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INTERACTION REGION DESIGN FOR DWA EXPERIMENTS AT FACET-II

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Abstract

The extremely intense beam generated at FACET-II provides the unique opportunity to investigate the effects of beam-driven GV/m fields in dielectrics exceeding meter-long interaction lengths. The diverse range of phenomena to be explored, such as material response in the terahertz regime, suppression of high-field pulse damping effects, advanced geometry structures, and methods for beam break up (BBU) mitigation, all within a single UHV vacuum vessel, requires flexibility and precision in the experimental layout. We present here details of the experimental design for the dielectric program at FACET-II. Specifically, consideration is given to the alignment of the dielectric structures due to the extreme fields associated with the electron beam, as well as implementation of electron beam and Cherenkov radiation-based diagnostics.

INTRODUCTION

The FACET-II facility will be home to one of the most intense electron beams in the world, and the only facility capable of providing both electron and positron beams for beam-driven wakefield accelerator research [1]. High field physics experiments, such as dielectric and plasma wakefield, ion motion, betatron radiation, and strong field QED, have been developed to utilize the FACET-II beam.

The dieletric wakefield acceleration (DWA) program at FACET-II is a continuation of the successful program at FACET, where many important phenomena were explored, such as: observation of GV/m acceleration and deceleration of electrons in dielectric structures [2], induced-conductivity in dielectrics by high-field THz waves [3], and the suppression of deflecting modes in planar-symmetric dielectric wakefield accelerating structures using elliptical electron bunches [4]. Due to the physics learned in these experiments, the dielectric program at FACET-II is built on further understanding the beam dynamics in meter-long, high gradient structures and optimizing the modal content for the highest longitudinal accelerating fields. This necessitates using structures up to 50 cm in length, apertures as small as 100 μm, and requiring diagnostics for determining both the modes established within the dielectrics and the effects on the charged particle beam.

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In previous experiments [2-4], a large vacuum chamber housed the dielectric structures, 6D motion system comprised of in-vacuum motors, coherent Cherenkov radiation (CCR) collection optics, and multiple OTR screens and mirrors for alignment of the structures to the electron beam. This chamber resided at the end of the common experimental area (IP), where other experiments were installed and occasionally had operating conditions which produced enough radiation to damage motors and cameras. The new layout of the FACET-II beamline, as shown in Fig. 1, places the DWA chamber (the *Kraken*), upstream of the main experimental area (IP) and next to the deflecting rf cavity (TCAV), the primary temporal diagnostic for the electron and positron beams. Because of the demanding UHV requirements of

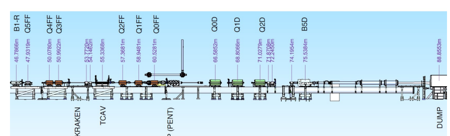

Figure 1: FACET-II beamline.

the high-field rf cavity, extra consideration must be given to cleanliness and types of components within the DWA chamber. Furthermore, the fields associated with the extremely high peak current (200 kA) electron beam have the potential to damage anything put in its path, such as OTR screens. Designing the experimental layout to accommodate the different structures, diagnostics, UHV requirements, and destructive electron beam, requires careful consideration and planning.

EXPERIMENTAL LAYOUT

Chamber Design

The location of the *Kraken* chamber, just upstream of the TCAV and over 10 meters away from the main IP, provides both advantages and disadvantages to the experimental design and execution compared to its previous location in FACET. The interception of the beam by other experiments, and sweeping of the beam inside the TCAV for temporal measurements, would send radiation downstream, which impacted motor and camera circuitry. This occasionally caused failure of the electronics, sometimes while performing the experiment, resulting in a required access and repair, both of which are difficult and discouraged after the multi-GeV

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beam has been transported to the dump. With the chamber located upstream, sensitive electronics are now less exposed to radiation and the failure rate is expected to be much lower.

