Recent Structure Based High Gradient Wakefield Experiments at Argonne

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Abstract. Dielectric structures promise to support high field, especially for short wakefield pulses produced by a high charged electron beam traveling in a dielectric tube. To push the gradient higher, we have tested two structures using recent upgraded Argonne wakefield accelerator facility that capable of producing up to 100 nC charge and bunch length of < 13ps (FWHM). Here we report on the experiment results that more than 80 nC beam passes through a 14 GHz dielectric loaded wakefield structure that produced an accelerating field of ~ 45 MV/m. The two structures consist of a cylindrical ceramic tube (cordierite) with a dielectric constant of 5, inner and outer radii of 5 mm and 7.49 mm, respectively, and with length of 102 mm and 23 mm long. We present measurements made with single electron bunches and also with two bunches separated by 1.5 ns. As a next step in these experiments, another structure, with an output coupler, has been designed and is presently being fabricated.

Keywords: wakefield, acceleration, dielectric.
PACS: 41.75.Lx, 41.75.Ht, 41.60.Bq, 41.20.Jb

INTRODUCTION

The Argonne Wakefield Accelerator Facility (AWA) is dedicated to the study of electron beam physics and the development of accelerating structures based on electron beam driven wakefields [1]. In order to carry out these studies, the facility employs a photocathode RF gun capable of generating electron beams with high bunch charges (up to 100 nC) and short bunch lengths. This high intensity beam is used to excite wakefields in the structures under investigation. The wakefield structures presently under development are dielectric loaded cylindrical waveguides with operating frequencies of 7.8 or 15.6 GHz.

The facility is also used to investigate the generation and propagation of high brightness electron beams. Presently under investigation, is the use of photons with energies lower than the work function of the cathode surface (Schottky-enabled photoemission [2]), aimed at generating electron beams with low thermal emittance. Novel electron beam diagnostics are also developed and tested at the facility.

The AWA electron beam is also used in laboratory-based astrophysics experiments; namely, measurements of microwave Cherenkov radiation and beam induced fluorescence of air [3].

AWA FACILITY

The AWA high intensity electron beam is generated by a photocathode RF gun, operating at 1.3 GHz. This one-and-a-half cell gun typically runs with 12 MW of input power, which generates an 80 MV/m electric field on its Magnesium cathode surface. A 1.3 GHz linac structure increases the electron beam energy, from the 7 MeV produced by the RF gun, to 14 MeV. The charge of the electron bunches can be easily varied from 1 to 100 nC, with bunch lengths of 2 to 5 ps rms, and normalized emittances of 30 to 200 π mm mrad. The schematic of the AWA facility is showing in Figure 1.

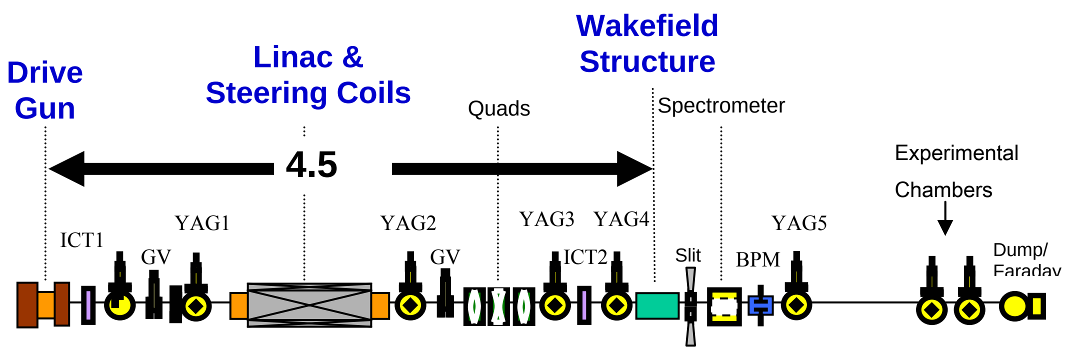

Figure 1. The AWA facility schematic layout. It produces up to 100 nC beam with pulse length of ~ 13 ps.

The AWA laser system consists of a Spectra Physics Tsunami oscillator followed by a Spitfire regenerative amplifier and two Ti:Sapphire amplifiers (TSA 50). It produces 1.5 mJ pulses at 248 nm, with a pulse length of 6 to 8 ps FWHM and a repetition rate of up to 10 pps. A final KrF Excimer amplifier is optionally used to increase the energy per pulse to 15 mJ. The generation of electron bunch trains (up to 64 bunches) requires each laser pulse to be divided by means of beam splitters into a laser pulse train. The laser pulses in the train arrive at the photocathode surface separated by an integer number of RF periods, thus ensuring that the electron bunches have the same launch phase.

