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Experimental observations of in situ secondary electron yield reduction in the PEP-II particle accelerator beam line ☆

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ABSTRACT

Beam instability caused by the electron cloud has been observed in positron and proton storage rings and it is expected to be a limiting factor in the performance of the positron damping ring (DR) of future linear colliders (LC) such as ILC and CLIC [1,2]. To test a series of promising possible electron cloud mitigation techniques as surface coatings and grooves, in the Positron low-energy ring (LER) of the PEP-II accelerator, we have installed several test vacuum chambers including (i) a special chamber to monitor the variation in the secondary electron yield of technical surface materials and coatings under the effect of ion, electron and photon conditioning *in situ* in the beam line (ii) chambers with grooves [3] in a straight magnetic-free section and (iii) coated chambers in a dedicated newly installed 4-magnet chicane [4] to study mitigations in a magnetic field region. In this paper, we describe the ongoing R&D effort to mitigate the electron cloud effect for the LC damping ring, focusing on the first experimental area and on results of the reduction in the secondary electron yield due to *in situ* conditioning.

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1. Introduction

In accelerator beam lines with positively charged beams, an electron cloud may be initially generated by photoelectrons or ionization of residual gas and increased by the surface secondary emission process. If an electron cloud forms in the accelerator beam line, it may couple with the circulating beam and cause beam instabilities, tune shift, vacuum pressure rise, ultimately affecting the machine performances. The electron cloud has been observed at many storage rings and it will likely be an issue for future machines aiming at high beam intensity [1].

Over the last few years at SLAC, we have investigated several possible countermeasures to reduce the electron cloud effect in the LC DR and we invested considerable effort on both simulation and experimental programs. During the last years of running of the PEP-II collider, in the Region 12 straight section of the positron beam line just downstream of the arc section, we have installed vacuum chambers consisting of three experimental areas to test electron cloud mitigations both in field-free and magnet regions [3,4]. In this paper, we describe a dedicated chamber installed to monitor the secondary electron emission coefficient or secondary electron yield (SEY or δ) of TiN and TiZrV non-evaporable getter (NEG) coating, copper, stainless steel and aluminum conditioning in the beam line *in situ* under the effect of electrons, photons and ions impacting the surface. We have instrumented the chamber with a retarding field analyzer (RFA) [5–8] electron detector to measure the intensity of the electron cloud current and the electron energy distribution. The RFA is described in a separate paragraph below. The goal of the experiment was to measure the change in the surface SEY and surface structure composition of sample materials directly exposed to dynamical beam effects and compare the results to the typical reduction in the SEY observed in laboratory set-ups when a material is irradiated with electron beams. Other suppression techniques such as clearing electrodes, grooves and novel coatings are also being tested and optimized at several other laboratories including CERN, INFN, in CesrTA at Cornell University and KEK-B at KEK.

2. Secondary electron yield (SEY)

Parameters determining the cloud formation are the secondary electron yield, secondary electrons emitted per incident electron and the secondary electron energy spectrum. Typically, the peak value (δ_{max}) of the SEY, at normal incidence, is δ_{max} ~1.5–2.2 for

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an "as-received" technical vacuum chamber material such as copper or stainless steel but ranges higher for aluminum, at $\delta_{max} \geq 2.3$ and can be over 3. The laboratory experimental set-up used at SLAC to measure the surface SEY and perform surface X-ray photon spectroscopy is described in detail in Refs. [9,10]. Note that in the apparatus, the SEY is measured with the use of an electron beam incoming at a 23° angle with respect to the sample surface normal. The SEY of technical surfaces material for accelerator vacuum chamber has been measured in the past at CERN [11,12], at KEK [13–15] SLAC [9,16,17] and at other laboratories [18].

2.1. SEY threshold and requirements

Previous simulations show that in a 6 km ILC DR an electron cloud is expected to develop with high densities for peak SEY values above 1.2.

In the ILC DR, a threshold for beam instability [2] will be reached for a cloud density of 1.4×10^{11} e/m^3. The most robust solution to mitigate the electron cloud is to ensure that the vacuum chamber wall has low secondary emission yield.

The impact of particles on a metallic surface reduces the surface SEY to low values [9–17]. This effect is known as conditioning. Typically, conditioning is provided by electrons from the electron cloud or photons and ions generated by the circulating beam. Even following the surface conditioning, electron clouds are still observed at several existing storage rings as CesrTA, Daphne and the B-factory KEKB. The efficiency of the conditioning may depend on several factors including the electron cloud current or radiation impinging the surface, the vacuum chamber material as well as the residual vacuum pressure. A competing effect to conditioning is the surface recontamination by the residual gas when the circulating beam is not present. Recontamination may increase the SEY over time. Thus, it is important to measure the effect of conditioning of samples exposed directly to an accelerator beam line as well as the recontamination effect.

