2508
doi:10.1017/S143192762200959X

Microsc. Microanal. 28 (Suppl 1), 2022

Separation of EBIC Modes with Two-Channel STEM EBIC

William A. Hubbard[1,2*], Ho Leung Chan[2], Matthew Mecklenburg[2], and B. C. Regan[1,2]

[1.] NanoElectronic Imaging, Inc., Los Angeles, CA, USA.
[2.] University of California, Los Angeles and the California NanoSystems Institute, Los Angeles, USA.
* Corresponding author: bhubbard@nanoelectronicimaging.com

Electron beam-induced current (EBIC) imaging is most commonly used to map current generated by the separation of electron-hole pairs in local electric fields [1]. This "standard" EBIC is generally larger than the secondary electron emission EBIC, or SEEBIC. Recently demonstrated in STEM, SEEBIC imaging measures the holes left behind by the emission of secondary electrons (SEs) from the sample [2]. SEEBIC is capable of much higher resolution than standard EBIC [3] and can generate contrast related to a number of different electronic properties, including conductivity [4,5]. While standard EBIC requires a local electric field, SEEBIC is virtually always present; any STEM EBIC image with standard EBIC contrast also has a (typically much smaller) SEEBIC component. These two components contain complementary information, and without decoupling the SEEBIC information is generally lost.

When an electron beam is incident on a pn junction, electron-hole pairs (EHPs) are separated in the junction's built-in electric field. If each charge has its own separate path to ground (or a virtual ground) the pair will produce a current (Fig. 1A); without separate paths the pair will recombine and produce no current. Attaching an EBIC amplifier (held at virtual ground) to each ground path will therefore produce images with equal and opposite standard EBIC contrast in the two channels. In SEEBIC, however, the hole left behind by SE emission is unpaired, and can reach ground through a single ground path, effectively generating an SE image. If, however, the sample is connected to two or more paths to ground, Fig. 1A, the hole will reach ground preferentially through the lowest resistance path and generate "differential SEEBIC" conductivity contrast [4,5]. For example, the SEEBIC-generated hole in Fig. 1A will have a higher probability of reaching ground through the closer ammeter (red) to the right.

Since the carriers in standard EBIC and SEEBIC are paired and unpaired, respectively, imaging with two STEM EBIC channels enables separation of the two modes with simple image arithmetic. Fig. 1B shows an ADF STEM image of device consisting of a GeSbTe (GST) strip patterned to span two TiN electrodes, all supported by a SiN membrane in a Si-based substrate, fabricated as described in [2]. The simultaneously acquired STEM EBIC images in Figs. 1C and 1D are dominated by the standard EBIC contrast caused by the Schottky barriers at each TiN/GST interface. Note that the two EBIC images, acquired on opposing electrodes, are approximately inverses of each other; for each hole that reaches one amplifier a corresponding electron must reach the other. Summing the two channels (Fig. 1E) cancels the standard EBIC carrier pairs, leaving behind only the SEEBIC signal. Subtracting the two channels (Fig. 1F) suppresses the SEEBIC signal, returning primarily standard EBIC.

In this presentation we will demonstrate the use of two-channel STEM EBIC to distinguish between contrast created by the different EBIC modes, including cases where image interpretation is impossible without this decoupling. While summing the EBIC signals in Fig. 1E returns the total SEEBIC, it does not preserve the differential SEEBIC contrast, which reveals valuable conductivity contrast. We will therefore also discuss alternative techniques for distinguishing between standard EBIC, SEEBIC, and differential SEEBIC contrast [6].

