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HIGH-POWER TESTING OF PEP-II RF CAVITY WINDOWS*

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Abstract

We describe the high-power testing of RF cavity windows for the PEP-II B-factory. The window is designed for continuous operation at 476 MHz with up to 500 kW throughput and has been tested to full power using a modified PEP klystron. The windows use an anti-multipactor coating on the vacuum side and the application and processing of this layer is discussed. The high-power test configuration, RF processing history and high-power performance are described.

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Abstract

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1. INTRODUCTION

The RF design of a self-matched RF window using a 10 inch (254 mm) alumina disk in a WR2100 size waveguide and its mechanical realization are described in earlier papers [1,2]. To counteract tensile stress on the perimeter of the disk when heated by RF fields, a stainless steel ring is shrunk onto the ceramic during the brazing process. The stainless steel ring puts the ceramic disk into compression and thus results in a rugged window design capable of handling the 500 kW of RF power. To remove heat from the window, a cooling channel is included in the stainless steel ring. Post-braze machining steps fine-tune and match the window at the desired frequency (see Figure 1). A knife-edge seal with a copper gasket is used to make a vacuum joint. To reduce multipactor each window is coated with titanium nitride. Two windows are assembled back-to-back onto a waveguide test chamber built to be evacuated, baked out and operated with up to 500 kW throughput power into a matched load. Thirteen windows have been built, eight have been baked out and tested.

We created a testing program to optimize the thickness and stability of the Titanium Nitride (TiN) coating. Too little coating may result in multipactor, too much and the ohmic losses may generate temperatures beyond our operating limits. It has also been reported [3] that TiN coatings can vary in resistivity due to exposure to various atmospheres, and we report on our experiments which confirm this observation.

2 TITANIUM NITRIDE COATING

Titanium nitride (TiN) coating is applied by a sputtering process with a 203 mm target. The target is smaller than the window (248 mm), two sputtering runs are required to coat the window. The first run coats the center and the second run (with the center masked) coats the outer perimeter of the window in approximately a 25 mm band. This flexibility allows us to preferentially coat the perimeter of the window with different coatings than the center.

The thickness of TiN is not directly measured. Rutherford backscattering (RBS) techniques are used to measure the number of TiN atoms per unit area on a test sample sputtered under the same conditions as the window. Thickness can be estimated based on lattice constants for TiN assuming a uniform coating density, but this method is inaccurate due to the surface roughness of the alumina window which has a peak-to-valley variation on the order of 100Å and coating thicknesses are, in general, much below this value. As a result, we characterize our coatings by the direct RBS measurement.

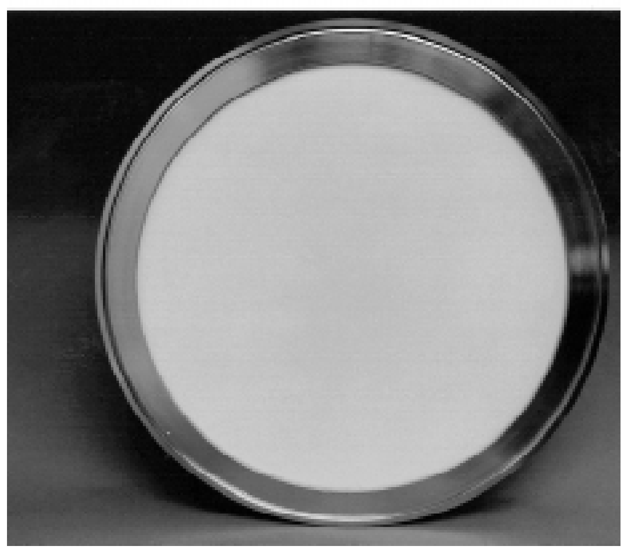

Figure 1. Ceramic disk with brazed stainless steel compression ring and post-machined knife-edge seal.

3 TEST PROGRAM AND RESULTS

Our test program evaluated the window performance under various operating conditions: a) with and without bakeout, and b) venting to Nitrogen after RF processing.

The vacuum test chamber for the back-to-back window test was designed with viewports to observe the window surfaces. Photo-multiplier arc-detectors sensitive to UV and visible light were also included in a position to observe the high-field triple junction portion of the window. An Infrared imaging camera was used to record window temperatures from the air

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side. Flow meters and thermistors were used to estimate total power loss in the individual windows. Data collection was done through Labview® on a Macintosh platform.

3.1 Coating of $6x10^{15}$ atoms/cm^2, no bakeout

Our first windows were coated with the "standard" SLAC coating thickness in the center used on the SLAC LINAC pulsed klystrons. The coating thickness tapered off towards the edge to about half that in the center. These first windows were operated without a bakeout. The test results are shown in Figure 2.

