

Inducing Electrically-Active Defects in a Gallium Arsenide Nanowire with an Electron Beam

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Electron-hole (e-h) separation efficiency is of critical importance to the functionality of solar cells and photodetectors. Electron beam-induced current (EBIC) imaging in SEM is a well-established method for measuring electron-hole (e-h) recombination lengths and mapping depletion regions [1], but SEM EBIC imaging has low resolution due to its large beam interaction volume [2]. Scanning transmission electron microscope (STEM) EBIC imaging can offer much better spatial resolution, as thinner samples and higher accelerating voltages result in a much smaller interaction volume [2, 3, 4]. In practice, STEM-EBIC is a major technical challenge because the devices must be electron-transparent. Focused beams of (typically) Ga ions are commonly used to thin samples to electron-transparency, but the Ga leaves a conductive damage layer behind [5], destroying the sample's semiconducting properties. Here we present STEM-EBIC images of clean, abrupt GaAs-gold interfaces in nanowire devices, and demonstrate that the GaAs's charge separation efficiency decreases with increased radiation exposure.

Gallium arsenide nanowires grown by selective-area metalorganic chemical vapor deposition (MOCVD) [6] are transferred to an electron-transparent silicon nitride window. Gold leads are patterned with e-beam lithography which connect each end of the nanowire to larger electrical contacts. Upon rapid thermal annealing, the gold contacts intrude into the GaAs nanowire, creating abrupt axial interfaces between the gold and gallium arsenide at each end (Figure 1A and 1B). These back-to-back nanoscale Schottky diodes exhibit electric fields that equalize the gold and GaAs work functions.

STEM EBIC images (Fig. 1D) reveal these electric fields at the GaAs-gold interfaces. Within the GaAs depletion region, the EBIC profiles are flat, while outside they decay exponentially (Fig. 1E) with a decay length equal to the e-h pair recombination length of the nanowire [1]. After prolonged imaging at 300 kV accelerating voltage, the HAADF channel does not change significantly, but the EBIC signal is dramatically reduced. Recombination centers created by the beam would have such an effect. Interstitial and vacancy defects can act as deep-level traps within the band gap of GaAs [7], and increase the probability of e-h recombination through the Shockley-Read-Hall process.

Lowering the accelerating voltage reduces the radiation damage, as shown in STEM-EBIC scans at 200 kV (Figure 2C). Although the nanowire junction is subjected to over an order-of-magnitude higher dose (in electrons per area) than the junction imaged at 300 kV, the reduction in EBIC signal is relatively small. This result is corroborated by prior work in electron-irradiated bulk GaAs, which reported a sharp drop-off in the generation rate of deep-level traps below 250 kV accelerating voltage [7, 8].

References:

