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THE ACHIP EXPERIMENTAL CHAMBERS AT PSI

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Abstract

The Accelerator on a Chip International Program (ACHIP) is an international collaboration, funded by the Gordon and Betty Moore Foundation, whose goal is to demonstrate that laser-driven accelerator on a chip can be integrated to fully build an accelerator based on dielectric structures. PSI will provide access to the high brightness electron beam of SwissFEL to test structures, approaches and methods towards achieving the final goal of the project. In this contribution, we will describe the two interaction chambers installed on SwissFEL to perform the proof-of-principle experiments. In particular, we will present the positioning system for the samples, the magnets needed to focus the beam to sub-micrometer dimensions and the diagnostics to measure beam properties at the interaction point.

INTRODUCTION

With the potential of delivering acceleration of particles with gradients in excess of more than one order of magnitude larger than conventional RF technology, dielectric laser acceleration (DLA) [1] represents one of the most promising candidates for the realization of table top accelerators and for reducing the dimensions of future high energy colliders. The technique is based on the interaction between charged particles and the electric field of a laser, mediated by a dielectric microstructure. It is capable of exceeding the conventional technology as it implies dielectrics instead of metals. Dielectric materials are capable of supporting much higher electrical fields before breakdown happens.

The Accelerator on a Chip International Program (ACHIP) [2], an international collaboration between seven Universities, three National Laboratories and a private company, has been established with the support of the Gordon and Betty Moore Foundation to advance the DLA technology. The final goal is the realization of an all-on-a-chip particle accelerator. The role of EPFL/PSI in the collaboration is to investigate DLAs at relativistic electron beam energy and perform proof-of-principle experiments, in particular using the electron beam of SwissFEL [3].

Our goal is to demonstrate gradients in excess of 1 GV/m for a dielectric length of 1 mm, resulting in an acceleration of 1 MeV [4] for the electrons.

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INJECTOR CHAMBER

Installed at meter 89 of the SwissFEL injector [5] is a chamber dedicated to experiments, see Fig. 1 where a breakout 3D representation of the setup is shown. It is composed of in vacuum manipulator, operated through a feedthrough by a stepper motor for the vertical translation and equipped with a camera box for detecting the electron beam signal on the screens (blue box on the left). Two different targets for transverse beam measurements (YAG:Ce and OTR foil) are installed on the manipulator as well as four different sample holders for the samples. Using the manipulator the samples can be inserted into the SwissFEL electron beam depending on the request of the different experiments.

A load-lock pre-chamber allows for installation of the samples on the sample holders without breaking the accelerator vacuum. A summary of the relevant parameters is reported in Table 1. Notice that in the low energy chamber the installation of a laser is not planned, hence the DLA studies are focused on the investigation of the wakefields induced by the microstructures on the electron beam and on assessing the radiation hardness of the materials used for the microstructures.

The chamber has been successfully commissioned and has been already used to perform a number of different experiments (see in the following).

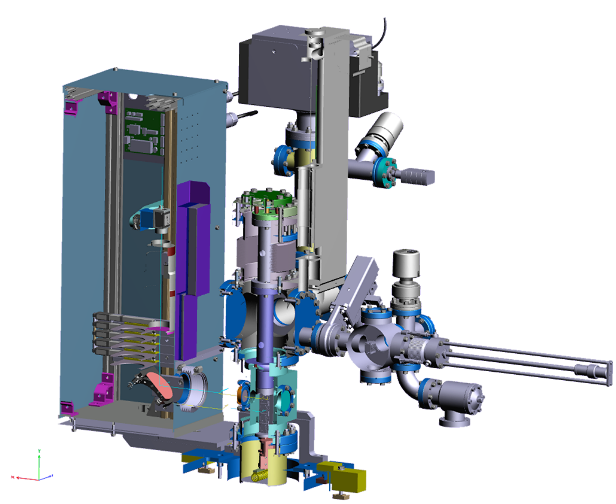

Figure 1: 3D breakout model of the ACHIP injector chamber.

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Table 1: Parameters for the Experiments in the Injector (Second Column) and in the Switchyard (Third Column). Notice that in the present installation no laser is foreseen in the injector chamber.

