Electron holography in study of doping profile

Dong Tang
Application Laboratory, FEI Electron Optics,
P.O. Box 80066, 5500 KA Eindhoven, The Netherlands

In the past years, with the shrinking size of semiconductor products, TEM has found more and more applications and become more and more popular in the industry. The recent development of doping profile observation using electron holography technique provides another strong justification for employing TEMs in semiconductor industry. Normally, the amount of the doped element is too little to be precisely detected by spectroscopy, such as EDS and EELS. The difference in electron beam amplitude passing doping area from that passing non-doping area is so small that the conventional TEM image does not show any visible contrast as well. However, electron wave phase is more sensitive to these trace elements. That means even though amplitude is almost equivalent, the phase may be somehow more different. Electron holography is to separate amplitude and phase of electron wave passing the specimen. The 2-D distribution of the doped element is displayed in the phase map.

Holography can be implemented easily in a TEM by adding an optical fiber coated with thin metal at the position of selected area aperture. It acts as a bi-prism that bends electron beam at its both sides to meet, creating interference fringes that carry both amplitude and phase information of the electron wave. A reconstruction is then done by software, which separate phase from amplitude. Since holography is an interference technique, the electron source must be as coherent as possible. Therefore, a field emission gun (FEG) operated at relatively low extraction is needed. To achieve the utmost coherent illumination, the condenser stigmator should be adjusted such that the beam, normally round, becomes an extreme ellipse perpendicular to the fiber. Because the size of doped area has an order of micro, the objective lens of microscope should be off for a large field of view. The better way to achieve this is to use a Lorentz lens positioned above the bi-prism rather than the default diffraction lens, which locates below the bi-prism. Due to low magnification of Lorentz lens, the fine fringes may not be visible. Microscope mounted with a Lorentz lens plus a Gatan Image Filter (GIF), which has extra 20 times magnification, is an ideal combination.

The specimen preparation is very demanding and crucial. The most of failures of doping profile studies come from the specimen preparation. First of all, the specimen thickness should not be too thin, so that the weak phase difference may be enhanced by the thickness, and should not be too thick. Secondly, the doped area to be studied should not be too far away from the specimen edge so that the interference fringes of the region of interest overlap with nothing else. Thirdly, the specimen must be conductive and not be charging. Charging may severely change the electron beam phase and alter the phase map.