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The effect of gas ion bombardment on the secondary electron yield of TiN, TiCN and TiZrV coatings for suppressing collective electron effects in storage rings

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Abstract

In many accelerator storage rings running positively charged beams, multipactoring due to secondary electron emission (SEE) in the beam pipe will give rise to an electron cloud which can cause beam blow-up or loss of the circulating beam. A preventative measure that suppresses electron cloud formation is to ensure that the vacuum wall has a low secondary emission yield (SEY). The SEY of thin films of TiN, sputter deposited non-evaporable getters and a novel TiCN alloy were measured under a variety of conditions, including the effect of re-contamination from residual gas.

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1. Introduction

The electron cloud effect (ECE) may cause beam instabilities in accelerator structures with intense positively charged bunched beams, and it is expected to be an issue for the positron Damping Ring (DR) of the International Linear Collider (ILC). Reduction of the secondary electron yield (SEY) of the beam pipe inner wall is effective in controlling cloud formation. We have previously measured the secondary electron emission (SEE) from a number of technical surfaces and coatings used in ring construction [1], including uncoated aluminum alloys [2]. Here, we present SEY (δ) measurements, after various treatments including ion bombardment, on TiCN, TiN and two differently deposited non-evaporable getter (NEG) TiZrV films on aluminum substrates. All samples were produced at Lawrence Berkeley National Laboratory (LBNL).

2. Experiment description and methodology

The system used to measure the SEY is described in detail in Ref. [2]. Measuring techniques included X-ray photoelectron spectroscopy (XPS) and residual gas analysis (RGA). Sample processing facilities were heating and ion bombardment.

The SEY (δ) definition is determined from Eq. (1). In practice, Eq. (2) is used because it contains parameters directly measured in the retarding target potential experiment:

$$\delta = \frac{\text{Number of electrons leaving the surface}}{\text{Number of incident electrons}} \qquad (1)$$

$$\delta = 1 - \frac{I_\mathrm{T}}{I_\mathrm{P}}. \qquad (2)$$

I_P is the primary current (the current leaving the electron gun and impinging on the surface of the sample) and I_T is the total current measured on the sample ($I_\mathrm{T} = I_\mathrm{P} - I_\mathrm{SE}$). I_SE is the secondary electron current leaving the target.

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The SEY is measured, at normal incidence, by using a gun capable of delivering an electron beam of 0–3 keV, working at a set current of 2 nA and having a 0.4 mm^2 spot size on the target. The measurement of the SEY is done while biasing the sample to -20 V. This retarding field repels most secondaries from adjacent parts of the system that are excited by the elastically reflected primary beam. The primary beam current as a function of the primary beam energy is measured and recorded each time before an SEY measurement, by biasing the target to $+150$ V, and with the same step in energy for the electron beam. A fresh current lookup table is created with each measurement. The SEY measurement, over the 0–3 keV range, takes around 5 min.

In order to study the effect of ion bombardment on the SEY, we used a micro-focussing scanning gas ion gun (Leybold IQE 12/38). The gun has two differentially pumped beam formation stages that reduce the sample system pressure compared to that inside the gun's electron-impact ionization chamber (into which the gas is directly injected). Ion energies from 250 to 5000 eV are possible. Five nines-pure hydrogen or nitrogen gases were used in this particular set of experiments. In an accelerator, the ions produced by beam ionization of residual gases have a spread in energy. In one of the ILC DR designs (6 km), the impact energy of the ions is around 140 eV [3]. Our ion gun is not designed to work below 250 eV; therefore, we have set the energy of the test ions to be 250 eV. The modest increase in ion energy will raise the nitrogen ion (momentum) and hydrogen ion (chemical) sputter yields from 0.1 to 0.15, for removing hydrocarbon contamination [4]. The outermost layers of the aluminum are composed of hydrocarbons and water on top of native oxide. All three materials raise the secondary yield [5]. The nitrogen momentum sputter yield is lower for the native aluminum oxide than for the loosely bound hydrocarbons and water; however, metal oxides are removable by the hydrogen chemical sputtering [6]. In our setup, the conditioning ions, hydrogen and nitrogen, are impacting onto the sample surface at an angle of 35° from the sample normal, with an ion density of $\sim 10^{10}\,cm^{-2}\,s^{-1}$. [N.B. This rate is 8 nA on 1 in. (2.54 cm) diameter sample.] The expected species content of the beam, for an electron-impact source using H_2 or N_2, is 50% charged (mostly single-charge diatomic) and 50% charge-exchanged energetic neutrals [7]. However, the beams will be referred to as "H_2^+" or "N_2^+".

The films, deposited on 6063 aluminum alloy substrates, are listed in Table 1, along with their treatment history. The TiZrV NEG films were produced either from an arc-melted cathode (A) or from a sintered powder cathode (B). The two different TiZrV deposition cathodes were used in order to discover which produced dense adherent films of proper stoichiometry. Both did and the results were consistent with the SAES films. The composition in NEG films prepared by CERN and SAES Getters® was studied earlier [1]. The composition, in at%, of the coatings TiCN, NEG A&B and TiN is listed in Table 2.

3. Results, TiCN

This ternary film was chosen to be a possible alternative to TiN or NEG coatings. It is known that as-deposited titanium nitride and carbide have a δ_{max} around or below 1 [9]; however, after deposition and air exposure, the SEY degrades to such extent that δ_{max} is above 1.5 [1,9,10]. We wanted to test whether a ternary alloy would have different properties when exposed to air than had the pure nitride and carbide. A film was magnetron sputter-deposited from a TiCN cathode in Ar/N_2 atmosphere onto aluminum sheet. The atomic film composition, measured by energy-dispersive X-ray spectrometry, is presented in Table 2. The results are presented in Fig. 1.

The SEY curve and δ_{max} of TiCN, air-exposed ("as-received"), and after heating are similar to that of TiN [11]. Short-term re-contamination by residual gas, at a pressure of 5×10^{-10} Torr, had a negligible effect on the SEY.

With respect to ion bombardment behavior, it is known that a glow discharge (argon or nitrogen) (ArGD or NGD) bombardment on technical surfaces will sputter-clean the surface to such an extent that its SEY will be very close from the atomically clean surface [12,13]. We can expect that such plasma will also work on thin films. However, a

Table 2
Atomic composition (at%) of the different coatings

	Ti	Zr	V	C	N
TiCN	12	–	–	55	33
TiZrV-A	29	25	46	–	–
TiZrV-B	33	25	42	–	–
TiN	51	–	–	–	49

Table 1
Measurement history of air-exposed thin film samples

Film	Measured as-received	Activated or baked	Vacuum re-contamination	Ion conditioning
TiCN/Al	Y	170 °C—2 h	Y	H_2 250 eV
NEG A	Y	215 °C—1.75 h	Y	N_2 250 eV
NEG B	Y	212 °C—2 h	Y	–
TiN/Al	Y	–	–	N_2 250 eV