by liquid nitrogen for many-fold increases of heat conductance of the sapphire optical element (sapphire disk) with the purpose of decreasing its heating and power losses during high frequency high power energy transmission.

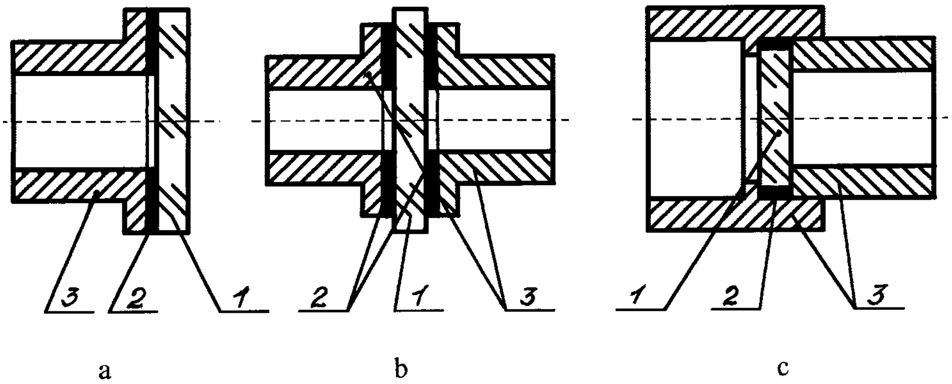

Fig. 1. Versions of metall-to-sapphire diffusion bonded and brazed windows constructions:

a – thermomechanically non-compensated diffusion bonded window; b – thermomecanically compensated diffusion bonded window with an protruding end face of leucosapphire disk; c – brazed window of envelope type; 1 – leucosapphire disks; 2 – aluminium gaskets or solder; 3 – metal branch pipes.

The metal-to-sapphire window consists of a leucosapphire disk 80 ÷ 100 mm diameter and 3,5÷6 mm in thickness diffusion bonded with titanium alloys VT 1-0 or VT6 branch pipes using aluminium alloy AD1 deformable gasket or brazed by melted aluminium alloys.

By its construction the window can be either thermomechanically non-compensated consisting from a leucosapphire disk diffusion bonded to a titanium branch pipe only in the one side (Fig. 1a, Fig. 2) or thermomechanically compensated consisting from a leucosapphire disk with two titanium branch pipes diffusion bonded to both sides of the disk (Fig. 1b,c; Fig. 2). Leucosapphire disks were polished up to a roughness Ra no more than 0,125 microns, titanium bodies with Ra no more than 165 microns, and aluminium deformable gaskets of the ring form were used. Leucosapphire disks after a polishing were calcinated in air at temperatures 1173 – 1273 K during two hours.

Metal were degreased by petrol and then were washed by ethyl alcohol (ethanol) before diffusion bonding. Diffusion bonding was carried out in vacuum on the installation UTS-1 [10].

The optimum process conditions were developed on the base of previously published technology [8] and are the following: diffusion bonding pressure 0,5÷0,1 MPa, temperature 893 ± 10 K, time of isothermal hold under pressure – 15 min, vacuum not worse than $10^{-3}$ Pa.

Manufacturing titanium-to-sapphire windows via brazing with aluminium has its own peculiarities. Studies of wetting of a titanium and its alloys by aluminium in vacuum $10^{-2}$-$10^{-3}$ Pa have shown, that wetting occures at the melting temperature of aluminium.

Fig. 2. Bulky diffusion bonded and brazed titanium-to-sapphire windows.

At the same time the satisfactory wetting of leucosapphire (Θ < 70°) is reached only at temperatures above 1273 K [4,11,12]. At lower temperatures much worse results are reached which are also poorly reproduced. Probably this is due to the fact that on aluminium there is oxide film which is removed with technologically acceptable rates at temperatures above 1273 K via the formation of gaseous products, mainly $Al_2O$. Microcracks on the surface of the mechanically polished leucosapphire at 1000 – 1100 K are not always filled by the melted aluminium and can serve as a source of microleaks. The saturation of aluminum by a few % of titanium promotes wetting of leucosapphire at temperatures below 1273 K. For creation of conditions maximally free from oxygen and carbon compounds an assembled titanium-to-sapphire unit was placed in the vacuum furnace in titanium container with titanium sponge. After a vacuum of $3 \div 5 \times 10^{-3}$ Pa had been reached heating was set on and a temperature of 893-903 K was reached with in 2 hours. Then an isothermal hold no less than 40 minutes for degassing and partial cleaning of the brazed surfaces was made. After this operation the temperature was increased to 983±20 K, during 10-12 minutes and brazing was conducted at this temperature during 5 minutes.

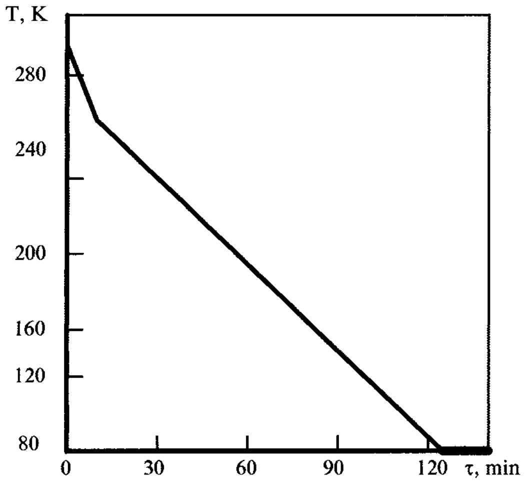

Fig. 3. Regime of test of windows on thermocycling at cryogenic temperatures.

All brazed samples passed the control on vacuum tightness with the application of helium leakage PTI-7a test. The samples, having a leak value not more than 5x10$^{-6}$ mm$^3$·MPa/s were then subjected to thermocycling tests which were carried out as follows:

1) double heating and cooling at the temperature regime 293-800-293 K with heating and cooling rates not more than 200 K/h;
2) thermocycling at the regime 293-77-293 K with cooling and heating rates no more than 100 K/h (Fig. 3).

Thermocycling on the first regime (at increased temperature) was conducted in maffle furnace in air. Thermocycling of samples at cr yogenic temperatures (2-nd regime) was carried out on a special bench. Tested samples have remained without disturbance of the vacuum tightness having retained a leak value no more than 5 x 10$^{-6}$ mm$^3$·MPa/s, in general after 180 thermocycles.

## CONCLUSION

Designs and process of manufacturing of bulky titanium-sapphire windows of up to 100 mm diameter capable for long duration under service conditions including thermocycling in a broad range of temperatures from 800 K up to 77 K without loss of vacuum tightness by diffusion bonding and brazing using aluminium were developed. Everyone of these technologies may be recommended for use for given specific units design. Thus, for manufacturing of enveloping type metal-to-sapphire units brazing technology is preferable and diffusion bonding technology may be recommended in all other cases.

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