In situ phase-shifting electron holography for precise measurement of electric potential, field, and charge density distributions across a biased p-n junction

Anada, S.[1], Yamamoto, K.[1], Sasaki, H.[2], Shibata, N.[1,3], Hori, Y.[2], Kinugawa, K.[2], Imamura, A.[2] and Hirayama, T.[1]

[1] Japan Fine Ceramics Center, Japan, [2] Furukawa Electric Co. Ltd., Japan, [3] The University of Tokyo, Japan

The semiconductor industry requires a reliable electric potential measurement technique for the development of future devices. Attempts to quantitatively measure electric potential distributions in p-n junction model structures have been made using off-axis electron holography. The previous studies have shown that the electron holography combined with *in situ* electrically-biasing technique can provide a quantitative electric potential map at the nanometer scale. However, the obtained potential distributions cannot be converted to reliable electric field and charge density distributions due to low precision and/or low spatial resolution of their measurements. In the present study [1], we used *in situ* phase-shifting electron holography, which can simultaneously achieve high precision and high spatial resolution, to obtain quantitative and reliable electric potential, field, and charge density distributions across a biased GaAs p-n junction.

A thin-film specimen was prepared by thinning one part of a bulk specimen with electrodes using a cryo focused ion beam (FIB) system. The specimen was loaded on a biasing TEM holder and then connected to a voltammeter. Off-axis electron holograms of the p-n junction specimen were acquired using an electron holography TEM (Hitachi HF-3300EH) with a double electron biprism system. We used a series of 50 holograms for electric potential mapping and achieved precision of 0.02 V and spatial resolution of 1 nm.

We obtained precise electric potential distributions across a biased specimen and successfully converted them to reliable electric field and charge density distributions. From the relationship between the applied voltage and measured height of the potential step across the p-n junction, the built-in potential of the p-n junction was determined to be 1.55 V. The electric field profiles showed that the unbiased p-n junction had a depletion layer with a width of 24 nm; the width increased to 26 nm under a reverse bias of −0.3 V and decreased to 22 nm under a forward bias of 0.5 V. Moreover, the charge density profiles indicated the presence of passivated dopants and/or trapped carriers even in the internal active layer of the specimen, with little damage introduced by FIB milling. We concluded that *in situ* phase-shifting electron holography can be used for reliable assessment of nanoscale semiconductor devices.

[1] S. Anada *et al.*, J. Appl. Phys., 122 (2017) 225702.

Acknowledgement: This research was supported by the project for promoting public utilization of advanced research infrastructure grant from the Ministry of Education, Culture, Sports, Science and Technology.