RECENT DEVELOPMENTS IN MODELING TIME-RESOLVED SHIELDED-PICKUP MEASUREMENTS OF ELECTRON CLOUD BUILDUP AT CESRTA

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Abstract

The Cornell Electron Storage Ring Test Accelerator program includes investigations into the mitigation of electron cloud buildup using a variety of techniques in custom vacuum chambers. The CESR ring accommodates two such chambers equipped with BPM-style pickup detectors shielded against the direct beam-induced signal. The signals recorded by a digitizing oscilloscope provide time-resolved information on cloud development. Results for diamond-like carbon, amorphous carbon, and titanium-nitride coatings have been obtained and compared to those for an uncoated aluminum chamber. Here we report on extensions to the ECLOUD modeling code which refine its description of a variety of new types of *in situ* vacuum chamber comparisons. Our results highlight the sensitivity afforded by these measurements to the modeled quantum efficiency for producing photoelectrons, their production location and energy distributions, as well as to the secondary yield and production kinematics. We use this sensitivity to draw conclusions comparing the photoelectron and secondary yield properties of the various vacuum chamber coatings, including conditioning effects as a function of synchrotron radiation dose. We find substantial conditioning effects in both the quantum efficiency for producing photoelectrons and in the secondary yield.

INTRODUCTION

The Cornell Electron Storage Ring Test Accelerator (CESRTA) program [1] includes the installation of custom vacuum chambers with retarding-field-analyzer (RFA) ports and shielded-pickup (SPU) detectors [2, 3]. The time-resolved measurements from the SPU detectors provide time structure information on electron cloud (EC) development, in contrast to the time-integrated RFA measurements [4]. The SPU measurements began in early 2010 and include a wide variety of electron and positron bunch spacings and populations for beam energies from 2.1 GeV to 5.3 GeV. This report concentrates on two-bunch studies at 5.3 GeV, where a witness bunch drives the EC formed by the passage of the leading bunch. The EC development results from the photoelectron production, the EC dynamics, and the secondary yield (SEY) properties of the vacuum chamber. The EC buildup simulation code ECLOUD [5] has been extended to model the SPU detector response, and generalized to provide the additional flexibility required to adequately model the SPU signals. This report employs the ECLOUD model to interpret SPU measurements and draw conclusions on the conditioning properties of TiN, amorphous carbon (a-C) [6] and diamond-like (DL) carbon [7] coatings on aluminum vacuum chambers.

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SHIELDED-PICKUP DETECTORS

Three SPU electrodes biased at 50 V collect charge migrating through ports in the top of the vacuum chamber. The centers of the electrodes are 0 and ± 14 mm from the horizontal center of the chamber, with the central electrode offset longitudinally. Each port comprises 169 vertical holes of 0.76 mm diameter arranged in concentric circles up to a diameter of 18 mm. The transparency factor for vertical trajectories is 27%. The approximate 3:1 depth-to-diameter ratio is chosen to shield the detectors from the signal induced directly by the beam. The front-end readout electronics utilize RF amplifiers with $50\,\Omega$ input impedance and a total voltage gain of 100. Digitized oscilloscope traces are recorded with 0.1 ns step size. The SPU measurements discussed in this paper were recorded with the central electrode.

ECLOUD SIMULATION CODE

The ECLOUD EC buildup simulation code consists of a photoelectron generation model, the time-sliced EC dynamics driven by space-charge, beam-kick, and magnetic forces, and a detailed model for secondary electrons produced by EC electrons striking the vacuum chamber wall. The calculation of EC kinematics determines arrival times, momentum vectors and charges of the macroparticles reaching the upper surface of the chamber at the positions of the pickups. A model for the acceptance of the SPU detectors has been added, as has an option to use the output of the synchrotron radiation photon tracking code SYNRAD3D [8] for the photoelectron production azimuthal distribution. Recent modifications to the ECLOUD code have included generalizing the photoelectron model to allow independent quantum efficiencies and energy distributions for photoelectrons produced by direct and reflected photons. Previous work has shown the sensitivity of these studies to photoelectron production parameters and the ability to discriminate between various processes contributing to the secondary yield model [9]. For example, the elastic yield determining the EC lifetime was found to be much smaller than the 75% value found for uncoated aluminum, reaching about 5% for the TiN and a-C coatings [3, 10]. Such an analysis for the DL-carbon-coated vacuum chamber installed in January 2011, has determined a similarly low value for the elastic yield.

