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An Analysis of Variations in Published Secondary Electron Yield Measurements of Copper

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Abstract

Energetic electrons incident on a surface can cause electrons to be emitted from the surface. Secondary electron yield (SEY) characterizes this as the number of electrons emitted from the material per incident electron, \( \Delta \delta \). This intrinsic material property has been studied for more than 100 years. However, it is notoriously difficult to measure absolute SEY, with widely disparate values often reported in the literature. Variations in SEY and the causes of these variations depend on the energy of incident electrons, \( \Delta \delta \), and n or \( \Delta \delta / \Delta \delta \), and E1, E2 and E\( \text{max} \) are the crossover energies where \( \Delta \delta \).

Comparisons of various studies of contaminated Cu surfaces are shown in Figure 2. Typically oxide layers increase the SEY. One cause of variation in reported SEY curves is the presence of thin contamination layers. Two common layers are oxides and carbon or organic contamination; these tend to affect SEY of bulk materials differently. If the surface layer is thicker than the penetration depth of incident electrons, the coated material will act as bulk contaminant. At lower energies where incident electrons penetrate the thinner contamination layers, SEY is dominated by the bulk substrate SEY. The SEY of these contamination layers is lower than for clean Cu.

Conclusion

Applications in vacuum, such as for electron optics or accelerators, require SEY data for high purity, clean, smooth Cu. Thus, one would do well to employ Cu data from smooth surfaces, particularly from in vacuo deposited studies. Applications for contaminated surfaces such as outgassing on spacecraft surfaces, low vacuum (particularly diffused pumped) environments, or plasma deposition apparatus often have organic contamination layers. Surfaces exposed to high electron beam fluxes (such as in SEM, x-ray rotating anodes, or accelerators) are known to accumulate carbon contamination layers.

An extensive materials database is being created which will pull in results from multiple SEY, BSEY, and photoyield studies. It will classify the results based upon what contamination type. Materials which have been “cleaned” by high energy ion-sputtering have lower SEY. Several methods can decrease surface roughness, thereby increasing SEY. These include mechanically polishing, thermal annealing, or overcoating with smooth layers with, for example, vapor deposition. Positively charged surfaces can similarly re-attract SE, thereby decreasing SEY.

CU. Applications of SEY

Surface topography of a sample can affect SEY by altering the fraction of emitted electrons recaptured through collisions with the surface (Figure 7). Rough surfaces with features on length scales comparable to electron penetration depths often decrease SEY (Seipter, 1985; Hilleret, 2000). Surfaces can be made rough with mechanical machining, including “as received” materials. Materials which have been “cleaned” by high energy ion-sputtering have lower SEY. Several methods can decrease surface roughness, thereby increasing SEY. These include mechanically polishing, thermal annealing, or overcoating with smooth layers with, for example, vapor deposition. Figure 3 depicts various studies as classified by roughness. We can infer that Bronstein (1969) may have had a rough surface morphology. Positively charged surfaces can similarly re-attract SE, thereby decreasing SEY (Figure 7). Contamination layers and oxide surfaces can lead to charged surface layers.

Using SEY data to categorize the results will depend on the energy of incident electrons, \( \Delta \delta \), and n or \( \Delta \delta / \Delta \delta \), and E1, E2 and E\( \text{max} \) are the crossover energies where \( \Delta \delta \). Tracking changes in these fitting parameters can help characterize variations in SEY and the causes of these variations.

V. Utility of Database

Applications in vacuum, such as for electron optics or accelerators, require SEY data for high purity, clean, smooth Cu. Thus, one would do well to employ Cu data from smooth surfaces, particularly from in vacuo deposited studies. Applications for contaminated surfaces such as outgassing on spacecraft surfaces, low vacuum (particularly diffused pumped) environments, or plasma deposition apparatus often have organic contamination layers. Surfaces exposed to high electron beam fluxes (such as in SEM, x-ray rotating anodes, or accelerators) are known to accumulate carbon contamination layers.

Use of technical Cu or Cu in oxidizing environments such as atomic oxygen in space or oxygen-rich plasma environments should use SEY for oxidized surfaces.

Surfaces that are not polished after machining or are sputtered can be modeled with SEY of rough surfaces.

Applications using commercial-off-the-shell (COTS) parts would do better to assume rough, oxidized samples.

IV. Surface Morphology and Charging

III. Contamination and Oxidation

Figure 3. Comparison of SEY curves of Cu samples with:
- Smooth surfaces (gray) \( \Delta \delta > 0.23 \)
- Rough surfaces (green) \( \Delta \delta > 0.25 \)
- Unknown surface morphology (purple)
- Smooth surfaces have higher \( \Delta \delta \)
- Rough surfaces decrease \( \Delta \delta \)
- Rough surfaces decrease \( \Delta \delta \) for C less than for clean Cu.

Figure 2. Comparison of SEY curves of Cu samples, categorized by estimated contamination type.
- Oxidized samples \( \Delta \delta < 0.98 \)
- Carbon coated samples \( \Delta \delta = 0.34 \)
- Unknown contamination
- Oxidized surfaces have higher yields than clean surfaces.
- Carbon coated surfaces have lower SEY than clean Cu surfaces.
- \( \Delta \delta \) is low for C.

Figure 1. Secondary electron yield curves vs incident energy from more than 100 years of historical studies of various Cu sources. This demonstrates the wide variation in published values associated with SEY. \( \Delta \delta \) varies widely with \( \Delta \delta \) > 2.5 with \( \Delta \delta > 2.5 \) secondary electrons emitted incident on a (presumably) similar Cu sample.

A mean value for clean Cu is estimated as \( \Delta \delta \) = 1.34 (Lide, 2012). For comparison presumably uncontaminated (vapor deposited thin films) samples have \( \Delta \delta \) = 0.83.

References


VI. Going Forward

An extensive materials database is being created which will pull in results from multiple SEY, BSEY, and photoyield studies. It will classify the results based upon what contamination type. Materials which have been “cleaned” by high energy ion-sputtering have lower SEY. Several methods can decrease surface roughness, thereby increasing SEY. These include mechanically polishing, thermal annealing, or overcoating with smooth layers with, for example, vapor deposition. Figure 3 depicts various studies as classified by roughness. We can infer that Bronstein (1969) may have had a rough surface morphology. Positively charged surfaces can similarly re-attract SE, thereby decreasing SEY (Figure 7). Contamination layers and oxide surfaces can lead to charged surface layers.

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