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VUV synchrotron radiation studies of candidate LHC vacuum chamber materials

R. Cimino[a], V. Baglin[b], I.R. Collins[b,*]

[a] *INFN, T , I a*
[b] *CERN, LHC D v , 1211 G va 23, S a*

Abstract

For the design of future accelerators, in particular, the beam vacuum of the large hadron collider (LHC), a 27 km circumference proton collider to be built at CERN, 'white light' (WL) and monochromatic VUV synchrotron radiation (SR) have been used to measure, both qualitatively and quantitatively, electron emission from candidate vacuum chamber materials. Emphasis has been placed on measuring the photoelectron yields (PY) and the energy distribution of the emitted electrons. These parameters are relevant to gas desorption, the LHC cryogenic cooling capacities and the possible creation of an electron cloud which may cause beam instabilities. Proposed materials, prepared on an industrial scale, such as 50 μm OFE Cu co-laminated onto a high Mn-content stainless steel, exhibit significant modifications when exposed to the WL spectrum from the BESSY TGM7 beamline. Surface cleaning treatments, such as sample annealing and ion bombardment, induce substantial changes to the electron emission which therefore indicate that such surfaces would not be constant, in terms of electron emission, during machine operation. Surfaces which are considered to be constant electron emitters, such as annealed TiZr alloys and commercial non-evaporable getters, were also investigated. These results and their implications for the choice of the material to be used for the LHC are discussed.

1. Introduction

The large hadron collider (LHC) will provide two counter circulating beams of protons with colliding energies of nominally 14 TeV in the center of mass, requiring superconducting bending magnets operating in superfluid helium at 1.9 K. In order to reduce the cryogenic power consumption at 1.9 K, the heat load induced by the beam will be intercepted on a beam screen, which operates at 5–20 K. The emitted synchrotron radiation (SR), with a critical energy of 44.1 eV, is a major consideration for the design of the vacuum system. Its radiated power induces a heat load of 0.2 W/m per beam and may: (i) stimulate gas desorption of weakly and tightly bound gases from the walls of the vacuum system either directly by photons or mediated by electrons [1, 2], (ii) create photoelectrons which can be accelerated towards the opposite wall by the positive space charge of the bunched beam with an average energy of 380 eV [3] leading to additional gas desorption and heat loads on the cryogenic system, and (iii) create secondary electrons which may contribute to electron multipacting [2]. This latter phenomenon is a resonant effect where a cloud of secondary electrons oscillate, in phase with the bunched beam, between opposite walls of the vacuum chamber. If the maximum of the secondary electron yield, δ, exceeds a critical value, the cloud may increase exponentially, leading to an unmanageable heat load and ultimately to beam loss.

Calculations based on simulations are in progress to estimate the cryogenic heat load due to photoelectrons and secondary electrons and, in doing so, will provide information on the sensitivity of the heat loads and electron cloud to the input parameters [3, 4]. It has been predicted that only the electrons emitted with a kinetic energy in the range between 1 and 6 eV play a role in multipacting. Realistic input values for the photoelectron yields (PY), the energy and angular distribution of the emitted electrons, the reflectivity, etc. from real materials, i.e. fabricated on the industrial scale, are required for design optimisation.

SR photoemission is an ideal tool to provide this information. Preliminary experiments have been per-

* Corresponding author. Tel.: 0041 22 767 2259; fax: 0041 22 767 5100; e-mail: ian.collins@cern.ch.

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formed giving qualitative information [5]. Quantitative information on the PY are presented together with detailed energy distributions of the photoemitted electrons. Studies addressing the important issues of changes in the electron emission due to SR and/or sample annealing were performed.

2. Experimental

The experiments were performed on the TGM7 beamline at the BESSY synchrotron light source [6]. Room temperature angle-resolved photoemission experiments, using photon energies between 20 and 100 eV, spanning the 44.1 eV critical energy SR spectrum of the LHC, were performed for a number of candidate vacuum chamber materials. The samples were installed via a fast load-lock into a UHV (10^{-10} Torr range) μ-metal experimental chamber equipped with a VG ARUPS 500 angle resolving electron spectrometer. All spectra presented here were recorded at 45° incidence and normal emission.

Both 'white light' (WL), obtained using the zero order of the monochromator, and monochromatic light were used as the excitation source. The calculated WL spectrum is shown in Fig. 1 together with the spectrum expected from the LHC bending magnet for comparison. The TGM7 WL spectrum, having a cut-off mainly determined by the poor reflectivity of the optical elements at energies higher than 150 eV, can be regarded as a distorted replica of the LHC bending magnet spectrum with a photon flux (photons/s/mm^2) roughly 1000 times higher than that in the LHC.

