Study on Single-Photon Detection by Silicon-On-Insulator Metal-Oxide-Semiconductor Field-Effect

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学 位 論 文 要 旨

Abstract of Doctoral Thesis

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論文題目：シリコン・オン・インシュレーター金属酸化膜半導体電界効果トランジスタによる単一光子検出の研究

Title of Thesis : Study on Single-Photon Detection by Silicon-On-Insulator Metal-Oxide-Semiconductor Field-Effect Transistor

論文要旨：

Abstract：

A single hole sensitivity operation has the unique property of directly detection photo-generated carriers one by one, which makes silicon-on-insulator (SOI) metal-oxide-semiconductor field-effect transistor (MOSFET) single-photon detector promising for novel function electronics operating at room temperature. Some prospective type single photon detector based on a scaled-down (gate length L= 65 nm and channel width W= 105 nm) SOI MOSFET, which features improved quantum efficiency (QE), low dark counts and higher operation speed. However, in these devices, a special double-gate structure with a short lower gate (LG) and a long upper gate (UG) covering the entire p-doped SOI area was used to create potential well below the LG to trap photo-generated holes. This complex structure resulted in still low QE, and might be an obstacle to general use. A simple structure of SOI MOSFET that can be found in ordinary integrated circuits is evaluated as a single-photon detector. A potential well created by $n^+p^-n^+$ junctions is used to trap photo-generated holes, and the presence of the holes is detected as increased electron current in the top or bottom channel. In this background, it is attractive to observed novel function of SOI MOSFET with different structure.

In this thesis, analysis of hole lifetime SOI MOSFET single-photon detector 1), effect of substrate voltage SOI MOFSET single photon detector on noise and hole lifetime 2) and novel function of SOI Fin-type field effect transistor as single photon detector 3) is demonstrated. Low-frequency noise and hole lifetime in SOI MOSFET are analyzed, considering their use in photon detection based on single-hole counting. The

noise becomes minimum at around the transition point between front- and back-channel operations when the substrate voltage is varied, and increases largely on both negative and positive sides of the substrate voltage showing peculiar Lorentzian (generation-recombination) noise spectra. Hole lifetime is evaluated by the analysis of drain current histogram at different substrate voltages. It is found that the peaks in the histogram corresponding to the larger number of stored holes become higher as the substrate bias becomes larger. This can be attributed to the prolonged lifetime caused by the higher electric field inside the body of SOI MOSFET. It can be concluded that, once the inversion channel is induced for detection of the photo-generated holes, the small absolute substrate bias is favorable for short lifetime and low noise, leading to high-speed operation.

Dark and maximum count rates are quantitatively correlated to device performances. From Simulation result the state-of-the-art charge sensor can realize maximum count rate of 7.6 Ms^{-1}, dark count rate of 0.01 s^{-1}, and the dynamic range of 178 dB with charge sensitivity of 10^{-5} e/√Hz.

In the SOI fin-type field effect transistor (FinFET) with multigate structure was investigated as a photon detector. We could successfully confirm the photodetection capability, in that the drain current histogram evolved toward the high-current side as the light intensity increased, reflecting the accumulation of photogenerated holes. Although the QE improved to 9.0% at λ= 400 nm, we could not attain better charge sensitivity or dynamic range as a photon detector. Further investigation in device structure and dimensions for higher charge sensitivity is anticipated.