Update on the Development of Externally Powered Dielectric-Loaded Accelerating Structures

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Abstract. We report on recent progress in a program to develop an RF-driven Dielectric-Loaded Accelerating (DLA) structure. capable of supporting high gradient acceleration. Previous high power tests revealed that the earlier DLA structures suffered from multipactor and arcing at the dielectric joint. A few new DLA structures have been designed to alleviate this limitation including the coaxial coupler based DLA structure and the clamped DLA structure. These structures were recently fabricated and high power tested at the NRL X-band Magnicon facility. Results show the multipactor can be reduced by the TiN coating on the dielectric surface. Gradient of 15MV/m has also been tested without dielectric breakdown in the test of the clamped DLA structure. Detailed results are reported, and future plans discussed.

Keywords: Dielectric-Loaded Accelerating (DLA) structures, multipactor, breakdown.
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INTRODUCTION

Dielectric-Loaded Accelerating (DLA) structures have been intensively studied in recent years. Gradient of 5.5 GV/m on axis in THz and 100MV/m in the microwave range have been demonstrated in a dielectric loaded waveguide by passing through a high intensity electron beam [1, 2]. In both cases, the peak gradient appears in a beam induced ultra-short wakefield pulse. Meanwhile, another approach, using an external rf power source to drive the DLA structures, has been used to investigate the properties of dielectric-based particle accelerator. In this approach, the rf pulse length is usually in the range of a few hundred nanoseconds. Unlike the wakefield-driven high gradient experiments, the long rf pulse in the external powered DLA structure can lead to serious multipactor and dielectric joint breakdown [3, 4]. Both issues limit the practical applications of DLA structures[1].

In recent years, Euclid Techlabs, in collaboration with the Argonne Wakefield Accelerator (AWA) group at Argonne National Laboratory (ANL) and the Magnicon facility at Naval Research Laboratory (NRL), has performed a series of experiments to study the methods to cure the multipactor and dielectric joint breakdown that occurred in the high power rf tests of DLA structures. In this article, we will report on the recent experimental results.

MULTIPACTOR SUPPRESSION

The issue of multipactor, which leads to strong rf power absorption, is associated with some physical properties of the loaded dielectric materials. In the past two years, we have concentrated on the study of multipactor reduction with experiments on DLA structures having surface coatings or different geometries. All the experiments were performed at Magnicon Facility of NRL which can provide up to 20MW, 11.424GHz, 200ns (FWHM) rf pulse. Unless specially mentioned, we only compare the high power rf transmission property of the different DLA structures because the reflection signal in all experiments was insignificant.

Figure 1 shows the testing results of two quartz based DLA structures. Two structures were loaded the same GE214 fused quartz tube but different geometries. Based on the physical model, the absorbed power due to the multipactor induced light is proportional to a^4 for a certain power level of the rf input, where a is the inner radius of the dielectric tube [5]. Obviously, the plot in Fig.1 shows this effect. However, we should point out that the reduction of multipactor is partially because the E_r/E_z ratio (representing the radial and longitudinal electric field respectively) of the accelerating mode (TM_{01}) in the DLA structure becomes smaller when using a smaller ID dielectric tube. E_r is a dominant factor to trigger the multipactor. To some extent, we can say that the multipactor is delayed by reducing the ID of the dielectric tube of the DLA structure.

