ARGONNE WAKEFIELD ACCELERATOR FACILITY (AWA) UPGRADES*

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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, RF pulses have been generated with up to 44 MW at 7.8 GHz, and 20 MW at 26 GHz. In order to reach higher accelerating gradients, and also be able to generate higher RF power levels, several upgrades are underway: (a) a new RF gun with a higher quantum efficiency photocathode (Cesium Telluride) will replace the RF gun that has been used to generate the drive bunches; (b) the existing RF gun will be used to generate a witness beam to probe the wakefields; (c) three new L-band RF power stations, each providing at least 25 MW, will be added to the facility; (d) five linac structures will be added to the drive beamline, bringing the beam energy up from 15 MeV to 75 MeV. The drive beam will consist of bunch trains of up to 32 bunches spaced by 0.77 ns with up to 60 nC per bunch, corresponding to a 6 GW beam power. 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 (PRESENT)

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 3 to 100 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;

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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.

AWA FACILITY UPGRADES

The AWA Facility is undergoing several major upgrades, which will considerably enhance its capabilities.

A new one-and-a-half cell RF gun (Fig. 1) will replace the existing one, as the source of drive bunches. The new RF gun will operate with a Cesium Telluride photocathode, and thus, due to the higher quantum efficiency of Cs_2Te (Fig. 2), it will be able to generate longer bunch trains with high charge per bunch. We plan to generate trains with up to 32 electron bunches, each separated by one L-band RF period, and with up to 60 nC per bunch. These longer bunch trains will, of course, generate longer RF pulses when traversing the wakefield structures.

Three additional L-band RF power stations, consisting of one 30 MW Litton klystron and two 25 MW Thales klystrons, and their respective modulators, will power six new linac tanks in the drive beamline. The Litton klystron (on loan from LANL, thanks to B. Carlsten and S. Russell) has been operated with its new modulator. The two Thales klystrons are presently under fabrication, and are expected to be delivered this year by the end of the Fall; their two new modulators are under construction at Argonne.

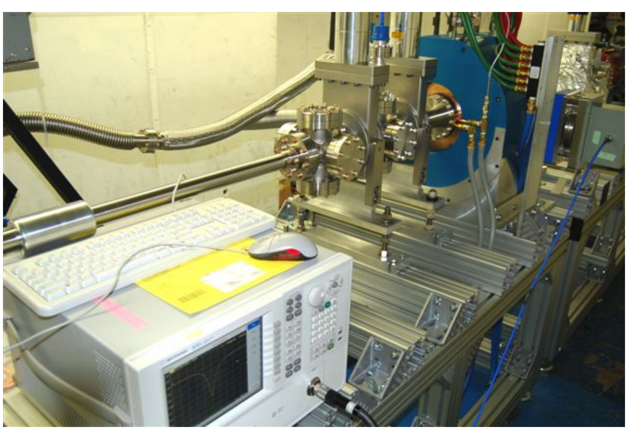

Figure 1: The new AWA RF gun (behind the blue solenoid) will replace the present drive gun. The two gate valves, and the long actuator connected to the back side of the gun, allow the insertion of the Cesium Telluride photocathode without exposing it to air.

The construction of the newly designed linac tanks (Fig. 3) is expected to start early this Summer, and it is projected to be completed by the Spring of next year. These new linacs will be seven-cell standing-wave π mode structures, designed to operate with 10 MW of input power and 11.2 MeV energy gain. Thus, the operation of the six new linac tanks will increase the energy of the beam produced by the drive gun from 8 MeV to 75 MeV. This will, of course, greatly increase the energy in the drive beam available to drive wakefields in the structures under test. The higher beam energy also implies a smaller physical transverse emittance of the bunches, facilitating their propagation through smaller aperture wakefield structures, and generating even higher wakefield amplitudes.