	Injector	**Switchyard**
Electron beam		
Energy	350 MeV	3 GeV
Charge	0.5 – 200 pC	1 pC
Beam size (rms)	1.4 – 25 μm	< 1 μm
Laser		
Wavelength		2 μm
Pulse energy	Not Available	500 μJ
Pulse duration		100 fs
DLA structure		
Length	3 mm	3 GeV
Gradient	0.75 GV/m	> 1 GV/m
Opening	90 μm x 500 μm	1.2 μm x 7 μm

SWITCHYARD CHAMBER

A further dedicated experimental chamber is planned to be installed in the higher energy section of the machine, in the switchyard transfer line to the ATHOS beamline. The manufacturing vacuum chamber has started and we plan to have it installed at beginning of 2018 during one of the planned shutdowns of SwissFEL. It will be placed on one of the existing girders to ensure adequate vibration stability. The relevant parameters for the experiment are summarized in Table 1.

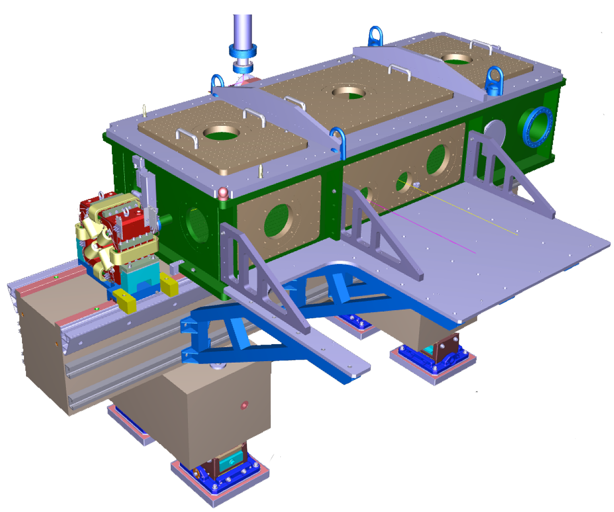

Figure 2: 3D model of the ACHIP chamber in the SwissFEL switchyard.

Chamber Design

A 3D model of the vacuum chamber is shown in Fig. 2. The pressure in the chamber will be 10^{-6} mbar, adequate to satisfy the beam transport requirements. Differently from the injector chamber, a dedicated Ti:Sa laser equipped with an optical parametric amplifier will be installed in a laser room above the experiment. Its photon beam, transported through a low-vacuum transfer line, will be available to perform acceleration experiments. To accomodate for the enlarged interaction length of 1 mm between the laser and the electron beam, we are planning a pulse front tilti with an angle of 45 degrees between the intensity and phase fronts of the laser, via a dispersive reflective grating [6].

In the chamber, an hexapod manipulator will be installed, allowing for 6-dimensional alignment of the DLA microstructure with respect to the incoming electron beam. On the same sample mount we foresee to install different profile monitors, including a YAG:Ce scintillator, a sub-μm resolution wire-scanner, as well as an OTR target. These will enable to diagnose the beam size along the propagation direction and to ensure the superposition, both longitudinal and transverse, between the electron beam and the laser. Symmetrically with respect to the interaction point there will be two permanent quadrupole triplets to obtain the required electron beam optics for the smallest beam size at IP and transport to the second half of the switchyard, where the last bending magnet can be used as a spectrometer to detect the interaction of e-beam and laser.

The quadrupoles, whose geometrical strength will be $-25.89\,\mathrm{m}^{-2}$ and $38.73\,\mathrm{m}^{-2}$, will be installed on two translation stages each, so that their position can be controlled remotely. The horizontal translation stage will have a longer travel range to enable a complete removal of the quadrupoles from the beam path to allow the normal beamline operation. The size of the quadrupole will be approximately 15 x 15 x 10 cm^3 inclusive of the mounting support, with opening of 5 mm.

Electron Beam

Using elegant [7] and ASTRA [8] the electron beam of the first foreseen experiments has been simulated, in Fig. 3 we report the optics along the lattice and in Fig. 4 the longitudinal and transverse phase space. The β-functions at IP are 1 cm and 1.8 cm in the horizontal and vertical directions, respectively. This, combined with the reduced emittance of the SwissFEL electron beam leads to expected (rms) beam sizes of 0.26 μm and 0.36 μm for the horizontal and vertical planes. Such beam sizes are adequate for full transmission of the electron beam through the DLA structure, cfr. Table 1.

FIRST EXPERIMENTS IN THE INJECTOR CHAMBER

Radiation Hardness Testing of Dielectrics

To consider dielectric structures as the basis for a linear electron accelerator of significant current, the effect of sending a high-power electron beam through the micron-scale apertures typical in optical scale dielectric accelerators must be fully understood. In addition to the effects of wakefields and Coulomb repulsion on the beam, the beam-induced damage on the dielectric material itself needs to be studied.

