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LOW RF LOSS DC CONDUCTIVE CERAMIC FOR RF WINDOWS*

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Abstract

Charging of RF windows has historically been problematic, frequently resulting in damage to the window severe enough that the window needs to be replaced. Many attempts have been made to prevent charging and therefore improve window lifetime, with moderate success. One approach to this problem is to introduce a small amount of DC conductivity to the ceramic itself, making the traditionally insulating window mildly conductive. This allows any charge on the surface of the window to drain rather than build until a discharge happens. A magnesium titanate ceramic has been developed with a small DC conductivity and used to make RF windows. Several window assemblies have been produced and tested, including 1.3 GHz waveguide and 650 MHz coaxial designs.

INTRODUCTION

Radio frequency couplers connect RF transmission lines to SRF cavities and provide power to the cavity as well as providing a vacuum barrier via RF windows. A variety of problematic electronic processes occur on the window and coupler surfaces, and can be responsible for damage and lost beam-time. Electrons from field emission and the beam, and X-rays from the cavity are the primary cause. In many cases, electrons striking the ceramic surface generate more free electrons because the secondary electron yield (SEY) coefficient is high for most ceramics. This generally results in multipactor behavior, which over time can damage the ceramic [1, 2]. More drastically, with sufficient charge accumulated on the ceramic an arc can form, potentially destroying the window [3].

Different methods have been applied to drain the charge accumulated on ceramics, but none have been proven completely reliable. In particular, coating the surface of the window with titanium nitride (TiN) has been reasonably successful in lowering the SEY and preventing charge accumulation. However, TiN coatings can fail due to poor adhesion, delamination as a result of prolonged thermal cycling, or direct removal from multipacting or arcing [4].

A new low-loss microwave ceramic based on magnesium titanate compounds with small DC electrical conductivity can eliminate the window charging problem in RF power couplers. Development of this conductive ceramic could significantly improve the operational reliability of power couplers in superconducting and normal conducting accelerators.

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WINDOW ASSEMBLY FABRICATION

The most challenging part of RF window assembly fabrication is the joining of the ceramic window to the metal components. Two brazing techniques were pursued for the conductive ceramic window assemblies. The first involved metallizing the ceramic and then employing a non-active braze alloy. The standard metallization method used for alumina of molybdenum manganese coating and nickel plating was not an option as the first heat cycle is performed above the sintering temperature of the conductive ceramic. Two alternative metallization options were investigated: a silver-based paint, or sputtering a layer of titanium followed by a layer of copper. Both were reasonably successful in sealing the waveguide window, however both resulted in leaks at the inner braze joint of the coaxial window.

The second brazing technique was to use an active braze alloy to directly bond the ceramic to metal. Several alloys were tried, covering a range of braze temperatures from 250-1050 °C. The alloy that resulted in the most successful seal of the waveguide window and both surfaces of the coaxial window was a silver-titanium-magnesium-tin alloy with a braze temperature of 250 °C (S-Bond 220M). Two waveguide window assemblies and one coaxial window assembly were brazed using the S-Bond 220M alloy.

HIGH POWER TEST RESULTS

A pair of conductive ceramic waveguide window assemblies were tested at high power in the 1.3 GHz test stand at JLab while the conductive ceramic coaxial window assembly was tested in concert with an alumina window assembly in the 650 MHz test stand at Fermilab.

1.3 GHz Waveguide Window

In the high power test stand at JLab the pair of windows were mounted on a rectangular waveguide box, the interior of which was evacuated via an ion pump. The test box contained two viewports so that infrared (IR) cameras could be used to measure the surface temperature of each window during the test. The frames of the windows were water cooled. The test stand is able to provide continuous wave (CW) RF power up to 12 kW in travelling wave (TW) mode, and 48 kW in standing wave (SW) mode.

The high power test results are shown in Fig. 1. Only one IR camera was available, so data were collected for each window on different days. The procedure during the test was to hold the power level constant for a minimum of 30 minutes until the window temperature equilibrated, then increase the power.

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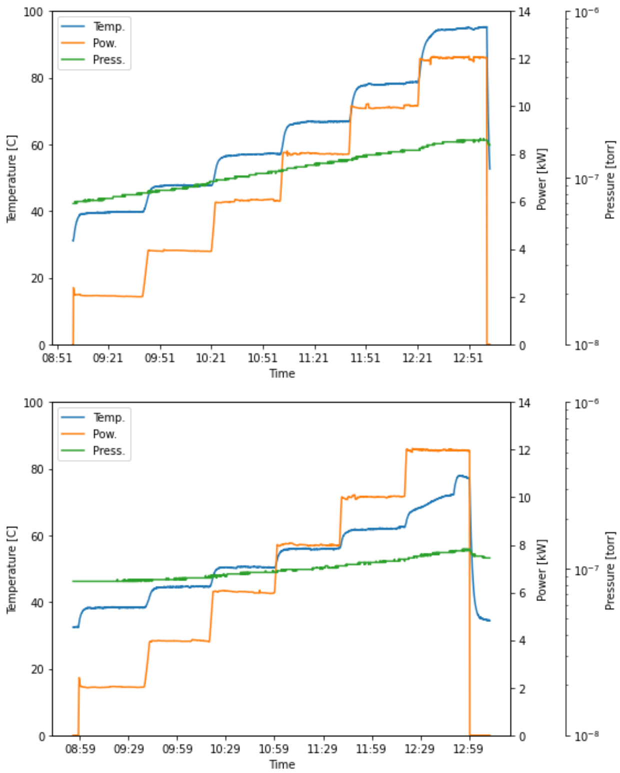

