博士論文（要約）

Study on Waveguide InGaAs Photodetectors on III-V CMOS Photonics Platform

（III-V CMOS フォトニクス・プラットフォーム上導波路型 InGaAs 受光器に関する研究）

A DISSERTATION
SUBMITTED TO THE DEPARTMENT OF ELECTRICAL
ENGINEERING AND INFORMATION SYSTEMS OF
THE UNIVERSITY OF TOKYO
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

December 1st, 2014

37-117379

Yongpeng CHENG (程　勇鵬)

Supervisor: Professor Mitsuru TAKENAKA

In this doctor thesis, we concentrate the studies on MSM InGaAs photodetectors monolithically integrated with InP photonic-wire waveguide on III-V CMOS photonics platform for the optical interconnect applications.

For the background in chapter 1, we give simple descriptions of the progress and problems for the electronic industries and also give some potential future trends and solutions, including:

- III-V materials introduction into present existing Si-based MOSFET industries for high electron mobility and low power consumption purposes in electronic view;
- Optical interconnects for high-volume, low interference, and low power-consumption data transmissions or communications between electronic elements in photonics view;
- Some platforms to realize the opto-electronic integrations for future super chips with high performance, including our own "III-V CMOS photonics platform" for my doctor researches.

In chapter 2, to demonstrate InGaAs photodetectors for optical interconnects on III-V CMOS photonics platform, we, at first, decide to use MSM electrical structures for easy fabrication and high speed considerations, and we checked several metals to find a suitable metal (Ni) and deposition method (metal evaporation) for our MSM photodetectors. Then, we explained the metal/ semiconductor contact mechanism and some common methods to evaluate the SBH of it; and then, we analyzed the Ni/ InGaAs contact in the perspective of dark current components; and next, we designed some contact structures and process flow to extract the dark current components for both Ni/ InGaAs contact and Ni-InGaAs alloy / InGaAs contact with different passivation layers; finally, by using only the junction leakage component, we tried to give a more precise evaluation for SBH of Ni/ InGaAs contact and Ni-InGaAs alloy / InGaAs contact. And we also make a comparison of the SBH value with other literatures. Thereby, based on these researches, we know the Ni/InGaAs contact characteristics deeply and it gives meaningful clues for our later simulations, designs and fabrications of InGaAs MSM photodetectors.

In chapter 3, by several electrical simulations, we designed 350nm i-InP waveguide layer and 200nm p-InGaAs PD absorption layer using the III-V/OI wafers on III-V CMOS photonics platform; and by some optical simulations, we know the propagation situations for the PD regions and found the reflection at the InGaAs edge is neglectable, and we also found 20μm PD length is enough for optical absorption and suitable for broad-band applications. Then, we successfully demonstrated the InGaAs MSM PD monolithically integrated with the InP photonic-wire waveguide on the SiO_2/Si wafer. Owing to the strong optical confinement in the III-V-OI layer, the 20-μm-long InGaAs MSM PD exhibits high responsivity of more than 1.05 A/W and the broadband operation covering the C- and L-band. Thus, the InGaAs PD on the III-V CMOS photonics platform enables WDM chip-scale optical interconnects monolithically integrated with high-performance InGaAs MOS transistors.

In chapter 4, to reduce the dark current of the 1st demonstrated MSM InGaAs PD on III-V CMOS photonics platform, we did several researches as follows:

- We checked the influences of the InP waveguide layer below and found the influences of the InP waveguide layer is small for the dark current view;
- By reducing the III-V mesa size and designing the electrode finger tips out of the III-V mesa, we reduced the dark current and it increases slower with voltage;
- After finding the real origin of the Ni/ InGaAs MSM PD dark current is surface leakage, we tried several passivation methods to reduce the surface leakage, including oxide passivation and Schottky barrier enhancement (SBE) layer passivation;
- Finally, we found InAlAs SBE layer and InP SBE layer are effective for surface leakage reduction and we obtained several contact properties of them in dark current component view, giving us enough proofs for later low-dark-current waveguide MSM InGaAs photodetector demonstrations.

In chapter 5, based on the analysis of small mesa size design and the SBE (InP and InAlAs) layer effects for Ni/InGaAs contact, we proposed the InP/InAlAs SBE layer structure and successfully demonstrated the low-dark-current InGaAs MSM photodetectors integrated with InP waveguide on the SiO_2/Si wafer. Owing to the SBE double layer and the small mesa size, the dark current is reduced to 7nA with the responsivity of 0.15A/W at 1V bias. And when we use 2V bias, the responsivity can be 0.2A/W. The responsivity can be further improved by gradually component changed InAlAs SBE layer. Thus, the demonstrated waveguide InGaAs PDs are suitable for low-power-consumption receiver chips fabricated on III-V CMOS photonics platform.

In chapter 6, we tried to demonstrate grating couplers for the integration view with our waveguide PDs on III-V CMOS photonics platform. At first, by simple calculations using “phase matching condition” and rough simulations using “RSOFT-Full wave” tools, we obtained the design of 0.64μm grating pitch with 100nm etching depth for the 1.55μm wavelength operation using our 350nm InP waveguide layer on the III-V CMOS photonics platform. And by several fabrications and tests for grating couplers with different structures, we obtained less than 6dB coupling efficiency with 40nm FWHM spectrum range and 1555nm peak wavelength by the structure of 0.66μm grating pitch, 100nm etching depth and 0.5 filling factor. And we can use this grating coupler structure for the PD integration in next chapter.

In chapter 7, we successfully make an integration of grating coupler and waveguide photodetectors on our III-V CMOS photonics platform: the photodetector works over 4 orders of I_{on} / I_{off} ratio even by 0dBm fiber optical input; The dark current is around 1nA which is one of the lowest records for the MSM PDs; The grating couplers integrated to the PDs also show good characteristics (1555nm central wavelength with ~80nm FWHM range), well matching to the previously demonstrated ones in chapter 6;

In chapter 8, we give our conclusions and future prospective to improve photodetector responsivity by using graded SBE layers.