Summary Session III:
Secondary Emission, Surface Effects and Coatings

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Abstract
Summary of the talks on secondary electron emission, surface effects and coatings given at the 8th ICFA Beam Dynamics Mini-Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings, Santa Fe, NM, February 16-18, 2000.

1 Talks

- R. Kirby: "Secondary Electron Emission Yields from Accelerator Materials"
- R. Rosenberg: "Surface Conditioning of Accelerator Components: Secondary Electron Yield and Chemical Analysis"
- N. Hilleret: "Study of Surface Characteristics Determining the Electron Cloud Growth"
- S.Y. Zhang: "Beam Scraping Effect in the SE Production"
- Ka-Ngo Leung: "TiN Coatings by RF Enhanced Sputtering"

2 Secondary emission and surface effects

Photo-emission by synchrotron radiation and secondary emission of electrons is an important parameter determining the build up of the electron cloud. This session has therefore been devoted to a review of the secondary electron emission effect from technical surfaces which are used as beam pipe materials and for the construction of accelerator components. The basic phenomenon of secondary electron emission from pure metals has been studied nearly a century ago and is well documented in the literature. More recently for the development of accelerating structures and particularly for high field super conducting cavities, the importance of secondary electron emission as a source of electron multipacting has become the topic of extensive studies[1]. An incident electron will penetrate into the surface and undergo multiple scattering. Secondary electrons which leave the surface have a wide energy spectrum: elastically reflected electrons with the energy of the primary incident electrons, 'true' secondary electrons, which have energies between 0 and about 40 eV and re-diffused primaries which have a wide distribution of energies between the elastic peak and the true secondaries. For 300 eV primaries, true secondary electrons represent about 60%, re-diffused primaries about 35% and elastically reflected primaries represent some 5% of the total number. Typically the secondary electron yield as a function of the primary incident electron energy first increases with energy, reaches a maximum at a few hundred electron volts and from then onwards, the yield curve slowly decreases towards high energies. For the multipacting studies it is

convenient to parameterise the yield curve by its maximum value, $\delta_{\max}$, and by the energy at which the maximum occurs, $E_{\max}$ [2].
For the case of perpendicular incidence the yield can be described by the expression $\delta(x) = \delta_{\max}\, 1.11 x^{-0.35}\left(1 - e^{-2.3 x^{1.35}}\right)$ where x is the normalised electron energy $x = E_{inc}/E_{\max}$. For the process of multipacting, only the part of the yield curve where δ exceeds unity is important.

A general overview of the secondary electron emission studies at SLAC starting with the early work for the multipacting of RF structures at SPEAR up to the most recent work for the TiN coating of vacuum chambers for PEP2 has been presented by R. Kirby. Secondary electron yields for pure metals are very low, e.g. in the literature, the secondary electron yield for pure aluminium is less than one. However, on samples of aluminium vacuum chambers the measured yield has a maximum between 2.5 and 3.5. Since the secondary electron yield of technical metals depends strongly on the roughness of the surface and on the composition of the omnipresent oxide layer, it has been important to measure the real surfaces under conditions which are representative for the particular application.

For computer simulations of multipacting in a given geometry it is important to know the dependence of the yield on the angle of incidence, θ. R. Kirby has derived an empirical relation $\delta(\theta) = \delta_{\perp}\, e^{\alpha(1-\cos(\theta))}$ with α = 0.5 for TiN coated aluminium as used in the LER of PEP2 and α = 0.45 for the ion sputtered copper beam duct of the PEP2 HER. Extrapolated from perpendicular to grazing incidence, these results suggest an increase of the yield by a factor of only 1.7 as compared to the previously assumed dependence of $(\sin\theta)^{-1}$. This more realistic dependence on the incidence angle has been used for more recent simulations.

3. Surface conditioning

During operation of accelerator and RF power components, it has been observed that a gradual 'conditioning' occurs. The effect of dosing of a surface with electrons or photons has been found to decrease the secondary electron yield and to result in a value of $\delta_{\max}$ which can be even lower than the measured value for the base material.
The detailed physical processes, which cause this reduction of $\delta_{\max}$ have been the subject of intensive studies by several groups but the effect is so far not fully understood. Nevertheless, there seems to be general agreement that it can be attributed to the formation of a carbon rich layer on the top surface. Carbon is known to have a low secondary electron yield. R. Rosenberg presented a summary of the work at ANL. In a series of on going experiments, a target has been inserted into the APS beam duct and the surface analysis compared before and after exposure to synchrotron radiation. From these measurements Rosenberg and co-workers conclude that the reduction of $\delta_{\max}$ is due to the formation of a carbonacious over layer and/or surface oxide reduction, a conclusion that agrees with the findings of several other researchers.

An alternative method to reduce the secondary electron yield is obtained by reducing the oxide layer to create a metallic surface or by depositing a fresh, clean top layer onto the surface. A promising novel method, as reported by N. Hilleret, is the use of getters, as they are known from vacuum pumps, which exhibit a low secondary electron yield after their surface oxide layer has been reduced by activation. A variety of surface treatments have been investigated to lower the secondary electron yield. To be fully efficient, these treatments need to be done *in situ* and in addition require baking the vacuum chamber to high temperature under vacuum to remove the adsorbed water layer. Conditioning by electron bombardment must be extended to a dose of the order of 10^{-3} C/mm^2 or alternatively (N. Hilleret) to 1 J/mm^2 to achieve the lowest secondary electron yield. There is no indication that the final secondary electron yield after conditioning depends on the base material (Al, Cu, stainless steel or Nb).

4 Surface coatings

The important aspect of the most suitable coating for achieving a low secondary yield within a UHV system has been addressed by several speakers. Historically, TiN has been used as a basic recipe to achieve such coatings against multipacting. For the aluminium beam duct of the LER of PEP2 a TiN coating has been achieved by nitrogen/argon ion sputtering. Very promising first results from an improved deposition method using RF-enhanced sputtering have been presented by K.-N. Leung.

S. Y. Zhang has demonstrated an interesting solution for reducing the extremely large secondary electron production by high energy gold ions in the AGS by using a striated collimator surface.

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1 see M. Furman and sessions II and IV

2 H. Seiler, J. Appl. Phys. 54 (11), 1983