IN SITU COMPARISONS OF CUSTOM VACUUM CHAMBERS

One fruitful analysis strategy has proved to be the comparison of SPU signals in chambers which have been swapped into the same location in the CESR ring and studied under identical beam conditions. The two regions in CESR equipped with SPU detectors differ in radiation environment, since the dominant source points are in dipole magnets of differing strengths. At 5.3 GeV, for example, the source dipole field is 3 kG (2 kG) in the west (east) region for a positron beam, resulting in a critical energy of 5.6 keV (3.8 keV). In addition, the situation with regard to reflected radiation is different. By comparing SPU signals recorded at the same place in the ring with the same beam energy, bunch spacing and bunch population, many systematic contributions to the comparisons are avoided, and relatively simple changes to the modeling suffice to quantify the different properties of the vacuum chambers.

Figure 1 shows such a comparison for an a-C-coated chamber in May and December 2010 for two 5.3 GeV 28-ns-spaced bunches each carrying 4.8×10^{10} positrons, corresponding to a bunch current of 3 mA. During the intervening time interval, CESR had operated at high current as an X-ray research facility, with the consequence that synchrotron radiation dose on the chamber had increased by a factor of about 20, from 8.1×10^{23} to 1.8×10^{25} γ/m. Also shown is the ECLOUD model optimized to reproduce the May measurement. Since the signal from the leading bunch arises from photoelectrons produced on the bottom of the vacuum chamber [3, 10], careful tuning of the energy distribution and quantum efficiency (QE) for photoelectrons produced by reflected photons is required to reproduce the size and shape of the signal. The signal from the witness bunch

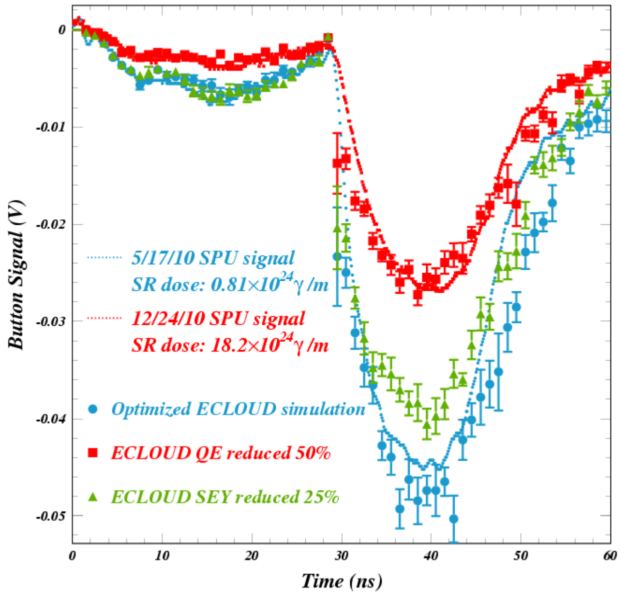

Figure 1: Shielded pickup signals measured in an a-C-coated chamber in May (blue dotted line) and December (red dotted line) of 2010 for two 5.3 GeV, 28-ns-spaced bunches each carrying 4.8×10^{10} positrons. The ECLOUD model optimized for the May data is shown as blue circles, the error bars showing the signal macroparticle statistical uncertainties.

includes additionally the contribution from secondary EC electrons accelerated into the SPU detector by the witness-bunch kick. The modeled witness signal is therefore crucially dependent on the SEY and production kinematics. Since conditioning affects both signals similarly, we can conclude that the change is in the QE rather than in the SEY. The December measurement is reproduced by a 50% decrease in the modeled QE for photoelectron production. A reduction in the SEY of 25% is inconsistent with the observed effect, since the modeled leading bunch signal remains unchanged.

Guided by the above comparisons, we can assess conditioning effects in the TiN- and DL-carbon-coated chambers in similar fashion. Figure 2 compares the SPU signals for two 8×10^{10} e^+ bunches in the TiN-coated chamber in April and June 2011, with accumulated synchrotron radiation doses of 5.9×10^{24} and 1.1×10^{25} γ/m, corresponding to integrated beam currents up to more than 730 amp-hours. Changes in the QE and SEY are less than a few percent. The conditioning effects in the DL-carbon-coated vacuum chamber are quite different, as shown in Fig. 3. Conditioning effects are clearly observed for a radiation dose increasing from 6.6×10^{24} to 1.3×10^{25} γ/m, corresponding to 370 and 730 amp-hours. Remarkably, the size and risetime of the signal from the leading bunch increased, indicating that the QE for photoelectrons produced by reflected photons increased somewhat, and that more photoelectrons were produced at higher kinetic energies. Despite the increase in photoelectron production, the signal from

