

HIGH POWER RF TESTS ON WR650 PRE-STRESSED PLANAR WINDOWS*

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Abstract

A new planar, ceramic window intended to be used with WR650 waveguide fundamental power couplers at 1300 MHz or 1500 MHz has been developed. It is based on the pre-stressed planar window concept tested in PEP II and LEDA. A test stand that made use of the 100kW CW 1500 MHz RF system in the JLAB FEL was commissioned and used to apply up to 80 kW travelling wave to the windows. Two different types of RF windows (brazed and diffusion bonded ceramics) with design specification of 50 kW CW in TW mode were successfully tested both as gas barrier (intended to operate up to 2 psi) and as a vacuum barrier. The vacuum windows were able to maintain UHV quality vacuum and were successfully operated in the 10^{-9} mbar range. An overview of the pre-stressed power windows, RF test stand, procedures and RF power testing results will be presented.

PRE-STRESSED PLANAR WINDOW CONCEPT

The RF power windows, when incorporated in waveguide couplers, are important devices operating under ultra-high vacuum which allow the transfer of the RF power to the superconducting accelerating cavities. A robust high-power design has been adopted, based on the successful PEP-II and LEDA RF window. In this design, the ceramic is pre-stressed to reduce or eliminate the tensile stresses from RF heating [1], [2], [3]. This was achieved by careful choice of materials and tolerances and tight control over the brazing process. Several windows have been produced and RF power tested at JLAB. To high RF power test these components a mobile, room-temperature stand has been manufactured and used to perform RF conditioning on two pre-compressed windows simultaneously. The RF power used to perform these tests was delivered to a fully-enclosed WR650 RF system, terminated with a high power RF load or, optionally, a variable short circuit.

WINDOW DESIGN AND FABRICATION

The RF design and fabrication of self-matched RF windows using alumina discs inserted in waveguides with different dimensions are largely described in [1], [2] and [3]. A similar approach, used to fabricate WR650 pre-stressed windows, has been presented in [5] and is summarized in this paper.

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HFSS Simulations

To determine ceramic dimensions, a High Frequency Structure Simulator (Ansoft HFSS) model with ceramic centered in a 1.5 inch thick iris plate, which had outer dimensions and hole patterns matching WR650 waveguide was implemented and used. To reduced the effects of variation in the electrical permittivity of the Al_2O_3 , ceramic samples with different thickness and same diameter have been tested using a network analyzer set up to make Thru-Reflect-Line (TRL) measurements. Based on these measurements a final thickness of 7.57 mm was chosen for the 1497 MHz ceramic.

Window Components

Al_2O_3 ceramics with thickness matching 1497 MHz in WR650 waveguide was brazed in a copper coated stainless steel ring. A water cooling channel was included in the stainless steel ring which was used to remove the heat from the window. After brazing, each window frame had a knife edge machined on its surface to mate with a standard 6 inch rotatable Conflat® flange.

Brazing

Brazing was done in a vacuum furnace using Au:Cu brazing alloy and an experimentally established temperature profile [1],[2],[3]. MoMn coating on the border of the ceramic and molybdenum keeper ring were used during brazing.

Temperature and vacuum were continuously controlled and monitored during brazing.

Another set of RF windows was produced using an alternative new method for ceramic bonding under compression (See Figure 1) developed at JLAB.



Figure 1: JLAB's pre-stressed planar window.

Low Power RF Measurements

RF impedance matching was checked at different stages in window manufacturing process. TRL measurements using an Agilent 8753S network analyzer were performed after ceramic brazing, after machining the Conflat knife (using a low RF power fixture and standard WR650 waveguides), and with two RF pre-stressed windows assembled on the test box.

Anti-multipacting Coating

A controlled, thin layer of chrome oxide was sputtered onto the vacuum side of the ceramic window to prevent multipacting, using an RF sputtering system and protocols developed at JLAB [6].

PREPARATION FOR RF TESTS

Cleaning

All components were degreased and cleaned for UHV requirements in an ultrasonic bath with 5% micro-clean detergent and then rinsed with deionised water, dried with dust-free nitrogen and stored in plastic bags filled with dry nitrogen until assembly on the test box.

Window Assembly and Vacuum Leak Checks

Window and instrumentation assembly on the test box was done in a class-100 clean room. Copper plated stainless steel rings with Bal Seal[®] type RF contacts on the air side and modified OFE copper gaskets on the vacuum side were used to assemble the ceramic window on the RF test box.

