

Time Resolved Analysis of the Positive Ion Dynamics in the Variable Pressure Scanning Electron Microscope

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In a variable pressure scanning electron microscope (VPSEM) the secondary electron (SE) emission signal is amplified via a gas ionization cascade, which is produced by the introduction of a positively biased electrode into the specimen chamber. Current flow induced in the biased (or ground) electrode through the movement of charge within the cascade is used to form an image rich in SE contrast [1]. A consequence of this type SE detection process is the generation of a significant concentration of positive ions within the specimen chamber. The presence of these positive ions enables imaging and analysis of uncoated non-conductive specimens at all electron beam energies without charging artifacts. Recent studies, however, have revealed that the positive ions can have a significant affect on SE contrast by (i) suppressing SE emission [2], (ii) reducing the ionization cascade amplification of the SE emission signal [3] and (iii) increasing the landing energy of the primary beam [4]. A detailed knowledge of the dynamic behavior of positive ions will therefore enable optimization of the SE image quality and correct interpretation of SE contrast in the VPSEM.

In this work, the time dependent behavior of the positive ion current was used to investigate the ion dynamics in the VPSEM. Time resolved ion current profiles were measured as a function of specimen stage geometry, biased electrode voltage (+30V to +550V), sample conductivity and atomic number, type of chamber gas (water vapor, nitrogen and argon) and gas pressure using four different types of grounded electrode arrangements; a grounded straight copper wire inserted into the gap between the specimen and the biased electrode, copper wire rings with a range of diameters positioned at various heights above the sample, aluminum cylinders centered over the specimen with an assortment of diameter and height configurations and the specimen stage itself. The electric field distribution for each of the above electrode configurations was calculated using commercial software (Quickfield™). In each experiment, the electron beam was positioned on the specimen in spot mode with a zero electrode bias. The ion current was allowed to stabilize before the bias voltage was rapidly switched to a pre-determined positive voltage. Once a steady state current was observed the bias was then re-set to zero volts, and the ion current was collected until it reached the initial zero bias signal level. The ionization cascade amplification was measured in all experiments. A Keithley 617 electrometer connected to an Eagle Technology 330kHz, 12 bit A/D board was used to measure the ion current as a function of time.

A typical time resolved ion current profile (shown in figure 1) exhibits three distinct regions over a ~40 second time interval; region 1 where the ion current (I_{ion}) increases since the ion generation rate (dG) is greater the ion de-ionization rate (dI) reaching a maximum at time t_{max} , region 2 where the I_{ion} decays as $dI < dG$ and region 3 where I_{ion} is constant where $dG = dI$. The results show that as the ion concentration grows the position of t_{max} decreases with an associated increase in the I_{ion} decay rate in region 2. Time resolved ion current profiles collected under identical experimental conditions and electrode arrangements varied significantly for water vapor, nitrogen and argon, reflecting the differences in the ionization / recombination efficiency, lifetime and mobility of each gas ion species. These profiles provide a measure of the capacity of each gas to form a positive ion space charge. A significant shift in the ionization gas gain curve as a function of pressure was observed for

different grounded electrode configurations, particularly the VPSEM conditions for maximum amplification when compared with the conductive stage as the ground electrode. The significance of these results in terms of SE image quality and interpretation of SE contrast in the VPSEM will be presented. A series of SE images were collected from a copper TEM grid under equivalent VPSEM conditions and grounded electrode configurations to illustrate these effects.

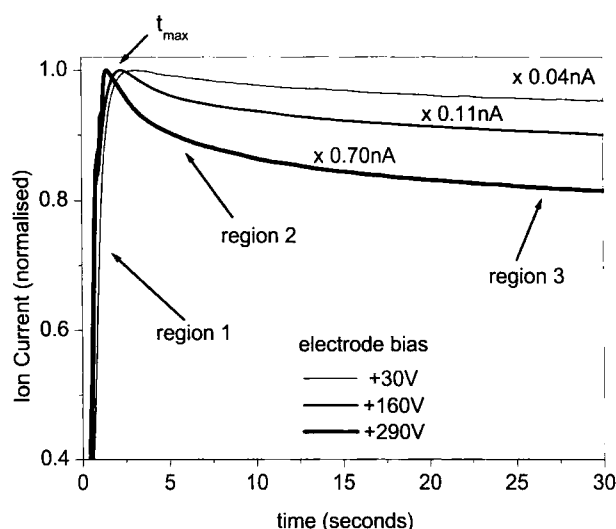


Figure 1: Typical ion current profile versus time for an insulating specimen measured from the grounded conductive stage. Pressure = 3.0 torr, Gas = Nitrogen, $E_0 = 20\text{keV}$, $I_b = 1\text{nA}$, Working Distance = 10mm

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