Figure 1: RF power (orange), window temperature (blue), and pressure (green) vs. time for each window during the 1.3 GHz high power test.

The first window exhibited very consistent and stable behavior, with the temperature quickly stabilizing at each power level and a gradual increase in the test box pressure. At the maximum available CW TW power of 12 kW, the temperature of the window reached 95.3 °C.

The second window behaved similarly as the first window up to 10 kW power. At 12 kW CW TW power, the window temperature increased steadily over the course of ≈25 minutes, then increased suddenly by several degrees, after which it began to decrease. A possible explanation for this is that there was a temporary issue with the water chiller used to cool the window, though the water flow or temperature were not recorded. The temperature for this window peaked at 78.0 °C, lower than the first window. Testing in SW mode was foregone so as to not risk damage to the windows.

The high power test resulted in both windows achieving the full 12 kW CW power in travelling wave mode with no unusual vacuum activity and no indication of any multipacting, breakdown, or other electron activity.

650 MHz Coaxial Window

Instrumentation for the high power test stand at Fermilab included: an IR and thermocouples for temperature measurements of the conductive ceramic window, exterior of the vacuum chamber, and window flanges; a residual gas analyzer (RGA); and electric pickups near each window. Cooling was provided by: forced air flowing through the coupler antennae, heat syncs on the flanges of each window, and air fans pointed at the window flanges and vacuum chamber. The test stand can provide up to 100 kW CW power in standing wave mode through the use of an RF reflector upstream of the couplers and a variable length of waveguide downstream of the couplers before the RF short. This also allows of the electric and magnetic field maxima to be positioned based on the location of the short. Four distinct field configurations (positions of the RF short and reflector) were measured during the high power test. Figures 2-5 show the results. In each figure, the temperature plotted corresponds to the thermocouples taped to the window flanges or vacuum chamber.

In the first field configuration (Fig. 2), 80 kW was achieved with very little vacuum activity. The maximum temperature of the conductive ceramic window was 51.4 °C, the maximum temperature on the conductive ceramic window flange was 41.8 °C and on the alumina window flange was 38.7 °C.

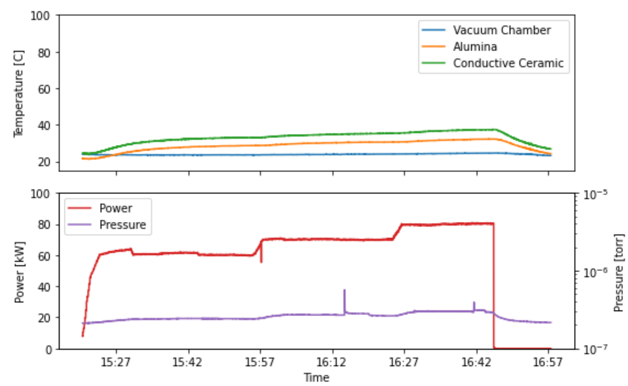

Figure 2: Temperature, power, and pressure vs. time for the first field configuration during the 650 MHz high power test.

In the second field configuration (Fig. 3), 80 kW was also achieved, though with increased vacuum activity. The maximum temperature of the conductive ceramic window was 61.8 °C, on the conductive ceramic window flange was 37.5 °C, and on the alumina window flange was 32.3 °C.

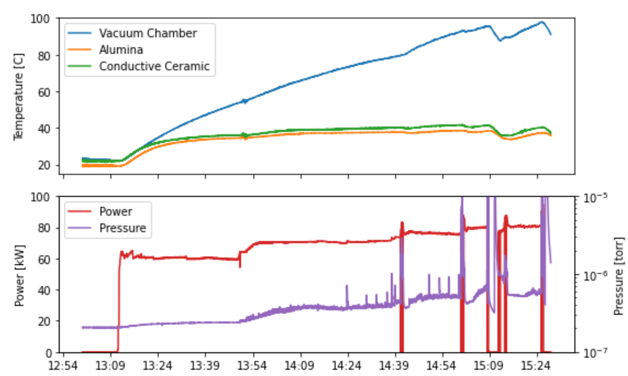

Figure 3: Temperature, power, and pressure vs. time for the second field configuration during the 650 MHz high power test.