Selected results from the studied samples, namely evaporated Au, 50 μm OFE Cu co-laminated onto high-Mn content stainless steel, hereafter called Cu co-laminated, air-baked Cu, Al, TiN, TiZr, electropolished Cu, Pd, SAES St 707™ non-evaporable getter, together with their surface conditionings, such as sample annealing, ion bombardment or WL cleaning, are presented.

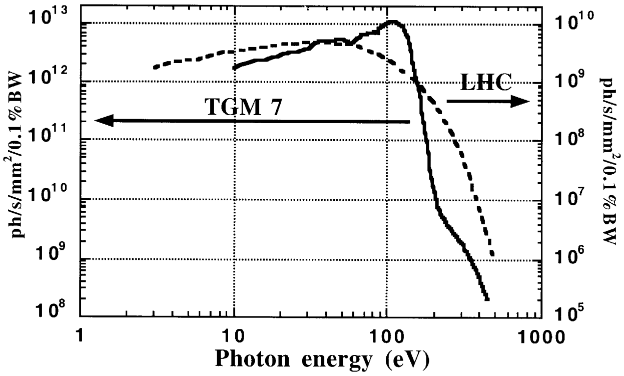

Fig. 1. Comparison between the LHC bending magnet photon flux with that obtained with the WL spectrum of TGM7 beamline in BESSY.

3. Results

The WL spectrum was used to measure the PY per adsorbed photon at 45° incidence from the various samples. The PY was measured from the sample drain current and the calibrated photon flux [7]. These PY are shown in the legends of Fig. 2 together with the corresponding energy distribution curves (EDC). As can be seen from Fig. 2 there does not exist a general form for the EDC, rather it is material dependant. In the case of

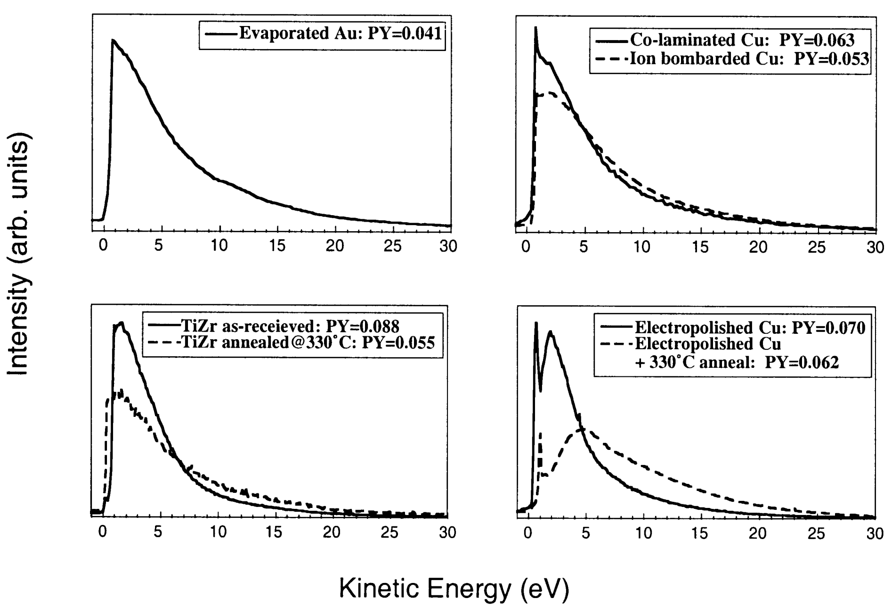

Fig. 2. Selected WL excited EDC. The kinetic energy is referenced to the vacuum level of the respective sample. The corresponding PY are shown in the legends.

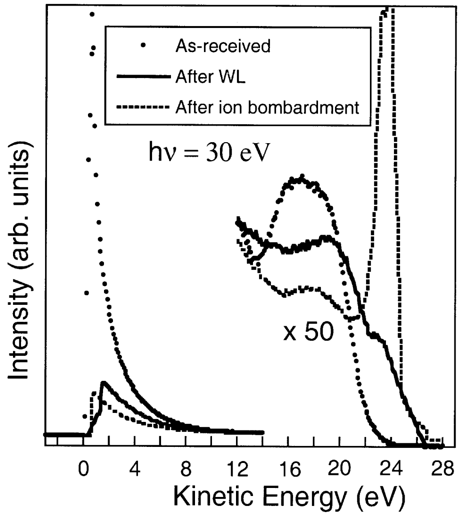

Fig. 3. Photoemission spectra taken with 30 eV photon: (a) as-received Cu co-laminated; (b) Cu co-laminated after WL exposure ($>10^{16}$ photons/mm^2); and (c) Cu co-laminated after ion bombardment (10^5 Ar ions/mm^2).

the Cu co-laminated sample the EDC may be simply modelled with a half Lorentzian of width, σ, of 3.7 eV.

