# Brazing, Welding and Design Aspects of a Multifunctional Titanium-Alumina Ceramic Component for a Space Application

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## Introduction

In January 2003, the European Space Agency (ESA) is launching its ROSETTA probe into space for the purpose of studying the comet Wirtanen. The University of Bern participates in this mission with the ROSINA module, which consists of three sensors designed to analyse the cometary gases. The Applied Technology and Development Group (GVE) has in recent years developed and produced various ion optical components for these three sensors. One of the instruments is a time-of-flight mass spectrometer, which, as for all space applications, has to be of small physical dimensions and low weight. For this reason, the reflectron type (RTOF) was chosen, whereby the reflection of the ions inside the vacuum enclosure multiplies the measurement (flight) path length, allowing the realisation of a high resoluting but at the same time very compact instrument. The resulting RTOF mass spectrometer has an overall length of about 1 m but is capable of analysing and separating light to moderately heavy molecules in the range of 1–300 amu (atomic mass unit): it is possible to clearly resolve nitrogen ($N_2$) and carbon monoxide (CO), despite a difference in the mass of the two molecules of only approx. $^1/_{3000}$.

The instrument uses two grid-free reflectors, both realized by GVE. One of the two reflectors, the so called “Integrated Reflectron”, is welded on at one end of the instrument. In Fig. 1 the complete RTOF can be seen, while Fig. 2 and 3 show the Integrated Reflectron ready for integration.

## Specifications of the Integrated Reflectron

In order to comply with the strict weight requirements, the Integrated Reflectron had to fulfill both structural and functional tasks: it is part of the spectrometer vacuum enclosure, while its internal surface generates the electric fields used to decelerate the incoming ion beam and reaccelerate it in the opposite direction. This type of construction implied that a challenging combination of requirements had to be achieved.

# *High geometric accuracy* The calculations of the ion trajectories showed that the Reflectron had to be assembled with a high geometric accuracy. Especially for the position of the back cover a maximum deviation of only 0.2 degrees was allowed, whereby between reference surface (front face of the adapter flange) and back cover there are not less than 19 parts joined together by brazing and welding.

# *UHV-tightness* During the 6 months before launch the integrity of the spectrometer is continuously checked. The functional tests can only be performed if inside the instrument the necessary ultra-high vacuum ($< 10^{-5}$ mbar) is kept at least during 7 days, since the access to the pump-off valve is only allowed once a week.

# *High-voltage-strength* The electrodes are separated by insulators which have to withstand voltage differences of up to –8 kV. The prescribed safety margin was 50% and the tests had to be performed for both operating conditions: vacuum inside and outside of the insulator as well as vacuum inside and air outside.
# *Mechanical strength* During launch the rocket structure transmits the vibrations to the instruments and therefore, in order to avoid failures, the European Space Agency allows only vibration tested components to be installed. The prescribed levels reached 35 G RMS in the random modus.
# *High and low temperature reliability* During its permanence in space the instruments are submitted to a temperature excursion of about 220°C. While the direct sun radiation can heat the spacecraft up to 170°C, the temperature can fall below –40°C when this effect is missing.

## Material choice

The strict weight limit, the stiffness and strength requirement, as well as the prohibition of ferromagnetic materials led to the use of titanium (Ti Gr.2 and Ti6Al4V) for the metal parts. Because of the poor electrical conductivity of the surface oxide layer, all the metal electrodes had to be gold plated. The high voltages applied required the use of alumina ceramic for the insulators, which shows adequate mechanical properties, as well.

## Construction philosophy

The decision of joining the titanium and the ceramic parts by brazing radically influenced the design of the Reflectron. It is well-known that the UHV-tight brazing of titanium is a critical operation which can lead to failures and the tests performed confirmed this fact. Furthermore other tests showed that the gold platings couldn't withstand temperatures as high as 800°C without completely diffusing into the base material.