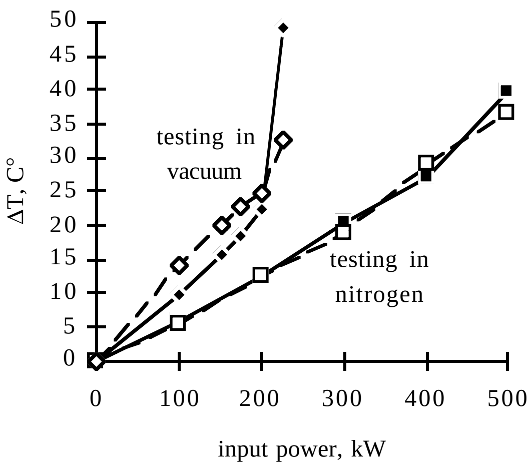

Figure 2. Windows #3 and #4 coated with $6x10^{15}$ atoms/cm^2 in the center.

Blue multipactor-induced glow on the alumina was observed above 200 kW and the temperature increased rapidly as shown. The vacuum test was terminated and the test chamber vented to nitrogen.

In order to estimate the temperature rise from just ohmic losses, the windows were operated up to 500 kW in an atmosphere of pure nitrogen. This test was repeated for various coating thicknesses on the alumina windows and the results are summarized in Table 1.

TiN coating (atoms/cm^2)	ΔT @ 250 kW (C°)	ΔT @ 500 kW (C°)
none	7	15
$6x10^{15}$	16	37
$9x10^{15}$	27	52

Table 1. ΔT measured from the center of the window to the input water temperature with RF power in an atmosphere of N_2. (TiN coating is measured in the center of the window.)

3.2 Coating of $9x10^{15}$ atoms/cm^2, with a bakeout to 150 C°

The next windows tested were sputter coated with $9x10^{15}$ atoms/cm^2 in the center, again the thickness tapered off towards the edge to about half that in the center. These were baked out to 150°C and RF conditioned up to 500 kW in one day. The maximum operating ΔT was 105°C on window #6. Window #3 operated 25° cooler. (see Figure 3.)

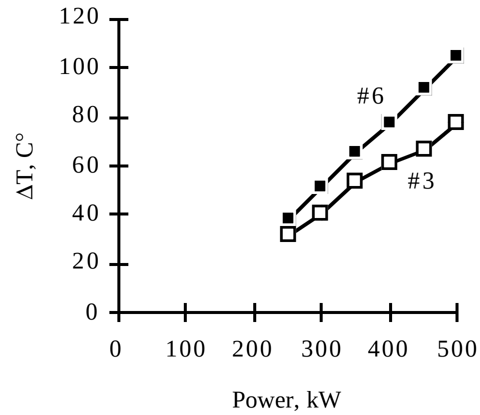

Figure 3. Window #3 and Window #6 operating in vacuum up to 500 kW.

The chamber was vented to nitrogen and ran with RF to 500 kW to determine the temperature due to ohmic losses. The temperature of window #6 was significantly lower during this run, and it was decided to go to vacuum again without bakeout. (This sequence of venting to nitrogen and going back to vacuum without bakeout is similar to what might be experienced during installation.) Operation at 500 kW was quite readily resumed, but surprisingly, the temperature of window #6 at 500 kW was the same low ΔT as during the nitrogen test. This suggested additional N_2 was absorbed by the coating on the window and its resistivity altered.

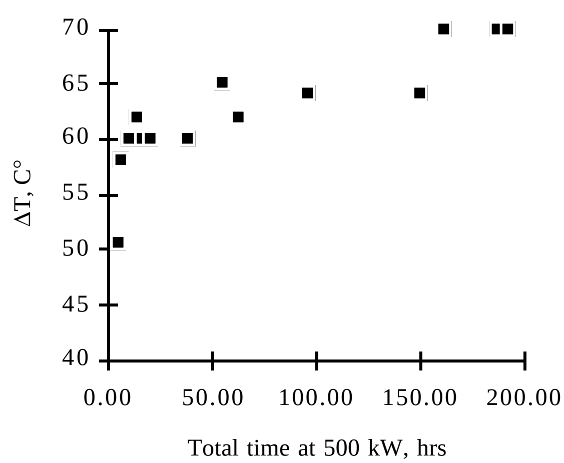

Figure 4. Measurements of ΔT of window #6 vs. accumulated testing time at 500 kW in vacuum after venting to N_2

As more hours were accumulated at 500 kW, the temperature slowly increased. (see Figure 4.) This result is most likely due to weakly-bonded nitrogen in the crystal lattice vacancies of the sputtered TiN. It is known, for example, the resistivity of TiN_x varies from 25-800 μΩ cm, depending on the value of x (.6<x<1.2 in the face-centered-cubic δ phase) and the grain size [3]. These effects will be studied in further experiments to optimize the TiN coating.

3.3 6x10^{15} atoms/cm^{2} at the center and edge, bakeout to 150C°

In an effort to bring down the ΔT at operating power levels, the coating thickness was lowered in the center of the window, yet increased at the very edge in the triple junction region. As shown in Figure 6, the operating temperature of these windows is half that of those shown in Figure 3.