Standard torque values were applied to tighten vacuum components and vacuum leak check was done using the residual gas analyzer (RGA) on the test cart. A final check for leaks was done using a plastic bag filled with Helium gas covering all assembled components. The RGA He gas trace monitored during this test was in the range of 10^{-12} Torr/sec. (See Figure 2).

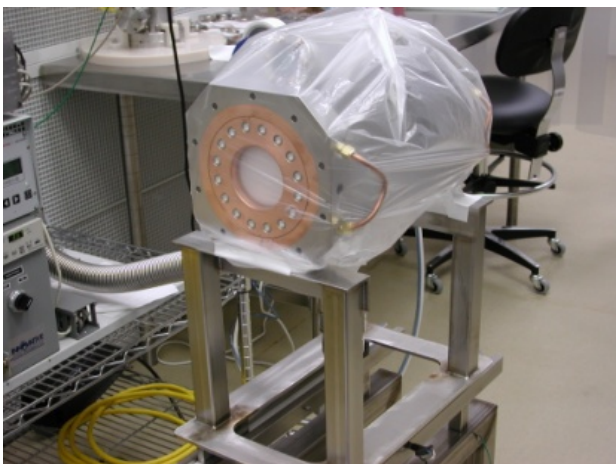


Figure 2: Vacuum leak check on pre-stressed windows assembled on RF test box.

Baking

Baking under vacuum of high RF power components is a recommended procedure which: a) minimizes the outgassing burden on the components submitted simultaneously to UHV and RF and b) identifies faulty components before going to the second step in the RF qualification process. The real life on an RF power components has an obligatory pass through this procedure, which is done under vacuum, ramping the temperature with a gradient of about 10°C/hr up to $150 - 200^{\circ}\text{C}$ (critical temperature range if materials with different thermal expansion coefficients (CTE) are used), soaking at high temperature of 150 or 200°C for 24 hours and then cooling down the system to room temperature with a controlled gradient.

Such procedures were successfully applied on similar components [3],[5]. A setup for bake with controlled temperature hot air was used (Figure 3) for pre-stressed windows assembled on the RF test box. During baking, the vacuum leak tight brazed joint failed on several pre-stressed windows, after reaching 150°C . For these RF power tests, the pre-stressed RF windows were not baked.



Figure 3: Test box with two pre-compressed windows ready to be baked under vacuum.

RF POWER TEST STAND

A mobile room-temperature test cart was manufactured and used to RF condition (under vacuum) two pre-stressed windows simultaneously.

The RF power generated by one 1497 MHz 100 kW CW klystron was applied to a fully-enclosed, RF shielded system terminated with a high power RF load or variable short circuit. The test was limited to 80 kW travelling wave by the power rating of the terminating RF load.

RF Stand Layout

The high power RF generated by the klystron (normally used for cavity FEL01-4) was transferred via WR650 waveguides to the test stand which had two RF power windows assembled on a test box operated under ultra high vacuum. The RF power was measured at two locations: a pair of directional couplers positioned on the waveguide coming from the klystron, and a second pair of

directional couplers after the test cell and before the RF termination.

As the JLAB free electron laser's Personnel Safety System requires operation with pressurized waveguides, a gas barrier based on a pre-stressed window, operating at 1.5 psi and water cooled with 2 gpm, was inserted before the E-bend feeding the RF to the test box (Figure 4).

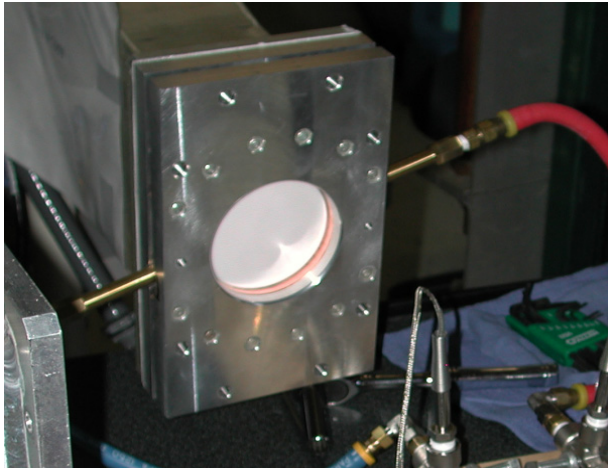


Figure 4: Pre-stressed windows used as gas barrier.

A diagram for the test stand for room temperature conditioning and RF testing of the pre-compressed ceramic windows is shown in Figure 5.