Due to the extreme lightweight concept the dimensions of the insulators were reduced to a minimum, whereby the smallest imperfection such as a contaminated spot on the ceramic surface dramatically impaired the performance of the whole component. Therefore, in order to achieve a reasonable production reliability, the idea of joining all the parts during one single brazing run was abandoned. Single brazed modules were produced, thoroughly tested and, if absolutely faultless, finally assembled by welding to form the Integrated Reflectron. Fig. 4 shows the section of the Reflectron, whereby the brazed subassemblies are apparent. Except for the welding of sub-assembly A with sub-assembly B, which was done by laser, all the other ones were done by electron beam.

## Sub-assembly B with Resistor Sectors

The electrostatic fields in two sectors (Resistor Sector 1 and 2 in Fig. 4) have to show a defined gradient, whereby the power consumption remains neglectable, despite the high voltages applied. This can be realized with tubes made of insulating material, whose inner surface is coated with a high resistance conductor. In this case helix-shaped resistor tracks totalling 15 m in length with an overall resistance of 1.5 GΩ were applied on the inner surface of two alumina ceramic tubes with an especially developed CNC dispenser.

The chosen high resistance paste needed to be burnt in air, making it impossible to use ceramic tubes with premetalized (e.g. with Mo-Mn) front faces. It was therefore necessary to develop a metalization method compatible with the resistor track material, since some tests showed the poor reliability of joints between titanium and not metalized alumina ceramic made with active filler materials. In particular it was rather impossible to produce UHV-tight components. An activated copper-tin alloy was applied at the front faces and heated in vacuum at about 900°C, whereby an excellent wetting of the ceramic surface took place. The produced layers were absolutely tight and could be brazed with eutectic alloy Ag28Cu. Furthermore the metalization process had to be thoroughly defined because the high temperatures required influenced the electical conductivity of the resistor tracks. Fig. 5 shows one of the Resistor Sectors ready for brazing.

Due to the high reactivity of the material, the titanium counterparts had to be coated with nickel in order to have a reaction barrier between liquid filler material and solid titanium. Several tests were necessary to obtain an adequate high temperature resistant nickel plating, whereby the adhesion with the base material during brazing was the most critical aspect.

Since, as already mentioned, the following assembly steps were done by welding, clean nickel-free zones were necessary. Masking techniques and postmachining of the plated parts were both successful.

The strict weight limit didn’t allow a self-positioning part design (see Fig. 6): the required geometric accuracy could only be achieved by the use of customized brazing and welding jigs. Several aspects such as thermal expansion and capacity as well as the high temperature geometric stability had to be considered, especially by the design of the brazing jig, which was realized by using a combination of titanium, ceramic, molybdenum and superalloys.

Before and after the EB-welding of the back cover the assembly was leak-tested with a helium detector.

## Sub-assembly A

The sub-assembly A consists of three cylindrical electrodes (adapter flange, lens and drift ring in Fig. 3) separated by two insulators. As mentioned before, titanium flanges were first brazed at both front faces of a ceramic ring in order to produce a single module – the so called insulator assembly – which could be separately tested and finally EB-welded to the gold plated titanium electrodes. In this case premetalized alumina ceramic rings were brazed to nickel plated titanium flanges with eutectic Ag28Cu filler material. Due to the mechanical configuration of the instrument these joints are higher stressed as the ones of the sub-assembly B and therefore copper interlayers in form of rings were put between titanium and ceramic in order to improve the joint toughness. These rings, which had a thickness of 0.5 mm, were nickel plated, as well, with the aim of preventing the diffusion of the silver-base filler alloy into the pure copper. The concentricity of both flanges was ensured by a brazing jig made of high temperature resistant materials. Fig. 7 shows a brazed insulator assembly.

The reduced thickness of the ceramic rings caused a critical behaviour of the insulator assembly from the electrical point of view, whereby bulged rings had to be added in order to cover the outer edge of the metal-ceramic interface, which was too highly stressed by the electric field. The rings were first pressed from annealed pure copper sheet with thickness 0.5 mm and then gold plated. Finally, they were laser brazed on the titanium rings of the insulator assemblies with a copper-tin alloy as filler material.

