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Title:

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A HIGH-POWER L-BAND RF WINDOW*

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Abstract

This paper discusses the design, fabrication and testing of a high power alumina disk window in WR1500 waveguide at L Band, suitable for use in the NLC damping ring RF cavities at 714 MHz and the LEDA Accelerator at 700 MHz. The design is based on the fabrication methods used for the successful PEP-II cavity windows. Four prototype windows at 700 MHz have been produced by LBNL for testing at LANL. The RF design and simulation using MAFIA, laboratory cold test measurements, fabrication methods and preliminary high power test results are discussed.

1 INTRODUCTION

High-power RF windows are key components for most accelerators. High reliability of windows is essential for the smooth and efficient operation of facilities, especially for machines with a large number of RF structures and / or high power requirements. RF windows have been identified as key components for early R&D as part of the LEDA program at LANL [1] and the NLC damping ring R&D activities at LBNL [2]. The two applications have similar frequencies and propose to use the same WR 1500 waveguide so a single common design can be used which is fine-tuned for each application [3]. A robust high-power design has been developed based on the successful PEP-II RF window [4]. In this design the ceramic is pre-stressed in compression to reduce or eliminate the tensile stresses from RF heating. This is achieved by careful choice of materials and tolerances and tight control over the brazing process. Four prototype windows have been produced at LBNL and delivered to LANL and two have been tested to high power in the LEDA test stand.

2 RF DESIGN

The window is a single alumina disk mounted in an iris in the waveguide, see figure 1. The basic dimensions were scaled from the PEP-II design (476 MHz in WR2100), to fit the new frequency and smaller waveguide. For simplicity the same waveguide dimensions are used on both sides of the window, unlike PEP-II where there was a step down to a smaller cross section on the vacuum side. The ceramic fits within the narrow dimension of the waveguide and the cooling flange and knife edge have the dimensions of a standard rotatable 10" Conflat flange. The dimensions are chosen so that the windows are self matched at the operating frequency without the use of posts or stubs. The only difference between the 700 MHz and 714 MHz designs is a small change in the thickness of the ceramic.

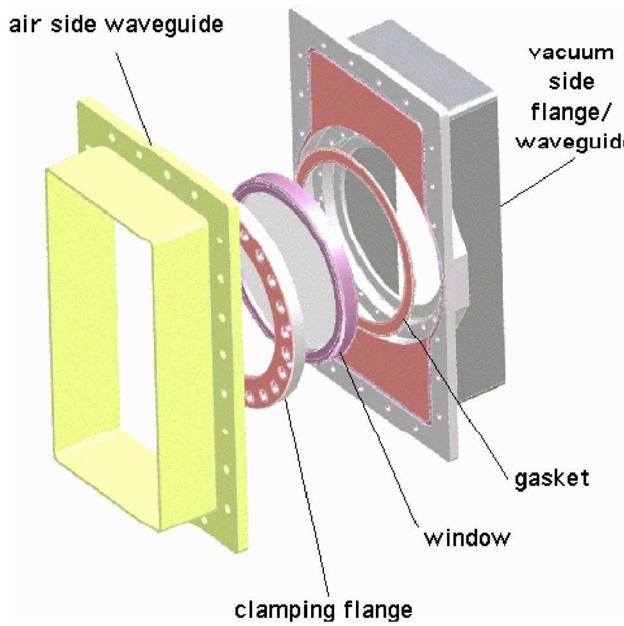

Figure 1. Waveguide window assembly.

The 3D time domain module in MAFIA was used to calculate the reflection and transmission coefficients over a band of frequencies and the dimensions were adjusted to obtain the two desired match points. Figure 2 shows the MAFIA model with the normal TM_{01} waveguide mode propagating. Figure 3 shows the calculated reflection coefficient for the LEDA design. The calculations were verified by measurements in a cold-test model before the production ceramics were ordered. Figure 4 shows the sensitivity of the match frequency to ceramic and iris thicknesses, and the calculated ghost modes. Fine tuning of the window thickness is possible when the knife edge is cut in the final window assembly.

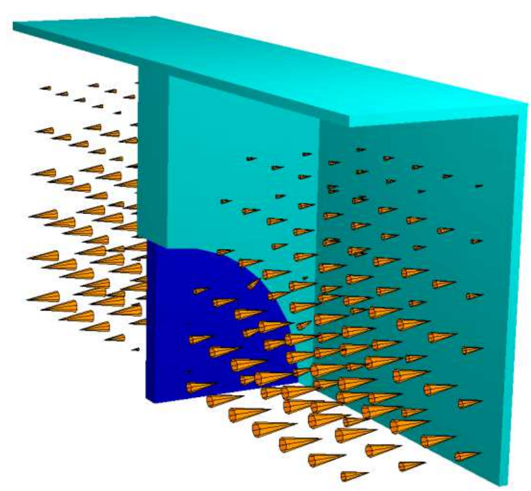

Figure 2. Window with TM_{01} mode propagating.