3. Dedicated vacuum chamber experimental set-up to monitor the in situ reduction in the secondary electron yield

To closely monitor the evolution of the SEY in an accelerator environment, we have built and installed a dedicated stainless steel in the PEP-II beam line. The chamber is instrumented with manipulators and transferring systems to (i) expose the samples to the beam environment then (ii) transfer the samples to a laboratory set-up [9,10] and (iii) measure their surface characteristics. It is crucial to maintain the samples in ultra-high vacuum (UHV) during transferring. This is achieved by means of specially designed load-lock manipulators provided with valves to insert samples in their working position and to retract them in a load-lock UHV chamber for transportation. Fig. 1 shows the chamber installation in the PEP-II LER. The load-lock manipulator system used to position the sample into the beam line is shown in Fig. 2.

The design of the vacuum chamber allowed the insertion of two samples at a time and at two different angles: (i) directly exposed to the fan of synchrotron radiation and we will refer to as 0° angle or (ii) at an angle 45° from the middle plane out of the synchrotron radiation fan.

During beam operation, the samples are left in the beam line for a period of several weeks until access to the machine tunnel is possible.

In particular during the installation in the beam line, the samples were positioned in contact with the chamber wall and facing the internal side of the beam line, as shown in Fig. 3, center.

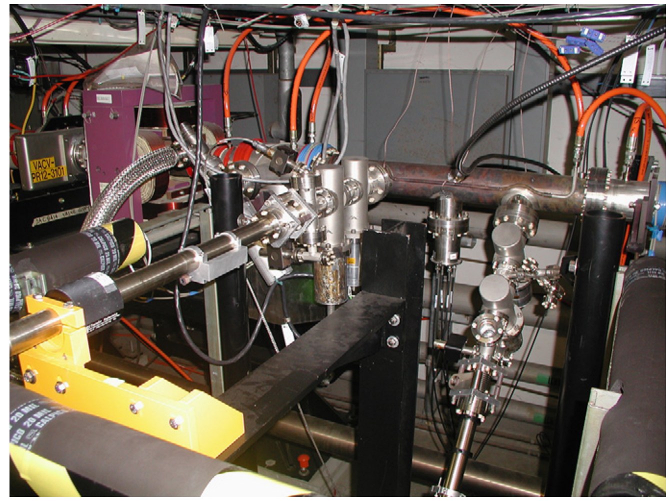

Fig. 1. Installation of the SEY test chamber in the PEP-II LER beam line, the chamber and the two sample transferring load-lock manipulator systems are visible at 0° and 45° positions. The electron detector and energy analyzer are also visible on the chamber located between the two manipulators.

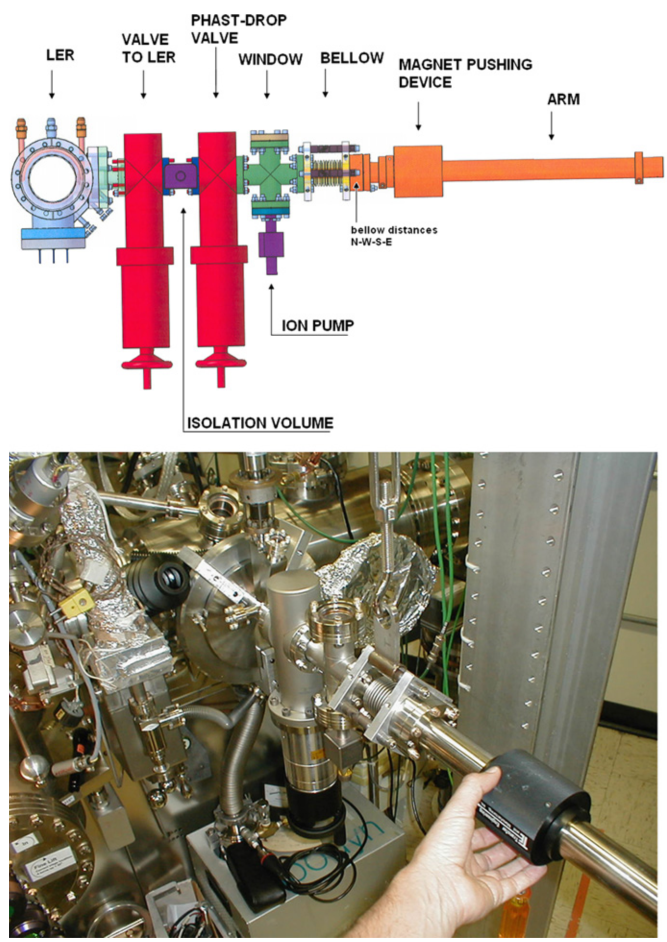

Fig. 2. Layout (up) of the load-lock system for positioning and transportation of samples under high vacuum. Load-lock system (down) attached to the surface analysis chamber for transferring samples under vacuum.

The positioning of the samples in the PEP-II beam line had to be done precisely for two reasons: (i) any misalignment of the sample would prevent the synchrotron radiation from the bend to hit its surface due to masking issue (ii) to avoid the presence of