

## IMPROVED DC GUN INSULATOR\*

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### Abstract

Many user facilities such as synchrotron light sources and free electron lasers require accelerating structures that support electric fields of 10-100 MV/m, especially at the start of the accelerator chain where ceramic insulators are used for very high gradient DC guns. These insulators are difficult to manufacture, require long commissioning times, and have poor reliability, in part because energetic electrons bury themselves in the ceramic, creating a buildup of charge and causing eventual puncture. A novel ceramic manufacturing process is proposed. It will incorporate bulk resistivity in the region where it is needed to bleed off accumulated charge caused by highly energetic electrons. This process will be optimized to provide an appropriate gradient in bulk resistivity from the vacuum side to the air side of the HV standoff ceramic cylinder. A computer model will be used to determine the optimum cylinder dimensions and required resistivity gradient for an example RF gun application. A ceramic material example with resistivity gradient appropriate for use as a DC gun insulator will be fabricated by glazing using doping compounds and tested.

### INTRODUCTION

User facilities such as synchrotron radiation light sources and free electron lasers require accelerating structures that support electric fields of 10-100 MV/m, especially at the start of the accelerator chain where ceramic insulators are used for very high gradient DC guns. These insulators are difficult to manufacture, require long commissioning times, and have poor reliability, in part because energetic electrons bury themselves in the ceramic causing a buildup of charge and eventual puncture, and also because large diameter ceramics are difficult to braze reliably.

These problems are well documented: the gun assemblies at ERLP have had problems with vacuum seal leaks after cool down from a bakeout [1]. In the last year, Jefferson Lab had three failures: one HV seal leak, and two punctured ceramics [2]. Assembly processes by the manufacturer have resulted in some failures of copper flanges to the bulk resistive ceramics [3].

### CONCEPT

A novel ceramic manufacturing process will be developed to incorporate bulk resistivity in the region where it is needed to bleed off accumulated charge due to highly energetic electrons. The process will be optimized to provide an appropriate gradient in bulk resistivity from the vacuum side to the air side of the HV standoff ceramic

cylinder. A novel metal-to-ceramic seal ring design will be used to minimize tensile stresses in the vacuum joint for both existing bulk resistivity ceramics as well as the novel coated ceramics.

A computer model will be used to determine the optimum metal-to-ceramic vacuum seal dimensions, coating dimensions, and required resistivity gradient for an example RF gun application. A ceramic material example with resistivity gradient appropriate for use as a DC gun insulator will be fabricated by glazing using doping compounds and tested. A novel metal-to-ceramic vacuum seal ring design will be incorporated for large diameter ceramic assemblies.

Ceramics with gradients in bulk resistivity will have a wide range of application in high voltage standoffs for electron guns in X-ray tubes and high power microwave tubes, as well as for high gradient accelerator guns.

### TECHNICAL APPROACHES

The goal of this project is to develop a ceramic assembly that will bleed off the accumulated build up of charge from energetic electrons, be robust, easy to manufacture, and process up to operating conditions in a timely manner. A computer model will be used to determine the optimum metal-to-ceramic vacuum seal dimensions, coating dimensions, and required resistivity gradient for an example RF gun application, and two possible technical solutions will be investigated: (1) a novel metal-to-ceramic vacuum seal ring design will be developed for large diameter ceramic assemblies, and (2) a ceramic material with resistivity gradient appropriate for use as a DC gun insulator will be fabricated by glazing using doping compounds and tested.

To date, bulk resistivity ceramics have become the only viable material for use in existing designs to bleed off charge buildup. However, because of the process and materials by which resistivity is added to normal alumina insulators, the ceramics have become difficult to braze to, causing manufacturing difficulties. In order to use these bulk resistivity ceramics, entirely new types of vacuum seals must be designed to minimize the stresses on the fragile metalizing that is used with the ceramics. The typical vacuum seals that are used with many years of experience with pure alumina just put too much shear stress on the joint.