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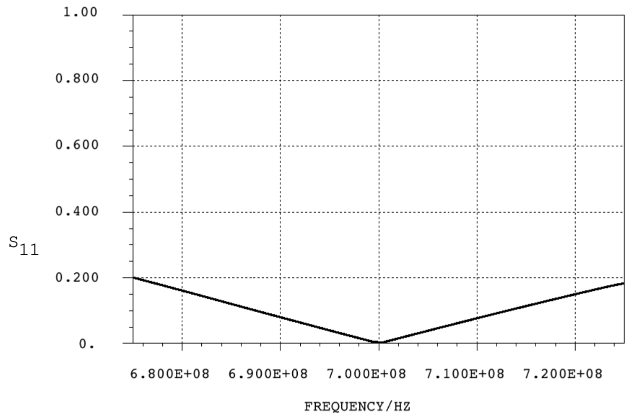

Figure 3. Calculated S_{11} of LEDA waveguide window.

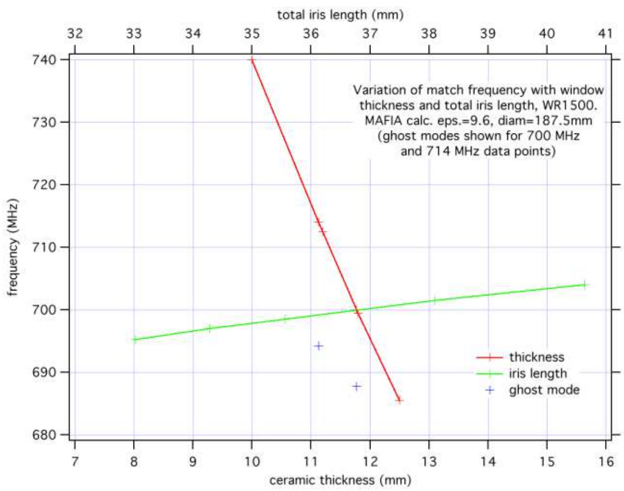

Figure 4. Tuning of window assembly.

3 MECHANICAL DESIGN AND FABRICATION

The mechanical design follows the assembly procedure developed for PEP-II. The window is brazed into a thick stainless steel flange containing a cooling channel. The flange is initially slightly larger than the ceramic but is constrained by an even thicker molybdenum keeper ring as the furnace temperature is ramped up, see figure 5.

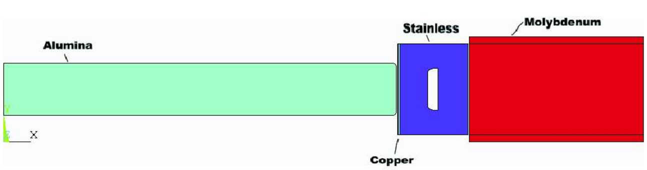

Figure 5. Material configuration for the window braze.

Once the stainless steel ring reaches it's yield point it plastically deforms and is kept from expanding as much as it would otherwise. As the temperature continues to rise the alumina disk catches up to the stainless steel / molybdenum combination, until the desired gap is attained at brazing temperature. On cooling down the stainless ring contracts more than the alumina putting the ceramic into compression. The outside of the stainless ring is "green" fired and the molybdenum keeper is titanium nitrided to prevent sticking. Careful control of the room temperature clearances and the use of shims allows the optimum brazing gap of 0.001" - 0.003" (25 - 76 µm), to be obtained each time. The furnace cycle contains a long hold period during the cool down to allow local stresses between the ceramic and the cooling ring to be relieved. Table 1 gives the furnace temperature profile. Figure 6 shows a window assembly ready for brazing. The process was simulated in ANSYS to fine tune the scaled dimensions and several ring tests were performed without ceramics first to check the parameters.

The first full braze attempt failed due to lack of baffling in the furnace, allowing direct radiant heating of the ceramic from nearby heater elements. Once this was rectified the following four brazes were successful, figure 7.

Table 1. Braze furnace temperature set points.

Temperature	rate	Hours
°C	deg/min	
23		0
960	10	1.6
960	hold, 1hr	2.6
1025	15	2.6
1025	hold 5 mins	2.7
440	1	12.5
440	hold, 10hr	22.5
40	1	29.1

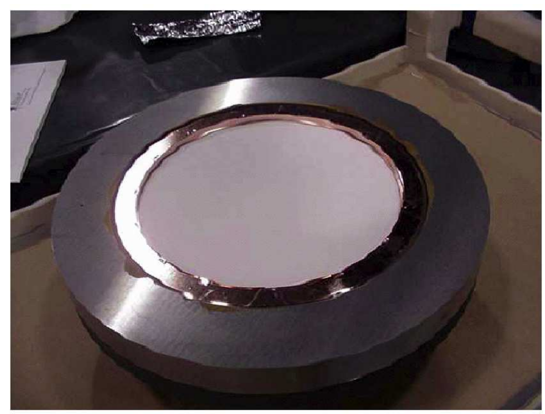

Figure 6. Fixtured window assembly ready for braze.

Figure 7. First successful window braze.