For the electron-beam welding of the sub-assembly it was only necessary to press the parts together, since in this case it was possible to design self-positioning interfaces.

## Integrated Reflectron: Assembly and Tests

Both fully tested sub-assemblies A and B were welded together by laser, whereby pure titanium as filler material and argon as protective atmosphere were used. For this last joint a self-positioning design was realized, as well, so the two parts had only to be pressed together in the revoluting support.

Before the Integrated Reflectron could be delivered further three tests had to be performed. The check of the dimensional and geometric accuracy showed that all measurements were within the prescribed tolerances and in some cases the deviations were caused by the single parts (e.g. out-of-roundness of the ceramic tubes) and not by the joints. The overall concentricity lay within 0.25 mm and the inner surface of the back cover was perpendicular to the center line with a precision of less than 0.2 degrees.

The vibration test simulated the loads occuring during launch. The frequency-load spectra were defined by the European Space Agency, while a customized support was designed to reproduce the instrument fixations. The Integrated Reflectron was leak-tested with a helium detector after the vibration test and since no damage could be observed, it was possible to proceed with the vacuum-keeping test.

The Reflectron was mounted on a steel flange connected to a turbomolecular pump and the interface was sealed with a gold wire joint, which ensured the UHV-tightness even at temperatures up to 400°C and the possibility of disassembly without damaging the component. The whole construction was provided with a hot air indirect heating system in order to produce an even temperature distribution. The Reflectron was evacuated and baked out at 300°C during 4 days (see Fig. 8), then the pump-off valve was closed, the heating turned off and the pressure monitored during 7 days. At the end of this periode the pressure didn't show any changes and was still lower than $2 \cdot 10^{-7}$ mbar, whereby the prescribed limit value was $1 \cdot 10^{-5}$ mbar.

## Conclusions

The chosen design and the applied technologies allowed to produce a reliable lightweight component, which fulfilled all specifications. Both flight model and flight spare items were successfully integrated in the respective instruments and contributed to their high performance; a resolution of $^{1}/_{5000}$ was achieved during recent calibration tests at the University of Bern.