The vacuum requirements near the TCAV are much stricter compared to the IP though. Because of the proximity to a high field rf cavity, pressures are required by SLAC standards [5] to be no worse than 1x10^{-9} Torr, with hydrocarbons of mass over 45 AMU limited to 1x10^{-11} Torr, at a bakeout temperature of 150 °C. The original *Kraken* chamber was designed with a differentially-pumped lid, capable of reaching 10^{-9} Torr, so reusing that chamber is desirable. However, motion control in six dimensions is required for precision alignment of the structures to the beam, but in-vacuum motors can't be used due to hydrocarbon outgassing. For example, typical picomotors intended for UHV are often rated for 10^{-9} Torr, but the hydrocarbon outgassing rates make these unsuitable in the presence of rf cavities at SLAC. It is possible that with significant pumping speed, over 1000 L/sec, more acceptable levels can be reached [6]. It should be noted though that this required pumping speed is to offset a single picomotor, where six are required.

Typical 6D manipulators mostly remedy our issue by removing the in-vacuum motors, however, they are intended to support samples on the order of grams, not the hundreds of grams our dielectric structure arrays are expected to weigh. This has lead to developing an alternative motion system, where the linear translation of a platform mounted outside of vacuum is coupled via bellows to the structure array inside the chamber, as seen in Fig. 2.

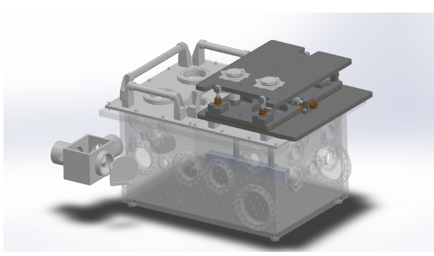

Figure 2: Kraken chamber. Modified lid for motion and THz interferometer shown.

Structure Alignment

As was demonstrated in [4], even a misalignment of 10 μm over a length of 1 cm can have a measurable transverse effect on the electron beam. Therefore, increasing the field magnitudes, as well as the interaction lengths, necessitates precise alignment of the dielectric structures to the beam. In order to achieve the μrad-precision alignment, the beam position and structure ends need to be imaged in the same plane. The first step here is to use an alignment laser.

By first marking the electron beam position using OTR foils located both upstream and downstream of the structure and establishing an e-beam trajectory, an alignment laser can be used to safely align the structure vacuum gap to the beam, while it is not propagating to the dump. This is precise enough to allow for transmission of the electron beam down the length of the structure, without impacting the dielectric material and causing damage. High magnification, long range objectives are then used to image the OTR generated on screens at either end of the structure. This allows for the beam position and vacuum gaps to be imaged in the same plane, such that more precise alignment can be achieved. Finally, the beam is allowed to traverse the structure while BPMs downstream are used to detect any transverse kick experienced due to small misalignments, which are then corrected to minimize the kick.

OTR Foil Melting There is a concern in using OTR foils near a focus for either beam tuning or alignment. Because of the extremely strong fields associated with the focused, high peak current beam, Ohmic heating at the surface of the foil due to the image current is expected to increase the local temperature of the foil to beyond the melting point of the metal (Ti: T_{melt}>1600 °C) [7]. By reducing the density of the beam, the associated Ohmic heating can be reduced to the point where surface melting is no longer a concern. This is evident in Fig. 3a, where round beams are considered, and Fig. 3b, for the case of two different size flat beams [8]. Because the DWA experiment naturally uses flat beams due to the planar-symmetry of the structures, it is believed that foil melting can be avoided. However, there are experiments being developed to investigate the use of different materials and angles for OTR at high fields, as well as an ionizing gas sheet diagnostic for a non-destructive, single-shot, beam size measurement [9].

