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SOFT X- RAY REFLECTIVITY AND PHOTOELECTRON YIELD OF TECHNICAL MATERIALS: EXPERIMENTAL INPUT FOR INSTABILITY SIMULATIONS IN HIGH INTENSITY ACCELERATORS*

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Abstract

High luminosity particle accelerators can suffer from serious performance drop or limitations due to interaction of the synchrotron radiation produced by the accelerator itself with the accelerator walls. Such interaction may produce a number of photoelectrons, that can either seed electron cloud related instabilities and/or interact anyway with the beam itself, potentially causing its deterioration. To correctly take these effects into account simulation codes depends on the realistic knowledge of Reflectivity and Photoelectron Yield of technical materials. In this work we present a mature technique to study such relevant experimental data for some of the mostly used technical surfaces in accelerators under realistic geometrical conditions. Some preliminary results will be presented and discussed.

INTRODUCTION

High-energy collider machines [1] and accelerator-based Synchrotron Radiation (SR) light sources with positive beams [2] suffer from serious performance drop or limitations due to the interaction of the SR with the accelerator walls, by which photoelectrons are created. To understand and control such detrimental effects it is essential to study in great detail the behavior of the chosen accelerator material under SR illumination. Then, the knowledge of photo yield (PY) and X-ray reflectivity (R) from technical materials is of utmost importance for optimizing ultimate performance at accelerators [1, 3–5]. In an arc of an accelerator the circulating beam, being deflected, produces SR with a given energy spectrum and beam divergence. Such SR illuminates the accelerator walls at a very grazing incidence angle (in the case of LHC of less than 2°). Most of the photon beam will be scattered/reflected away, some will create photoelectrons which, in a field free region, may interact with the accelerated beam. In the presence of the dipole magnetic field perpendicular to the orbit plane, the electrons photoemitted in the orbit plane, being affected by the magnetic field, are constrained to move along the field lines, thus they will not be able to cross the vacuum chamber and gain energy from the beam. On the other hand, the scattered photon beam will soon illuminate top and bottom walls, emitting photoelectrons perpendicular to the orbit plane (hence parallel to the magnetic field) that will only spiral along the field lines, free to interact with the accelerated (positive) particle beam. Such photoelectrons are capable to seed e-cloud related effects in accelerators efficiently participating to secondary electron production and, eventually, to multipacting. E-cloud related resonant phenomena are not the only detrimental effects occurring in accelerators and originated by the background electrons. Ohmi and Zimmerman when analyzing some of the beam instabilities observed at KEKB, introduced the concept of 'single beam instability threshold' and suggest that the mere existence of a certain electron density in the accelerator (for the SuperKEKB case around $7\text{x}10^{11}$ e^{-}/m^{-3}) is able to detrimentally affect beam quality [6]. Hence, even in the absence of resonant phenomena, such electron density has to be carefully simulated, controlled and careful material choice is needed for its mitigation. These simple reasoning show how important it is to determine the photon reflectivity of accelerator walls and its photo yield experimentally. Preliminary work done [1,3–5,7] was performed under geometrical conditions which were far from the very grazing ones in accelerators, and the results are not directly applicable to real situations. This paper presents some experimental tools developed to analyze properties of optical elements designed for Synchrotron Radiation, and adapt them to the study of technical surfaces used in accelerators.

EXPERIMENTAL

To perform such PY and R measurements at the very grazing geometries typically occurring in real machines, one of the best option available was the use of the "soft x-ray optics beamline for at-wavelength metrology at BESSY-II" [3] and its Reflectometry experimental station [8]. Reflectometry or at-wavelength metrology is a powerful and most essential characterization tool for the development and characterization of optical elements [9]. With this method the reflectivity of a material (mirrors, crystals), the diffraction efficiency of gratings or the transmission of thin films is investigated at the design wavelength for the optical element. Since the optical constants of the coating materials involved are dependent on wavelength, information on reflectivity at a certain wavelength can be obtained only by this method and cannot be deduced from any other diagnostics technique. A dedicated 'optic' beamline is successfully in operation at the Berlin BESSY-II storage ring. It collimates vertically and focusses horizontally the bending magnet radiation by a toroidal mirror, disperses it by a plane mirror/plane grating monochromator (PGM) and refocusses the monochromatic light by a cylindrical mirror

