A General Empirical Model of Secondary Electron Yield and Its Application in Monte Carlo Simulation of a Microporous Gold Surface

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Abstract: *We present a general empirical model of secondary electron yield (SEY), which successfully fits the experimentally measured SEY of a flat gold surface for both normal and oblique incidence of primary electrons. This empirical model is applied in a two-dimensional Monte Carlo (MC) simulation to estimate the effective SEY reduction of a microporous surface. The simulation results are in very good agreement with the experimental data.*

Keywords: Secondary electron yield; empirical model; microporous surface; Monte Carlo simulation

Secondary electron emission (SEE) from solids causes effects like electron cloud, electrostatic discharge [1], and multipactor effect [2,3] in rf accelerators, microwave components, and satellite communication systems leading to a degradation of device and system performances. SEE is characterized by the secondary electron yield (SEY) [1-4] which refers to the average number of emitted secondary electrons per incident primary electron on a surface. In this paper, we propose a general empirical SEY model [5] to fit the experimentally measured SEY of a flat gold surface. The empirical model is then applied in a two-dimensional Monte Carlo (MC) simulation to calculate the SEY of a microporous gold surface.

We construct our general empirical model of SEY for flat surfaces based on Vaughan's empirical formula [6] and include angle dependent parameters to fit experimental measurements [5]. For a primary electron impacting upon the surface at angle θ with respect to the surface normal, the SEY δ is given by,

$$\frac{\delta(\theta)}{\delta_{max}(\theta)} = (we^{1-w})^k, \text{ for } w \leq w_c \tag{1a}$$

$$\frac{\delta(\theta)}{\delta_{max}(\theta)} = c/w^d, \text{ for } w > w_c. \tag{1b}$$

Here, $w = E_i/E_{max}(\theta)$ and we set $w_c = 4.28$. E_i is the impact energy of the primary electron. The angle dependent parameters $E_{max}(\theta)$ and $\delta_{max}(\theta)$ are given by

$$E_{max}(\theta) = E_{max0}(1 + k_{sE1}\theta + k_{sE2}\theta^2 + k_{sE3}\theta^3 + k_{sE4}\theta^4), \tag{2}$$

$$\delta_{max}(\theta) = \delta_{max0}(1 + k_{s\delta}\theta^2/2\pi), \tag{3}$$

where $E_{max0} = 0.7KV$ and $\delta_{max0} = 1.6$ are the parameters for normal incidence ($\theta = 0$) on gold surfaces studied in this work and $k_{sE1} = -6.85$, $k_{sE2} = 26.76$, $k_{sE3} = -32.26$, $k_{sE4} = 12.65$, and $k_{s\delta} = 1.8$ are fitting constants. The parameter k in Eq. (1a) is given by,

$$k = a_0\left(1 + \frac{k_a\theta^2}{2\pi}\right), \text{ for } w \leq 1, \tag{4a}$$

$$k = b_0\left(1 + \frac{k_b\theta^2}{2\pi}\right), \text{ for } 1 < w \leq w_c, \tag{4b}$$

and the parameters c and d in (1b) are respectively given by,

$$c = c_0\left(1 + \frac{k_c\theta^2}{2\pi}\right), \tag{5a}$$

$$d = d_0\left(1 + \frac{k_d\theta^2}{2\pi}\right). \tag{5b}$$

We adopt the values of empirical coefficients $a_0 = 0.76$, $k_a = -3$, $b_0 = 0.12$, $k_b = -2$, $c_0 = 1.375$, $k_c = 0.8$, $d_0 = 0.35$, $k_d = 0.5$ in Eqs. (4) and (5) to fit the experimentally measured data. Figure 1 shows that the experimental measurements [5] (black lines) and proposed empirical fitting of SEY (blue lines) from a flat gold surface for different incident angles are in very good agreement, whereas Vaughan's model [6] (red lines) is not able to accurately predict the angular sensitivity of the experimental measurements. Although demonstrated for gold in this work, our proposed general SEY model is expected to be able to fit virtually any SEY measurement data with proper choice of the fitting coefficients for different materials.

The empirical model in Eqs. (1)-(5) is employed in a MC simulation to study the SEY of a microporous gold surface for normally incident primary electrons (Fig. 2). In the MC simulation, we track the secondary electrons inside the well (with SEY according to the empirical model above for each surface impact) until all the secondary electrons either escape the well or are absorbed by the inner surfaces. The average SEY from the rectangular well is $\delta_p = N_e/N_0$, where N_e is the total number of escaping electrons estimated from the simulation, and $N_0 = 10^4$ is the number of primary electrons. The effective SEY of a porous surface with a given porosity ρ is [1,4],

$$\delta_{surf} = \delta_p\rho + \delta_f(1-\rho), \tag{6}$$

where δ_f is the SEY of a flat surface. The SEY model parameters for the flat region, bottom surface and the side walls of a well are assumed to be the same.

