

A HIGH THERMAL CONDUCTIVITY WAVEGUIDE WINDOW FOR USE IN A FREE ELECTRON LASER*

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Abstract

A high thermal conductivity waveguide window with a goal of propagating greater than 100 kW average power operating at 1500 Mhz has been designed, analyzed and tested. The favorable material properties of Beryllia (BeO) make this possible. The window is brazed to a soft copper frame and then the frame is brazed to a KOVAR flange, providing the vacuum seal. RF analysis combined with thermal/structural analysis shows the benefits of the material. The KOVAR flange with a CTE, coefficient of thermal expansion, that matches that of BeO enables a strong braze joint. RF testing to 35 kW has been successful. This design can be expanded to applications with lower frequencies and higher average power, i.e., larger windows

1 INTRODUCTION

The Free Electron Laser Facility being developed at Jefferson Lab requires much higher RF power throughput than is needed for their main facility. Much of the accelerator technology for the free electron laser is taken from the main facility which uses a two window design. The window design for the FEL consists of a room temperature warm window and a 2K cold window like the main facility. The warm window design from the main facility does not work at the power levels required for the FEL, therefore, Jefferson Lab initiated the development of a warm window using the cold window design as a baseline. In a corroborating effort, Northrop Grumman began developing a backup warm window design to enable greater than 100 kW average power operating at 1500 Mhz. The design was developed as a direct replacement in the FEL warm window location.

2 MECHANICAL DESIGN

The design evolved as a backup warm window that would fit in the TJNAF envelope. Preliminary analysis between alumina and beryllia windows showed that for standard grade material the high thermal conductivity of beryllia, shown in Table 1, resulted in low thermal gradients, and therefore low thermal stress within the window.

Table 1: Comparison of Thermal Conductivity's at 25C

Material	W/mK
Copper	380
Beryllia	300
Alumina	20

To match the thermal expansion of beryllia, KOVAR was chosen as the flange material, minimizing thermal stresses in the beryllia during the braze cycle [1]. A thin OFHC copper frame, .010 inches thick, between the beryllia window and the relatively stiff flange was added for strain relief and for its high thermal conductivity. Figure 1, shows a solid model of the window, the copper frame, and the KOVAR flange, which was copper plated.

The preferred BeO window geometry was an 'off the shelf' flat piece of Thermalox 995, .100 inches thick, from Brush Wellman. The thickness was chosen to keep the stress due to pressure low while using a stock size of standard grade material, ensuring repeatable material properties. Presently there is no multipacting coating on the window

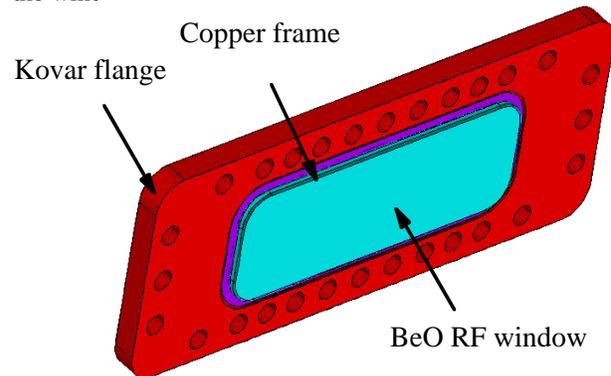


Figure 1: BeO RF Window, Flange and Frame

3 RF DESIGN

RF analysis was used to determine the S parameters for the structure and to optimize the structure within the requirements set by the envelope and mechanical design. Table 2 compares the electrical properties of BeO with other standard grade candidate materials.

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Table 2: Comparison of Electrical Properties

Material	Dielectric Const (1MHz)	Loss Tangent
Beryllia (Thermalox 995)	6.7	.0003
AlN	9.0-10.0	
Alumina	9.0	.0003

To optimize the structure with a .100 inch thick BeO window, metal 'wings' forming an iris were added to the flanges. These iris 'wings' are shown in figure 2. RF results showed wings were needed on both sides of the window.

