HIGH GRADIENT WAKEFIELD ACCELERATION (~ GV/m) IN STRUCTURES: GOALS OF THE UPGRADED ARGONNE WAKEFIELD ACCELERATOR FACILITY (AWA)*

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Abstract

New technology needs to be developed for future compact linear colliders. The AWA Facility is dedicated to the study of advanced accelerator concepts towards this goal. The facility uses high charge short electron bunches 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, several facility upgrades are underway: a new RF gun with a higher QE photocathode; a witness beam to probe the wakefields; additional klystrons and linac structures to bring the beam energy up to 75 MeV. The drive beam will consist of bunch trains of up to 32 bunches with up to 100 nC per bunch, corresponding to a maximum beam power of 10 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. A key advantage of wakefield acceleration in structures is the ability to act on electrons and positrons in basically identical fashion.

AWA FACILITY

The mission of the Argonne Wakefield Accelerator Facility (AWA) is to develop technology for future High Energy Physics accelerators. The facility has been used to study and develop new types 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

The use of electron beam driven wakefields to achieve high gradient acceleration has received 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

*Work supported by the U.S. Department of Energy under contract No. DE-AC02-06CH11357.

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accomplished in dielectric loaded structures as well; planned experiments will explore the use of longitudinal slots on the metallic outer shell of dielectric structures, as a possible scheme to damp dipole modes. Dielectric structures also hold the promise of withstanding higher electric fields without material breakdown. A significant advantage offered by wakefield 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 has several major upgrades presently underway, which will considerably enhance its capabilities.

A new one-and-a-half cell RF gun (Fig. 1) is presently being commissioned. It will replace the existing RF gun 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 100 nC per bunch. (It should be noted that the two upper limits, i.e. 32 bunches and 100 nC per bunch, cannot be reached simultaneously, since this would load the accelerating fields in the RF gun to an unacceptable level.) 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 in October of 2010; the construction of their two new modulators at Argonne is nearly finished.

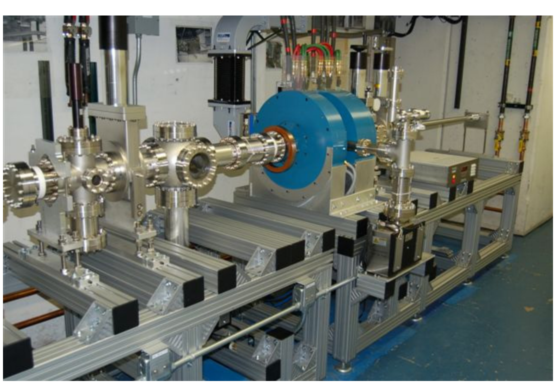

Figure 1: The new AWA RF gun (between the blue solenoids) is being commissioned, initially with a copper photocathode, which will soon be replaced with a Cesium Telluride photocathode. This gun will replace the present drive gun as the source of drive bunches.

The contract for the construction of the new linac tanks [1] has been awarded, and completion of the project is expected in the Spring of 2011. These new linacs (Fig. 3) 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, allow significantly more energy to be extracted from the drive beam as it drives 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.

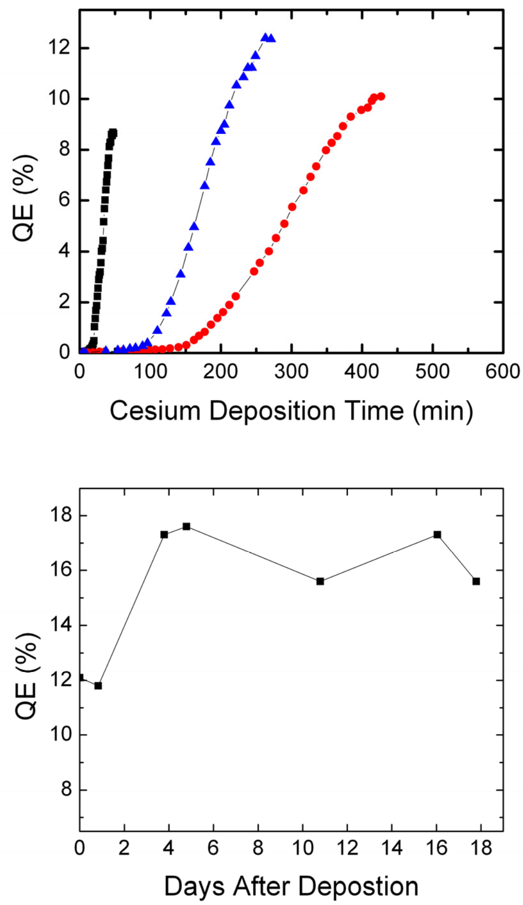

Figure 2: Cesium Telluride quantum efficiency: (a) time evolution during Cesiation in the fabrication chamber. The curves correspond to three depositions made at different rates; (b) lifetime of photocathode kept in preparation chamber for eighteen days. The quantum efficiency can show a slight increase in the initial few days, but typically it will start to decrease in a few weeks. The non-uniformity of the QE across the large surface of the photocathode (25 mm diameter) had initially been an issue, but improvements in the geometry of the deposition process have solved the problem.