WAKEFIELD EXPERIMENTS

We have recently built and tested two 14 GHz cylindrical dielectric loaded standing-wave wakefield structures. Both structures (cordierite) have inner and outer diameters of 10 and 15 mm, and a dielectric constant of 4.8. Their lengths are 102 and 23 mm long respectively. The standing-wave structures have weakly coupled field probe (-60 dB) to monitor the wakefields generated by the driving electron bunches. An RF mixer circuit is used to convert the signal down to 5 GHz, which is then displayed on a high bandwidth oscilloscope (LeCroy Wavemaster 8600A). Figure 2 shows the output of the mixer circuit for various bunch charges for the 102 mm tube. As expected, the signal is stronger for higher bunch charges. The phase of these signals is arbitrary, since the 10 GHz local oscillator is not phase locked to the klystron that powers the RF gun and linac. The highest charge passed through this tube is 43 nC which corresponds to 23 MV/m on axis field.

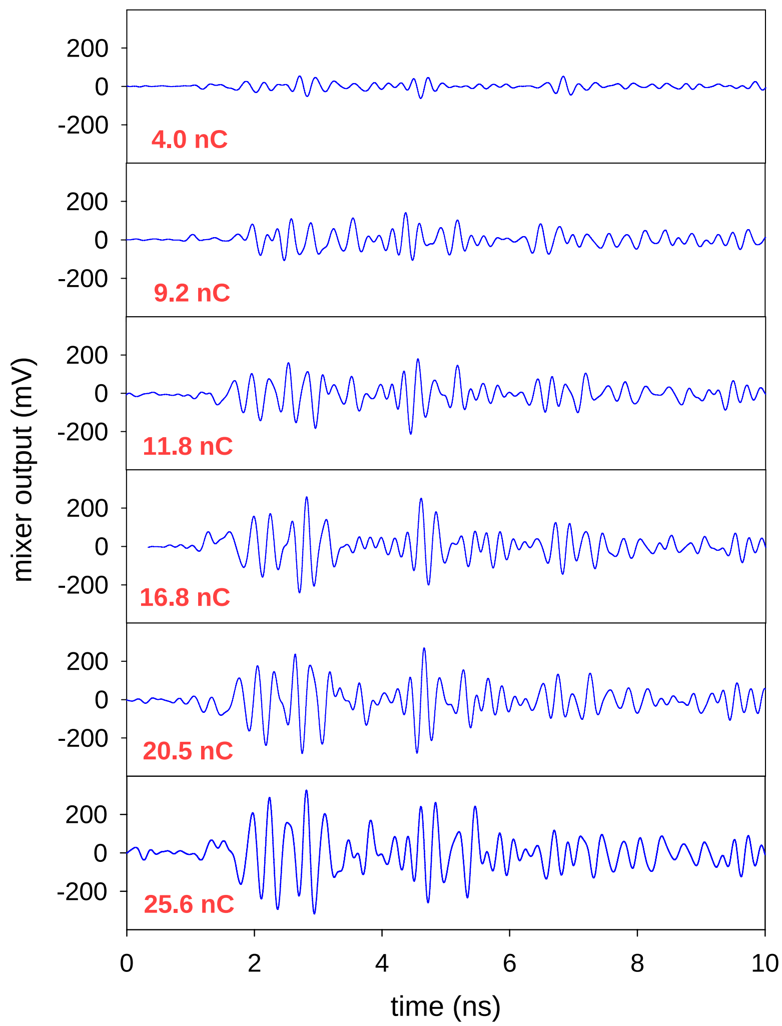

FIGURE 2. Output of RF mixer for various bunch charges plotted as a function of the charge in the drive bunch

MAFIA simulations (Fig. 3) show that a 43 nC electron bunch traversing this structure generates a peak axial electric field of 23 MV/m on axis. In this relatively short structure, several longitudinal modes are excited, but the generated RF power is distributed mainly among four modes: $TM_{0,1,9}$, $TM_{0,1,10}$, $TM_{0,1,11}$, and $TM_{0,1,12}$.

Wakefield measurements were also made using two electron bunches separated by 1.5 ns (two RF periods of the klystron frequency). Figure 4 shows the RF mixer output for each bunch alone and also for the two bunches together.