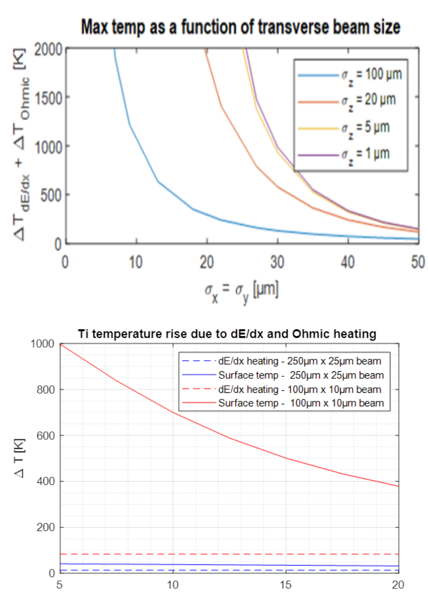

Figure 3: Foil temperature increase for (a) round beams (top) and (b) flat beams (bottom).

CCR Diagnostics

Knowledge of the mode frequencies and amplitudes generated inside the structure can provide important insight into both the material response to the fields and behavior of the beam as it interacts with the dielectric boundary. Dissipation of the CCR pulse within the structure can be attributed to the

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peak field experienced within the dielectric [3], while the presence and relative strength of hybrid electric and magnetic (HEM) modes is evidence of the beam propagating off-axis down the structure [4]. It is important to first efficiently outcouple the modes from within the structure to free space, so that the radiation can be transported to relevant diagnostics.

Recent DWA experiments at FACET have taken advantage of Vlasov antennas, where an asymmetry in the exit boundary causes the modes to be converted and launched at an angle into free space, as shown in Fig. 4. The radiation is then collected by an off-axis parabolic mirror and quasi-optically transported to a Michelson-type, THz interferometer [10]. An advantage to using a Vlasov antenna instead of a traditional impedance-matching transition into, e.g. a horn, is that the radiation and collection optics are removed from the beam axis, where a high amount of background THz radiation exists due to coherent radiation generated by the ultrashort electron beam. Efficient, low noise transport of CCR has been accomplished with cylindrical structures, but we are currently engaged in studies for optimization in planar-symmetric structures [11].

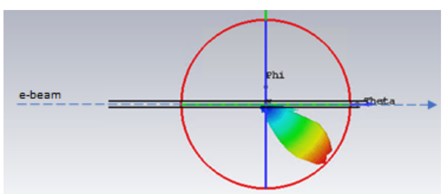

Figure 4: Outcoupling of CCR and emission off-axis.

Electron Beam Diagnostics

Understanding the beam response to its self-driven wakes in the dielectric structure can be accomplished with electron beam diagnostics already in place at FACET-II.

Typical transverse phase space diagnostics for monitoring effects such as beam break up (BBU), centroid kicks, or quadrupole focusing, can be found in the existing downstream BPMs and OTR screens already used for beam transport. The prior experience with these BPMs [4] show beam centroid resolution of approximately 10 µm, providing µrad resolution given the position of the BPMs over 10 meters downstream from the dielectric structures, sufficient for precise measurement of any integrated transverse forces experienced by the beam. OTR screens, far removed from the focus, provide excellent resolution of the beam shape and size, important for determining the presence of BBU and quadrupole wakes.

The energy changes of the electron beam can be determined by the relatively high resolution dump spectrometer. Quantifying longitudinally-correlated changes in energy within the electron bunch due to decelerating (or accelerating) Cherenkov wakefields is very important for determining electric field gradients experienced within the dielectric structure. With a resolution of 5-15 MeV/pixel for the energy spectrometer [2], observation of the effects of longitudinal wakes on the drive and/or the witness the bunch should be easily discernible.

SUMMARY

Designs for dielectric wakefield experiments at FACET-II are underway, with the layout understood. UHV requirements in the area have required modifications to the existing chamber and motion system. Because of the high beam intensity, there must be careful use of OTR foils during alignment due to concerns of surface melting. The natural use of flat beams for planar-symmetric structures alleviates this concern, however, dedicated experiments will also be conducted to explore different materials and incidence angles for OTR imaging, as well as an ionized gas sheet for a beam size diagnostic. Lastly, outcoupling CCR into free space using a Vlasov antenna will reduce background noise and allow for clean measurement of modes generated inside the dielectric structures.

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