DEVELOPMENT AND TESTING OF X-BAND DIELECTRIC-LOADED ACCELERATING STRUCTURES*

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Abstract

Dielectric-loaded accelerating (DLA) structures offer the potential of a simple, inexpensive alternative to copper disk-loaded structures for use in high-gradient rf linear accelerators. A joint Argonne National Laboratory/Euclid Techlabs/Naval Research Laboratory study is under way to investigate the performance of X-band DLA structures using high-power 11.43-GHz radiation at the NRL Magnicon Facility. The initial goal of the program has been to develop structures capable of sustaining high accelerating gradients. The two significant problems that have been discovered are multipactor loading of the structures and rf breakdown at joints between dielectric sections. This paper reports the results of several recent structure tests that have demonstrated significant progress in addressing these issues. The longer-range goal of the program is to study electron acceleration in DLA structures. For this purpose, we are developing a compact X-band test accelerator. This paper reports the initial operation of a 5-MeV injector for the new accelerator.

INTRODUCTION

In recent years, there has been a major effort to understand the high gradient limits of conventional disk-loaded metal accelerating structures, as well as to develop alternative structures that may be capable of higher gradient operation. One promising concept is the dielectric-loaded accelerating (DLA) structure, in which a smooth dielectric-lined metal tube replaces a periodic metal structure [1]. A DLA structure can be used as a slow-wave electron accelerator by choosing an appropriate liner material, typically a low-loss ceramic with high dielectric constant, and choosing the inner and outer radii of the dielectric to match the phase velocity of the TM_{01} accelerating mode to *c*. Argonne National Laboratory (ANL), Euclid Techlabs LLC, and the Naval Research Laboratory (NRL) are carrying out a joint program, in collaboration with the SLAC National Accelerator Laboratory, to develop X-band DLA structures for use in high-gradient linear accelerators. The DLA geometry is simpler and may be easier to fabricate than a conventional copper slow-wave structure, can have comparable shunt impedance, and permits simple suppression of higher-order modes [2]. In addition, DLA structures have no field enhancements at the dielectric surface, while conventional disk-loaded structures have a typical factor-of-two field enhancement on the metal irises. However, there are problems unique to DLA structures, including strong single-surface multipactor, due to the normal component of electric field at the dielectric surface, and field enhancements at discontinuities in the dielectrics. These phenomena are under intensive investigation [3,4]. The DLA structures are developed by ANL in collaboration with Euclid Techlabs, and high-gradient tests are carried out at NRL and SLAC. This paper presents a progress report on recent tests at NRL, as well as an update on the development of a compact test accelerator to study acceleration in DLA structures.

DESCRIPTION OF THE NRL MAGNICON FACILITY

Figure 1 shows a schematic diagram of the NRL Magnicon Facility. Its heart is a high-power magnicon amplifier tube that was developed jointly with Omega-P, Inc. as an alternative to klystrons to power X-band accelerating structures [5]. The magnicon operates over the frequency range of 11.424-11.430 GHz, and can produce ~25 MW of output power in 200-ns FWHM pulses at up to 10 Hz, and 10 MW in 1-μs flat-top pulses. Its output is extracted through two SLAC-style WR-90 waveguide lines, each with a high power TE_{01} output window, and SLAC-style directional couplers. These two lines are connected to a power combiner assembly that was developed by SLAC. Using the combiner permits the power from both lines to drive a single load, or to drive two separate loads with an adjustable power split. Two test stands are located adjacent to the magnicon output. The first, a 5'x25' raised platform, 8' high, is used for pulse compressor experi-

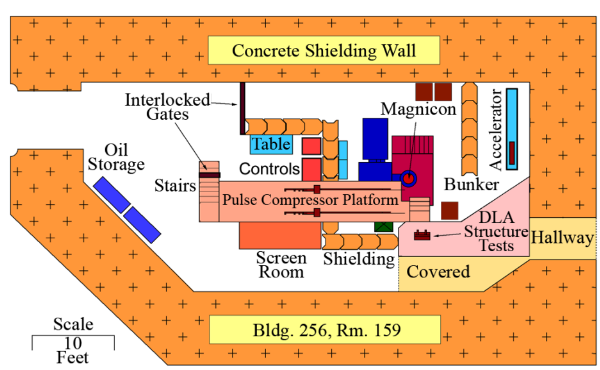

Figure 1: Floor plan of NRL Magnicon Facility.

