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Effect of the incident electron fluence on the electron emission yield of polycrystalline Al_2O_3

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ABSTRACT

The electron emission yield due to electron impact on polycrystalline Al_2O_3 is measured with a technique based on the use of a Kelvin probe (KP method) and a pulsed electron beam. The KP method allows the clear discrimination between the external effects of charging and internal ones. The effect of the incident electron fluence on the yield in the region where the yield is higher than one is investigated. An overall drop of the electron emission yield with increasing the electron fluence is observed. This result is clearly associated to the internal effects of positive charging. Indeed, the recombination of the generated secondary electrons with the accumulated holes beneath the irradiated surface leads to the decrease of their mean free path and to the decay of the secondary electron emission yield.

1. Introduction

The electron emission of insulator materials induced by electron irradiation plays a major role in many applications such as in scanning electron microscopy (SEM) [1–3], Hall Thruster technology [4,5], charging of satellites submitted to radiations [6,7], radiation detectors [8,9], etc. In most of these applications, the knowledge of "the" electron emission yield (EEY or σ) of the material is highly required. The EEY is defined as the ratio of emitted electron number to the incident electron number. The emitted electrons are low energy secondary (few eV) and backscattered electrons (SE and BSE). In insulators, the measurement of the EEY is made more difficult as the sample charges under irradiation. To minimize charging or to maintain it at acceptable level, short electron pulses were generally used [10,11]. Both, internal and external effects of charging may lead to substantial change on the EEY curves. A comprehensive description of the influence of charging on the EEY is given by Cazaux [12–14]. The internal effects interfere with the transport of SEs undergoing emission [12,14–22] whereas external ones concern the effects of the electric field produced by the trapped charge into the vacuum on the incident electrons and on the emitted ones [1–3,12–14,21]. For a better understanding of the effects of charging on the yield, it is interesting to make a clear distinction between these two effects. For this purpose, an EEY electron pulse measurement method based on the use of a Kelvin probe (KP) was developed recently [23]. The ability of this method to discriminate between the internal effects of charging and the externals ones was demonstrated on MgO [22]. In this paper, the internal effects of charging on the EEY of polycrystalline Al_2O_3 are investigated. In particular, the focus is put on the influence of the incident charge fluence on the EEY curves in the 50–2000 eV incident electron energy range.

2. Experimental setup and methods

2.1. Sample

The studied sample is disk-shaped polycrystalline Al_2O_3 (2 mm thick and 20 mm in diameter). For outgassing purpose, the sample was kept under vacuum during 24 h before beginning the experiments.

2.2. Experimental setup

A schematic diagram of the experimental arrangement is shown in Fig. 1. Cryogenic pump associated to oil-free molecular-diaphragm pumps allows the system to be maintained at vacuum level below 5×10^{-7} Torr. The sample is mounted in a holder which can be positioned so that the electron beam strikes the entire

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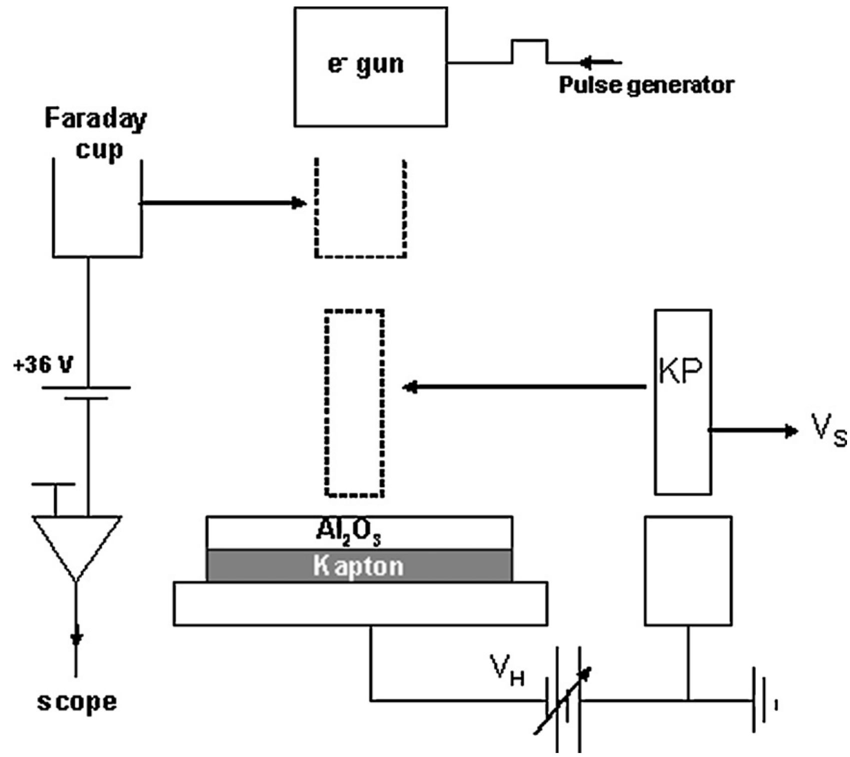