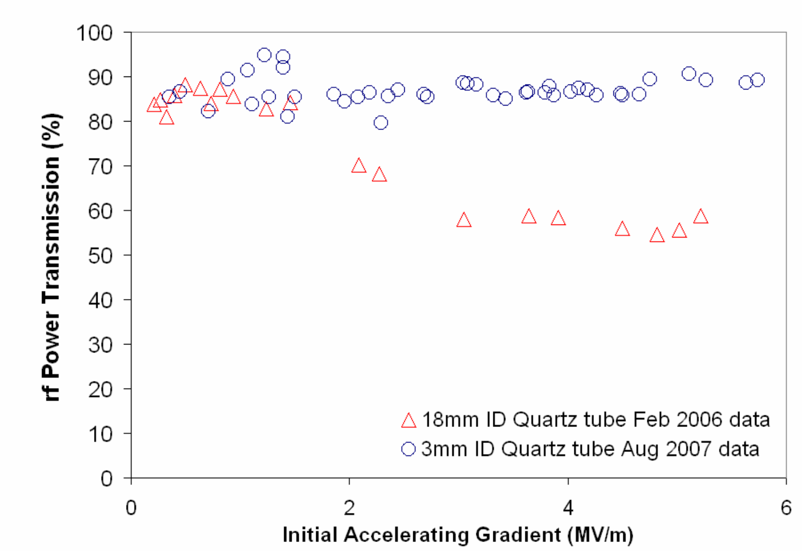


FIGURE 1. Comparison of the high power rf transmission in two quartz-based DLA structures with different size of the beam channel.

To suppress the multipactor, we tried TiN coating on the dielectric surface using the Atomic Layer Deposition (ALD) technique. We tested two sets of dielectric tubes, quartz and alumina, before and after the coating. The results are plotted in Fig.2 and Fig.3, respectively. In both cases, the thickness of TiN coating is 1.3nm. We can conclude from both figures that the TiN coating can significantly reduce the multipactor but cannot eliminate it.

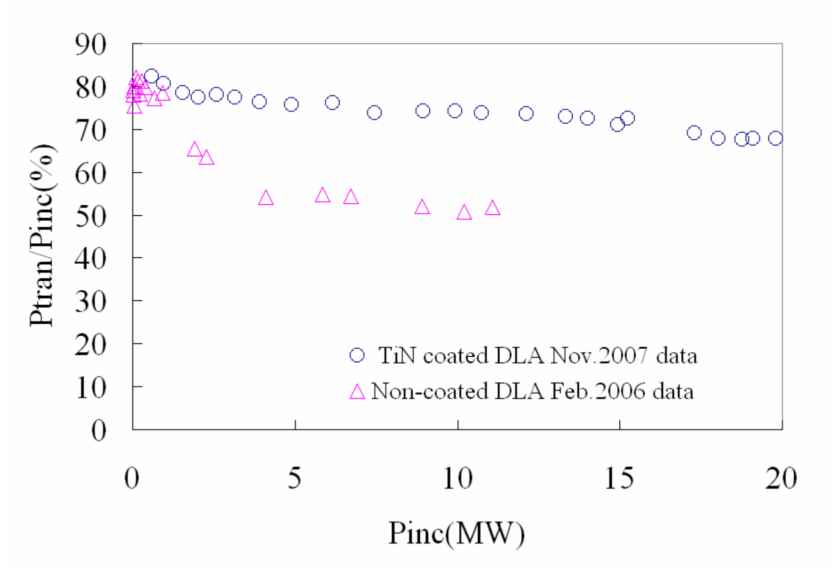


FIGURE 2. Comparison of the high power rf transmission in two quartz based DLA structures: TiN surface coated and Non-coated