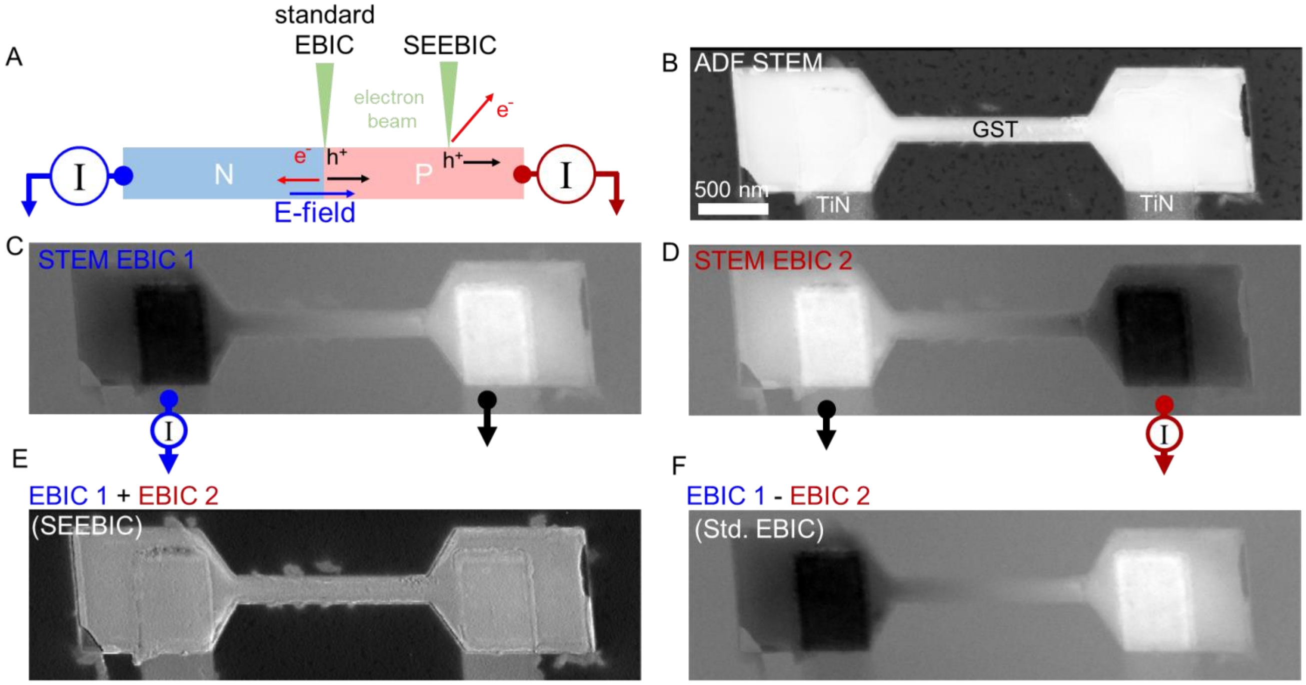

Figure 1. The diagram (A) shows standard EBIC and SEEBIC generated on a pn junction which is attached to an EBIC amplifier on either terminal. (B) The annular dark-field (ADF) STEM image shows a patterned strip of GeSbTe (GST) between two TiN electrodes. STEM EBIC images are simultaneously acquired on the device in (B) from the left (C, blue ammeter) and right (D, red ammeter) electrodes. The images in (B), (C), and (D) were acquired simultaneously. The current meters are both held at virtual ground. In the EBIC images both standard EBIC and SEEBIC are present, but the standard EBIC signal is dominant, appearing as bright/dark patches at the TiN/GST interfaces. Summing the two EBIC images yields the total SEEBIC signal (E) and subtracting them yields mostly the standard EBIC signal (F).

References:

[1] TE Everhart, OC Wells, and RK Matta, Proceedings of the IEEE, **52** (1964). p. 1642–1647
[2] WA Hubbard et al, Physical Review Applied, **10** (2018), p. 044066
[3] WA Hubbard et al., Applied Physics Letters **115** (2019), p. 133502.
[4] M Mecklenburg et al, Ultramicroscopy, **207** (2019), p. 112852.
[5] WA Hubbard et al., Advanced Functional Materials **32** (2022), p. 2102313.
[6] This material is based upon work supported by the Defense Microelectronic Activity under Contract No. HQ072721C0002, and by NSF STC award DMR-1548924 (STROBE), NSF award DMR-2004897, and the Semiconductor Research Corporation (SRC).