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Parameterization of Secondary and Backscattered Electron Yields for Spacecraft Charging

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Spacecraft charging codes model the interactions between energetic electrons and spacecraft materials through material properties called electron yields (EY). The accuracy of spacecraft charging calculations can be critically affected by the availability of accurate EY data for materials and by how the measured data are parameterized for use with spacecraft charging codes. This work investigates the effectiveness of two EY fitting models.

Most often total electron yield (TEY) is characterized by two separate parameterized curves, a secondary electron yield (SEY) curve for low-energy emission <50 eV and a backscattered electron yield (BSEY) for high energies >50 eV. Typical semi-empirical models describe the SEY as a function of incident electron energy in terms of material properties such as atomic number, mean excitation energy, electron range, and mean free path. Other purely empirical models use parameters which define the shape of the resulting curves rather than physical material properties. The models are usually presented in reduced form, with yields scaled by the maximum yield \( \eta_0 \) and energies scaled by the energy \( E_0 \).

The complexity of SEY models considered here can be classified by the number of free fitting parameters, beginning with \( \eta_0 \) and \( E_0 \) to include a total of 2, 3, 4 or 5 parameters. BSEY models considered include a single-parameter empirical model widely used in spacecraft charging codes and extended empirical models with 3 and 4 free parameters.

Some electron yield models were found to be more effective than others at approximating the measured yield curves of certain materials or energy ranges; this has been quantified for each of several common spacecraft materials using \( \chi^2 \) statistical analysis. The implementation of parameterized electron yield models in various spacecraft charging codes is also discussed.

I. Introduction

Electron induced electron yield describes how a material will charge electrically due to electron emission caused by incident electron, photon, or ion bombardment. Understanding this process is critical to the fields of spacecraft charging, electron microscopy, particle accelerators, as well as many others. Many spacecraft charging models use understanding of electron yield to predict how spacecraft will react to the space plasma environment and to mitigate negative effects such as electrostatic discharge, the production of stray electric fields, and cathodoluminescence. The effectiveness of these models relies heavily on the accuracy of available yield data and on the chosen mathematical models used to fit this data.

II. Assumptions

The majority of yield models all make some common assumptions. The most popular assumptions are listed below:

- The problem is limited to 1 Dimension (Normal incidence only is considered)
- A Continuous Slowdown approximation is made (Energy is deposited continuously over path of incident electrons.)
- The number of secondary electrons (SE) are assumed (Electrons produced per angle of incidence assumed to be constant)
- The probability of emission is estimated (Probability of SE depends on an exponential decay term and the probability of overcoming the surface barrier)
- An electron range model is selected for SE (Various models exist, the most common are power law models)

III. Secondary Electron Yield

The majority of secondary yield formulas are written in the Reduced Yield Formulas ([Katz et al., 1997]). It is used in plots where it is plotted against \( \varepsilon \), which is dependent on parameters \( m \) and \( n \). Many models use some variation of this form. Table I gives a summary of many models listing their free and fixed parameters along with the appropriate ratios for \( r = \frac{\varepsilon}{E_0} \).

IV. Backscattered Electron Yield

The equations that the US MPG uses to model BSEY as a function of incident energy originate from NASA's spacecraft charging simulation software NASA 2Kv (Katz, et al., 1997). The formula that NASA uses to model BSEY has little to no physical basis. It was designed to reproduce the typical BSEY trends, which have been seen experimentally. This model has a fixed maximum height of 1.0 at 1000 eV, and the only free parameter \( \eta_0 \) adjusts the high-energy asymptotic value (See Table 2, Fig. 3).

NASCAP Parameterizes BSEY curves in terms of an effective atomic number \( Z_{eff} \).

\[ Z_{BSEY} = \frac{Z_{eff}}{\eta_0} \]

The BSEY for normal incidence at high energies (above ~10keV), \( \eta_0 \), has a constant value (Burke, 1977; Darlington, 1972) given in terms of \( Z_{eff} \) by the relation (Katz, 1977) while the BSEY as a function of incident energy is given by (Katz, 1977) (See Table 2). The BSEY model reduces to zero at 50 eV, to a maximum value at 1000 eV, and then it falls toward a horizontal asymptote of \( \eta_0 \). A similar method of calculating BSEY is utilized by the SPENVIS program assuming a value for \( \eta_0 \) of 1. – 0.7358\( Z_{eff} \)\( E_0 \)\( E_0 \) for surface energy values 1,000 eV < \( \varepsilon \) < 100,000. Where \( Z_{eff} \) is the atomic number. With no explicit method mentioned in the SPENVIS literature, there are many options for users to determine \( Z_{eff} \) in the case of polyatomic molecules. A simple mean associated yield, \( \eta_0 \), has a much smaller effect upon the parameters.

An alternative method to determine 2 specifically defined to characterize photon energy absorption, has been determined by Manohara (Manohara 2007) where \( \eta_{BSEY} \) is the effective (average) atomic energy absorption cross section, and \( \Delta \) is the effective energy absorption cross section.

V. Photo-Yield and Ion-Yield

The total yield (TEY) is comprised of 4 different yield sources. SEY, BSEY, ion yield, and photo yield. \( \eta_{ion} = \eta_{BSEY} + \eta_{EY} + \eta_d \) if \( \eta_d \) dips below 1,ie. There are more electrons impinging on the surface than leaving, a net negative charge will begin to form. This net negative charge creates a repelling force towards low energy electrons and prevents their capture by the surface. Because this negative charge does not affect SE and BSE only, charge accumulation rapidly leading to an abrupt increase in negative charge accumulation. \( \eta_0 \) is affected by negative charge accumulation due to the electrodynamic attraction between the negative surface and the positive ions. However, \( \eta_0 \) has a much smaller effect upon as observed by (Olsen, 1983.)

The total yield associated with ion bombardment of a sample is typically very small and so is often overlooked in favor of a electron yield consisting of SEY and BSEY only. The reasoning behind the practice of overlooking ion-yield can be made from the small yields associated with the large Ion Energy. At high yield the associated with Ho ions is only 1.4 electrons (See Fig. 2b.)

Photoemission at constant reflectivity ([Lai, 2008]) increases approximately as \( \eta_{EY} \), where \( q \) is the angle of incidence from normal. Because reflectivity scales with \( \eta_{EY} \) and photo-yield is directly proportional to reflectivity, changes to the incidence angle will also affect the charge rate (See Fig. 2b,c).

VI. References