HIGH POWER TESTING OF A FUSED QUARTZ-BASED DIELECTRIC-LOADED ACCELERATING STRUCTURE*

C. Jing#, Euclid Techlabs, LLC, 5900 Harper Rd., OH-44139
J. G. Power, R. Konecny, W. Gai, Z. Yusof, ANL, Argonne, IL 60439
S. H. Gold, Plasma Physics Division, NRL, Washington DC, 20375
A.K. Kinkead, LET Corporation, Washington, DC 20007
V. Dolgashev, S. G. Tantawi, SLAC, Menlo Park, CA, 94309

Abstract

We report on the most recent results from a series of high power tests being carried out on rf-driven dielectric-loaded accelerating (DLA) structures. The purpose of these tests is to determine the viability of the DLA as a traveling-wave accelerator and is a collaborative effort between Argonne National Laboratory (ANL), Naval Research Laboratory (NRL), and Stanford Linear Accelerator Center (SLAC). In this paper, we report on the recent high power tests of a fused quartz-based DLA structure that was carried out at incident powers of up to 12 MW at NRL and 37 MW at SLAC. We also report on test results of a TiN coated quartz structure, that exhibits good multipactor suppression.

INTRODUCTION

For the past decade, the Argonne Wakefield Accelerator (AWA) group at ANL has been working on externally powered Dielectric-Loaded Accelerating (DLA) structures, in collaboration with NRL and SLAC. A series of high power rf tests has been performed, and considerable progress has been made [1]. Two issues were addressed during the development of X-band traveling wave DLA structures: multipactor and dielectric joint breakdown. The dielectric joint breakdown due to the local field enhancement is an engineering issue that may be solved by an approach based on a newly designed gapless rf coupling technique [2]. 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 with experiments on a quartz based DLA structure. This structure is designed to have a large E_r/E_z ratio. Based on the physical model, this may enable the entire multipactor region to be investigated with the available amount of rf power [3].

We first performed high power rf testing of the quartz based DLA structure in Feb. 2006 at the Naval Research Laboratory. In the experiment, a 12 MW 200 ns wide rf pulse went through the tube without breakdown (the highest available at NRL magnicon facility at that moment). Multipactor was observed but with different characteristics compared to other materials like alumina: the fraction of the rf power absorption due to the multipactor remained constant when the incident power was raised beyond a certain level. Photomultiplier Tube (PMT) measurements were included in the experiment for the first time to observe the light emission time evolution and intensity. Detailed information can be found in ref. [3].

HIGH POWER TESTING AT SLAC

After the successful experiment at NRL, the quartz based X-band DLA structure was tested again at SLAC in Dec. 2006, where a SLAC 50 MW klystron was used to power the structure. The major parameters of the test structure are summarized in Table 1. The loaded quartz tube is a single piece with both inner ends tapered for impedance matching. The OD of the dielectric tube was chosen so that we can share the existing X-band rf coupler with other experimental DLA structures.

Table 1: Parameters of the quartz based DLA structure.

Geometric and accelerating parameters	Value
ID / OD of dielectric tube	17.94 mm /24.16 mm
Dielectric constant	3.78
Loss tangent	2×10^{-5}
Length of dielectric tubes	194.8 mm
Group velocity Vg	0.38c
Shunt Impedance R	27.9(MΩ/m)
R/Q	3614(Ω/m)
Field ATTN	0.35 dB/m

The high power testing configuration is similar to the setup at NRL. We have three bidirectional couplers and diodes or peak power meters to record the forward, transmitted and reflected rf power; two CCD cameras to monitor the emission light from multipactor; a PMT to measure the time structure of the multipactor.

In the experiment, we studied the effect of varying the rf pulse lengths. No signature of bulk dielectric breakdown was observed up to 36 MW, 20 ns wide rf pulse, and 5Hz of the pulse repetition rate (the klystron maximum output for this pulse width), which is equivalent to 9 MV/m gradient on axis and E_r = 10 MV/m on the dielectric inner surface. Limited by time, we also conditioned the structure to 25 MW with 50 ns rf pulse. No signature of bulk dielectric breakdown was observed. Figure 1 shows the testing results for the 20 ns pulsed rf.

*Work is supported by DoE, Office of High Energy Physics, and ONR.
#jingchg@hep.anl.gov

1-4244-0917-9/07/$25.00 ©2007 IEEE

The highest input is 36.67 MW, but only the well conditioned data are plotted. It shows a saturation stage at the 50% transmission level, but has not yet reached the second crossover of the secondary electron yield curve (the multipactor is expected to disappear when the electric field inside the dielectric tube is higher than this threshold [4]).