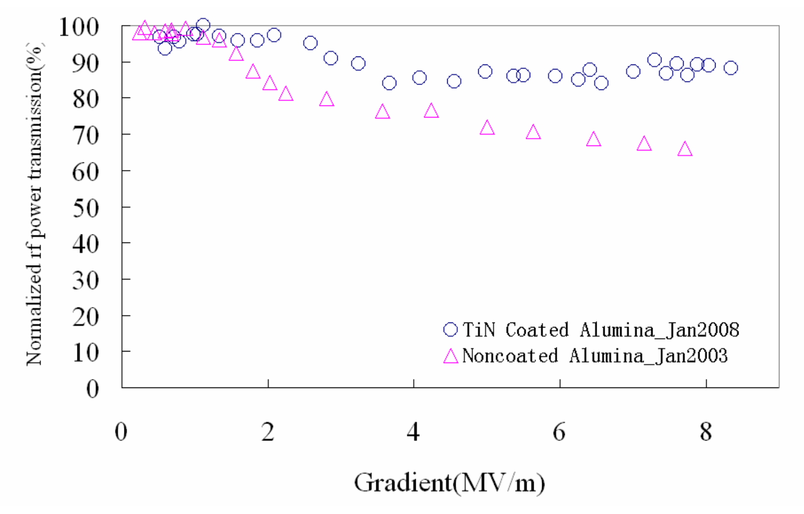
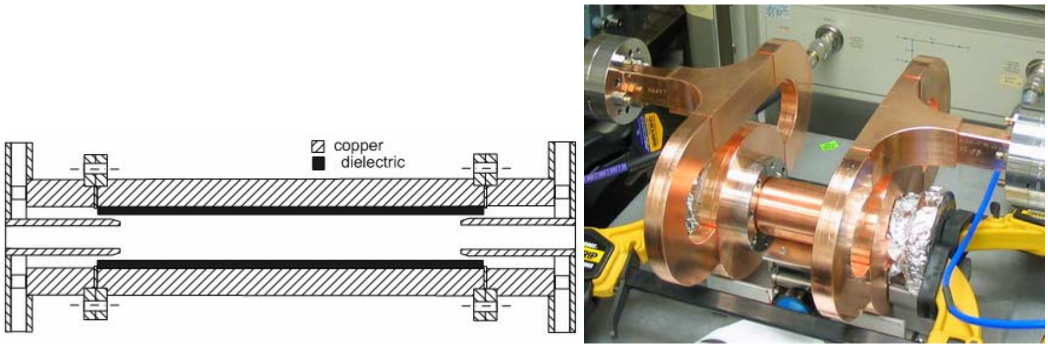


FIGURE 3. Comparison of the high power rf transmission in two alumina based DLA structures: TiN surface coated and Non-coated

GAP-FREE DLA STRUCTURES

Dielectric breakdown caused by the local field enhancement at the gap of the dielectric joint is a critical issue which limits the gradient of the DLA structures [4]. The key factor to solve this issue is to design a gap-free DLA structure. To date, two new structures have been developed and tested; one uses a coaxial type rf coupler and the other uses a clamped dielectric-loaded waveguide to ensure only a solid piece of dielectric tube being used in the DLA structure.

Figure 4 shows the coaxial coupler based gap-free DLA structure. The coaxial-type coupler implements the TE to TM mode conversion through a transient TEM mode so that the mode and impedance transitions can be achieved simultaneously without using a separate tapered dielectric section [4]. The central acceleration section is only a simple straight dielectric-lined circular waveguide, which thus eliminates any points for potential rf arcing. A structure using this scheme has been built and high power tested. However, an unexpected arcing happened at a few MW input during the test. Examination after the test showed some chemical residue from the final cleaning process led to the arcing at the input rf coupler.

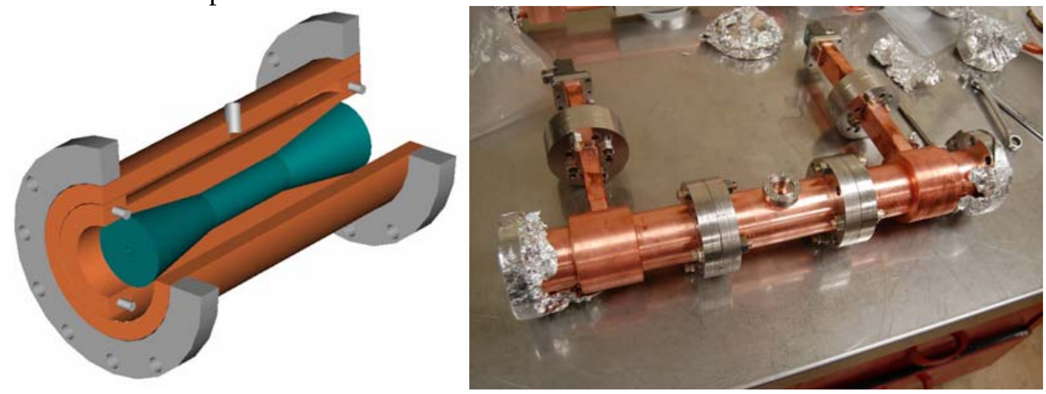


(a) (b)

FIGURE 4. (a) 2D view of the coaxial rf coupler based gap free DLA structure; (b) the coaxial rf coupler based gap free DLA structure under the bench test.

