Real Time Acquisition and Calibration of S/TEM Probe Current Measurement Simultaneously with Any Imaging or Spectroscopic Signal

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Advances in S/TEM optics and detector technology have enabled many new capabilities for quantifying imaging and spectroscopic signals. Quantitative ADF-STEM [1,2], EDXS [3,4], and EELS [5,6] offer the potential to recover 3D structure and composition information at nano- and atomic-resolution on absolute scales. Critical to these techniques is knowledge of the incident probe current. Increasing the accuracy and precision of this measurement correspondingly increases the accuracy and precision with which one can quantify the number and type of atoms. Current approaches perform a probe current measurement at the beginning of the session or experiment and assume this value remains constant throughout. This approximation is necessary because existing methods for measuring probe current - via Faraday cup (holder) or by calibrating the output of the CCD, STEM detector, phosphor screen, or GIF drift tube - all require the collection of the entire unscattered beam [1,7]. Thus, they cannot be employed while a specimen is inserted in the path of the beam, and so cannot be performed simultaneously with other measurements. While the approximation may be acceptable for certain electron emission sources (e.g., high-quality Schottky emitters), as the field of quantitative microscopy continues to advance even greater accuracy will be needed, rendering this assumption increasingly problematic. This is particularly true for *in situ* S/TEM and other experiments with long acquisition times. Already the constant-current assumption is unsuitable for cold field-emission guns (CFEGs), which offer analytic performance superior to Schottky emitters: higher brightness, greater spatial coherence, and a significantly lower energy spread together yield better spatial and energy resolutions. But this comes at the cost of reduced stability of the emission current, which decays non-linearly with time (e.g., Figure 1b-c) and can vary significantly across even a single image. The instrument used in this work averaged a spread (max-min) in probe current across a single image of ~6%. If CFEGs are to be employed for accurate quantitative STEM and spectroscopy, and to push the field as a whole, a new approach to current measurement is needed.

Here we present an approach for real time measurement of the incident probe current concurrently with the acquisition of any other imaging or spectroscopic signal. In this approach, the (calibrated) current signal arising from the probe-forming aperture due to the impingement of the electron beam during normal operation is employed as a measuring the probe current (Figure 1). Simultaneous acquisition of this aperture current with the probe current confirmed a reliable and repeatable linear relationship between the aperture and probe currents (e.g., Figure 1d), despite any non-linear excursions of the probe current itself. Having validated this usage of the aperture signal, it was converted into a form for optimal read-in by Gatan's Digiscan II hardware. This enables the aperture current - and thus the probe current - to be collected in time-synced real time on a pixel-by-pixel basis with any signal being collected by the Gatan Microscopy Suite software (Figure 1e). The resulting "probe current image" is acquired and readable in the same manner as any other image acquired in GMS.

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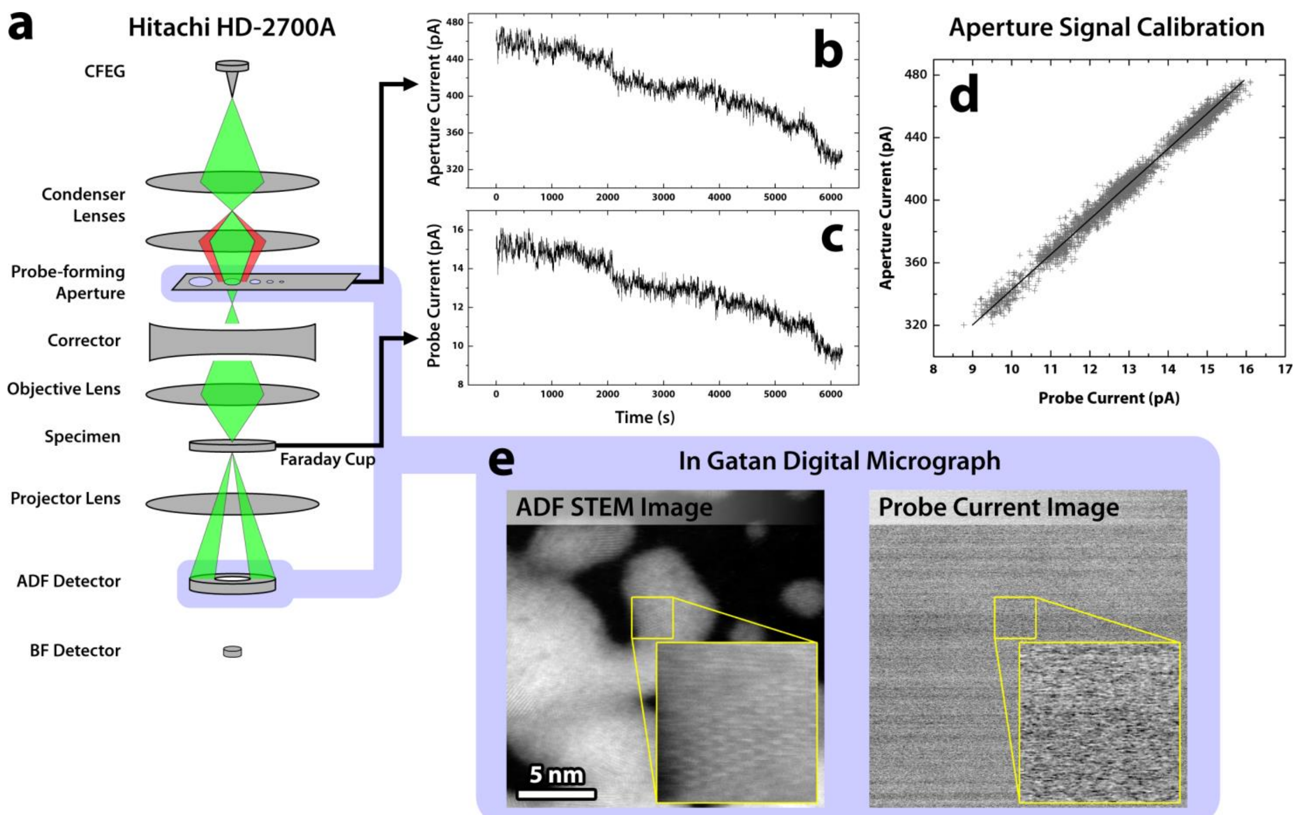

Figure 1. (a) Simplified diagram of the relevant internals of the HD-2700A STEM used in this work. (b-c) Example of concurrently acquired probe and probe-forming aperture current signals revealing (d) the linear relationship between the two. A Faraday cup holder was used to make these measurements. (e) Simultaneously acquired ADF-STEM and aperture current (and thus probe current) images.