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ments, and passes over the concrete shielding wall. The second, a 10'-high concrete deck area, is used for testing DLA structures. A 6'x10' concrete bunker in the upper right corner of the diagram houses the accelerator.

NEW TESTS OF DLA STRUCTURES

Four tests of new DLA structures have taken place since the report at the last Particle Accelerator Conference [6]. These results are described in this section.

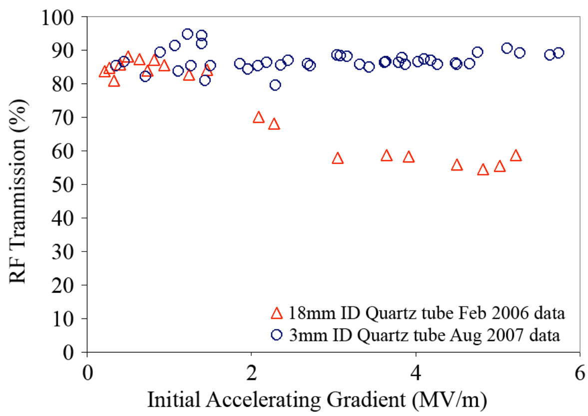

Figure 2: RF transmission percent versus accelerating gradient for 3-mm and 18-mm ID quartz tubes.

The first test was of a 3-mm ID quartz structure. The rf matching into this structure required tapering both the ID and OD simultaneously, while maintaining a metal boundary at the quartz OD. This was accomplished by using two separate quartz sections, with one piece consisting of one complete end taper, the straight section and the inner portion of the second end taper. The second piece consisting of only the outer portion of the second end taper, so that after assembly, there was no break along the axis at the inner diameter. Figure 2 shows a comparison of the rf transmission of this structure as a function of accelerating gradient compared to that of a comparable 18-mm ID quartz structure. It is noteworthy that the smaller diameter structure showed no evidence of the strong multipactor loading seen in the larger diameter structure. This is consistent with the predicted scaling of multipactor with radius [7]. This test was ended by rf breakdown at a small crack at one end of the quartz tube.

The next test was of an 18-mm ID quartz structure with a 1.3-nm TiN low-SEE (secondary electron emission) coating applied by ALD (atomic layer deposition). Figure 3 shows a comparison between the transmission through this coated structure as a function of incident power and through a comparable quartz structure lacking the TiN coating. It is clear that the coating resulted in a substantial reduction in the multipactor loading.

The third test was of a 1-cm ID alumina structure with a TiN coating applied by ALD. In this case, the experiment also tested a new coaxial coupler design. Figure 4 shows a comparison of the transmission through this structure as a function of accelerating gradient compared to that through

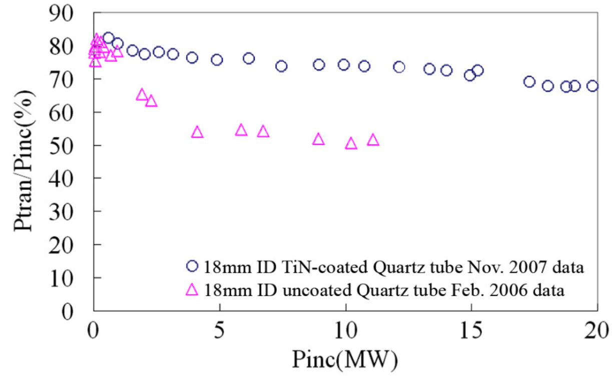

Figure 3: RF transmission percent versus incident power for 18-mm ID quartz tubes, uncoated and with TiN coating.

an uncoated alumina structure. In this plot, the transmission percentage has been normalized to the value at low power. The loss through the uncoated structure has also been normalized to account for a different structure length. Again, the TiN-coated structure shows significantly reduced multipactor loading.

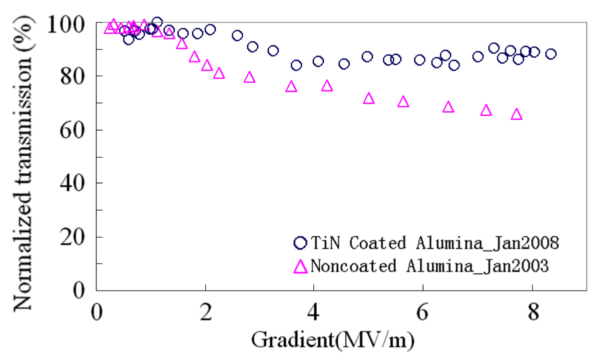

Figure 4: Normalized RF transmission percent for 1-cm ID alumina tubes, uncoated and with TiN coating.