The most recent DLA structure we tested is the clamped DLA structure, shown in Fig.5. Instead of using the combination of two complicated coaxial rf couplers and a simple dielectric-lined waveguide, we use a new gap-free DLA scheme that consists of two well-tested TE_{10}-TM_{01} mode converters and a relatively complicated clamped dielectric-loaded waveguide as the central accelerating section. The dielectric tube that was used, which has flared ends for the impedance matching, was machined directly from a solid piece of dielectric material. Two sectional copper jackets are clamped together to hold the boundary conditions of the accelerating mode (TM_{01}). The longitudinal gap along the copper jackets has no effect on the TM_{01} mode since it does not require transverse surface current; instead, the unwanted hybrid modes which have azimuthal surface currents will be disturbed. The outermost copper tube is to hold the vacuum. An extra pumping port is attached at the center.

We have built one clamped DLA structure using the quartz as the loaded material. The geometrical dimensions are shown in the first row of Table 1. Limited by the experiment time, we tested this structure to the input rf level of 16.5MW without the dielectric breakdown, which is equivalent to the gradient of 15MV/m on axis. The testing result is plotted in Fig. 6. The 10% rf transmission drop at the beginning reflects the multipactor induced loss, which is correlated to the fluorescent light we observed in the experiment.



(a) (b)

FIGURE 5. (a) 3D view of the clamped DLA structure; (b) assembled the clamped DLA structure using the TE_{10}-TM_{01} high power rf couplers.

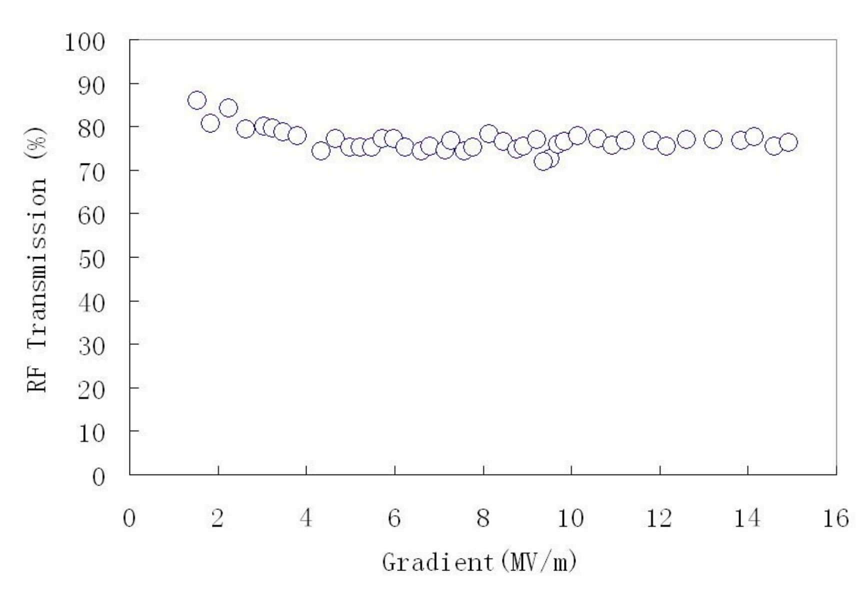


FIGURE 6. High power rf testing result of the quartz based clamped DLA structure.

TABLE 1. Calculated gradient for two DLA structures.

Loaded Material	Dimensions	Gradient per 10MW	Gradient per 20MW	Gradient per 50MW
Quartz (ε=3.75)	ID=3mm OD=12.95mm	11.6MV/m	16.4MV/m	25.9MV/m

MCT-20 (ε=20)	ID=6mm OD=9.13mm	19.5MV/m	27.6MV/m	43.7MV/m

FUTURE PLAN

The initial success of the clamped DLA structure encourages us to test some other high impedance DLA structures using the similar scheme, for example, the structure shown in the second row of Table 1. We plan to use the X-band Pearson's rf flange and KEK high power rf TM_{01} mode launcher to build and test the new structure, which can sustain a higher rf power [6].

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