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onto the exit slit with low divergence. Behind the exit slit a three-axis UHV-reflectometer chamber is attached permanently to the beamline as described elsewhere [3, 8]. By use of interchangeable gratings (1228, 366 l/mm) the available energy range is between 10 eV to 2 keV. Optical or other type of filters are present and can be used to actively "filter" the bending magnet radiation. An interesting option is the possibility to operate the beamline in zero order, i.e. with a white light (WL) spectrum impinging on the sample. This can be obtained by setting the mirror-grating system to work when the grating will just act as a mirror. Also, as shown in fig. 1 the high-energy cut-off can be selected by the incidence angle on the mirror/grating combination. With this option quantitative radiation damage studies can be done, since the incident beam intensity and its spectral dependence is known. The figure 1 shows the power spectrum available at the optics beamline, calculated for various grating/mirror incidence angles and with or without the insertion of some available absorption foils. Such various WL spectra are then compared with the one emitted from the BESSY-II bending magnet. The use of the beam line as a calculable [10] source of WL with different power spectrum depending on the filters in use and on the angle of incidence of the grating-mirror system, (larger angles corresponds to a spectral density with reduced number of high energy photons), has been used for the first time in this context and not only allows us to measure effective PY for differently weighted WL spectrum, but also to check for irradiation effects on the studied technical systems. Electron irradiation effects and consequent surface modifications are well known to occur [1, 11, 12]. It has systematically been observed that when a surface is exposed to an electron beam, its Secondary Electron Yield (SEY) decreases being a well known process, called "Scrubbing", adopted to mitigate any detrimental effects of e^- cloud related instabilities, for instance, in LHC [1]. Since, also photon irradiation has been observed to scrub [1, 4] the availability of this WL mode allows us to study in detail photon scrubbing and is potential effect on PY and (much more marginally) on R.

Standard measurement schemes with a reflectometer setup are shown in Fig. 2. Reflectivity is measured typically with a monochromatic beam as function of the incidence angle θ, at a fixed photon energy hν, or as a function of the photon energy at a fixed incidence angle. Absolute values for R are determined by a sample-in sample-out technique by measuring the incident intensity Io with the detector placed in the direct beam position before and after measuring the reflected intensity I (to check stability). The absolute value of reflectivity is then given by R = I/ I_0. Scattered light is measured at fixed energy and incidence angle while varying only the detector angle θ_{det} around the specular beam. With these techniques information on surface roughness and interface quality and its chemical composition, (multi-)layer thickness, and, of course, optical constants can be addressed [13]. As a photon counter we use a calibrated light detector (GaAsP-photodiode from Hamamatzu) with a known efficiency as function of photon energy [14]. It allows us to easily convert its readings into the number of incident photons/sec, after normalization to the ring current. The used set-up has been designed to measure long dimension gratings and optical elements, and can therefore host samples as long as 110 mm. This, and the high quality and low vertical dimension (about 300 μm) of the impinging collimated beam, allowed us to measure R and PY with θ up to a few degrees.

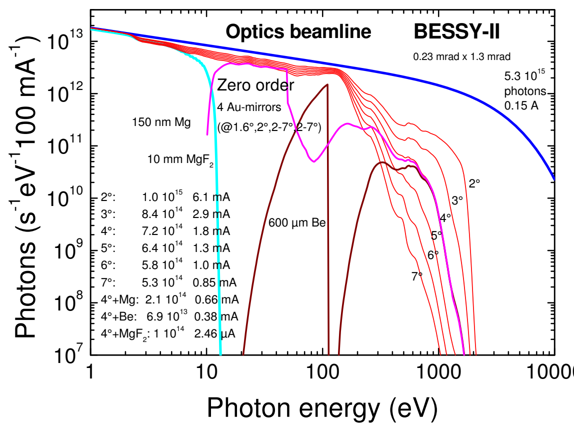

Figure 1: White light power spectrum (and its integral value on the table on the left side) at the sample position in the reflectometer, when the optics beamline is operated in zero order with different filters and at different grating/mirror angle. Note that the incident spectrum (blue curve) corresponds to a total power of 1.6 Watt which can be decreased and controlled by varying the beam line settings. Ampere data in the table on the left refer to expected photocurrents on the photodiode. Simulations with REFLEC [10].