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.

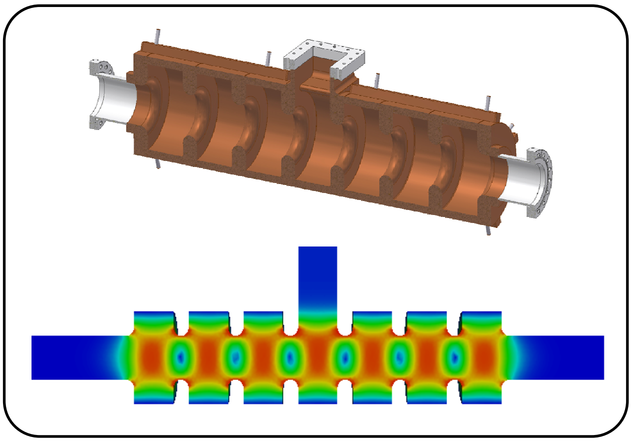

Figure 3: CAD rendering and field map of the new AWA linac tanks. The 3D numerical simulation was performed with Omega3p.

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

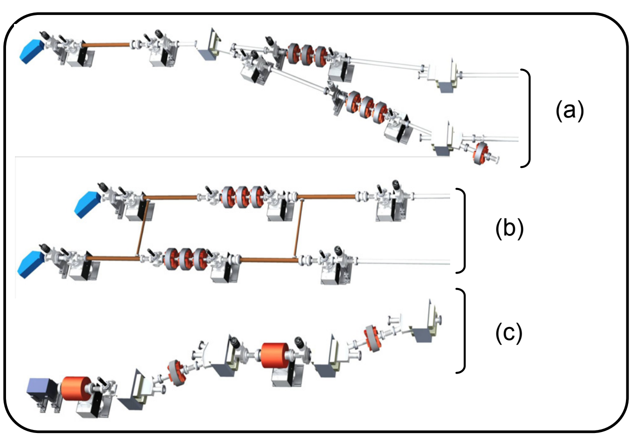

Figure 4: Different legs of the new AWA beamline switchyard will be dedicated to specific types of experiments: (a) collinear wakefield acceleration; (b) two-beam-acceleration and RF power generation; (c) phase space manipulation (emittance exchange) and beam diagnostic development.

CONCLUDING REMARKS

In the past few years AWA has demonstrated high gradient fields (100 MV/m) in dielectric based wakefield structures [2]. Generation and extraction of RF power using beam driven dielectric structures has also been demonstrated [3 - 5]. 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. As an example, Table 1 shows the main parameters of a pair of structures that will likely be tested as soon as the upgraded AWA Facility becomes available.

Table 1: 26 GHz TBA Structures

Decelerating structure	**Accelerating structure**
ID / OD / length (mm) 7.0 / 9.068 / 300	ID / OD / length (mm) 3.0 / 5.025 / 300
Dielectric constant 6.64	Dielectric constant 9.70
Group velocity 0.254 c	Group velocity 0.111 c
R/Q 9.79 kΩ/m	R/Q 21.98 kΩ/m
RF Power (50 nC) 1.33 GW	R_{sh} 50.44 MΩ/m
Peak gradient 167 MV/m	E_0 (1.26 GW) 316 MV/m
Energy loss 20.5 MeV	E_{loaded} (1.26 GW) **267 MV/m**

REFERENCES

[1] J.G. Power et al., “Upgrade of the Drive Linac for the AWA Facility Dielectric Two-Beam Accelerator,” in proceedings of IPAC 2010, Kyoto, May 2010.

[2] M. Conde et al., “High Gradient Excitation and RF Power Generation using Dielectric Loaded Wakefield Structures,” in proceedings of LINAC’08, Victoria, September 2008.

[3] 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).

[4] F. Gao et al., "Multi-Nanosecond High Power Pulse Generation at 7.8GHz with a Dielectric-loaded Power Extractor," IEEE Transactions on Nuclear Science **56** (3), p. 1492 – 1497, (2009).

[5] C. Jing et al., "The First Experiment of a 26 GHz Dielectric Based Wakefield Power Extractor," in proceedings of IPAC 2010, Kyoto, May 2010.