## Pictures

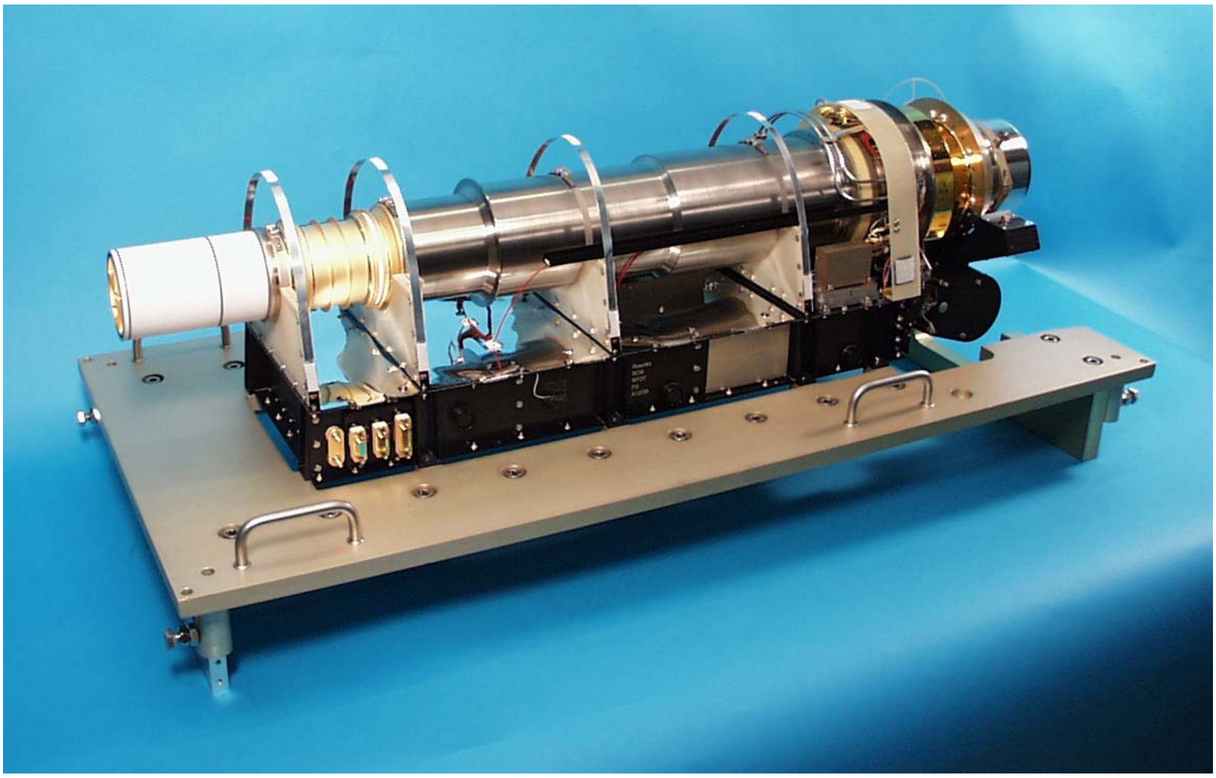

**Figure 1.** RTOF mass spectrometer [courtesy of University of Bern]

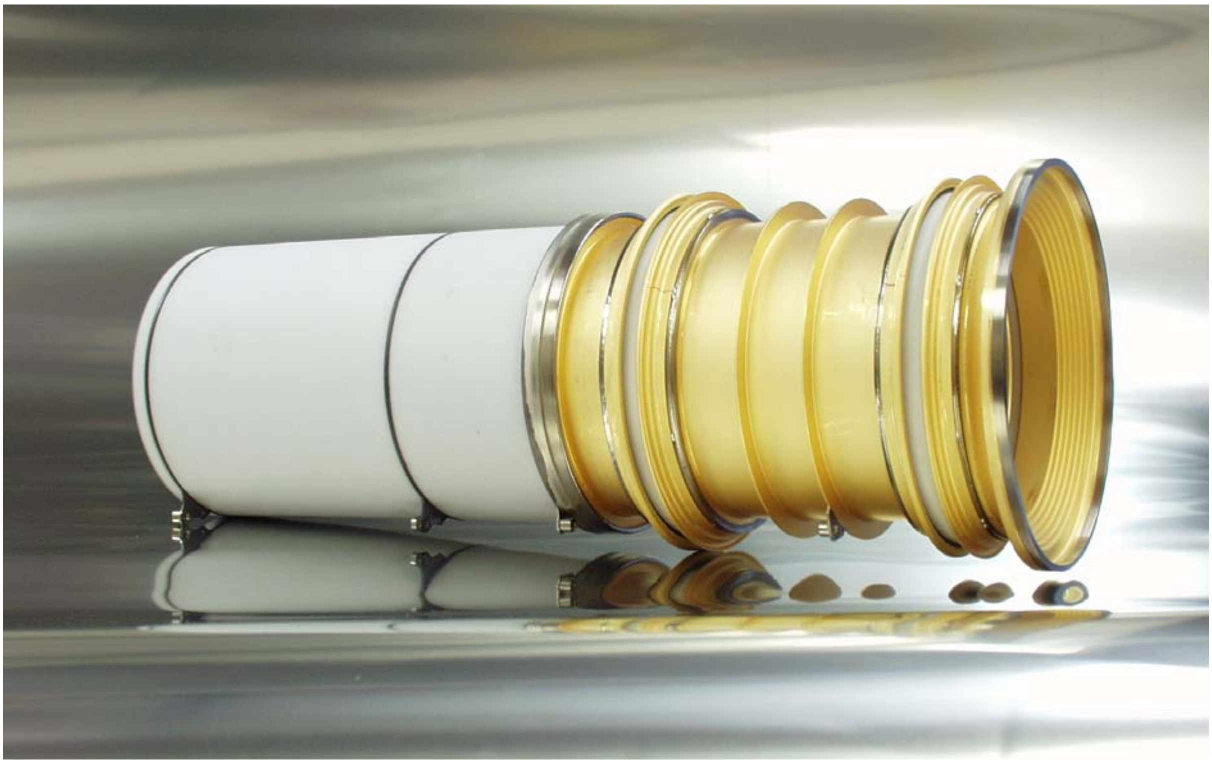