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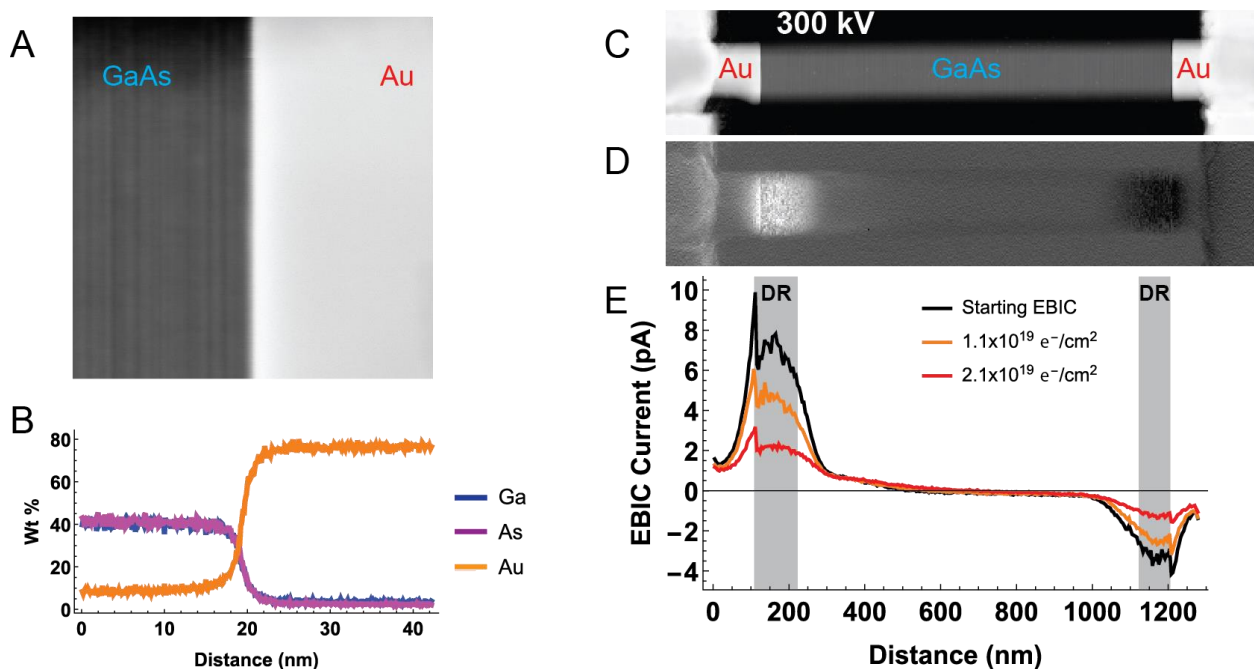


Figure 1. A) High-mag HAADF image of the sharp GaAs-Au junction acquired at 300 kV with a corresponding B) EDS line profile; the distance scale in B) also applies to A). C) HAADF image of the entire back-to-back diode device and D) simultaneously-acquired EBIC image. E). EBIC line profiles taken at increasing electron dose. The depletion region (DR) is shaded gray, and the distance scale in E) also applies to C) and D).

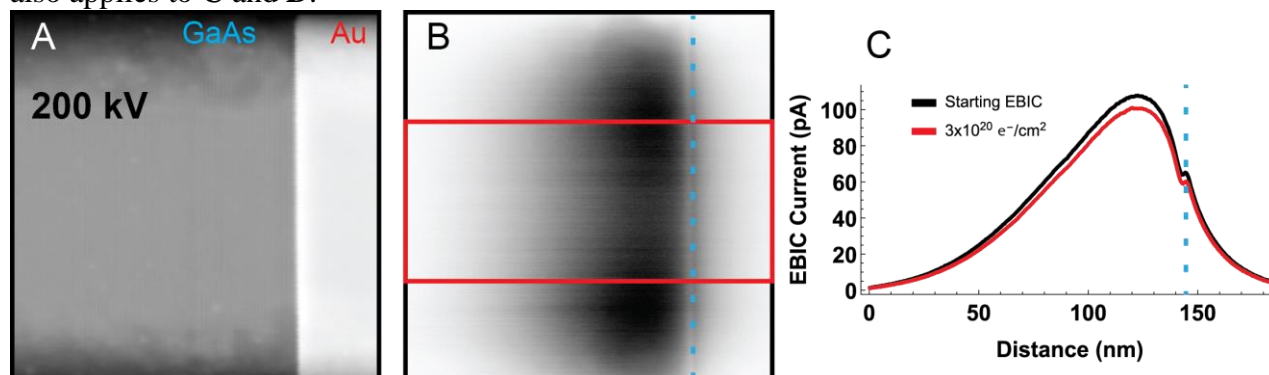


Figure 2. A) HAADF image of a different GaAs-Au junction acquired at 200 kV with B) simultaneously-acquired EBIC image. C) EBIC line profiles taken from the red ROI of B) before and after irradiating the sample with a very large electron dose. The distance scale described by C) applies to A) and B).