Spectrally resolved two-photon microscopy for three-dimensional imaging and evaluation of semiconductor materials

（課程博士・様式７）（Doctoral qualification by coursework,Form 7）

学 位 論 文 要 旨

Abstract of Doctoral Thesis

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論文題目： スペクトル分解二光子顕微鏡を用いた半導体材料の三次元観察と評価に関する研究

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論文要旨：

Abstract：

This dissertation presents a method for three-dimensional imaging of defects and dopants in wide band gap semiconductors by spectrally resolved two-photon fluorescence microscopy. Tightly focused light beam radiated by titanium-doped sapphire laser is used to obtain two-photon excitation of selected area of the semiconductor sample. Photoluminescence intensity of a specific spectral range is selected by optical band pass filters and measured by photomultiplier tube. Reconstruction of specimen image is done by scanning the volume of interest by piezoelectric positioning stage and measuring the spectrally resolved photoluminescence intensity at each point.

The method was used to observe intrinsic defects in zinc oxide nanorods sample containing nanoparticles of length in range of 2.5-3.5 μm and diameter in range of 0.3-0.5μm. The sample was scanned in search for crystalline structure point defects, oxygen vacancies and zinc antisites. The study found agglomerations of the above defects and image of their distribution was acquired. The results and analysis of depth of penetration and achievable resolution for the said wide band gap semiconductor material is presented

Another investigated application was imaging of depth and distribution of doped areas in semiconductors, namely gallium doped zinc selenide. Imaging abilities were compared with the confocal fluorescence microscopy. The developed two-photon microscope was able to image the whole doped area, which was beyond capabilities of the industrially-available confocal microscope. Additionally the study found the extent

of diffusion of the dopant ions throughout the volume of the sample, which was impossible to image with confocal microscope.

Our method was proven to be effective in volume imaging of mechanical as well as intrinsic defects of the wide band gap semiconductors, with high axial resolution. The resolution of the method was calculated using the equations available in the literature. The theoretical lateral resolution of two-photon fluorescent microscope with presented parameters is 163 nm, and the theoretical axial resolution is 1198 nm, however it has to be noted, that in presented cases the resolution is additionally affected by the excited charge carrier diffusion. High carrier lifetime and mobility in the semiconductors results in radiative recombination of some charge carriers outside of the irradiation area. Precise impact of this phenomenon on the resolution is impossible to predict. Maximum imaging depth was estimated at 35 µm for zinc oxide monocrystals and is dependent on the sample.

Two-photon imaging inflicts minimal harm to the sample, and can be considered as a nondestructive method. Therefore this method can be used for quality control of preprocessed semiconductors by detecting mechanical impurities as well as determining the content of intrinsic defects by testing the same sample at any stage of production of semiconductor devices. Other methods of volume defect identification, like XRD, provide information only about the existence of various defects, without the ability to image them. Imaging of these defects will help in gaining a better understanding of their source and propagation, and might lead to significant improvements in suppressing the formation of impurities during the processing of semiconductors.