**Figure 2.** Integrated Reflectron ready for delivery

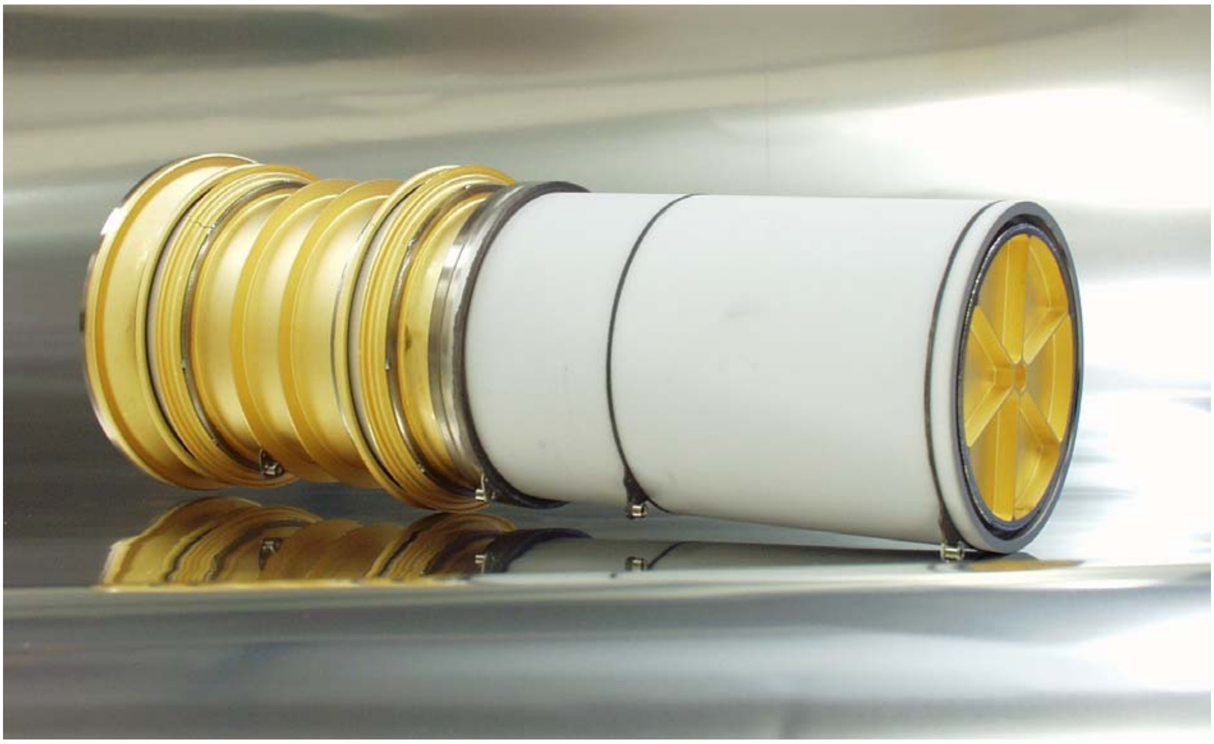

**Figure 3.** Integrated Reflectron ready for delivery

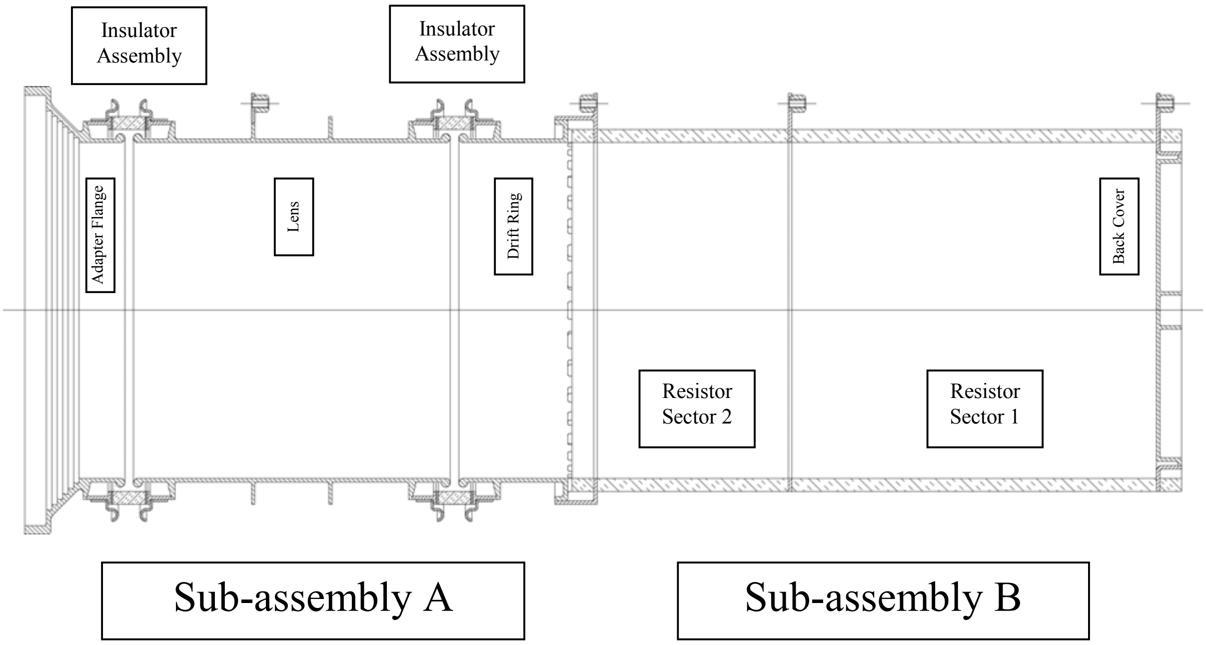

