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A simple method for energy calibration of keV incident electron beam using a contactless electrostatic voltmeter probe

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Abstract: A simple method is proposed to calibrate the energy of an electron beam. An electrical floating metal foil is irradiated by the incident electrons. The electron energy is deduced from the magnitude of the surface potential developed on the irradiated conductor surface. The measurement of the surface potential is made outside the vacuum chamber on a metallic slab connected through a coaxial feedthrough to the electrons irradiated sample. The energy calibration obtained by this method is compared to the conventional method based on measuring the energy position of the backscattered electrons elastic peak.

Calibration of the electron beam energy in the range of few eV to hundreds of eV is crucial for many fields of science and technology where the interaction of low energy electrons with surface plays a critical role, such as, in Hall effect thruster technology^{1,2} multipactor discharge in microwave devices^{3,4}, nuclear fusion⁵ and high energy physics⁶. For instance, the control of the electron beam energy with a relative accuracy of 1 eV is required for the evaluation of the multipactor risk in microwave spacecraft components^{7,8}. The electron gun energy should be regularly measured and calibrated. The commonly used calibration method is based on use of electron energy analyzers (EEA). The EEA could be either positioned in front of the electron beam to monitor directly the energy distribution of the incident electrons^{9,10} or facing the irradiated sample to monitor the energy of the elastic backscattered electrons peak¹¹. However in many electron irradiation facilities, these methods cannot be used due to the reduced space into the chamber. We propose here as alternative an easily implementable calibration method. The method was applied to EGL2 Kimball Physics electron gun attached to the vacuum chamber (10^{-9} mbar) equipped with a hemispherical electron energy

analyzer (SIGMA). The experimental setup is shown in the Fig. 1.

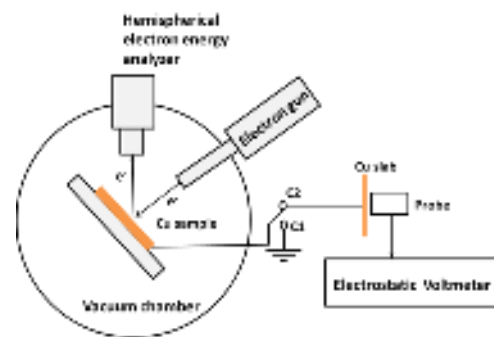


FIG. 1. Schematic of the experimental setup

A Cu foil was fixed on the sample holder. The sample can be either grounded (C1) or connected through a BNC coaxial feedthrough to an electrical floating copper slab (C2) placed at ambient atmosphere outside the vacuum chamber. The surface potential of the Cu slab can be measured with a Non-Contacting Electrostatic Voltmeter Probe (Kelvin Probe type) connected to an electrostatic voltmeter (Trek-344).

The principle of the method is based on the measurement of the electric charge induced by the electron beam on the electrical floating copper sample. When a solid is hit by incident electrons, the energy transfer can result in the emission of

secondary electrons (SE) and backscattered electrons (BSE). The number of the electrons emitted under the impact of the incident primary electrons is called the Total Electron Emission Yield (TEEY). The TEEY measured on the polycrystalline Cu sample is shown in Fig. 2(a). A description of the TEEY measurement method can be found in the reference¹². For incident energies, E_0 lower than 32 eV the TEEY is lower than 1. $E_{C1}=32\text{eV}$ is the first crossover energy of the Cu foil.

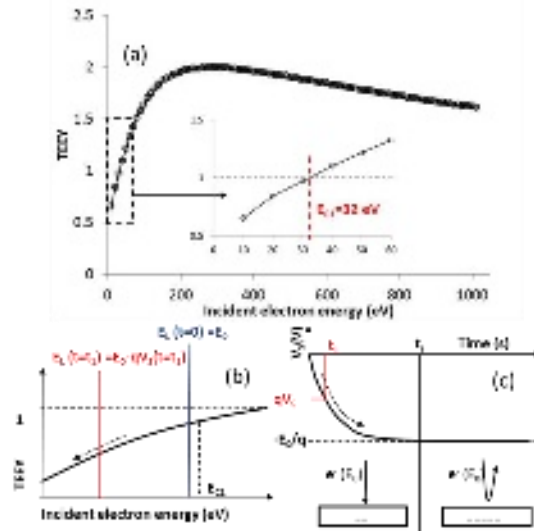


FIG.2. (a) TEEY measured on the Cu foil. (b) and (c) the principle of the method

The principle of the method is sketched in the Fig.2c). Consider the situation where the Cu foil is kept electrically floating (C2). If its surface is irradiated by electrons with energy, E_0 , lower than E_{C1} a negative charge should be accumulated on the whole system formed by the Cu foil/connector/Cu slab. The electric field generated into the vacuum chamber, decelerates the next incoming electrons, in such way that the landing energy E_L , decreases gradually from E_0 to $E_L = E_0 + qV_S$ (Fig. 2(b)). V_S is the built-up negative surface potential on the Cu foil and $q = 1.6 \cdot 10^{-19} \text{ C}$. The reduction of E_L leads in turn to the reduction of the TEEY and the increase of V_S and so on. The steady state of charging is reached when all the incident electrons are repelled: $E_L = 0 \text{ eV}$ and $E_0 = -qV_S$ (Fig.