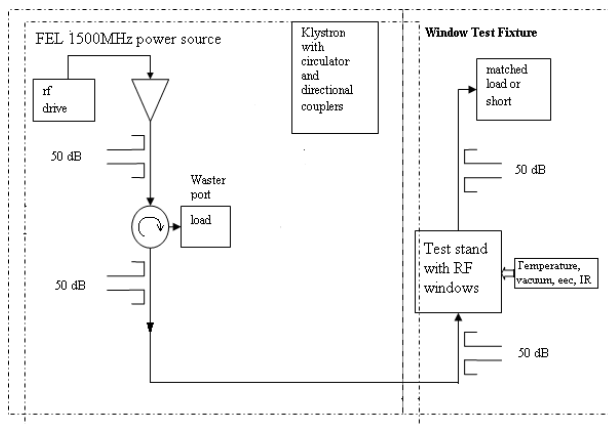


Figure 5: FEL 1500 MHz room temperature stand for pre-stressed windows testing.

Test Cart

The window test box was made from a WR650 copper plated stainless steel waveguide terminated with 1.5" thick octagonal flanges accommodating two compressed windows. The length of the WR650 waveguide was determined by HFSS simulations and checked after machining by TRL measurements (S_{11} better than -27 dB at 1497 MHz) [4].

The test box is provided with instrumentation ports for: vacuum system, vacuum gauge, two electron pick up antennae, two sapphire optical view ports, fittings for water cooling of the flanges, temperature sensors and was fixed on a mobile cart.

08 Ancillary systems

The test box was connected via bellows to a pumping system with preliminary pump, turbo-molecular pump, vacuum gauge and controller, and residual gas analyzer.

Waveguide adapters (with view ports for arc detector on the air side of the windows) were used to insert the test cart in WR650 waveguide.

Instrumentation

During RF conditioning and power testing, in addition to RF controls, data regarding temperatures and cooling water flow, vacuum, electron activity, arc and IR detectors and FLIR camera were logged and used to modulate the RF power and/or used to provide machine protection interlocks for the test cart (See Figure 6.).

Two view ports that were centered on the waveguide E-bends just prior to the test cell, were used to monitor ceramic temperature using a FLIR camera or commercial IR sensors. Standard K-type thermocouples were used for monitoring the temperature readings at different locations on the test stand during RF power tests. Low conductivity cooling water interlocked using water flowmeters, was used to provide cooling on the border of the ceramic, the test box flanges or RF terminating load.

A fast RF-vacuum feedback module was used to safely perform RF power conditioning (in pulse or CW mode of operation) [5], [7].

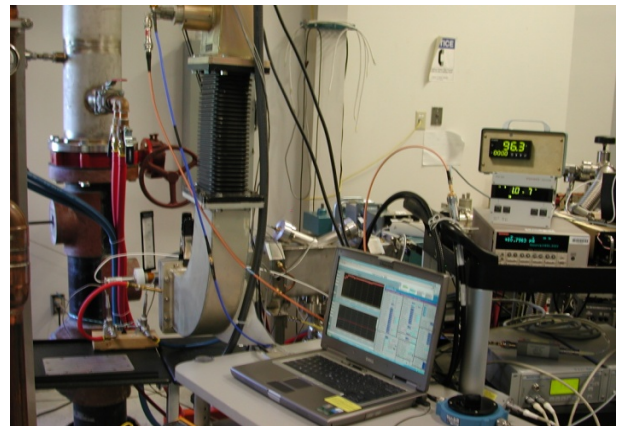


Figure 6: FEL 1500 MHz room temperature stand for pre-compressed windows testing.

Optical signals from arc detectors on the vacuum side as well as on the air side of each pre-stressed window were interlocked to the fast RF board to ensure component protection in case of arcing events. A handheld calibrated portable unit was used to check for RF leakage out of the RF transmission lines and associated components prior using the system to perform high-power RF tests.

EPICS and LabView Controls and Data Acquisition Programs

The LLRF controls for the test stand were implemented in EPICS. Standard CEBAF commissioning screens were used. Standard CEBAF klystron interlocks affecting the LLRF drive were also enabled during these tests.

A LabView program was developed and used during commissioning and RF power tests to acquire various data: RF power, vacuum in the test box, electron activity, as well as temperature from the FLIR camera, IR sensors and K-type thermocouples.

RF Test Stand Commissioning

Commissioning was done in TW mode of operation, replacing the test box with a piece of WR650 waveguide. During commissioning, gas barriers with Kapton foil and pre-stressed RF window were tested. The gas barrier with water cooled (2 gpm, inlet water temperature 35.5°C) pre-stressed ceramic remained in place for all subsequent RF power tests. Temperatures measured on the gas barrier with pre-stressed ceramic, at different locations (ceramic centre T_c , ceramic border T_{bo} , gas barrier flange T_{fl}) and RF power levels are summarized in Table 1 and Figure 7.