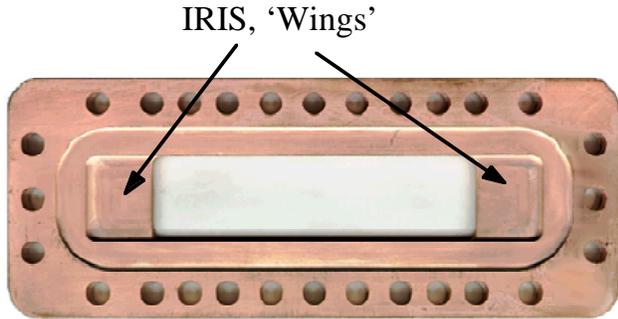


Figure 2: RF window and Iris ('wings') and flange

The following MAFIA RF analysis results were obtained for a wing width of .750", and a wing thickness of .100", Table 3.

Table 3: S Parameter Results

S11 amplitude	S11 phase	S21 amplitude	S21 phase
.0066	87.30	.99956	-2.740

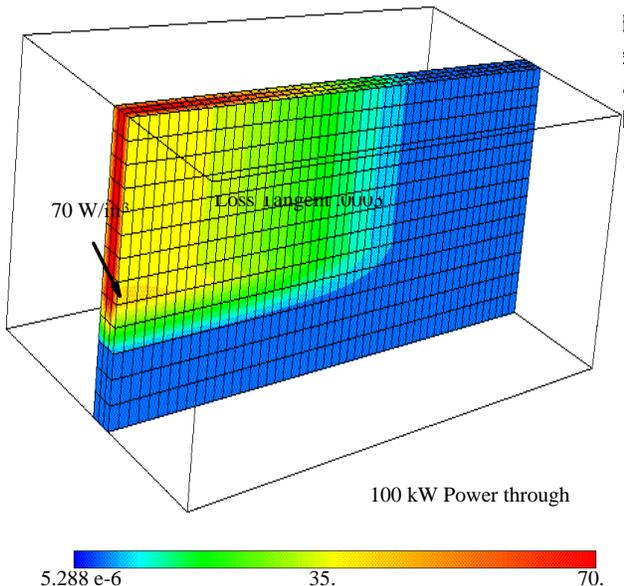


Figure 3: Heat loss contours determined by MAFIA

4 THERMAL ANALYSIS

The power loss distribution calculated in MAFIA was then mapped into an ANSYS finite element model. This model was used to determine thermal gradients and stresses in the window. Figure 4 shows the resulting temperature contours in the window, the frame, and the flange. On the edge of the flange a boundary temperature of 20C was set. The results show very small gradients in the window and a temperature rise of 29C between the window and the flange edge.

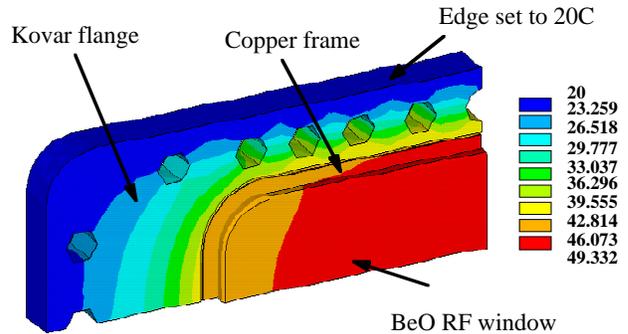


Figure 4: Temperature contours from ANSYS

5 STRUCTURAL ANALYSIS

Structural analysis was completed using the temperature contour data shown in figure 4. Symmetry conditions were applied to the two cut boundaries of the model and it was held perpendicular to the window face allowing the window and flange to expand freely. Stress results are shown in figure 5 for the assembly, they do not include pressure loads. Von Mises stresses are given here which show that the copper frame attached to the window and flange is the most highly stressed component.

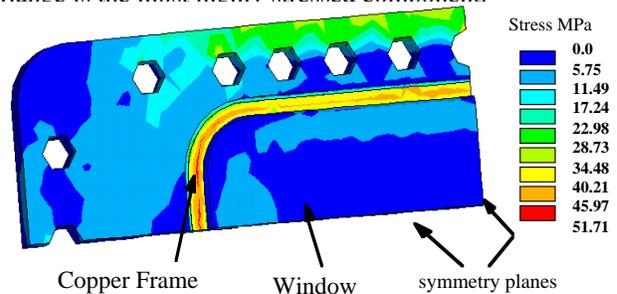


Figure 5: Von Mises contours of the window assembly

Though not indicated here, the stress in the frame is primarily compressive. The thermal stress in the copper could be mitigated by minimizing the thermal gradients in the flange. Figure 6 shows the stresses that develop in the BeO window. The high thermal conductivity of the ceramic results in low thermal stresses.