The materials studied exhibit PY in the range (0.035–0.835) $\pm$ 0.010. However, significant changes in the electron emission due to intense SR occurred. Monochromatic SR, with its reduced photon flux by a factor of about 1000 with respect to the WL spectrum provides information on the electron emission before exposure to intense WL. Monochromatic SR was therefore used as a tool to monitor and follow changes induced by WL irradiation or sample conditioning. Fig. 3 shows the effect of WL irradiation and ion bombardment of the Cu co-laminated sample. WL exposure modifies drastically the intensity of secondary electron tail. The changes in the valence band are considerably less marked. On the other hand, ion bombardment appears to be most efficient in cleaning, as determined from the appearance of a Fermi edge at 26.7 eV and Cu 3d derived states at about 3 eV below the Fermi level.

In addition, a 'low photon dose' WL spectrum, i.e. a WL spectrum one would expect before any strong cleaning by SR occurred, can be reconstructed from the summation of the monochromatic spectra, however it may be inaccurate due to the limited number of monochromated spectra from which it is generated. It can been seen in Fig. 4 that differences exist between the WL spectrum reconstructed from the summation of the monochromatic spectra and that measured with WL, in the case of activation of the TiZr sample at 330 $\pm$ 30°C for 4 h at $\leqslant 10^{-8}$ Torr. Here the spectra have been normalized to their high energy tails. The estimated dose during the acquisition of the WL spectrum is estimated to be greater than 10^{16} photons/mm^2, corresponding to

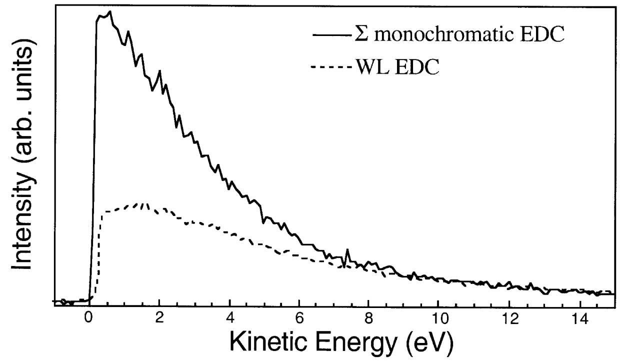

Fig. 4. Reconstruction, by summation of monochromated EDC, of the 'low photon dose' WL spectrum from the activated TiZr sample in comparison with the WL EDC corresponding to a 'high photon dose' WL spectrum.

about 5 h of LHC operation at nominal machine parameters. The intensity and lineshape changes may be attributed to additional surface cleaning due to high photon dose WL. In the case of the as-received TiZr sample (not shown) dramatic differences are observed. The reconstructed WL spectrum is dominated by a narrow and intense peak (<1 eV FWHM) at low kinetic energies which is almost totally absent in the measured WL spectrum. In both these examples significantly less electron emission occurs below about 6 eV kinetic energy after WL exposure.

4. Conclusions

The PY of various candidate vacuum chamber materials have been studied with room-temperature angle-resolved photoemission using the TGM7 WL as the excitation probe.

Significant beam cleaning occurs during WL exposure and the measured PY should therefore be regarded as high photon dose values. Monochromatic SR was used both as a tool to follow changes in the electron emission and to reconstruct a 'low photon dose' WL spectrum.

In general, the electron emission of the as-received surfaces are subject to significant modifications either when exposed to the WL spectrum or due to surface conditioning. These changes indicate that such surfaces would not be constant, in terms of electron emission, during machine operation.

Surfaces which are considered to be constant electron emitters, such as annealed TiZr alloys and commercial non-evaporable getters, were investigated. These surfaces exhibited modifications, although significantly less pronounced than as-received surfaces.

Ultimately, the LHC vacuum chamber material must exhibit an acceptable electron emission during machine operation.

Additional studies, similar to those presented here, on other materials are required to optimise the surface properties of the LHC vacuum chamber material.

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