博士論文(要約)

Study on monolithic integration of InGaAsP optical modulator and InGaAs driver MOSFET on III-V CMOS photonics platform

(III-V CMOS フォトニクス・プラットフォーム上における **InGaAsP** 光変調器および **InGaAs** 駆動用 **MOSFET** の モノリシック集積に関する研究**)**

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論 文 の 内 容 の 要 約

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Si electro-photonic integrated circuit (EPIC) has been enabled to realize ultra-small EPIC using a strong optical confinement by large refractive index differences between Si and buried oxide layer (BOX). The monolithically integrated Si MOSFET based on mature Si CMOS technology serve high compatibility of electronic-photonic integration. However, the Si which has indirect bandgap structure, is not a suitable for monolithic integration of active optical component such as optical source. The conventional InP based photonics has been widely used for optical communication and it was very proper to realize active component. Therefore, various EPIC based on III-V photonics have been demonstrated in early 1980's even technological difficulties. But, the weak optical confinement was not a CMOS compatible and poor MOS interface of III-V material prohibit the monolithic integration of III-V MOS devices. To overcome these problems, the III-V CMOS photonics platform has been suggested. The III-V CMOS platform is realized by III-V on insulator (III-VOI) wafer by direct wafer bonding (DWB) method. This III-VOI wafer serve the strong optical confinement by large refractive index differences between III-V and SiO_2 same as Si photonics. Moreover, the improved MOS interface of III-V material enable to realize MOSFET. Thus, the III-V CMOS photonics platform give the potential of monolithic integration of ultra-small III-V photonic components and III-V electronics. Recently, there are several photonic and electronic devices such as ultra-small array waveguide grating (AWG), sharp-bend waveguide (WG) and InGaAs-OI MOSFET have been reported on III-V CMOS photonics platform. Nevertheless, the monolithically integrated active photonic component such as optical modulator and electronic device are not reported yet on III-V CMOS photonics platform because of several issues. One is the large propagation loss of WG, another one is the thermal budget control for monolithic integration. The high resistance of lateral P-I-N junction also one of issue.

In this thesis, we demonstrated the monolithically integrated InGaAsP optical modulator with InGaAs driver MOSFET on III-V CMOS photonics platform with solving above problems.

Firstly, the effect of pre-bonding annealing on III-VOI wafer was investigated. The micro-void generation while post annealing process prohibit the optical propagation of waveguide. By applying pre-bonding annealing process, we successfully suppressed void generation. The void density was highly reduced from 10^6 to 10^3 after post annealing process at 600°C. Then propagation loss by sidewall roughness was reduced by optimization of process condition. By electron-beam (EB) lithography and controlling etching condition, the roughness of sidewall of waveguide was reduces from 11 nm to 4 nm.

Secondly, low resistive lateral P-I-N junction was formed by Zn diffusion and Ni-InGaAsP alloy junction. The conventional ion implantation process which is needed high temperature activation process, was replaced to Zn diffusion and Ni-InGaAsP alloy method. By Zn diffusion method, the sheet and contact resistance of p^+ region was highly reduced compare to Be ion implantation method. Moreover, the Ni-InGaAsP alloy was firstly demonstrated to replace Si ion implantation. The Ni-InGaAsP alloy enable to make a low resistive n^+ junction with low temperature under 350°C. Although the total process temperature was suppressed to 500°C, the access resistance of InGaAsP P-I-N junction was reduced from 2.4 Ω·cm to 0.4 Ω·cm. Using these result, we demonstrated the InGaAsP optical modulator using optical absorption. The InGaAsP modulator shows almost -40dB/mm attenuation at 40mA/mm current injection which is almost 2 times larger than Si modulator. By numerical analysis, we investigated that this large attenuation comes from the inter-valence band absorption of InGaAsP.

Finally, we firstly demonstrated monolithically integrated InGaAsP asymmetric Mach-Zehnder interferometer (MZI) modulator and InGaAs driver MOSFET. The InGaAsP modulator shows shift of free-spectrum range (FSR) by current injection and it needs almost 2.2 mA for π shift. While modulator operation via InGaAs driver MOSFET, we obtained the phase shift of InGaAsP modulator by gate bias change.