2(c)). In principle, it is therefore possible to measure the energy of the electron beam by measuring the induced surface potential on the Cu slab (Fig.1).

An experimental demonstration of this principle is illustrated in Fig.3. The following protocol is applied:

- 1-The e-gun energy is set to 10 eV, V_S falls quickly to a steady value to almost -10 eV.
- 2-The electron gun energy is incremented by 10 eV ($E_0 = 20 \text{ eV}$), as the impact energy becomes $E_L = E_0 + qV_S = 10 \text{ eV}$, negative charge is implanted again at the sample surface and V_S reaches a new steady state $V_S = -20 \text{ eV}$, and so on.

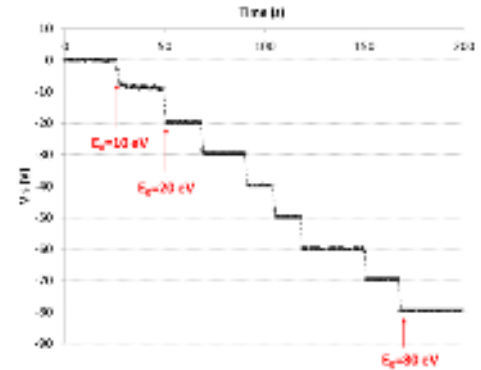


FIG.3. Variation V_S on the Cu slab over the time during the increment of the electron gun energy from 0 eV to 80 eV by 10 eV step.

The apparent instantaneous decreases of V_S from one steady state to another reflect the limited acquisition frequency of the electrostatic probe. In order to scan all the target electron beam energies including energies higher than E_{C1} , it is imperative to ensure two conditions: (i) the first electron irradiation should be performed at incident energy, $E_0 < E_{C1}$ and (ii) the electron impact energy increment, $\Delta E = E_L$, should be always lower than E_{C1} . If the condition (ii) can be easily satisfied by all commonly used electron guns, the condition (i) is difficult to achieve in some cases. Indeed, some commercial electron guns are designed to work for incident electron energies higher than 100 eV. In this situation the Cu foil could be replaced by low TEEY material¹³ to increase E_{C1} over 100 eV.

The elastically backscattered electrons from the irradiated Cu surface are emitted at the same energy of the incident one. Therefore, the energy position of the elastic peak is commonly used to calibrate the energy of the electron gun when an EEA is available. The energy positions of the elastic peaks of the Cu foil were measured using the hemispherical electron energy analyzer for incident electron energies varying from 10 eV to 200 eV. The measured electron gun energy as function of the set energy on the electron gun using both the elastic peak method and the proposed method are plotted together in the Fig. 4. The measured elastic BSE peaks at 30 eV is also shown in the inset of the Fig. 4. A very good agreement between the two methods is obtained. A slight deviation from the slope=1 was observed at very low energy for both the methods, which is an indication of a small non linearity of the used electron gun at very low energy.

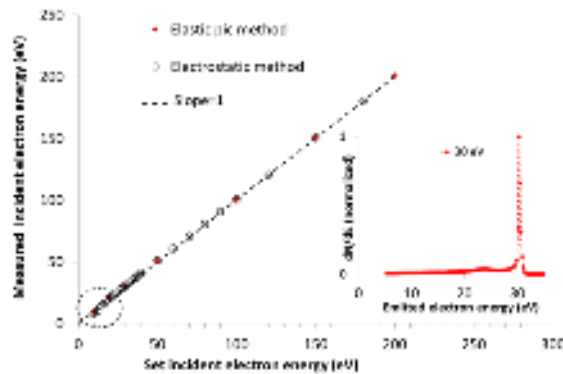


FIG.4. Comparison between the developed method and the elastic peak method. The measured elastic BSE peak under 30 eV electron irradiation is shown in the inset.

Note that for the both methods a systematic error of about 1 eV should be considered. This error is mostly related to the uncertainties on the work functions differences between:

- (i) the sample (Cu) and the electron gun filament (tantalum) for the developed method and (ii) the EEA (stainless steel) and electron gun filament for the elastic peak method.

A novel and inexpensive electron beam energy calibration method is presented in this note. It does not require any adaptation of the vacuum chamber provided that an electrical connection to the sample holder is available and can be therefore easily implemented even in the smallest vacuum chambers

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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