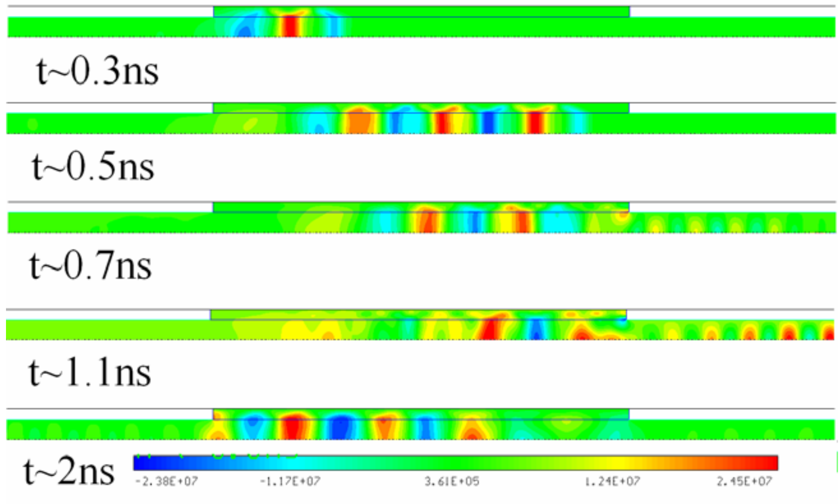

FIGURE 3. A sequence of snapshots showing the amplitude of the axial electric field calculated by MAFIA for a 43 nC electron bunch. The bunch propagates from left to right, initially through the cylindrical beam pipe, and enters the dielectric lined structure, where the radiation is generated. Most of the excited modes remain trapped in the standing-wave structure, but some of the higher order modes escape through the beam pipe.

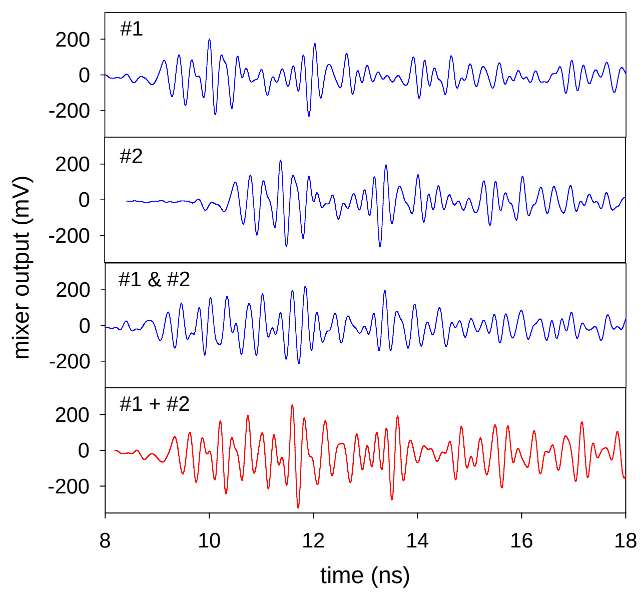

FIGURE 4. RF mixer output showing the signal from: (a) bunch #1 alone; (b) bunch #2 alone; (c) bunches #1 and #2 separated by 1.5 ns (two RF periods of the klystron frequency); (d) numerical addition of the signals from (a) and (b), which is not strictly the correct approach, since the relative phases of these two signals are arbitrary due to the free running local oscillator in the RF mixer circuit.

Another caveat is the fact that the laser intensity of the pulse that generates bunch #2 decreases when pulse #1 is present, due to depletion in the excimer laser amplifier; thus, the charge of bunch #2 is lower when bunch #1 is present.

