THE ARGONNE WAKEFIELD ACCELERATOR FACILITY (AWA): UPGRADES AND FUTURE EXPERIMENTS*

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Abstract

The Argonne Wakefield Accelerator Facility is dedicated to the study of advanced accelerator concepts based on electron beam driven wakefield acceleration and RF power generation. The facility employs an L-band photocathode RF gun to generate high charge short electron bunches, which are used to drive wakefields in dielectric loaded structures as well as in metallic structures (iris loaded, photonic band gap, etc). Accelerating gradients as high as 100 MV/m have been reached in dielectric loaded structures, and RF pulses of up to 44 MW have been generated at 7.8 GHz. In order to reach higher accelerating gradients, and also be able to generate higher RF power levels, a photocathode with higher quantum efficiency is needed. Therefore, a new RF gun with a Cesium Telluride photocathode will replace the electron gun that has been used to generate the drive bunches. In addition to this, a new L-band klystron will be added to the facility, increasing the beam energy from 15 MeV to 23 MeV, and thus increasing the total power in the drive beam to a few GW. The goal of future experiments is to reach accelerating gradients of several hundred MV/m and to extract RF pulses with GW power level.

AWA FACILITY

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. In order to carry out these studies, the facility employs a photocathode RF gun capable of generating electron beams with high bunch charges and short bunch lengths. This high intensity beam is used to excite wakefields in the structures under investigation.

The facility is also used to investigate the generation and propagation of high brightness electron beams, and to develop novel electron beam diagnostics.

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 photocathode surface. A 1.3 GHz linac structure increases the electron beam energy, from the 8 MeV produced by the RF gun, to 15 MeV. The linac is an iris loaded standing-wave structure operating in the $\pi/2$ mode with an average accelerating gradient of 7 MV/m; it has large diameter irises to minimize the undesirable wakefields generated by the passage of high charge electron bunches.

The charge of the electron bunches can be easily varied from 1 to 100 nC, with bunch lengths of 2 mm rms, and normalized emittances of 30 to 200 π mm mrad.

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 2 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 (presently up to 16 bunches) requires each laser pulse to be divided by means of beam splitters into a laser pulse train. The charge in each electron bunch is determined by the energy in each laser pulse and the quantum efficiency of the photocathode material. Typically, single bunches of 100 nC can be produced (with a maximum of 150 nC occasionally reached). Experiments have used various combinations of number of bunches and charge per bunch; e.g., 4 x 25 nC or 16 x 5 nC.

WAKEFIELD ACCELERATION

In the quest for high gradient acceleration, the use of wakefields has been the focus of considerable attention. It offers the advantage of using a relativistic beam to transport the energy to the accelerating structures, decreasing the difficulties of generating and distributing RF power by conventional means; wakefields naturally constitute RF pulses that are of short duration and high peak intensity.

Research at the AWA facility has been exploring various types of wakefield structures, including photonic band gap structures, metallic iris loaded structures, and also more exotic schemes using metamaterials. The main focus of the facility, however, has clearly been the development of dielectric loaded structures. They offer the advantage of simple geometry and easy fabrication with accelerating properties that compare favourably with conventional iris loaded metallic structures: the axial electric field is uniform across the transverse cross section of cylindrical structures, and the uniform cross section of the structures presents no geometric features to cause field enhancement. The damping of the undesirable deflecting dipole modes seems to be more easily accomplished in dielectric loaded structures as well;

*Work supported by the U.S. Department of Energy under contract No. DE-AC02-06CH11357.
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planned experiments will explore this issue. Dielectric structures also hold the promise of withstanding higher electric fields without material breakdown. A significant advantage offered by dielectric structures in comparison with other wakefield schemes is the ability to accelerate positron bunches or electron bunches in basically identical fashion.

RECENT AND PLANNED EXPERIMENTS AT AWA

During the past few years, several experiments have been carried out at AWA with the goal of demonstrating the generation of high gradient wakefields, and the ability of the dielectric materials to withstand these high intensity fields without electric breakdown. These tests [1] were conducted using short standing-wave structures and reached accelerating gradients as high as 100 MV/m, albeit with a pulse duration of only a few nanoseconds.