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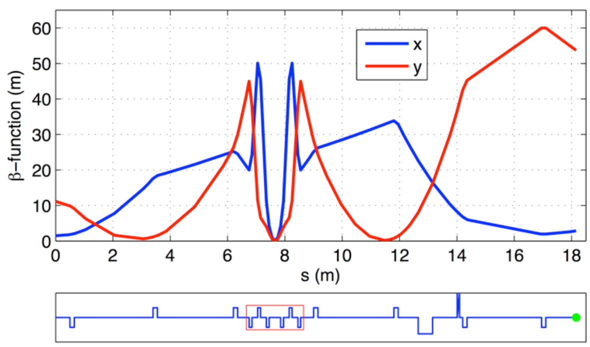

Figure 3: Horizontal (blue) and vertical (red) β-functions for the DLA experiment at the switchyard of SwissFEL. The lower sketch shows the corresponding magnetic lattice. The smaller rectangles mark the quadrupole magnets, the larger one shows the position of the dipole magnet before the profile monitor, indicated by a green circle. Image reproduced from [4].

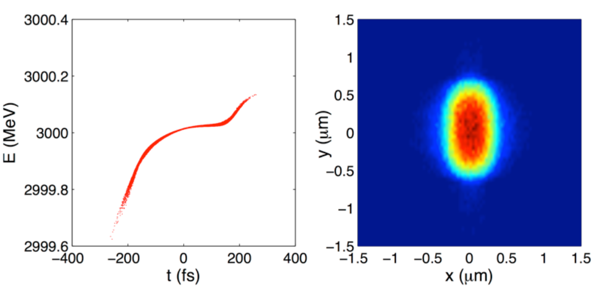

Figure 4: Longitudinal phase-space (left) and transverse profile (right) of the simulated electron beam at the experiment location. The rms pulse duration is 92 fs, the rms energy spread is 42 keV, and the rms beam sizes are 0.26 µm (horizontal) and 0.36 µm (vertical) Image reproduced from [4].

Therefore, the 350 MeV electron beam at the SwissFEL injector chamber has been used to study the radiation hardness of the materials proposed to be the components of DLAs, e.g. Al_2O_3, SiC, and Si, by placing directly in the path of the electron beam. The materials have been examined for signs of structural damage under an optical microscope and an SEM. We are preparing an infrared spectrometer to assess the change in the optical properties of the materials.

Test of Wire-Scanners with Sub-Micron Resolution

This experiment is aimed at testing the prototype of a wire scanner with sub-micrometer spatial resolution. The geometrical resolution of a standard wire scanner depends on the wire width: the smaller the width, the higher the resolution. Instead of metallic wires stretched onto a wire-fork, the prototypes were fabricated using nanotechnology fabrication techniques based on electron beam lithography on a Silicon chip with a central Si_3N_4 membrane. On this membrane two metal (Au or Ni) wires are electroplated. The improvement of the resolution is critical for the ACHIP project as in the high-energy chamber experiment the electron beam will have sub-µm size. In the experiments in the injector chamber we tested UH-vacuum and radiation robustness, as well as performing transverse profile measurements with the smallest beam sizes possible. Comparison with a traditional a 5 µm Tungsten wire has also been performed [9].

Beam-double Pillar Structure Interaction

Transmitting an electron beam through the small aperture of the dielectric structures proposed for the ACHIP project is an experiment in itself. We will use a suitably expanded structure and low energy electrons to test the ability to fully transmit the electron beam through it. As wakefields could potentially seriously degrade the electron beam quality, we will evaluate the effect of the interaction of the electron beam with the double pillar structure, by measuring the emittance and energy distribution after the interaction, for different bunch charges and electron beam lengths.

Processional Magnetization Reversal of Ferromagnets

Modern magnetic recording technology demands operational speeds far beyond the nanosecond regime, which require the investigation of magnetic excitations on a time scale much shorter than the spin lattice relaxation time (∼ 100 ps). The goal of this experiment is to provide a visual demonstration of switching on picosecond timescales for in-plane and out of plane magnetic nanostructures, by using the electron beam field as the magnetic pulse excitation. After exposure to the electron beam, the samples will be measured using scanning transmission X-ray microscopy (STXM) and X-ray magnetic circular dichroism (XMCD). The samples inserted in the SwissFEL electron beam were 25 nm thick in-plane magnetized $Ni_{80}Fe_{20}$ Py islands of length 500 nm and width 250 nm.

CONCLUSION

We presented the two experimental chambers for the ACHIP experiments in SwissFEL. A first chamber, installed in the injector part of the machine, has been commissioned and is presently available for experiments. A second chamber in the high energy part of the machine is in advanced construction phase and we plan to install it beginning of 2018.

ACKNOWLEDGEMENT

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