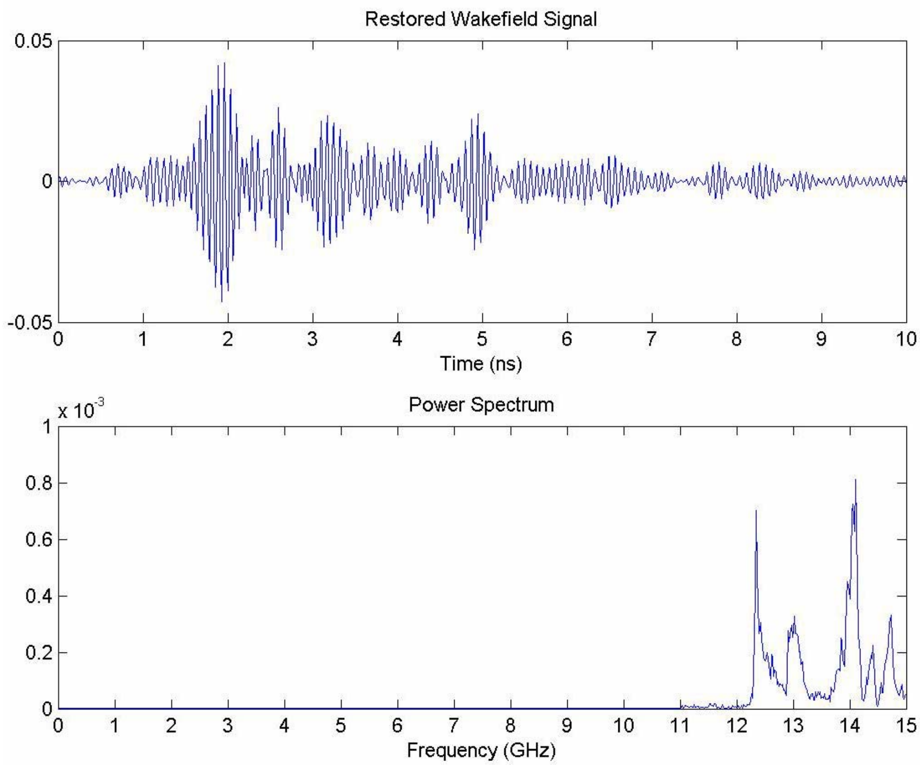

FIGURE 5. RF mixer output: (a) signal generated by a 86 nC electron bunch; (b) peak value of the wakefield amplitude for each excited wakefield modes.

We have also performed another experiment using a 23 mm long structure. The detection circuit is identical with the 102 mm case. Here we have optimized the machine and able to generate and pass high charges through the tube. Figure 5a) shows the output of the mixer for an 86 nC bunch passing through the 23 mm long structure, the highest bunch charge that has traveled through this structure. This corresponds to 45 MV/m on axis. The detected RF signal showed now sign of RF breakdowns. The choice of 23 mm is for multi-beam superposition only and is not related to beam transmission. The high current multiple drive beam experiment will be conducted very soon. In the Figure 5b), the first peak near 12.3 GHz is a dipole mode and excited by a charge traveling off-center; the peak near 14.1 GHz is the dominated longitudinal wakefield.

NEXT STEPS

From the experience we gained here, we have designed another structure to be tested with inner radius of 2.75 mm and outer radius of 4.12 mm. With 100 nC beam, more than 160 MV/m can be achieved. The MAFIA simulation is shown in Figure 6. The experiment is planned in the near future.

We will make further wakefield measurements with the present 15 GHz structure; namely, we will vary the spacing between the bunches and also the number of bunches. We will also change the length of the structure, in order to preferentially excite some of the longitudinal modes.

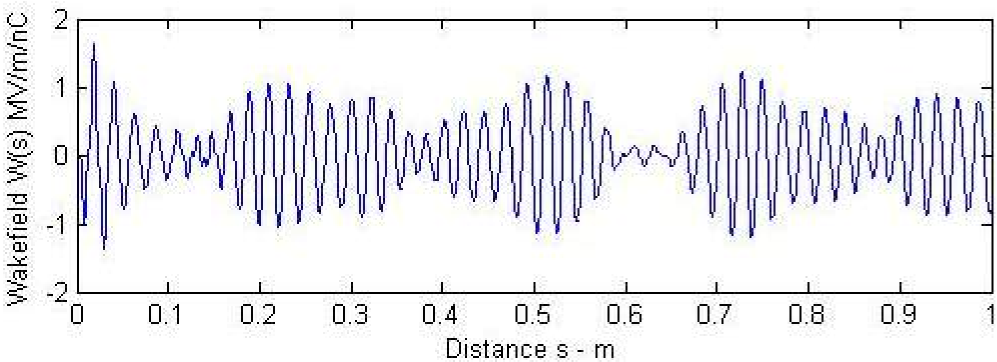

Figure 6. Calculated wakefield in a small structure. For 100 nC beam passing through the structure, 160 MV/m on axis field will be produced.

New dielectric loaded structures are presently under construction, and will be tested shortly. One of them will use a ramped bunch train in order to achieve a transformer ratio higher than two. Another one will be an energy extractor, that is, the RF power source of a two beam accelerator system. We will soon begin fabrication of high quantum efficiency Cs_2Te photocathodes, which will allow us to test wakefield structures using long trains of high charge bunches. In addition, with this long pulse train, we could also test another way of wakefield acceleration scheme: two beam acceleration. The experiment apparatus is under fabrication now at ANL.

ACKNOWLEDGMENTS

Work supported by the US Department of Energy under contract No. W-31-109-ENG-38. The authors wish to express their deep appreciation for the invaluable technical support provided by Felipe Franchini.

REFERENCES

1. M.E. Conde et al., "The Argonne Wakefield Accelerator Facility: Capabilities and Experiments," Eleventh Advanced Accelerator Concepts Workshop, edited by V. Yakimenko, AIP Conference Proceedings 737, Stony Brook, New York, 2004, pp. 657-662.
2. Z. Yusof et al., "Schottky-Enabled Photoemission in a rf Accelerator Photoinjector: Possible Generation of Ultralow Transverse Thermal-Emittance Electron Beam," *Phys. Rev. Lett.* **93**, 114801.
3. AIRFLY: Air Fluorescence Induced by Electrons in a Wide Energy Range, The AIRFLY Collaboration, Proceedings of the 28th International Cosmic Ray Conference, July 31 - August 7-15 2003, Tsukuba Japan, 837.