Another series of experiments at AWA aimed at generating and extracting RF power from the dielectric loaded wakefield structures. RF pulses of up to 44 MW were generated at 7.8 GHz, using a train of four bunches with approximately 25 nC per bunch [2,3].

Presently, experiments are being conducted using the AWA drive beam to excite wakefields in a photonic band gap structure. This structure [4] consists of an array of copper rods distributed in between four parallel copper plates, constituting three cells; there is an opening on the center of the plates for the passage of the electron beam. Table 1 lists the main parameters of the PBG structure.

Table 1: Parameter of PBG Structure

Rod radius	1.64 mm
Distance between rods	10.96 mm
Iris diameter	9.61 mm
Iris thickness	1.71 mm
Length of cell	8.75 mm
Operating frequency	11.42 GHz
Phase shift per cell	$2\pi / 3$
Group velocity	0.05 c
Quality factor Q	5461
R / Q	10.5 kΩ/m
Accelerating gradient	7.1 (P(MW))-½ MV/m

Preliminary measurements have been made using a small antenna placed near the edge of the structure to monitor the electric fields excited by the passage of the drive electron bunches. Figure 1 shows the FFT of the antenna signal, indicating two peaks which correspond to the TM_{01}-based modes with the highest R/Q values; numerical simulations show that there is a third TM_{01}-based mode at 11.1 GHz, however it is weakly excited due to its lower R/Q value.

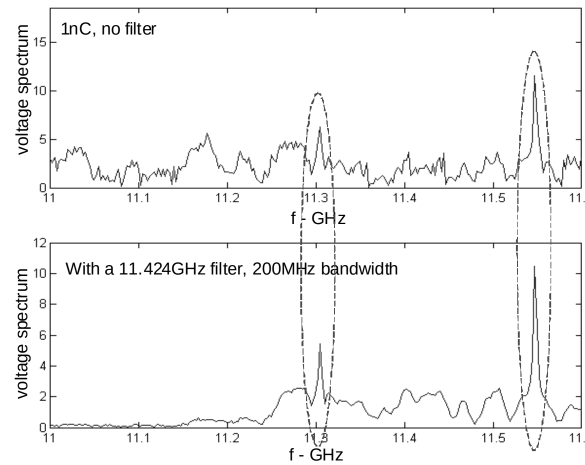

Figure 1: FFT of the antenna signal, used to probe the electric field at the edge of the PBG structure. The plots show the signal without and with a band pass filter.

The PBG experiment will be followed by measurements using a 26 GHz dielectric loaded structure, with the goal of demonstrating efficient generation and extraction of RF pulses at this higher frequency. Figure 2 shows some very preliminary data obtained with this structure. The plots show the RF pulse that exited the output coupler of the structure, after its frequency was down converted in an RF mixer, and finally displayed on a high bandwidth oscilloscope; the second plot shows the FFT of the previous signal, indicating that the expected frequency was observed. This power extraction experiment is part of a series of experiments that will be carried out in collaboration with Euclid Techlabs. Other experiments which are part of this joint effort include: (a) Tunable Dielectric Loaded Wakefield Structure, to demonstrate the ability to tune the frequency of the driven wakefields by means of a thin ferroelectric layer subject to a DC electric field and temperature changes; (b) Enhanced Transformer Ratio Collinear Wakefield Acceleration, to demonstrate a transformer ratio higher than four using a ramped bunch train in a dielectric structure; (c) Transverse Mode Damped Dielectric Structure, to demonstrate the use of longitudinal slots and RF absorbers to damp deflecting dipole modes in a dielectric loaded structure.

A couple of future experiments will be performed in collaboration with Omega-P, YALE, and Columbia University: (a) Two Channel Planar Dielectric Structure, to demonstrate wakefield acceleration in two parallel dielectric channels with distributed coupling; (b) Concentric Two Beam Acceleration in Dielectric Structure, to demonstrate wakefield acceleration using a hollow cylindrical drive bunch and a concentric witness bunch.