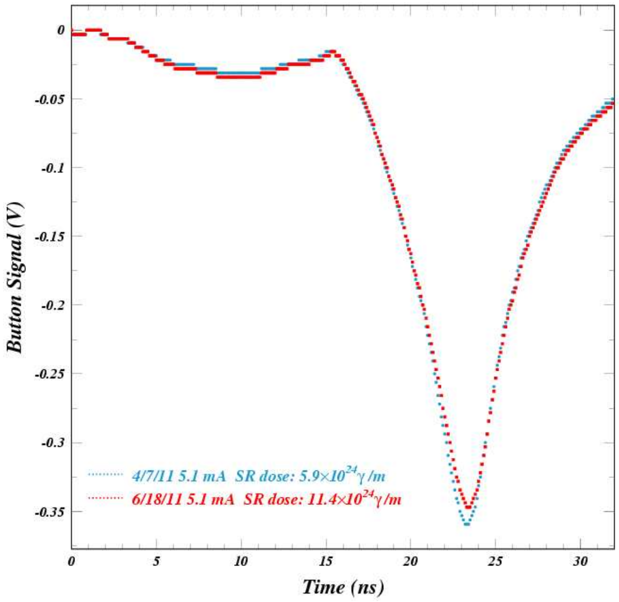

Figure 2: SPU signals showing conditioning effects in the TiN-coated aluminum vacuum chamber

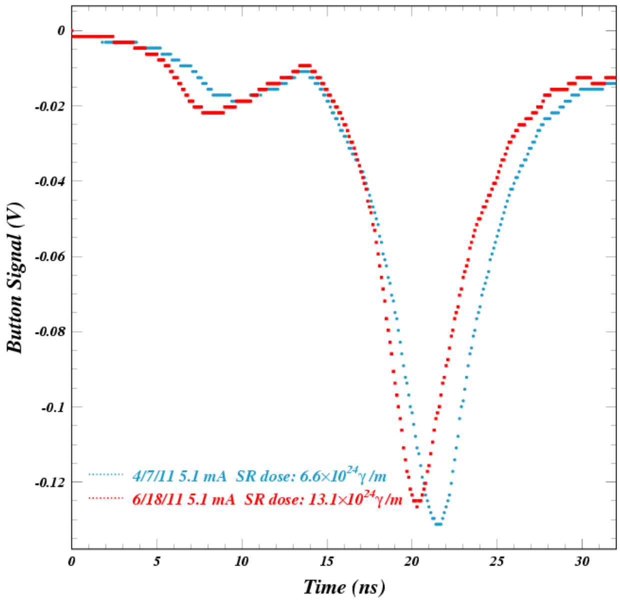

Figure 3: SPU signals showing conditioning effects in the aluminum vacuum chamber coated with DL carbon

the witness bunch decreased, showing that the conditioned SEY is significantly lower. Future modeling efforts will provide quantitative estimates for these changes.

SUMMARY

The time-resolved shielded-pickup measurements of EC buildup at CESRTA provide detailed information on photoelectron production and SEY characteristics of various mitigation techniques such as coatings of TiN, a-C and DL carbon. Shielded-pickup witness bunch measurements for the same beam energy, bunch population and radiation environment have provided direct comparisons for uncoated aluminum and TiN and a-C coatings. Such *in situ* comparisons also provide information on beam conditioning of the coatings. The work presented here concentrates on comparisons of the three coatings for various levels of accumulated synchrotron radiation dose, ranging up to 10^{25} γ/m corresponding to over 730 amp-hours at 5.3 GeV. The conditioning effect for the a-C coating was found to be a factor of two reduction in QE for a factor of two increase in photon dose to 1.8×10^{25} γ/m. The change in SEY was less than a few percent. Based on the modeling result for the a-C-coated chamber, the SPU signals for various states of conditioning were interpreted for the TiN and DL carbon coatings to provide information on conditioning effects. The changes in QE and secondary yield of the TiN coating for doses between 5.9×10^{24} and 1.1×10^{25} γ/m were less than a few percent. In contrast to the reduction in QE observed for a-C, the DL carbon coating exhibited an increase in QE when the radiation dose increased by a factor of two up to 1.3×10^{25} γ/m, while the SEY decreased significantly.

Development work in this modeling effort for the SPU measurements continues. In particular, work to improve the reflectivity model in SYNRAD3D is underway [8, 11]. Further understanding of EC development and mitigation techniques will be obtained from the SPU measurements with electron beams and solenoidal magnetic field scans.

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