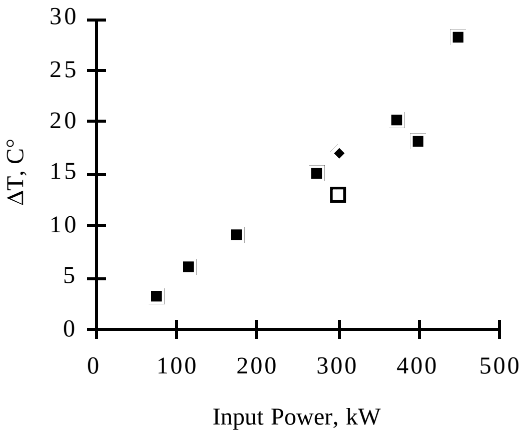

Figure 5. The ΔT (from the center of the window to the input water temperature) of windows with 6x10^{15} atoms/cm^{2} on windows #5 (❑), #8(■), and #9(♦), operating in vacuum at the RF power levels noted.

4. BAKEOUT

4.1 Bakeout Temperatures

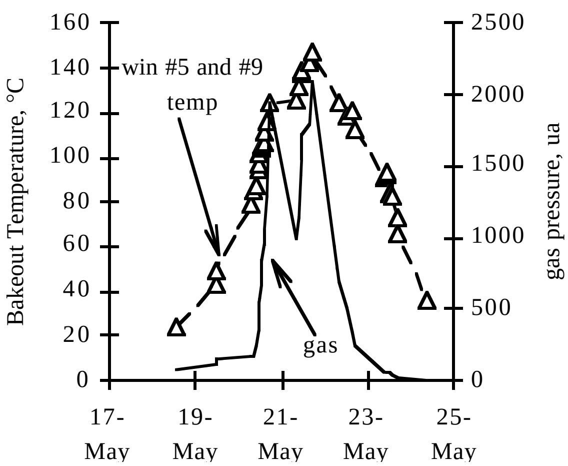

Figure 6. Bakeout temperatures and gas pressure achieved during the 5 day bakeout

The processing time of the windows appears to be strongly dependent on the maximum temperature achieved during bake and the length of time at bake. Windows #5 and #8 were baked out to 135-140°C and took two to three days to achieve 450 kW. Windows #3 and #6 were baked out to 150°C for less than eight hours and processed quickly to 500 kW in a day. Windows #5 and #9 were baked out from 145-155°C for over 12 hours and processed very fast to 300 kW in less than an hour without any signs of electronic activity or outgassing.

The most likely reason for the unusually easy, gas-free processing of windows #5 and #9 to 300 kW of RF power is shown in Figure 6. Two outgassing peaks were observed above 100°C: one in the 120-130°C range, and another in the 140-150°C range. The first peak is probably due to the outgassing of metal surfaces, and the second peak probably due to the outgassing of alumina surfaces resulting from the likely higher bonding energy of gasses in alumina.

Figure 7 shows the response to the application of 300 kW after the windows have already been run for 12 hours at this power level. No pressures rise, gas bursts, or light emission was observed.

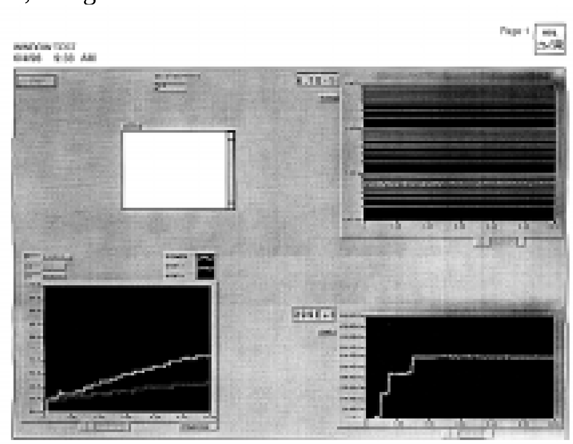

Figure 7. Labview screen showing IR measured temperatures on the left, RF power on the lower right, and gas pressure at the upper left for windows #5 and #9.

5. CONCLUSIONS

The 6x10^{15} coating which tapers down in thickness towards the edge of the window allows glowing caused by multipactor and is believed to be too thin. The 9x10^{15} coating prevents glowing, but caused ohmic heating to be close to the allowable maximum. The 6x10^{15} coating which is "topped off" at the edges has low ohmic heating and less tendency towards glowing. Aditional tests are needed to verify that this coating method is optimum. Bakeout to 150C° is necessary to go through the second peak and remove gas from the surface of the alumina ceramic.

REFERENCES

[1] M. Neubauer et al, "High-Power RF Window Design for the PEP-II B Factory," Proc EPAC 94, June 27-July 1 1994, London

[2] M. Neubauer et al, "High-Power RF Window and Coupler Development for the PEP-II B Factory," Proc PAC 95, May 1- May 5 1995, Dallas TX

[3] B. Burrow et al, "A correlation of Auger electron spectroscopy, x-ray photoelectron spectroscopy, and Rutherford backscattering spectrometry measurements on sputter-deposited titanium nitride thin film," J. Vac. Sci. Technol. A 4 (6), Nov/Dec 1986, p2463-2468