The initial fraction of the rf transmission at a low power levels is relatively small for the 20 ns rf pulses. This is due to the bandwidth limitation of the structure which has been verified during the experiment by changing the pulse width. The transmission baselines are similar to the bench test results once the pulse width exceeded 100 ns. We also systematically studied the characteristics of the multipactor as a function of the rf pulse length. Figure 2 shows the behavior of the rf transmission and reflection with pulse length varying from 100 ns to 400 ns, 100 ns per step. We can see all the data follow the similar trend: the transmission fractions are decreasing in parallel to the bright light emission from the multipactor, but being saturated at around 50% of the rf loss.

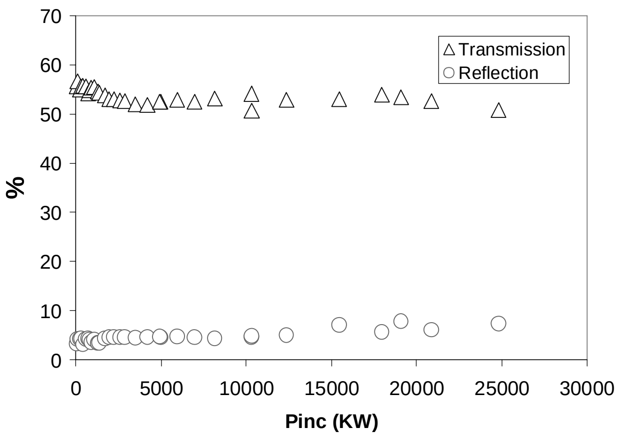

Figure 1. High power rf testing data with 20 ns pulsed rf.

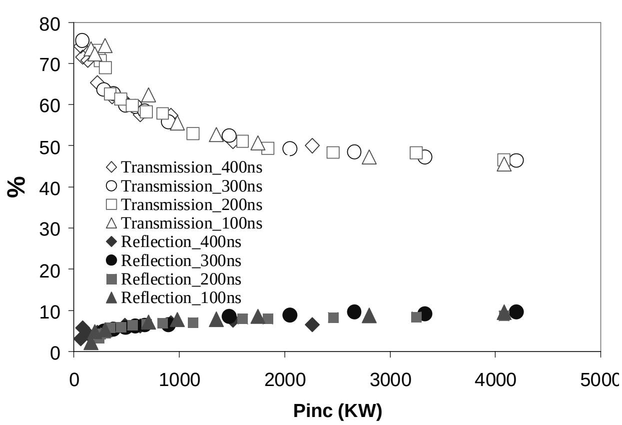

Figure 2. Systematic characterization of rf/multipactor in the structure as a function of varying rf pulse length.

Figure 3 shows typical scope traces of the incident, transmitted and reflected rf signals detected by the diodes, and the multipactor light signal from the PMT captured at the same moment (cable lengths to convey all signals are the same). It is clear that the multipactor can reduce the transmitted rf power and increase the reflection simultaneously. We also can see in Fig. 3 that the multipactor needs time to build up but the buildup time become very short if the incident power increases. Therefore, unless the incident rf power is high enough to go beyond the multipactor region (not yet demonstrated), a short pulse length will not help reduce the multipactor.

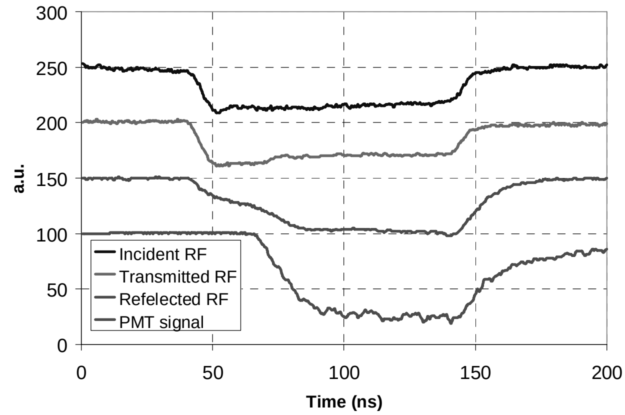

Figure 3. Typical scope traces of diode detectors and PMT.

