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The ACHIP experimental chambers at the Paul Scherrer Institut

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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, with the goal of demonstrating that laser-driven accelerator can be integrated on a chip 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.

1. Introduction

With the potential of delivering acceleration of particles with gradients of more than one order of magnitude larger than conventional RF technology, dielectric laser acceleration (DLA) [1–5] 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) [6], an international collaboration between 7 Universities, 3 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 energies and perform proof-of-principle experiments, in particular using the electron beam of SwissFEL [7,8].

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 for the electrons [9].

2. Injector chamber

Installed at meter 89 of the SwissFEL injector [10] there is a chamber dedicated to experiments, see Fig. 1 where a 3D representation of the setup is shown. It is composed of an 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

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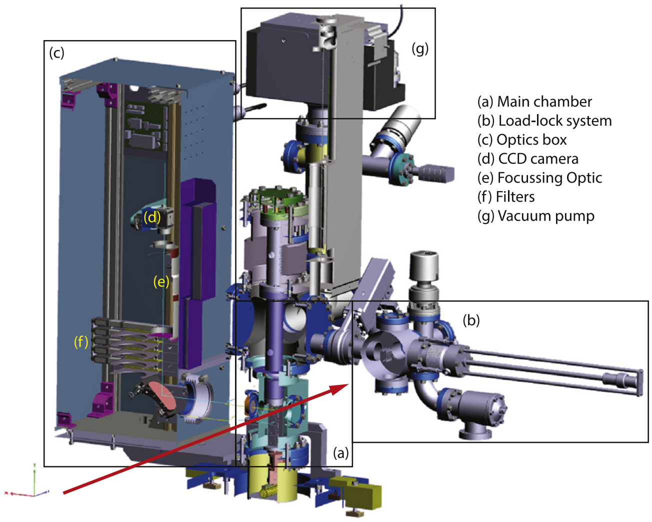

Fig. 1. 3D model of the ACHIP injector chamber. The direction of propagation of the e-beam is shown as a red arrow.

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 for 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	1 mm
Gradient	0.75 GV/m	> 1 GV/m
Opening	90 μm × 500 μm	1.2 μm × 7 μm

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).

3. 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 soft X-ray beamline. The manufacturing of the vacuum chamber has started and we plan to have it installed at beginning of 2018 during one of the 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.

3.1. 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 accommodate for the enlarged interaction length of 1 mm between the laser and the electron beam, we are planning a pulse front tilt with an angle of 45° between the intensity and phase fronts of the laser, via a dispersive reflective grating [11].

In the chamber, a hexapod manipulator will be installed, allowing for 6-dimensional alignment (x, y, z and three angles) 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 the interaction point 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 transverse position (horizontal and vertical) 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 normal beamline operation. The size of each quadrupole will be approximately $15\times15\times10\ \mathrm{cm}^3$ inclusive of the mounting support, with opening of 5 mm.

3.2. Electron beam

Using elegant [12] and ASTRA [13] the electron beam of the first foreseen experiments has been simulated. Fig. 3 shows the optics along the lattice and Fig. 4 the longitudinal and transverse phase space of the electron beam at the interaction point. The β-functions at the interaction point 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, see Table 1.

In Fig. 5(left) an example of the longitudinal phase space of the electrons is shown after the interaction with the laser in the DLA. The simulated data have been obtained superimposing a dumped periodic energy modulation on the electron beam, roughly describing the interaction of the electron beam with the laser in the DLA structure. One can clearly see that the energy is modulated on the 2 μm scale of the laser wavelength, as in the first experiments the electron beam pulse duration (∼500 fs rms) will be (much) longer than the laser period. While such experiments are not new, we will focus on the demonstration of higher accelerating gradients (in excess of 1 GeV/m) with full transmission of the electron beam. In the future, we will explore the possibility of generating a suitable electron beam (via extreme compression or directly at the photoinjector gun) to demonstrate net acceleration.

Also in Fig. 5(right) the normalized electron beam distribution at the spectrometer screen, located at the end of the beamline, is shown as a function of the position on the screen itself. Different values of the peak accelerating gradient in the DLA structure were considered, showing that, even measuring the projected energy profile, we would still be able to clearly distinguish changes when the energy of the beam is modulated. Note that the resolution of the screen systems installed in SwissFEL is 150 lp/mm [14]. Such systems have been used to measure beam sizes of 16.4 μm (rms) [15], hence we believe that their resolution is adequate.

4. First experiments in the injector chamber

4.1. 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

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