AWA FACILITY UPGRADES

Several upgrades are presently being implemented, and will considerably enhance the capabilities of the facility. An additional L-band RF power station will allow the

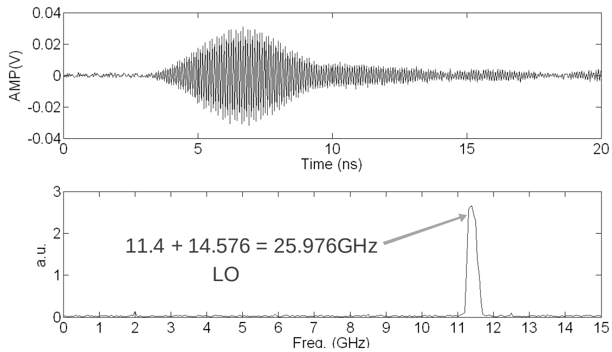

Figure 2: RF pulse extracted from a 26 GHz dielectric loaded wakefield structure, observed on an oscilloscope after its frequency was down converted in a RF mixer (the frequency of the local oscillator was set at 14.576 GHz). Also shown is the FFT of the voltage signal.

energy of the drive beam to be increased from 15 MeV to approximately 23 MeV; the modulator has been built and commissioned, and the 30 MW Litton klystron (on loan from LANL, thanks to B. Carlsten and S. Russell) has already been operated at the 26 MW level. This second klystron will power a second RF gun, which will generate the witness beam to probe the wakefields generated by the drive beam. In fact, the RF gun which presently produces the drive beam will in the near future be dedicated to the generation of the witness beam, and a new – just completed - RF gun (Fig. 3) will become the new drive gun. This new RF gun is also a one-and-a-half cell gun, almost identical to the existing one, but its back side was designed to more readily accept the replacement of photocathodes while under vacuum. Thus, this new drive gun will operate with Cesium Telluride photocathodes, allowing the generation of long electron bunch trains with high charge per bunch.

A second linac structure will be installed in the drive beamline, and will also be powered by the second klystron. This will increase the energy of the drive beam from 15 MeV to approximately 23 MeV.

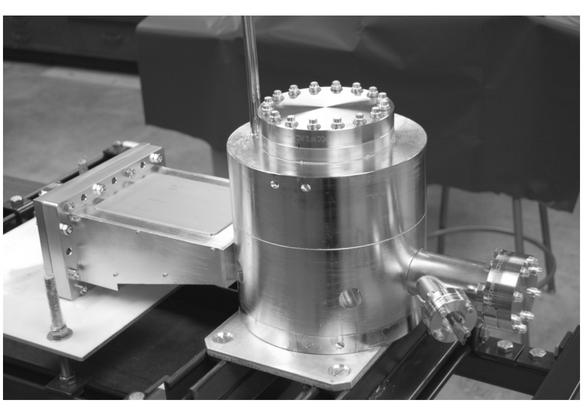

Figure 3: New RF gun after final brazing cycle. Once commissioned, it will be used to generate the high charge drive bunches, using Cesium Telluride photocathodes.

Plans for further facility upgrades are presently being developed. The addition of two or three new L-band RF power stations, in conjunction with the addition of four more linac structures in the drive beamline, would increase the beam energy to approximately 75 MeV. This would, of course, greatly increase the energy in the drive beam available to drive wakefields in the structures under test. The higher beam energy would also imply a smaller physical transverse emittance of the bunches, facilitating their propagation through smaller aperture wakefield structures, and generating even higher wakefield amplitudes.

CONCLUDING REMARKS

In the past couple of years AWA has demonstrated high gradient fields (100 MV/m) in dielectric based wakefield structures. Generation and extraction of RF power using beam driven dielectric structures has also been demonstrated. Several experiments exploring new designs and new features of dielectric based wakefield structures will be conducted in the near future.

Concomitantly, AWA is undergoing upgrades that will enhance its capabilities. These upgrades will allow the generation of longer bunch trains with high charge per bunch. The higher beam energy will make it possible to excite high gradient wakefields in longer accelerating structures, thus generating hundreds of MV/m over meter scale structures. The second RF gun will provide “witness” bunches to probe the wakefields, demonstrating high gradient acceleration.

Once the upgrades are completed, the goal is to achieve accelerating gradients on the order of 0.5 GV/m in structures with approximately 3 mm apertures. The generation and extraction of RF pulses with power levels on the order of GW shall also be demonstrated.

In addition to high gradient experiments, outside users have been using the facility for research in advanced accelerator physics, high brightness beam generation and diagnostics, beam instrumentations and laboratory astro-physics experiments (AIRFLY, etc).

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