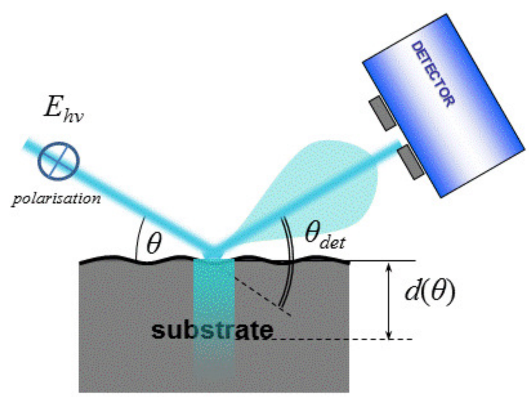

Figure 2: Geometry in reflectometry experiments.

RESULTS

To show the potentiality of the technique and of the available set-up, we present here some selected results without aiming to a comprehensive description of the whole data set

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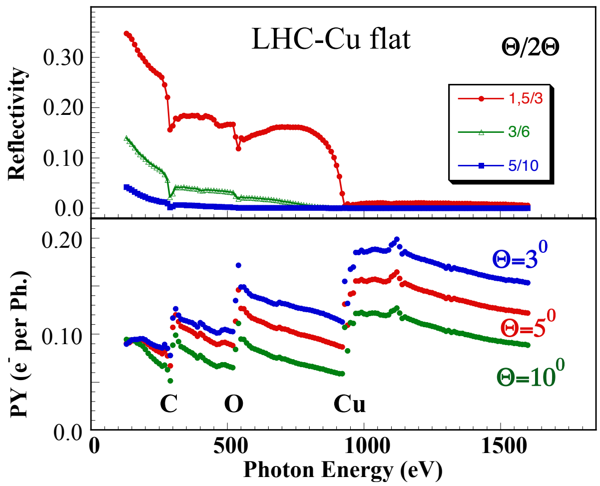

Figure 3: PY (bottom panel) at different incidence angles and R for various incidence angles θ and emission angle 2 θ for an LHC-Cu sample representative of the flat part of the beam screen, as function of photon energy.

collected. This will be done in forthcoming publications. The data shown here are on Cu technical samples representative of LHC inner beam screen [1, 3]. The samples, all about 100 mm long and 20 mm wide, were isolated from the sample holder by a kapton foil to allow the contemporary acquisition of reflectivity (as measured from the photodiode) and photo yield (as derived from the current emitted by the sample during irradiation with a well defined photon flux). In fig. 3, the reflectivity (top panel) and PY (bottom panel) of such a LHC Cu sample are shown as function of the photon energy for selected incidence angles. Resonance structures due to absorption of the Carbon and Oxygen contaminated surface layers (C, O k-edges at 284.4 eV and 543.1 eV) and of Cu (Cu L3-edge at 932.7 eV) give rise to abrupt changes of R and PY. As a general trend we observe higher reflectivity at lower grazing angle incidence and at low photon energy and an increase of the photon yield for increasing photon energy (which is expected considering that more energetic photons have more energy to donate to the low energy electrons which mainly contribute to the total PY) [4]. From fig. 3, we also note that, for all photon energies, the PY increases at decreasing incident angles. This can be attributed to the reduced photon penetration at very grazing angles, so that, since more surface is irradiated at lower incidence angles, more electrons are produced by the photoelectric effect closer to the surface which are more ready to escape into vacuum.

CONCLUSION

We have shown that the optical behaviour of a material is strongly dependent on its surface properties and surface quality. Reflectometry can then be fruitfully performed and the photon energy and the incidence angle dependance can give insight into the properties of the substrate and its contamination, while the amount of specular radiation and the scattered light distribution give information on the optical quality of the surface. At the BESSY-II optics beamline one can measure photon reflectivity and photo yield (electrons/photon) data for different samples of interest for accelerator tubes of high energy machines both using standard monochromatic photon beam as well as differently weighted WL spectra.

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