Table 1: Temperatures measured on the pre-stressed window used as gas barrier.

RF (kW)	T(min)	T_c (°C)	T_{fl} (°C)	T_{bo} (°C)
25	60	61-70	49	60
35	15	75-88	54	67.5
51	45	100-125	72	89.9
61	60	119-152	84	107.7

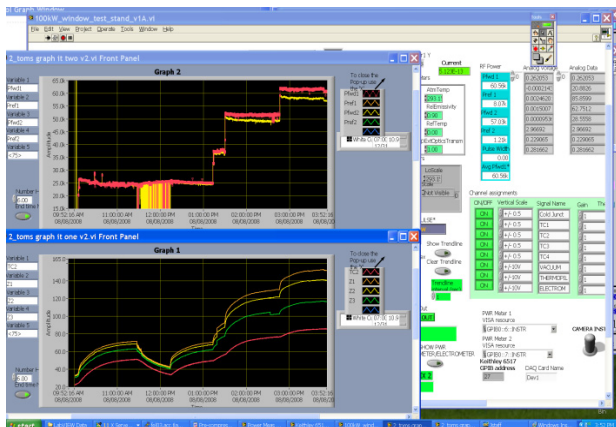


Figure 7: Temperatures measured on pre-stressed window used as gas barrier at different power levels. (T_c (brown and yellow)), T_{bo} (green), T_{fl} (red).

RF POWER TESTS

RF Power Tests in TW Mode

To perform RF power tests on the two pre-stressed windows assembled on the test box, conditioning was started in traveling wave (TW) mode. This process was performed in pulse as well as in CW mode of operation, assisted by a fast RF feedback loop, which modulates the RF pulse amplitude as function of test box vacuum.

A fast interlock system on the vacuum controller’s analog output switched RF off if the coupler vacuum exceeded 5×10^{-7} mbar. The RF permit was obtained after the vacuum pressure was better than 2×10^{-7} mbar.

After several hours of RF conditioning (See Figure 8), constant RF power was transmitted through the two

windows without any vacuum activity for at least one hour at different power levels up to 60 kW (Figure 9).

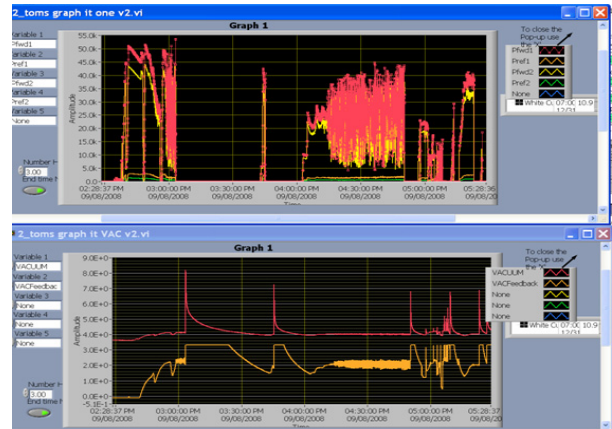


Figure 8: Conditioning in TW mode, RF vacuum feedback loop assisted. Upper traces are of RF power between 0 and 55 kW. Lower traces are vacuum signal (red) and vacuum feedback attenuator control signal (orange) arbitrary units.

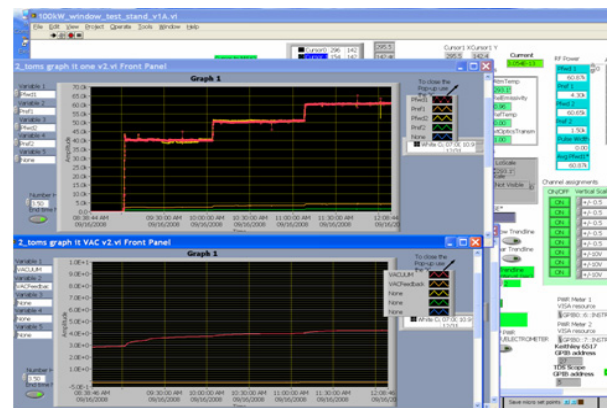


Figure 9: Constant CW RF power tests at different power levels in TW mode up to 60 kW. Upper and lower plots same signals as Figure 8. RF power traces 0 to 70 kW.

Temperature FLIR images of the ceramics were recorded while the system was operated in TW mode at different power levels. Figure 10 displays temperature distribution on the ceramic while at 40 kW CW.