**Figure 4.** Section of the Integrated Reflectron

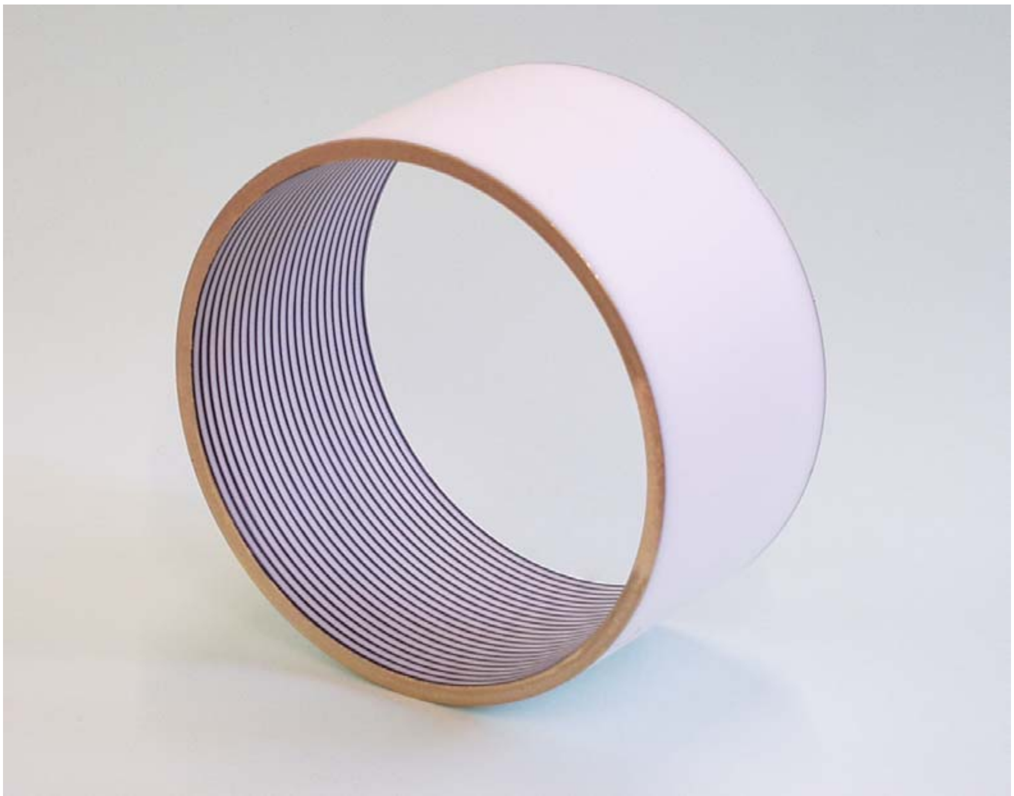

**Figure 5.** Resistor Sector 2, helix-shaped resistor tracks inside, metallization on front faces

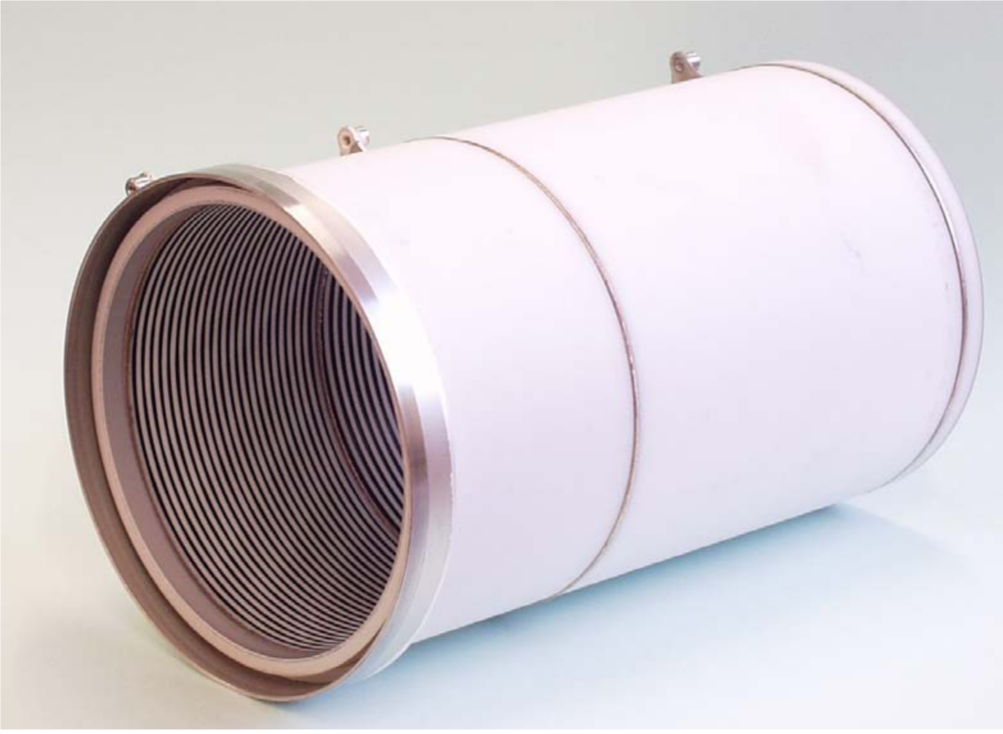

**Figure 6.** Brazed resistor assembly

**Figure 7.** Insulator assembly

**Figure 8.** Vacuum-keeping test

## Aknowledgements

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