A Study on Silicon-On-Insulator Nanowire Photodetectors with Bow-Tie Surface Plasmon Antenna

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

学位論文要旨

Abstract of Doctoral Thesis

専　攻：　　　　　　　　　　　　　氏　名：

Course：Department of Nanovision Technology　　Name：SHARMA YASH

論文題目：

Title of Thesis : A Study on Silicon-On-Insulator Nanowire Photodetectors with Bow-Tie Surface Plasmon Antenna（ボウタイ表面プラズモンアンテナ付きシリコン・オン・インシュレーター　ナノワイヤ光検出器の研究）

論文要旨：

Abstract： The main objective of this research is to put forward a novel idea of incorporating a surface plasmon (SP) antenna in the shape of a bow-tie to photodetectors, viz. silicon-on-insulator (SOI) nanowire pn-junction photodiode and SOI nanowire n-channel metal-oxide-semiconductor field-effect transistor (MOSFET). SOI nanowire photodiodes are expected to realize high speed operation due to the reduced parasitic capacitances, associated with small geometry and lower dielectric constant of the buried oxide below the silicon (Si) layer. However, they suffer from poor sensitivity due to the small Si thickness and the small area for light absorption.

Scaled-down SOI MOSFET (gate length L= 65 nm and channel width W= 105 nm) has been recently characterized to be used as single-photon detector centered on counting single holes, having various advantages and can outperform the conventional single-photon detectors. Conventional photodiodes, for instance, avalanche photodiodes and photomultiplier tubes rely on carrier multiplication to detect the incident photons. However, the carrier multiplication process leads to after pulses, high operational voltage, large dark counts and long electron transit time. SOI MOSFET photon detector based on single-hole counting can overcome such issues since the detection mechanism is based on counting holes one by one. However, it suffers from low quantum efficiency due to less light absorption area.

By incorporating a surface plasmon (SP) antenna, the light absorption efficiency in a small thickness can be enhanced, and the light receiving area can be

increased simultaneously. It is expected that when the light enters the nanoantenna, it resonantly excites the surface plasmons on the surface of gold bow-tie structure. Initially, the bow-tie is closed, but a nanogap can be created at the junction of the bow-tie by electromigration. The excited surface plasmons can result in an enhancement of electric field near the nanogap. Eventually, the optical near field will generate extra carriers within the depleted Si nanowire. A bow-tie structure is considered mainly for the simplicity of the design and it can also be used as a gate electrode of the SOI MOSFET, and can possibly enhance the electric field near the nanogap generating extra holes to be counted by the MOSFET. This may lead to increment in the quantum efficiency of the SOI MOSFET photon detector. Similarly bow-tie antenna can increase the cathode current in SOI pn-junction photodiode.

In the first part of the thesis, we explain the fabrication process of the nanowire photodetectors. Top-down approach is used, mainly because of the better control on the nanowire size and position and the repeatability of the processes involved. The fabrication process comprises of various process steps of electron beam lithography, dry/wet etching, metal and dielectric deposition and annealing. Pre-developed recipes are used when available. New recipes are also developed to fabricate the devices efficiently.

In the next part of the thesis, we perform electrical and optical characterization of pn-junction photodiodes in visible incident light. We demonstrate the formation of nanogap in the bow-tie antenna by controlled passage of current through the bow-tie structure, thereby creating a nanogap by electromigration. The nanogap size can be quantitatively estimated by the tunneling current. Finite-difference time-domain simulations are also performed, which clearly show the electric field generated in the bow-tie structure is concentrated at the nanogap and there is an enhancement of light absorption in the Si nanowire under the bow-tie antenna.

In the final part of the thesis, we experimentally demonstrate single-hole counting operation of the SOI nanowire MOSFET. The hole generation rate is observed to be directly proportional to the intensity of the incident light.

Since the fabrication process is compatible with the CMOS fabrication in the semiconductor industry, such devices bring about the new functionality of photon detection to CMOS integrated circuits.