Coated ceramics for charge depletion are not new to the industry, but thick coatings are. With low voltage DC guns, operating well below 100 kV, existing coating technologies are perfectly adequate, because the field emitted electrons that find their way to the ceramic surface are not energetic enough to go through it. Because we are in the 500 kV to 750 kV regime, thick coatings are a requirement, if the bulk resistive ceramics

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don't do the trick. Typically thick glaze coatings are not used on ceramics because of the tensile stresses that develop between the glaze and the substrate during cool down. In this case, however, since the coating is located on the ID of a cylinder, the glaze is under compression during cool down from the melt temperature. This means we can experiment with novel slurries of glaze and resistive materials such as chromium oxide, and we can build up a thickness of 1-2 mm by a molding process which should be sufficient for 500-750 kV electrons.

## VACUUM SEAL RINGS

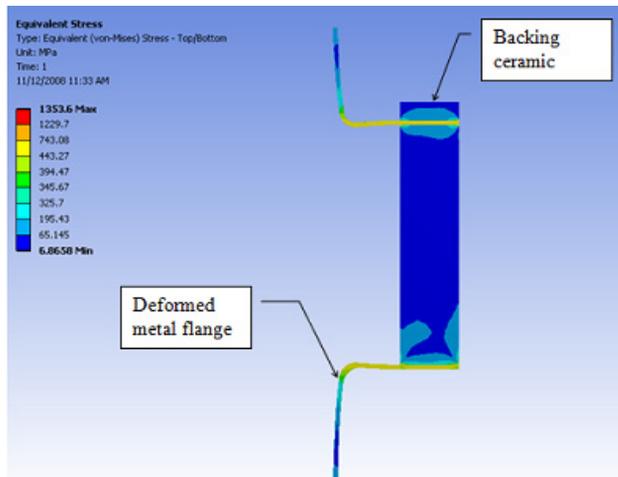


Figure 1: A cylindrical ceramic to metal seal. Vacuum side to the left, air side to the right. 12" diameter x 2" high, .5" thick. The flange material is 1 mm thick. Axisymmetric ANSYS run from 1000C to room temperature using kovar and ceramic. It is assumed the kovar is fully bonded to the ceramic, and there is no stress relief in the joint during cool down.

Bulk resistivity ceramics are standard alumina doped with a resistive material and are being recommended for the next generation HV Seal assembly[4]. However, brazing seals to these ceramics have been difficult to manufacture. The vacuum joints may need active braze alloys (ABA) that tend to have low vapor pressure materials, because the standard Mo-Mn metalizing for pure alumina may not be reliable when there is a high degree of shear stress in the joint. Failures have been experienced with brazes to copper portions of the gun assembly with the bulk resistivity ceramics, and thermally cycled brazes have failed in the field. Most failures of the flange joint appear to have pieces of the ceramic left adhering to the flange. This tends to indicate excessive tensile stresses in ceramic.

"Inverted" guns with the ceramic high voltage seal stem between the high voltage cathode and focus electrode and ground have been used in X-ray tubes, and experimented with in DC guns [5], and proposed for accelerator applications [1,6,7]. While these proposals may move the problem around, they have not been shown to eliminate the problem of charging ceramics. Recent advances in simulations has provided some additional tools to

calculate equipotentials with and without charging ceramics [7].

## Computer Modeling of Ceramic Assemblies

Large diameter metal to ceramic brazes are difficult to make because of the stress buildup from differential contraction between the metal and the ceramic during cool down from the brazing temperature to room temperature. Deformation and stresses of a typical metal to ceramic braze are shown in Figure 1. The top joint is with a backing ceramic which produces uniform stress on the top and bottom of a kovar seal ring. The bottom joint is without a backing ceramic, and the stress in the joint tends to produce a failure as the kovar seal ring tears away from the ceramic.

