Analysis of GaAs compound semiconductors and the semiconductor laser diode using electron holography, Lorentz microscopy, electron diffraction microscopy and differential phase contrast STEM.

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In order to develop and manufacture semiconductor devices which are key components of the optical telecommunication products, such as the semiconductor laser diode, it is essential to confirm whether it is manufactured as designed. Electric potential distributions of the semiconductor devices are designed in nanoscale, so two dimensional methods to evaluate the electrical potential in the semiconductors with a high spatial resolution are necessary for product management. The observation of the gallium arsenide (GaAs) model specimen was carried out by using the electron holography and Lorentz microscopy [1].

Lorentz images and intensity profiles are shown in FIG 1 (a)-(f). The p-n junctions are clearly seen in both the 0.6 mm under-focused and over-focused images, but hardly any interfaces of different dopant concentration can be observed in the images. FIG 2 shows the electron holographic reconstructed phase image. The p- and n-type regions are clearly seen as areas of dark and bright contrast, and some differences in the changing dopant concentrations can also be seen.

A phase image of semiconductor laser diode by the electron holography is shown in FIG 3 [2]. In FIG 3(a), the interface region is approximately 5 µm. And the spacing between interface fringes is approximately 30 nm. Next, in order to observe the pn junction near the active layer in a high spatial resolution, the photograph was taken by changing the interference fringes conditions. The expanded phase image of a part of FIG 3(a), surrounded by a dotted line, is shown in FIG 3(b). Since the interference region is approximately 1.5 µm, and the interference fringe spacing is 5 nm, the spatial resolution is approximately 15 nm. As can be recognized from the phase image, we can understand that more detailed structure can be observed in the higher spatial resolution in comparison with the phase image in FIG 3(a). Here, the designed location of the pn junction was positioned at the dotted line, but it was found from the electron holography observation results that the pn junction did not exist in the original position. This semiconductor laser diode could not have the expected output characteristics. The structural defect of the pn junction, found out in this observation, is considered to be the cause.

For other semiconductor electric voltage evaluation methods by TEM, electron diffraction microscopy [3] which is one method of phase reconstruction method, differential phase contrast [4] (DPC) which is one method of STEM are also effective and possible to be utilized complementarily with the electron holography. We will
discuss about these methods applied for semiconductor in this presentation.

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References

FIG. 1. Observation of GaAs with step-like dopant concentration. a-c) Under-focused images. d-f) Over-focused images.

FIG. 2. Phase image of GaAs specimen reconstructed by phase-shifting method.

FIG. 3. (a) Phase image of the semiconductor laser diode using electron holography. (b) Enlarged phase image from dashed frame in FIG 3 (a). (Designed location of the p-n junction was at dashed line.)