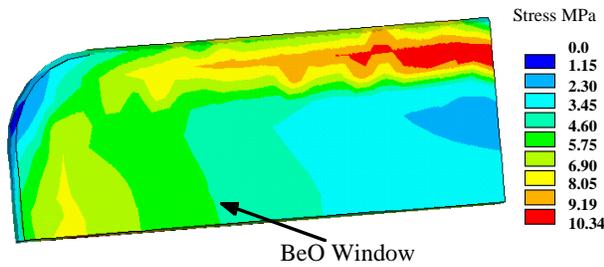


Figure 6: Von Mises stress of the BeO window

6 RF TESTS

Thomas Jefferson National Accelerator Facility (TJNAF) provided the facility and manpower to test the window. Figure 7 shows the layout of the high power test. The space between the PN001 JLAB window and the BeO test window was evacuated by a 160 l/s Vac-Ion pump while the waveguide between the BeO window and the load was at atmospheric pressure. The window flanges were water cooled. The baseline pressure prior to testing was 1.4×10^{-9} torr. Temperatures at different locations of the waveguide and window flanges were monitored by thermocouples. Temperature of the BeO ceramic was measured by an infrared thermometer through a viewing port on the waveguide elbow. The waveguide between the two windows was equipped with a pick-up probe to monitor the electron current. A vacuum interlock and an arc detector interlock were used to prevent a catastrophic destruction of the ceramic. During the test, the incident and reflected powers, the vacuum pressure, the electron current, the temperature of the BeO ceramic and the temperatures of the window flanges were continuously monitored and recorded.

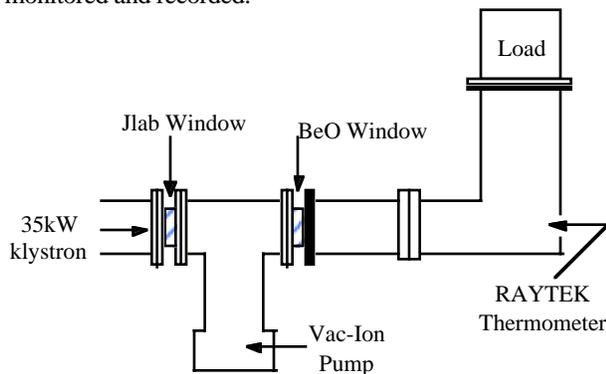


Figure 7: RF window test set up

Prior to applying high CW power, the windows were first submitted to high pulsed power (pulse length .01 ms - .1 ms, with a repetition rate of 100 Hz). Table 4 shows the temperature rise of the BeO ceramic as the power is increased. The temperature of the ceramic at zero power was 28C. The vacuum pressure increased to 9.4×10^{-8} torr at 35 kW and no electron current was detected.

Table 4: Temperature Rise In BeO Ceramic

Power (kW)	BeO Temp C	T(BeO)-27.7 ΔT C
0	27.7	0
5.04	35	7.3
10.1	40.8	13.1
15.1	45.7	18
20.2	51.2	23.5
25.2	58.2	30.5
35	70.9	43.2

The temperature rise between the coolant and the BeO window was much higher than expected. This could be from high losses in the braze material, which was not included in the model.

7 CONCLUSIONS

Analysis shows that for the expected power loss in the window the goal of 100 kW of through power at 1500 Mhz is achievable. The high thermal conductivity of BeO results in low thermal gradients within the ceramic. Modifications to the design which would include coolant nearer the ceramic would ensure lower ceramic temperatures. Modifying or eliminating the braze process is expected to decrease the heat loss and therefore decrease the thermal gradients within the assembly. BeO as an RF window material shows promise based on the analysis and tests to date.

8 REFERENCES

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