Various joints will be investigated with designs for buffer layers between the metal flange and the ceramic, as well as novel flange configurations to minimize the deformation in the metal flange. The novel flange design will incorporate two forms of buffers to reduce stress on the vacuum joint. The first is the use of heavy copper plating or copper wafers on both sides of the metal seal ring facing the ceramic. The copper thickness will be determined by analysis and will be stress relieved during cool down.

## Brazing of Metal to Ceramic joint with Novel Flange Design

The braze cycle will be optimized in an effort to minimize the residual stresses in the braze joint, the goal being to produce a joint that is nearly "stress free." However, even if the most sophisticated flange design were to be used, one with buffer layers and conformal bends, cooling down from the braze cycle would still create shear stresses between the ceramic and the metal flange. Therefore, annealing processes during cool down will be used to minimize these residual stresses. Braze cycles have been experimented with and found to produce significantly lower stress assemblies when annealing processes are implemented in conjunction with a buffer layer [8].

## COATED CERAMIC ASSEMBLIES

Chromium oxide has been used to minimize breakdown in high voltage guns [9]. We propose to create a novel coating process with chromium oxide, or similar material, and a clear glazing compound used in ceramics. Typically, thick coatings are not used in ceramics, because of the tensile stresses resulting from the cool down from the melt temperature to room temperature when the glaze is applied to the outside surfaces of cylindrical shapes. In this case, however, the coating is applied to the inside of the cylinder and will be in compression during cool down. It is anticipated that the build-up of a thick surface 1 to 2 mm in thickness can be achieved when the slurry of glaze and chromium oxide is applied to the inside of a 12 inch ceramic cylinder. The coatings will also be annealed during cool down with hold periods at specific temperatures to allow stress relieving.

Sources and Injectors

T02 - Lepton Sources

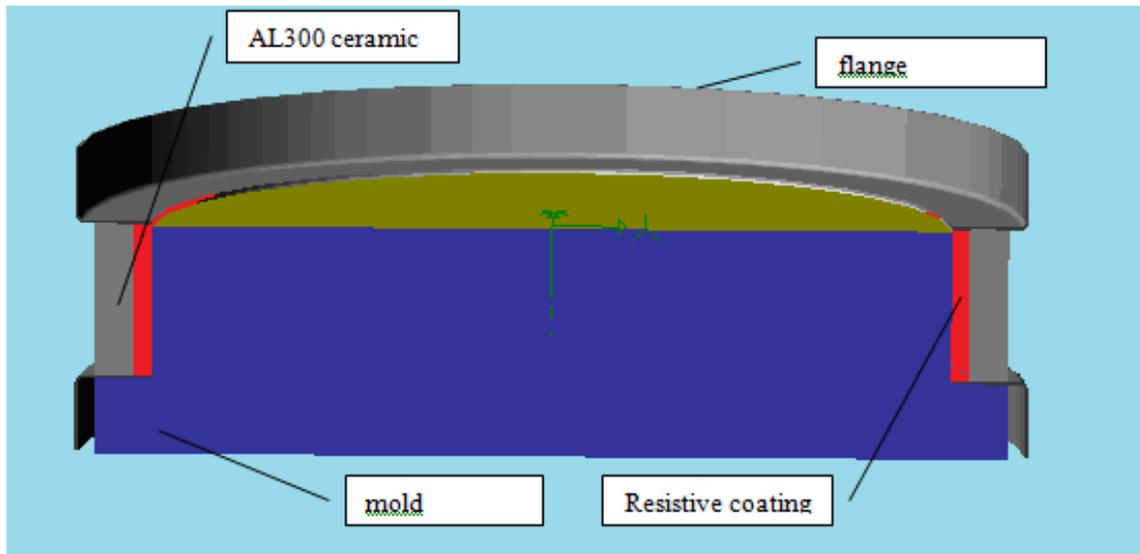


Figure 2: The thick resistive coating is molded into place on the ID of the ceramic

Specially design fixturing will mold the coating to the ID of the ceramic cylinder and be scalable for the full height ceramic. Figure 2, shows how the molding of the thick glaze material will work with the test samples. The mold is made from standard glass molding materials.

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