Spikes in the vacuum pressure of the chamber that tripped the safety interlock limited the achievable power to 30 kW

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for the third field configuration, shown in Fig. 4. In this case, the maximum temperature on the alumina window flange was 39.3 °C, on the conductive ceramic window flange was 28.3 °C, and on the conductive ceramic window was 35.0 °C.

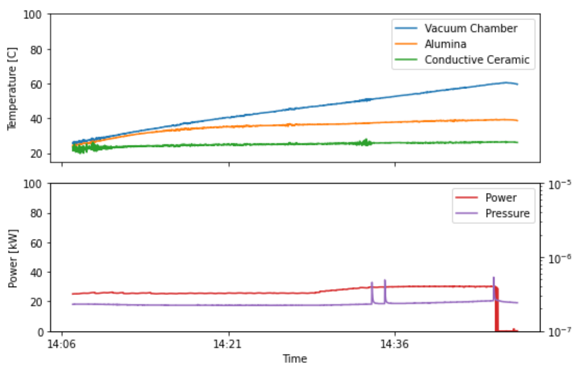

Figure 4: Temperature, power, and pressure vs. time for the third field configuration during the 650 MHz high power test.

Figure 5 shows the results of the fourth field configuration, which was again limited by vacuum activity to 50 kW. The maximum temperature on the alumina window flange was 44.4 °C, on the conductive window flange was 28.8 °C, and on the conductive ceramic window was 37.1 °C.

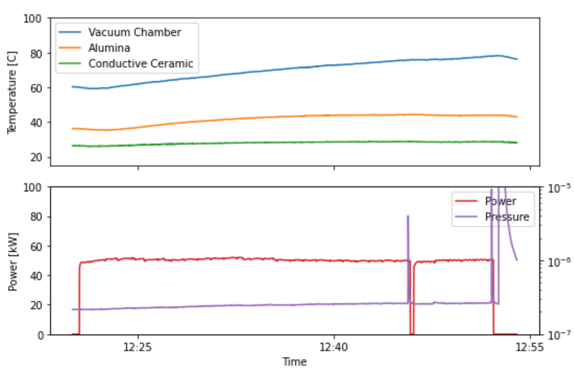

Figure 5: Temperature, power, and pressure vs. time for the fourth field configuration during the 650 MHz high power test.

An RGA scan taken at 80 kW power showed the partial pressures of the braze alloy components (including tin) were all $<10^{-9}$ torr. The decision was made not to push the power level higher in the first two field configurations so as to not risk damaging the windows.

Figure 6 shows photos of the two windows before and after the high power test. There is no visible difference in the conductive ceramic window. However, after the test, the alumina window had a grey metallic appearance, whereas before it was white. This is likely due to multipactor activity that was observable on the electric pickup near the alumina window during the test.

The temperature of the conductive ceramic window was higher than the alumina window for the two field configurations for which 80 kW was achieved, indicating the electric field maximum was closer to the conductive ceramic window. For the field configurations that were limited to 30 and 50 kW, the temperature of the alumina window was higher than the conductive ceramic window. The discoloration of the alumina surface and large signal on the electric pickup near the alumina window are evidence of multipacting on the alumina window that limited the achievable RF power.

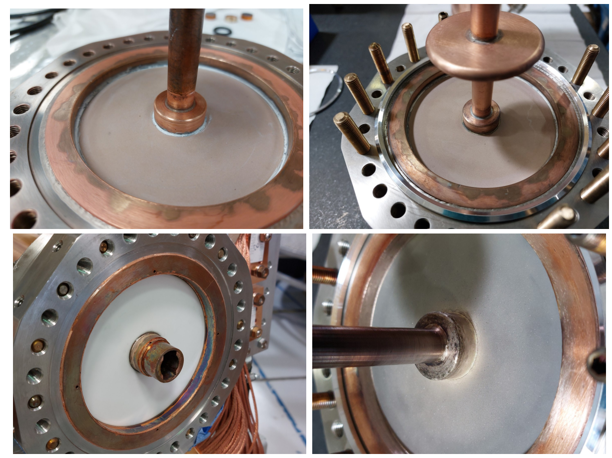

Figure 6: Photos of the conductive ceramic (top) and alumina (bottom) windows, before (left) and after (right) the high power test.

CONCLUSION

Conductive ceramic windows have successfully been tested at high power. The 1.3 GHz waveguide windows reached the maximum available travelling wave CW power of 12 kW with no sign of multipactor or breakdown. The 650 MHz coaxial window reached 80 kW CW power in standing wave mode, outperforming an alumina window. Both results were administratively limited. These tests indicate this conductive ceramic offers the potential to improve the performance and increase the lifetime of high power RF couplers.

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