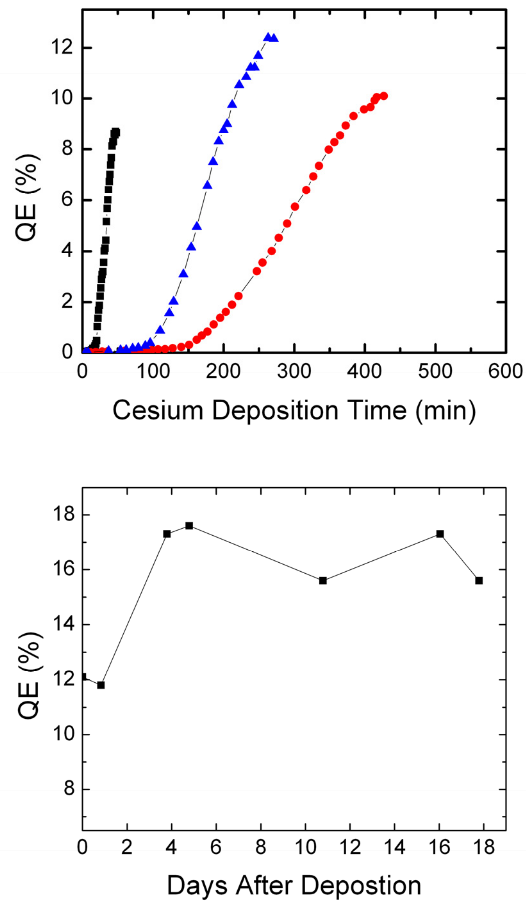

Figure 2: Cesium Telluride quantum efficiency: (a) time evolution during Cesiation in the fabrication chamber. The curves correspond to three depositions made at different rates; (b) lifetime of photocathode kept in preparation chamber for eighteen days. The quantum efficiency can show a slight increase in the initial few days, but typically it will start decreasing after a few weeks.

The commissioning of the new drive gun will free up the existing gun, which will then be used to generate a witness beam to probe the wakefields produced by the drive bunches.

A new beamline switchyard (Fig. 4) will be constructed to allow concomitant experiments: (a) collinear wakefield acceleration; (b) RF power generation and two beam acceleration; (c) phase space manipulation (emittance exchange, etc); (d) high brightness beam generation; (e) beam diagnostic development. This flexible beamline switchyard will allow a quicker and more efficient transition among several concurrent experimental setups.

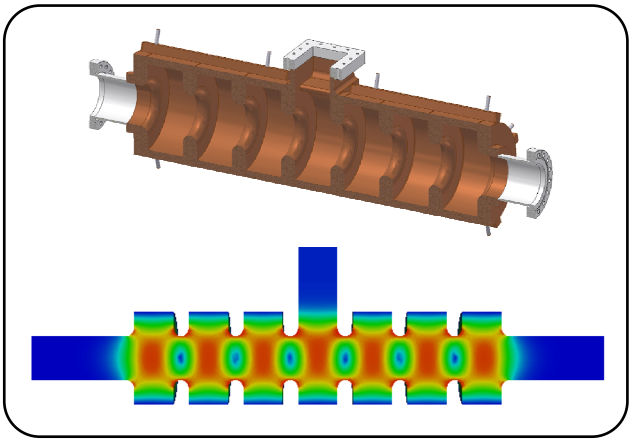

Figure 3: CAD rendering and field map of the new AWA linac tanks. The 3D numerical simulation was performed with Omega3p.

In order to house the upgraded AWA Facility, the present bunker will have to be enlarged. The expanded bunker will extend past the perimeter of the building, into a new annex. The design of the new bunker and building annex have been completed and are awaiting funding approval.

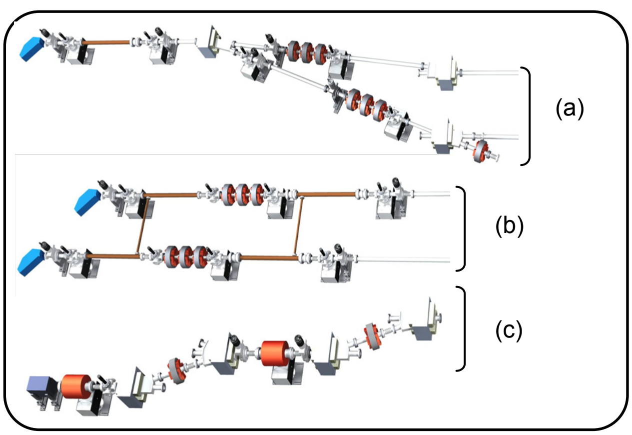

Figure 4: Different legs of the new AWA beamline switchyard will be dedicated to specific types of experiments: (a) collinear wakefield acceleration; (b) two-beam-acceleration and RF power generation; (c) phase space manipulation (emittance exchange) and beam diagnostic development.

CONCLUDING REMARKS

In the past few years AWA has demonstrated high gradient fields (100 MV/m) in dielectric based wakefield structures [1]. Generation and extraction of RF power using beam driven dielectric structures has also been demonstrated [2 - 4]. 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).

REFERENCES

[1] M. Conde et al., "High Gradient Excitation and RF Power Generation using Dielectric Loaded Wakefield Structures," LINAC'08, Victoria, September 2008, MOP067; http://www.JACoW.org.

[2] F. Gao et al., "Design and Testing of a 7.8 GHz Power Extractor Using a Cylindrical Dielectric-loaded Waveguide," Physical Review ST Accel. Beams 11, 041301(2008).

[3] F. Gao et al., "Multi-Nanosecond High Power Pulse Generation at 7.8GHz with a Dielectric-loaded Power Extractor," accepted for publication at the June 2009 issue of IEEE Transactions on Nuclear Science.

[4] C. Jing et al., "A 26 GHz Wakefield Power Extractor," in these proceedings.