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Faraday cup sensor for electron and UV beams

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Abstract. We leverage the energy-dependent production of secondary electrons and natural photoemission of metals to infer properties of incident electron and UV photon beams. By measuring electron beams with and without a voltage applied to a suppressor grid directly above an anode, we can directly estimate both the beam current and secondary electron yield. With the suppressor grid off, photoemission currents associated UV photons will be measured. We demonstrate this technique in the laboratory using a Faraday cup beam monitor and electron and VUV sources.

Introduction

Consider the Faraday cup design in Figure 1. Here there is a retarding potential grid, a suppressor grid, and an anode electrode that feeds into an electrometer. We consider incident electron beams here.

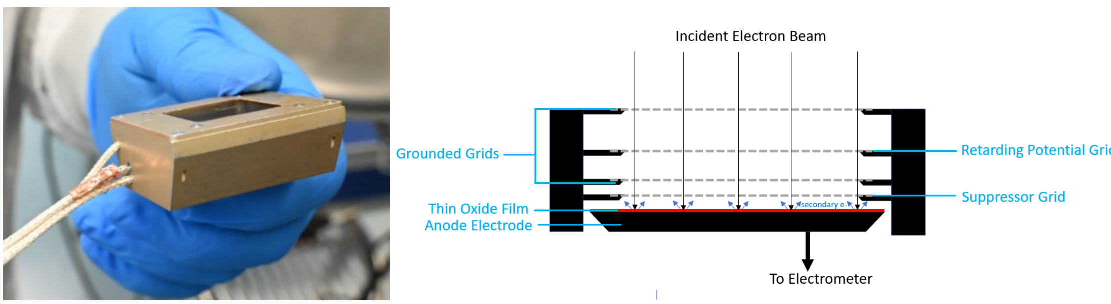

Figure 1. (left) Photograph of a Faraday cup sensor used for demonstration of the technique in this memo. (right) A representative cross-section of Faraday cup showing key elements. This design was used in the beam characterization of the Dual Electron Spectrometers (DES) on the Fast Plasma Investigation (FPI) on NASA's Magnetospheric Multiscale (MMS) mission [*Pollock et al.* 2016, SSR, doi:10.1007/s11214-016-0245-4]. Incident charged particle or photon beams will pass through several grid elements and reach an anode, where the corresponding current is measured by an electrometer element. Secondary electrons are emitted from the anode upon impact. A negative voltage can be applied to the suppressor grid in order to reflect those secondary electrons back to the anode. A retarding potential grid allows for the exclusion of either electrons or ions below a specified energy, depending upon grid voltage polarity. The effective area of the Faraday cup anode is approximately ~3.5cm^2.

The current measured from the anode from an incident electron beam consists of the primary (incident) current, I_e and secondary electrons emitted from the surface with yield δ_e. The total measured current with zero volts applied to the suppressor (i.e., the suppressor is 'off') is,

$$I_{off} \approx I_e(1-\delta_e). \quad (1)$$

When a voltage is applied to the suppressor that is sufficiently large and negative to reflect the secondary electrons back to the anode that are generated from the area under the grid (i.e., the suppressor is 'on'), the second term goes to zero such that the measured current becomes,

$$I_{on} \approx I_e. \quad (2)$$

Given measurements from the Faraday cup of equations (1) and (2), the secondary electron yield can be estimated as,

$$\delta_e \approx 1 - \left(\frac{I_{off}}{I_{on}}\right). \quad (3)$$

This approach is a common method for measuring secondary electron yields from samples [*Henrich,* 1973, RSI; *Scholtz et al.,* 1996, Philips, J. Res.].

We now consider the addition of a significant photoemission source (e.g., the Sun) for applications in space. Here there are additional source terms corresponding to photoemission:

$$I_{off} \approx eF_\gamma\big((1+g)\delta_\gamma\big), \quad (4)$$
and
$$I_{on} \approx eF_\gamma\big(-g\delta_\gamma\big). \quad (5)$$

The flux of incident photons is defined as F_γ, the secondary electron yield per photon is δ_γ, e is the charge of an electron, and g is an additional geometry-based factor that corresponds to the fraction of the incident light that reflects from the anode and generates photoelectrons from grounded Faraday cup surfaces below the suppressor grid that reach the anode regardless of whether the suppressor grid is on or off.

Laboratory Measurements

As a demonstration, we exposed the Faraday cup sensor shown in Figure 1 to an electron beam and Krypton UV source (116.5nm and 123.6nm emission lines). Measured I_{on} and I_{off} are shown as a function of energy in Figure 2a. The inferred secondary electron yield using equation (3) is shown in Figure 2b along with a best-fit curve based on analytical modeling of secondary electron yields on materials. The data is well ordered by the yield model, with the peak occurring at several hundred eV and decaying with increasing energy.

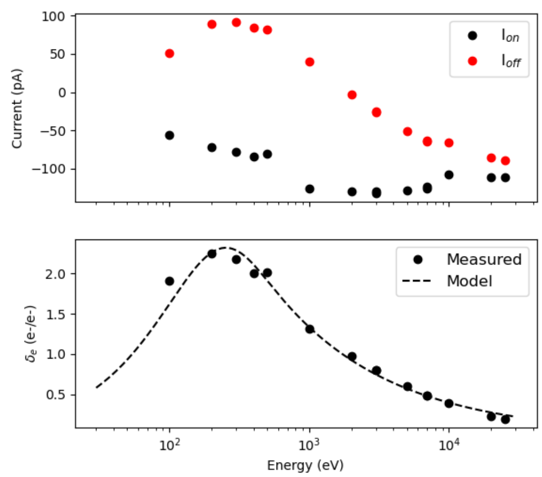

Figure 2. (top) Measured I_{on} and I_{off} for electrons as a function of energy. (bottom) Inferred secondary electron yield with equation (3) with best-fit curve using parameters from *Guo et al.,* [2019, AIP Advances, doi: 10.1063/1.5113671] with B = 0.73, A= 37, n = 1.52, and α = 0.024.

For a measured ~120nm UV flux of ~1.9×10^{13} photons/cm^2/s, I_{off} and I_{on} were +4.3nA/cm^2 and -93 pA/cm^2, respectively. These data were used with equations (4) and (5) to calculate g ~ 0.022 and δ_γ ~ 0.001, in line with expectations for photoemission of aluminum at these wavelengths [Cairns and Sampson, 1966, NASA-CR-94614].

Concluding Remarks

We have demonstrated that novel operation of a simple Faraday cup sensor can be used to infer not only current densities from electron beams but the average beam energy and the flux of UV photons. We have shown this technique to be effective in the laboratory, providing a high quality calibration reference for charged particle instrumentation.

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