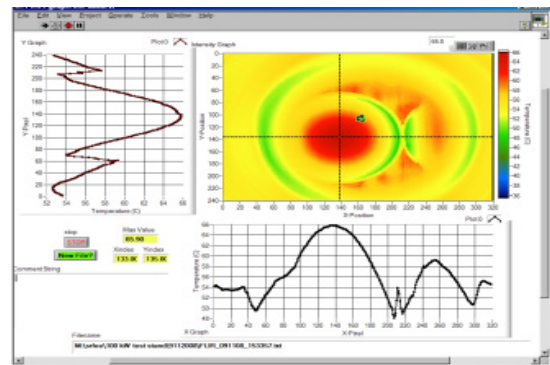


Figure 10: FLIR image of the pre-stressed ceramic after one hour at 40 kW CW in TW mode. Temperature range on the ceramic 42 – 66 °C.

RF Power Tests in SW Mode

Tests in standing wave (SW) mode were performed in steps of forward RF power of 5 kW up to 30 kW, moving the short circuit over a distance greater than $\lambda/2$, without any vacuum activity (See Figure 11). At 30 kW a vacuum outburst took place triggering molecular redistribution inside the box test.

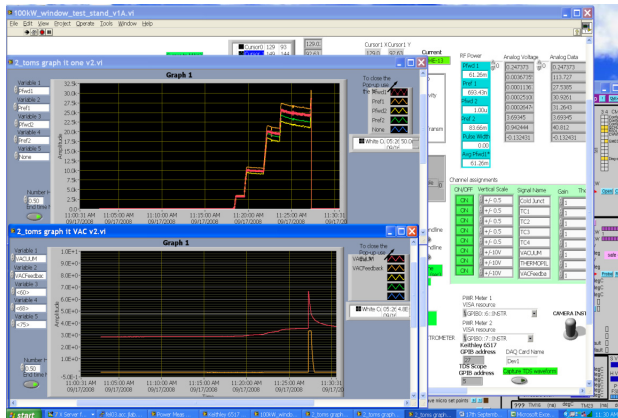


Figure 11: Ramping RF power in SW mode up to 30 kW when a vacuum outburst took place. Upper and lower plots same signals as Figure 8. RF power traces 0 to 32 kW.

After this event, vacuum activity was present for different positions of the short circuit, however, the test was continued up to 25 kW fully reflected power, which has equivalent electric fields of 100 kW local peak power. (See Figure 12).

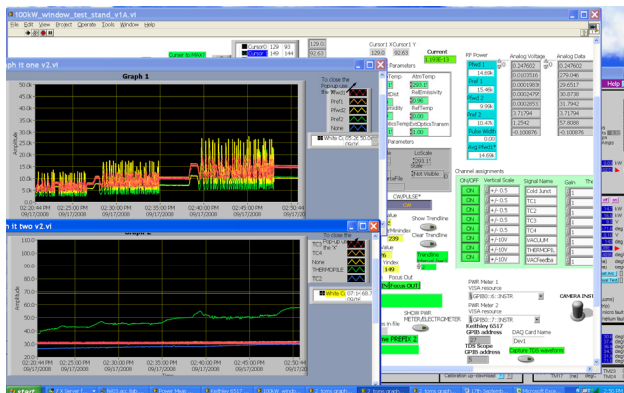


Figure 12: RF power in SW mode up to 25 kW. Upper traces RF power scaled 0 to 50 kW. Lower traces are thermocouple based temperature readings scaled 20° C to 110° C.

INSPECTION AFTER RF POWER TESTS

Pre-stressed Window as Gas Barrier

The pre-stressed window fulfilled its role during all tests in travelling wave and standing wave modes. Not being exposed simultaneously to RF and vacuum has provided important thermal response data for this type of windows. No tracking or metal plating due to arcing discharges was observed after RF power testing.

Brazed Pre-Stressed Windows

The brazed pre-stressed window maintained vacuum during all RF power tests; the water cooled ceramic border had a stable temperature of 82°C after one hour CW at 60 kW. No traces of arcing discharge were noticed after RF power testing.

Compression Bonded Window Response

The compression bonded window maintained vacuum during all RF power tests, the ceramic border without water cooling warmed up to a stable temperature of 106°C after one hour CW at 60 kW. No traces of arcing discharge were noticed after RF power testing.

CONCLUSIONS

Simulation, manufacturing, and testing methods for pre-stressed RF ceramic windows were implemented at JLAB. Several 1500 MHz ceramic windows were brazed or bonded and successfully tested as gas barrier and as RF power windows.

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