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Secondary electron yield of Au and Al_2O_3 surfaces from swift heavy ion impact in the 2.5–7.9 MeV/amu energy range

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Abstract

We report on the secondary electron yields of Au and oxidized aluminum (Al_2O_3) by impact of heavy ions with energies ranging from 7.92 MeV/amu ($^{12}C_6$) to 2.54 MeV/amu ($^{107}Ag_{47}$). The obtained results, the first in this energy range using medium-heavy ions, extend the validity of proposed scaling laws obtained with lighter ions. Measurements have been performed using the SIRAD irradiation facility at the 15 MV Tandem of the INFN Laboratory of Legnaro (Italy), to evaluate the performance of ion electron emission microscopy at SIRAD.

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1. Introduction

The SIRAD heavy ion irradiation facility, located at the 15 MV Tandem accelerator of the LNL, INFN National Laboratory of Legnaro (Italy), is dedicated to radiation damage studies in silicon detectors and devices [1]. An important part of the experimental program is the study of ion induced single event effects (SEE) in microelectronic devices and systems. Global device characterizations are routinely performed; a wide selection of swift ion species, from Li to Au, is available to test most modern technology electronic devices for high energy physics and space applications.

An ion electron emission microscope (IEEM) has been implemented to extend SEE study capabilities to include the reconstruction of the impact points of individual ions with micrometric resolution [2–4]. An IEEM is a system of electrostatic lenses that transports and focuses secondary electrons, emitted by surfaces impacted by energetic heavy ions, onto a two dimensional electron detector such as a micro channel plate (MCP). The coordinates of single ion impacts are then reconstructed with micrometric lateral resolutions.

The efficiency of an IEEM relies on a high electron yield per ion impact of the surface under study. Normally, the surface of a semiconductor device under test (DUT) is a poor electron emitter. In addition, the efficient electron collection of the microscope can be altered by any target surface roughness. Adequate secondary electron emission could be ensured by placing thin self-standing flat membranes of expected good electron emitters, as Au or Al, on top of the DUT.

Since no experimental data of secondary electron emission were present in the literature for the energetic heavy ions typical of the SEE program at SIRAD, we performed

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measurements of the secondary electron yield on Au and oxidized Aluminum (Al_2O_3) targets employing a wide range of ion beams accelerated at the LNL Tandem.

2. The experiment

The ion species, charge state (Q) and kinetic energy (KE) of the ion beams used in this experiment are reported in Table 1.

A simple Faraday cup system (Fig. 1) was used to perform the yield measurements: the secondary electrons emitted by the target, electrically grounded, were suppressed or collected by an independent electrode, depending on the voltage polarity of the latter. This basic structure, repeated into a multi-cup system, was mounted onto a sample holder allowing different targets to be moved in and out of the beam without breaking the vacuum in the chamber ($p \approx 5 \times 10^{-6}$ mbar).

The targets were one Aluminum foil (oxidized) and three Au targets (one bulk and two gold depositions, 70 μg/cm^2 and 200 μg/cm^2, on 2 μm thick mylar).

During irradiation the collector voltage V_c was slowly ramped up from −100 V to 100 V in steps of 1 V/s. Currents on the target and collector were measured simultaneously as a function of the collector voltage V_c with a precision multi-source pico-ammeter (HP-4142 B).

Typical target currents are shown in Fig. 2. When V_c is large and negative enough ($V_c \leqslant -35$ V) the target current consists only of the incoming positive beam current and is recorded with a negative sign; when electron emission is not suppressed the pico-ammeter measures a larger negative current due to the contribution of the electron current. As the collector voltage is increased to more positive values electron collection becomes more efficient and for $V_c \geqslant 10$ V it is complete. Indicating with I_{beam} the target current with complete suppression and with I_t the target current with complete collection, the electron yield per ion impact is given by

$$Y_t = Q \times (I_t - I_{beam})/I_{beam}, \qquad (1)$$

where Q is the charge state of the ions before impact. The yield values obtained using the collector currents through the formula $Y_c = Q \times I_c/I_{beam}$, where I_c is the collector current with complete collection, are perfectly consistent and are not discussed here for brevity.

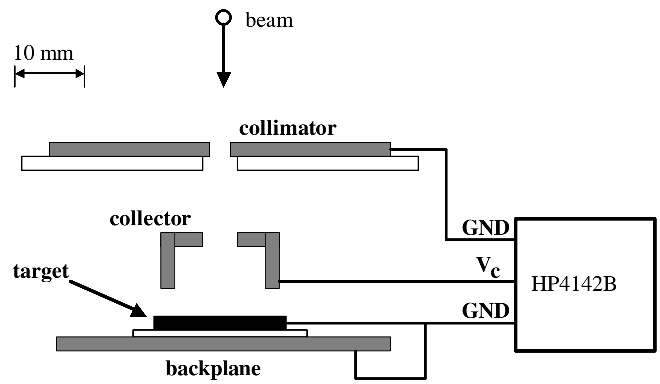

Fig. 1. Sketch of the measurement setup.

The secondary electron yields obtained using the target currents are reported in Table 1. The uncertainty in the pico-ammeter and voltage supply are negligible compared to the dominant uncertainty, of the order of a few percent, in establishing the current plateau levels in the current versus collector voltage curves (Fig. 2). Typical beam currents were in the range 10–25 nA but consistent results were obtained with beam currents as low as 1 nA; i.e. the secondary electron emission values reported in Table 1 were not space-charge limited.

The latter consideration enables us to consider the relatively smooth slope of the curve in Fig. 2 across $V = 0$ V as due to a physical effect, i.e. the spread in energy of the emitted secondary electrons at the metal surface. Fig. 3 shows the slope of the curve across $V = 0$ V for a 158 MeV ^{28}Si beam on Au target: very similar results have been obtained by varying ion species and metal target. The FWHM of the change in the slope across $V = 0$ V is ~5 eV and is a rough measure of the energy spread of the secondary electrons. This value experimentally confirms what was assumed in [2] to estimate the spatial resolution and the transmission efficiency of the IEEM.

3. Secondary electron emission of metals

When a swift ion (energies > 100 keV/amu) impinges on a metal target free electrons are produced all along the ion

Table 1
Ion species, energy, surface LET values (SRIM2003) and measured average yields from Au and Al_2O_3 targets

Ion	Q (e)	KE (MeV/amu)	LET_{Au} (eV/A)	$LET_{Al_2O_3}$ (eV/A)	Y_{Au} (%)	$Y_{Al_2O_3}$ (%)
$^{12}C_6$	+6	7.92	145	66	10.9 ± 5	8.2 ± 10
$^{16}O_8$	+7	6.81	272	123	18.2 ± 5	12.6 ± 10
$^{19}F_9$	+8	6.47	348	163	22.3 ± 5	15.5 ± 5
$^{35}Cl_{17}$	+12	4.91	1139	527	56.7 ± 10	33.9 ± 10
$^{48}Ti_{22}$	+14	4.08	1744	872	85.2 ± 6	48.2 ± 8
$^{28}Si_{14}$	+11	5.64	796	357	40.0 ± 5	24.0 ± 5
$^{58}Ni_{28}$	+14	3.60	2448	1230	91.5 ± 10	81.3 ± 12
$^{79}Br_{35}$	+18	3.16	3231	1731	123.0 ± 10	86.0 ± 12
$^{107}Ag_{47}$	+20	2.54	4344	2427	129.8 ± 10	119.5 ± 12