4 FINAL FREQUENCY MEASUREMENTS

Figure 8 shows the measured reflection coefficient of the first finished window in the real vacuum flange. The match was better than -47 dB and the frequency was 697 MHz (0.4% below the target value). The match at 700 MHz was about -33 dB, which is acceptable for high power testing. The average best match frequency of the first 5 windows is 696.625 MHz, which is 3.375 MHz below the target frequency, possibly because of a small difference in the dielectric constant of this batch of ceramics. This would require a 0.169 mm (0.0066") reduction in the ceramic thickness to correct for future windows and a further 0.702 mm (0.0276") to tune the window up to 714 MHz for the NLC. The final thicknesses would be 11.31 mm (0.4454") and 10.78 mm (0.4244") respectively.

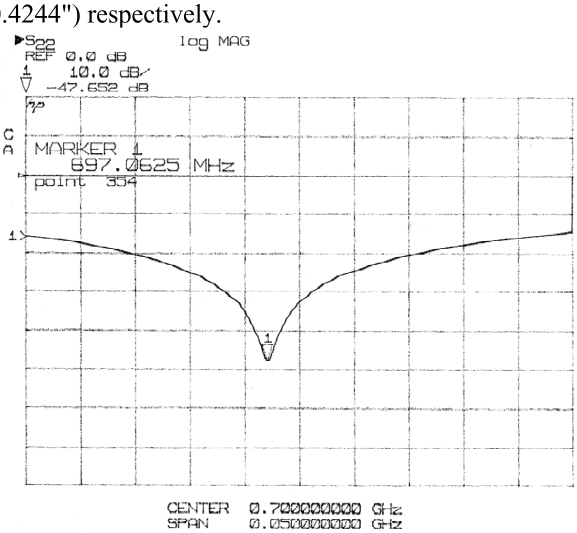

Figure 8. Window final frequency measurement in spool.

5 HIGH-POWER TESTING

The windows were titanium nitride coated with approximately $6x10^{15}$ atoms/cm^2 and the vacuum chamber assembly was baked to over 150°C before high-power testing. Only two of the four windows have been tested so far, but preliminary results are good. The windows were tested in transmission at LANL. The windows conditioned fairly quickly with moderate outgassing at each new power level. The full power of the test stand was reached within 20 hours of processing, corresponding to just over 800 kW CW forward power, see figure 9. The power density in the ceramic is three times higher than the PEP-II windows. The windows were operated at between 750 and 800 kW for about 8 hours before the test was terminated. The window temperatures reached equilibrium after about an hour, figure 10, and the chamber vacuum stabilized at $8x10^{-8}$ Torr at full power. There were a number of arcs and vacuum bursts during processing, which was somewhat aggressive due to the limited duration of the test, but the vacuum recovered quickly and there was no glowing so the TiN coating was effective. The two windows are now installed on a life test stand at LANL and have so far run for approximately 1806 hours and 916,211 kW hours.

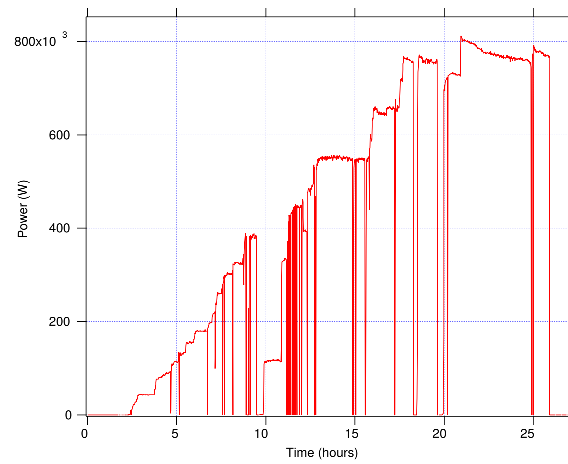

Figure 9. RF power during preliminary test.

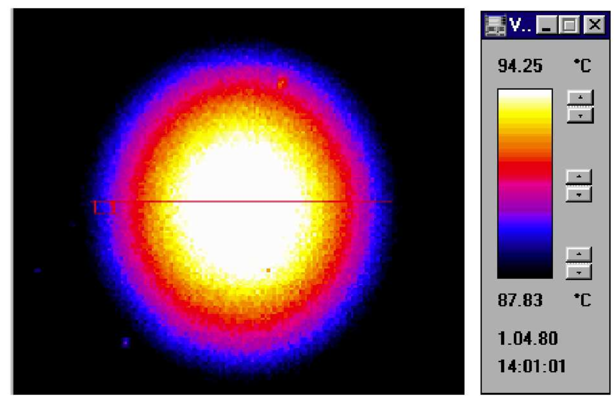

Figure 10. Window thermal image at 770 kW.

6 CONCLUSIONS

We have designed a waveguide window suitable for high power operation at L band in WR1500 waveguide. The design can be tuned to 700 or 714 MHz by changing only the ceramic thickness. The pre-stressed ceramic concept is based on the successful PEP-II window and a similar fabrication process is employed. Four prototype windows have been fabricated at LBNL and delivered to LANL. A pair of windows has been tested to over 800 kW CW and run for about 1806 hours and 916 MWh. The other two windows will be tested in the future. The fabrication process is suitable for transfer to industry if large scale manufacture is required, and projected costs are competitive with currently available alternatives.

7 REFERENCES

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