Fig. 1. Schematic view of the experimental setup. The Kapton film guarantees the lack of electric contact between the sample and the sample holder.

sample surface. The sample holder can be biased to chosen potential. The electron beam incidence is set normal to the sample surface. The incident charge is measured using a Faraday cup connected to a 350 MHz TDS5034B oscilloscope trough a Femto-DHPCA-100 high speed and a low noise current amplifier. ELG2 Kimball instrument electron gun (3–2000 eV) with a μs electron beam pulsing capacities was used as the electron source. The incident charge fluence per current pulse varies with the primary beam energy in the range of 8×10^{-13} C to 2×10^{-12} C which corresponds to incident current density of 9 nA/cm^2 to 25 nA/cm^2. The sample surface potential is measured prior and after the pulse irradiation with high-sensitivity (3 mV) Trek-6000B-15C Kelvin probe, connected to Trek-323 electrostatic voltmeter. The lateral resolution of the probe is of about 4 mm. All the measurements are performed at room temperature.

2.3. Methods

The measurement principle of the EEY was described in detail elsewhere [23]. In brief, the KP method is a three steps method. In the first step, the surface potential is measured with the KP and adjusted to an initial negative surface potential value V_{Si}. V_{Si} is chosen so that the surface potential is always kept negative during the electron pulse with respect with the grounded inner shell of the vacuum chamber. This ensures that all electrons reaching the sample surface from within the sample are truly emitted. In the second step, the KP is removed and the sample is irradiated by a pulse of charge Q_i. In the third step, the KP is repositioned in front of the sample surface in order to measure the new value of the surface potential, V_{Sf}. The surface potential variation $\Delta V_S = (V_{Sf} - V_{Si})$ can be either positive or negative depending if the EEY is greater or lower than one. The sample/sample-holder system forms a capacitance C. Knowing C, the electron emission yield is given by Eq. (2)

$$\sigma = 1 - \frac{C\,\Delta V_S}{Q_i} \qquad (2)$$

Between two electron pulses the sample is discharged. This is achieved by alternating short electron pulses where $\sigma < 1$ when the sample is positively charged and where $\sigma > 1$ when the sample is negatively charged [10,19,23]. Note that the "as received" samples are usually charged before being exposed to electron beam and may in some cases exhibit a surface potential of hundreds of volts (positive or negative). Therefore the discharging procedure is systematically applied prior to the measurement of the yield. The capacitance C was measured in situ thanks to the method described in ref. [24]. For this purpose, V_S was set to +50 V by biasing the sample holder. The sample surface is then irradiated with pulses of 5 eV. Due to the high positive V_S and low energy incident electrons, we may reasonably assume that the emission yield is almost zero and that the entire incident charge remains on the sample surface. C is then deduced from the slop of Q_i versus ΔV_S characteristic shown in Fig. 2. C is found to be 1.65 pF.

3. Results and discussion

The sample surface was irradiated by one pulse or by a sequence of electron pulses of 25 μs length. The incident charge per pulse as the function of the incident energy is given in Fig. 3. Fig. 4 shows the electron emission yield curves measured on Al_2O_3 with irradiation duration ranging from 25 μs to 175 μs. An overall decrease of the EEY is observed when the incident electron fluence is increased. The values of the surface potential before and after 175 μs irradiation (respectively V_{Si} and V_{Sf}) and also ΔV_S as the function of the incident electron energy are shown in Fig. 5. It is important to point out that even if ΔV_S is positive ($\sigma > 1$), the surface potential is always kept negative (before and during the irradiation) with respect to the grounded inner shell of the vacuum chamber. Consequently, the decrease of the EEY as the function of the electron fluence cannot be associated to an external effect of charging, such as the attraction of the SEs by the positively charged surface [12–14,21,25,26]. Only internal charging effects can be involved to explain such behavior. Note also that this behavior is not specific of Al_2O_3: qualitative