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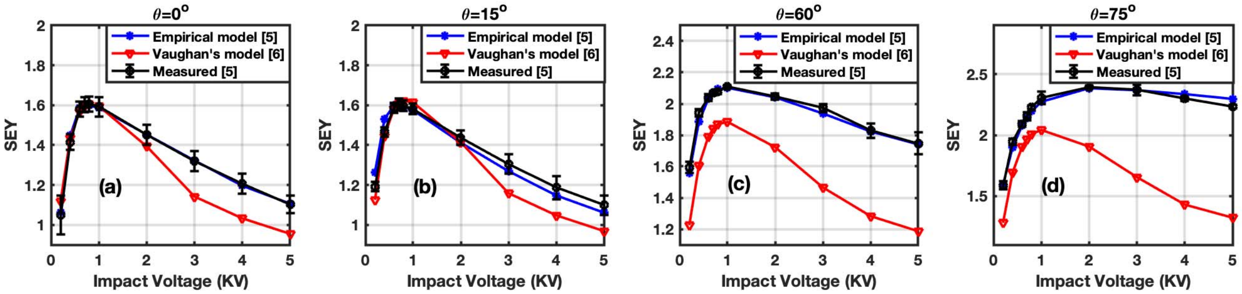

Figure 1: Comparison of experimental measurements (black lines) [5], proposed empirical model's fitting (blue lines), and Vaughan's model's prediction (red lines) of SEY for a flat gold surface for the incident angle of (a) $\theta = 0^o$, (b) $\theta = 15^o$, (c) $\theta = 60^o$, and (d) $\theta = 75^o$. Error bars represent a 95% confidence interval of the experimental data. The predicted SEY curve from the proposed empirical SEY model (blue line) in Fig. 1(a) is overlaid with the measured SEY curve (black line).

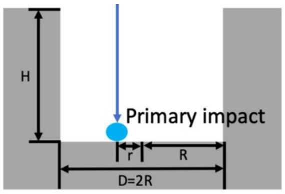

Figure 2: The 2D rectangular well geometry assumed in our Monte Carlo model. The rectangular pores have height H, radius R, and diameter D. A primary electron is shown incident on a random location on the bottom surface at a distance r from the center of the pore.

Figure 3 show the MC results (blue lines) for the effective SEY for microporous gold surfaces with pore aspect ratio $A_R = H/D = 3.02$ and porosity $\rho = 0.40$, and with $A_R = 3.52, \rho = 0.50$, which are in good agreement with the experimental results (black lines) [5]. The SEY from a porous surface (Fig. 3) is found to be significantly lower than that from a flat surface (Fig 1a). The slight overestimation of the simulation results (especially for impact voltage larger than 1 kV) is due to the simplified assumptions of the 2D simulation model compared to the 3D geometry of the experimental samples.

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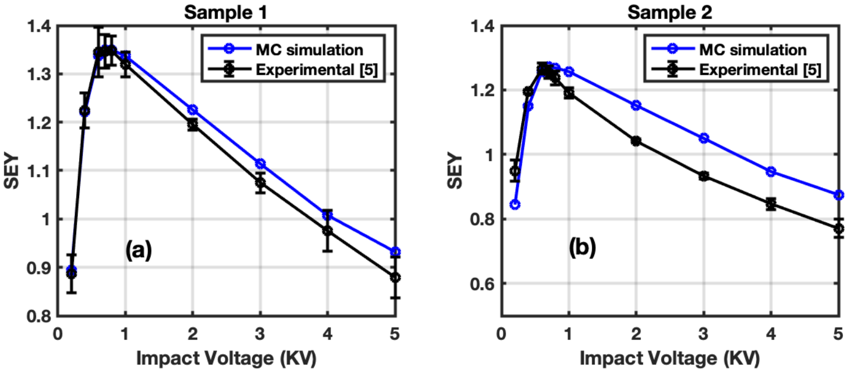

Figure 3: Comparison of experimental measurements (black lines) [5] and MC simulation results (blue lines) of SEY for normal incidence on two different samples of microporous gold surface with different aspect ratio of pores, A_R, and surface porosity, ρ: (a) sample 1 with $A_R = 3.02, \rho = 0.4$, (b) sample 2 with $A_R = 3.52, \rho = 0.50$. Error bars represent a 95% confidence interval of the measured data.