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Low-energy electron beam on an insulator surface: Impact of the charging process on the diffraction by mica muscovite

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Abstract

The expected low-energy electron diffraction by an insulator is deduced from the consequence of the surface charge distribution on the diffraction process. If the yield of secondary electron emission is greater than unity, the surface reaches electrostatic equilibrium and charges positively. Then incident electrons are simply accelerated and their wavelength is shortened, so the diffraction condition is modified. We show that this modification is strictly compensated by the deviation of the diffracted backward electron crossing the charged surface. The diffraction pattern displays the same geometry, size and symmetry but the diffracted intensity is modified. Through this process the low energy electron diffraction is shown to be an efficient tool to investigate the charging process induced on insulator surfaces by an electron beam. This is exemplified with the surface of mica muscovite, where we relate the oscillation of the surface charge to the evolution of the intensity of the diffraction spots.

Keywords: Electron diffraction; Insulator; Surfaces; Secondary electrons; Charging

1. Introduction

The observation and subsequent investigation of the surface material by an electron beam has been largely developed. It is of significant interest in many fields of physics, ranging from scanning electron microscopy to electron multiplier, Auger spectroscopy or electron diffraction. These methods have been designed to study the surface of conducting materials but surprisingly they prove to be efficient for the study of insulating surfaces too, in particular for the case of muscovite mica [1]. The charging process of insulators by a beam of charged particles complicates the fundamental phenomenon, however various techniques have been used in order to reduce the spurious effects

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(see for example [2,3]). For an electron beam, the resulting surface potential arises from the competition between the trapping of negative electrons and the emission of secondary electrons into vacuum, which leave positive charges within the material.

In the present study we focus our investigation on the charging process at the surface of an insulating material, during a low-energy electron diffraction (LEED) experiment. In this low-energy range for the primary beam, the yield of secondary electrons is a growing function of the energy of incident particles. So two regimes must be considered. Firstly, below a threshold energy of typically 50 V, the yield is less than unity so that the surface charges negatively [4,5]. The surface potential reaches the value of the electron energy and a mirror effect is observed, so the diffraction pattern cannot be observed because the electrons cannot reach the surface of the specimen. Secondly, above the threshold, the insulating surface reaches an electrostatic equilibrium. In fact the surface charges positively. This leads to an increase in the effective work function so as to reduce the yield of secondary electrons. When the yield reaches a value of unity, the current of secondary electrons is exactly adjusted to the current of the incident beam [6], so the diffraction pattern can be easily observed as in metallic specimens.

Here we will investigate the impact of these positive charges on the diffraction of low-energy electron by an insulator, when the yield is greater than unity. We will show that the geometry of the diffraction pattern is not modified, but each diffraction spot undergoes a specific change in its intensity. This is related to the well-known evolution of the LEED intensity with the wavelength of the electron. Without entering the complex three-dimensional (3D) and multiple diffraction process [7], which drives this evolution, it can nevertheless be directly measured and utilised to evaluate the surface charge. In this work, this method is applied to the study of a mica muscovite sample irradiated by a low-energy electron beam (60–130 eV). The evolution of the spot intensity has been investigated using an oscillating LEED method [8], where the oscillatory component of the diffraction intensity can be accurately measured. Here we clearly demonstrate that the oscillation of the diffraction pattern intensity is strictly related to the oscillation of the surface charge. The surface potential evolution is evaluated to 0.2 V peak at a temperature of 550 K and for an excitation frequency of 0.13 Hz.

2. Diffraction by an insulator: the role of the surface positive charge

The electric field induced on insulators by electron bombardment can be evaluated by using electrostatic macroscopic arguments and some microscopic information about the mean-free-path of charged particles [9,10]. For a semi infinite insulator bounded by vacuum and submitted to low-energy electrons, two distances must be considered: on the one hand, the mean-free-path for inelastic secondary electrons (energy about 2 eV), that leave positive charges at the surface; on the other hand, the larger mean-free-path of incident low-energy electrons (around 100 eV) that leave negative charges within the sample. When combined with image charges this charge distribution creates a nonuniform electrical field, which tends to repel the positive charges toward the outmost atomic layer, and the negative charges toward the volume [9]. Electron diffraction, which only concerns elastic events, occurs in a zone located in between these two charge distributions. So the net effect for the diffraction is produced by positive charges located around the topmost atomic layer of the crystal.

Let us now evaluate the low-energy electron diffraction by the surface of a charged insulator. We consider an incident electron beam with energy E and wave vector $\boldsymbol{k}$, so that $E = \frac{\hbar^2 k^2}{2m}$. The elastically backscattered electrons give rise to diffraction (Bragg) spots, when the scattering vector component parallel to the surface is equal to a vector of the 2D reciprocal lattice (within the framework of the kinematic theory [11]): $\boldsymbol{K}_\parallel = \boldsymbol{k}'_\parallel - \boldsymbol{k}_\parallel = \boldsymbol{G}_\parallel$.

The energy conservation insures that the scattered wave vector is identical to the incident vector, in modulus: $k' = k$. This allows to calculate the perpendicular component $k'_\perp$ for a particular diffraction spot: $k^2 = k'^2 = k_\perp^2 + k_\parallel^2 = k'^2_\perp + k'^2_\parallel$.