The fourth test was of transmission through another 3-mm ID quartz structure. However, this structure was fabricated from a single piece of quartz with inner and outer tapers at both ends. Providing the metal boundary at the outside of the quartz section required a clamped assembly, in which two metal halves enclosed the quartz structure. That, in turn, was placed within an outer metal vacuum jacket. This structure was tested up to a gradient of 15 MV/m with no sign of rf breakdown (see Fig. 5).

THE DIELECTRIC-LOADED TEST ACCELERATOR

A compact X-band accelerator is being developed in order to test DLA structures as part of a working accelerator [8]. Figure 6 shows a photograph of the first section of the accelerator, consisting of an injector section, 3 focusing quads, and a dipole steering magnet, plus an ICT and YAG plate for beam diagnostics. The injector [9] uses a LaB_6 cathode, and a 24-cell disk and washer accelerating structure, and is designed to be driven by ~5 MW of rf

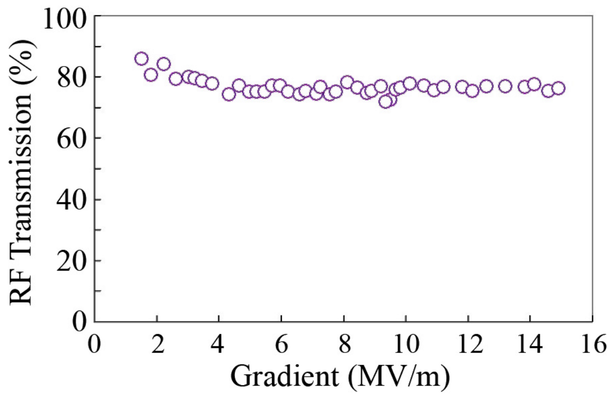

Figure 5: RF power transmission percent versus incident power for clamped quartz structure.

power from the magnicon. It is designed to inject 5 MeV, ~5 pC electron bunches into dielectric structures up to 50 cm long. The injector and structure will be fed by separate waveguides from a power combiner/ phase shifter assembly connected to the magnicon. This will allow the injector to operate at constant power while the power and relative phase of the accelerator section is varied. The energy gain will be measured with a magnetic spectrometer.

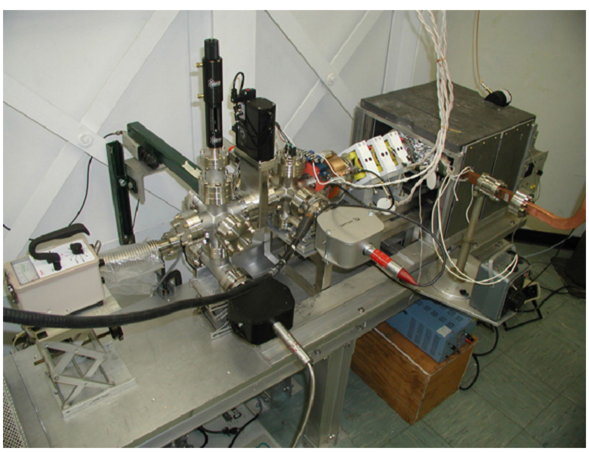

Figure 6: Photo of injector in accelerator bunker.

The injector was first turned on in July 2008. Using 6 MW of drive power, it demonstrated a peak current of ~10 mA at ~3.5–5 MeV. However, poisoning of the LaB_6 cathode was evident, due to a pressure rise during operation. Also, after a short period of operation, persistent arcing was observed from the cathode. The damaged cathode was replaced in February 2009, and operation was recently resumed.

SUMMARY

The goal of this program is to develop and test X-band dielectric-based accelerating structures. The tests to date have studied multipactor and breakdown effects, and have determined that effective low SEE coatings can substantially reduce the multipactor loading. They have also shown that the key to high-gradient operation is to avoid discontinuities in the dielectric structures. A gradient of 15 MeV per meter has been demonstrated without breakdown, and higher gradient structures are in preparation. In the near future, we plan to carry out tests of acceleration through dielectric structures using the new X-band accelerator facility at NRL. These accelerator tests will continue to explore the potential of externally driven dielectric structures in accelerator applications.

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