EXPERIMENT ON A TUNABLE DIELECTRIC-LOADED ACCELERATING STRUCTURE*

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Abstract

Dielectric-Loaded Accelerating (DLA) structures are generally lacking in approaches to tune the frequency after fabrication. A tunable DLA structure has been developed by using an extra nonlinear ferroelectric layer. The dielectric constant of the applied ferroelectric material is sensitive to temperature and DC voltage. Bench testing shows a tunability of +18MHz/°C. A beam test is scheduled at Argonne Wakefield Accelerator facility immediately after this conference.

INTRODUCTION

The need for frequency tuning (or phase velocity adjustment) of any accelerating structure arises from the fact that the phase velocity of the assembled accelerating structure will, in general, differ from the design phase velocity due to various sources of error. In a Dielectric-Loaded Accelerating (DLA) structure, these errors can be caused by machining tolerance of the dielectric dimensions, thermal expansion of the structure, dielectric constant heterogeneity, etc [1]. One approach to vary the frequency of a DLA structure is to apply a thin layer of a ferroelectric material outside the layer of conventional ceramic (see Figure 1). A DC bias voltage or temperature control is used to vary the permittivity of the ferroelectric layer and thus tune the overall frequency of the DLA structure. Use of a DC bias voltage is able to provide a very fast frequency tuning ability (e.g. fast switching < 10 ns) [2]; meanwhile, the temperature variation can provide a very wide tuning range (e.g. 14 MHz/°K for a cylindrical Ka-band tunable DLA as demonstrated in [1]).

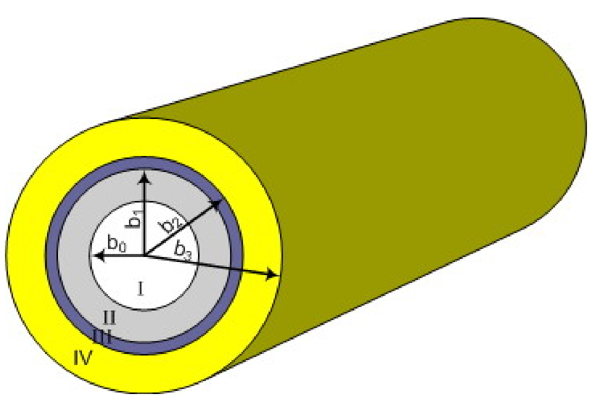

Figure 1: Configuration of the tunable DLA structure: Region I---vacuum; Region II---dielectric tube; Region III---ferroelectric tube; Region IV---copper.

A TUNABLE DLA STRUCTURE

A tunable standing wave DLA structure, shown in Fig.2, has been constructed. It consists of four segments of 1 inch long double-layer dielectric tubes (the inner layer is forsterite with a dielectric constant of 6.64, and the outer layer is a BST based ferroelectric layer with dielectric constant of 300) and two copper end plugs housed in a copper tube. An E-field probe is built in to the structure to monitor the rf signal for future beam experiments. This structure is designed to be tuned by changing only the temperature of the dielectric. An apparatus has been built to control the temperature of the structure, where the tunable DLA structure is located in a set of contoured copper tubes driven by a chiller. In the beam experiment, a drive bunch will excite a strong wakefield inside the cavity, which can be detected through the rf probe and via its effects on the following witness beam. The frequency of the probe signal and the energy of the witness beam will change when temperature of the structure changes. It notes that, unlike the usual metal cavity, the frequency of the tunable DLA structure has a positive temperature dependence which is caused by the dielectric constant of the ferroelectric layer varying with the temperature.

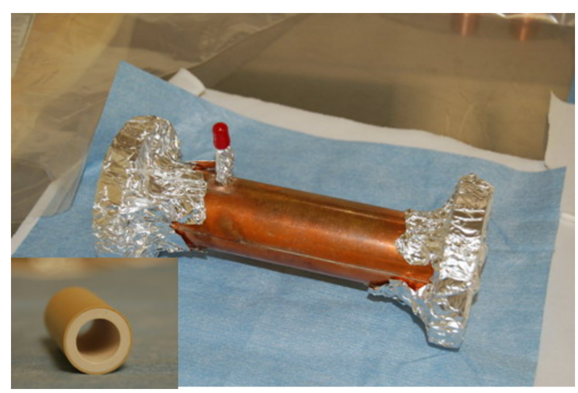

Figure 2: The finished tunable standing wave DLA structure. b0=4.79mm, b1=6.99mm, b2=7.49 mm, referring to Fig.1.

BENCH TEST

A bench test of the developed tunable DLA structure has been performed at Argonne National Laboratory. A pair of simple TM_{01} mode launchers was made for the bench test. The test setup is shown in Figure 3: a chiller

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is connected to the temperature control apparatus; two thermocouples are used to monitor the structure temperature; a network analyzer connected to a mode launcher is used to measure the frequency response of the structure (S_{11}). In addition, a thermal isolation layer covering the outside of the structure (not shown in Fig.3) was used during the measurement.

Figure 3: Setup for bench testing the tunable standing wave DLA structure.

Frequency response (reflection loss, S_{11}) is plotted in Fig. 4. Three major modes are identified in good agreement with simulation results. A temperature scan was performed for one TM_{02} mode (~13 GHz). The results are plotted in Fig. 5 in which significant temperature tunability has been observed. Note that there exists a discontinuity of the frequency response over the temperature in the tunable DLA structure, which is due to the frequency shift between two combined modes. As a comparison, we also measured the temperature tunability of a conventional DLA structure, where we replaced the double layered ceramic tubes with the same length of cordierite tube (dielectric constant of 4.7, inner radius of 4.79 mm and outer radius of 7.49 mm). The result is plotted in Fig.5. As we expect, there is a barely perceptible frequency change with varying temperature. A slightly negative frequency response slope shown in Fig. 5 is due to the thermal expansion of the copper tube.