MULTIPACTOR SUPPRESSION

To date, the TiN coating seems to be the best choice to suppress the multipactor based on the experiences from the rf window. We have tested a TiN coated alumina DLA structure [1]. It shows some improvement but no total multipactor suppression. We recently employed a new coating technique, Atomic Layer Disposition (ALD), to obtain a more uniform and thickness controllable coating. Our first try was a 1.3 nm TiN coating on the quartz based DLA structure (see Figure 4). Rf bench tests (S-parameter measurements) did not show much difference from the uncoated case. We high power tested the structure at NRL magnicon facility on April 2007 (200 ns rf pulse length and 5Hz pulse repetition rate).

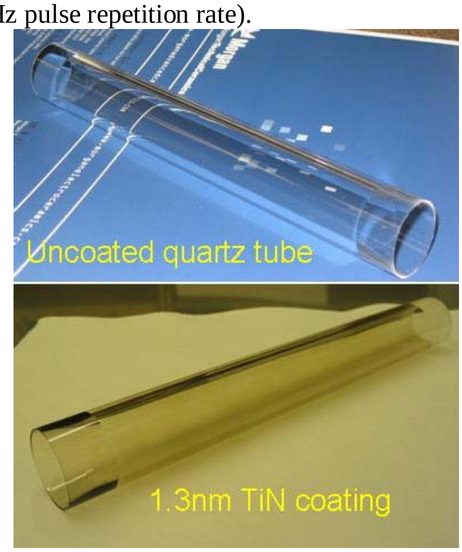

Figure 4. Comparison of the quartz tube before and after TiN coating .

In the experiment, we observed dramatic difference from the test of the uncoated structure: a very faint light was observed when the input rf power over ~2 MW but it could be conditioned away. Figure 4 shows a comparison of the high power rf testing results between the uncoated DLA structure (200 ns data at SLAC) and the TiN coated one at NRL. No light was observed in the conditioned data at NRL. It demonstrated that a TiN coating using ALD technique can effectively suppress the multipactor.

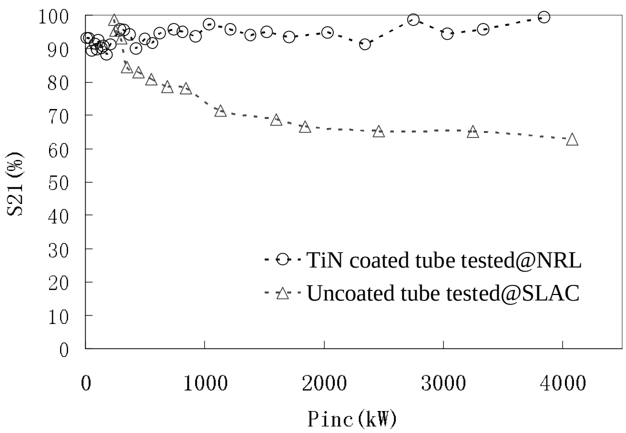

Figure 5. Comparison of the high power rf testing results of the uncoated and coated quartz based DLA structures (normalized to S21 for comparison).

However, the coating was partially peeled off when the incident rf power was over 12 MW which led to major arcing inside the structure. Poor vacuum condition in the experiment (limited by pumping time) might have caused the coating damage at this rf power level. We also expect a better high power rf performance with a slightly thicker coating, like 2 nm in thickness. (A 5.7 nm TiN coating on an alumina tube was bench tested before the high power rf testing. The results showed a strong rf absorption).

FUTURE PLANS

TiN coatings on more DLA structures with different loading materials will be tested in future. An optimal coating thickness to handle high power rf and suppress multipactor will be investigated.

REFERENCES

[1] C. Jing, W. Gai, J. G. Power, R. Konecny, S. H. Gold, W. Liu, and A. K. Kinkead, IEEE, trans. P.S. vol.33, No. 4, 2005, pp.1155-1160.

[2] C. Jing, A. Kanareykin, R. Konecny, J. G. Power, S. H. Gold, and S. Kazakov, this proceeding.

[3] C. Jing, W. Gai, R. Konecny, J. G. Power, W. Liu, S. H. Gold, A. K. Kinkead, A. Kanareykin, and S. Kazakov, Proc. 12th Advanced Accelerator Concepts Workshop, AIP Conference Proceedings, vol.877, M. Conde, C. Eyberger eds., Dec. 2006, pp.303-310.

[4] L. Wu and L. K. Ang, Phys. Plasmas, Vol.14, 013105 (2007).

1-4244-0917-9/07/$25.00 ©2007 IEEE