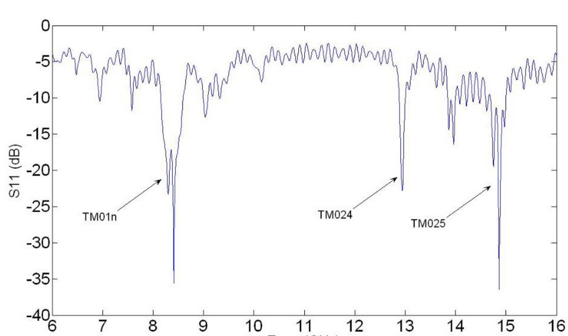

Figure 4: Modes measured in bench test of the tunable standing wave DLA structure.

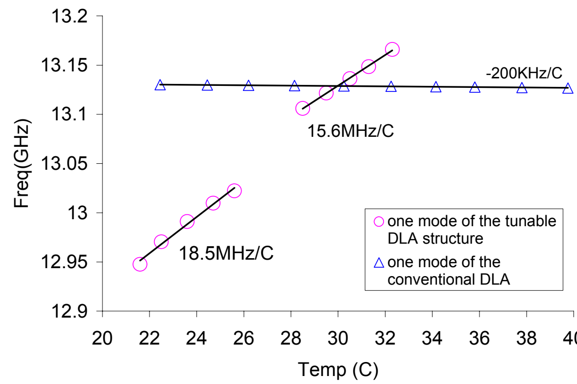

Figure 5: Comparison of the temperature dependence of modes of the tunable and the conventional standing wave DLA structures.

BEAM TEST SIMULATIONS

The AWA facility is currently undergoing a large scale upgrade including the construction of a new 75 MeV beamline, new LLRF system, and control system upgrades. Meanwhile, the experiments are still tightly maintained for the existing 15 MeV beamline. A few experiments are in the queue. We expect to have the next beamline time available around June.

In this waiting period, we have performed a beam test simulation using Particle Studio®. Note that 6 mm bunch length is used in the simulation due to the finite memory.

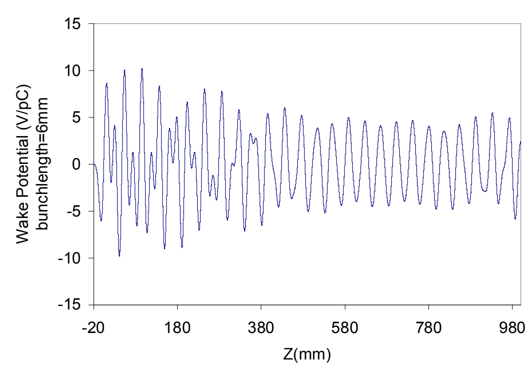

Figure 6: The normalized wake potential of the tunable standing wave DLA structure.

This will lead to a large discrepancy in terms of the absolute field level. However, in the experimentally observable frequency range, the simulation results are still valid, and they are a good guidance to the real beam experiment. Figure 6 shows the induced wake potential from the electron bunch. Since the high order modes in general decay very quickly, this plot provides useful information on positioning the witness bunch.

In the beam experiment, we plan to tune the structure frequency by varying the structure temperature because dielectric constant of the outer ferroelectric layer has a

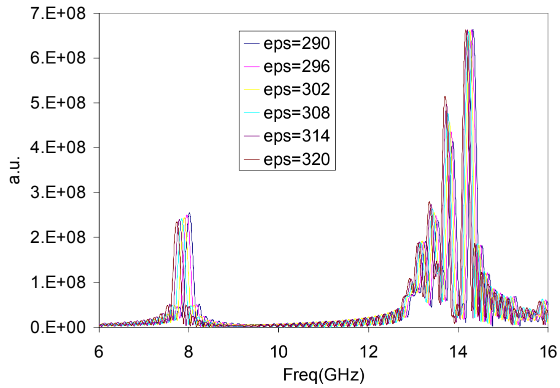

Figure 7: Frequency spectrum of the low order modes of the tunable standing wave DLA structure varies with different dielectric constants in the ferroelectric layer.

strong dependence on temperature. Therefore, the energy of a witness bunch, which is launched at a fixed distance behind the drive bunch, will change accordingly when temperature changes. In the simulation, we changed the dielectric constant of the ferroelectric layer to simulate the temperature change. The frequency spectrum of the first two modes with different dielectric constants of the ferroelectric layer is plotted in Figure 7. Finally, Figure 8 characterizes the relation of the frequencies of the 1st two modes and dielectric constant change of ferroelectric layer. Combining the results from Figure 5, we may conclude that there are 3 units of ε_r change per °C change for this particular tunable DLA structure.

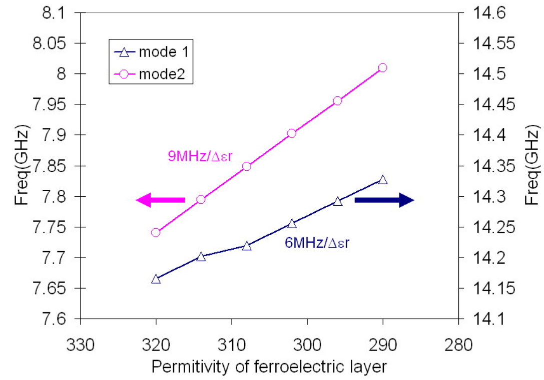

Figure 8: Frequencies of the first two modes vs. dielectric constant change of the outer ferroelectric layer.

REFERENCES

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