博士論文（要約）

Study on Active Optical Devices using Lateral p-i-n Junctions on III-V CMOS Photonics Platform

（横方向 **p-i-n** 接合を用いた **III-V CMOS** フォトニクス・プラットフォーム上アクティブ光デバイスに関する研究）

一宮 佑希

Yuki Ikku

Department of Electronic Engineering and Information Systems

The University of Tokyo

December 1st, 2014

Supervisor: Associate Professor Mitsuru Takenaka

博士論文の要約

Si photonics platform has been thought to be a promising technology which realizes optical interconnect and small communication devices with low cost. However, integration with active devices such as lasers has been a problem for Si photonics. On the other hand, conventional InP-based waveguide devices where lasers can be monolithically integrated have been suffered from the weak optical confinement, which prevents large scale integration. To overcome these problems, we have proposed III-V CMOS photonics platform which can integrate high performance III-V-compound semiconductor-based MOSFETs and compact III-V-based photonic-wire waveguide devices by using III-V-on-Insulator (III-V-OI) wafers fabricated by wafer bonding. The large index contrast between the III-V and SiO_2 enables strong optical confinement as like in Si photonics. III-V CMOS photonics also enables monolithic integration of active and passive optical devices. Using this platform, sharp-bend waveguides, ultra-small AWGs and InGaAs MOSFETs have been demonstrated. Carrier injection type 1 × 2 Mach-Zehnder interferometer (MZI) InGaAsP photonic-wire optical switches have also been demonstrated. Although this switch has been the first electrically driven active device on III-V CMOS photonics platform, there have been several problems. One is the large propagation loss in the waveguides, another is the unreliability of the thermal resistance of the III-V OI wafers and the other is the high access resistance of the lateral pin junctions. These problems are common to many active devices on III-V photonics platform including laser diodes.

In this thesis, we have solved these three problems of active devices on III-V CMOS photonics platform. Then, compact and low-crosstalk optical switches have been

demonstrated.

Firstly, the amount of the carrier-induced refractive index change in InGaAsP was estimated. Compared to Si, the index change was predicted to be about 5 times larger in InGaAsP with lower absorption, which indicates that InGaAsP is the better material for switches and modulators.

Secondly, the propagation loss induced by the scattering from the top and the bottom of the waveguide was reduced by inserting InP passivation layer. The loss from the sidewall was reduced by Al_2O_3 passivation and optimizing the etching process. As a result, propagation loss of 1-μm-wide waveguide was reduced to 1.2 dB/mm. Then, the propagation loss was predicted to be reduced to the comparable value with Si waveguides by using the EB lithography instead of the photolithography.

Thirdly, thermal tolerance of the III-V-OI wafer was investigated. Generation of the voids on III-V-OI wafers after high temperature annealing was suppressed by increasing the temperature of the reactor where the Al_2O_3 bonding interface was deposited. After that, we have found that the interface between InP and Al_2O_3 is seriously damaged by high temperature annealing and that deteriorates the thermal tolerance of the III-V-OI wafers. This problem was solved by the re-capping and PECVD SiO_2 bonding interface.

Then, resistances of the lateral p-i-n junctions were investigated. We have found that the sheet resistance of the p^+ region which was formed by ion implantation of Be was high. The resistance of the p^+ region was reduced by using Zn diffusion instead of the ion implantation. In addition, contact resistance was reduced by annealing the diodes at 300 ºC. From these results, the access resistance of the lateral p-i-n junction was estimated to be 2.4 Ω·cm.

Using these results, 2 × 2 Mach-Zehnder interferometer InGaAsP photonic-wire optical switches have been demonstrated with low propagation loss and resistance. The length of the phase shifter was 500 μm and the driving voltage was 2V. Low-crosstalk of -30 dB was obtained thanks to the large carrier-induced refractive index change in InGaAsP. The crosstalk value was about 8 dB lower than the theoretical limit in Si optical switches. We have also demonstrated optical switches with 50-μm-long phase shifters. In spite of the small phase shifter length, low crosstalk of -29 dB was obtained, which is about 10 dB lower than the limit of Si optical switches.

After that, the resistance of the lateral p-i-n junction was found to be lowered by reducing the length of the 'i' layer.

Finally, we have numerically analyzed electro-optic effects and carrier depletion effects in InGaAsP for high speed InGaAsP photonic-wire modulators. Largest index change was predicted on p-InGaAsP(110) wafer when the angle of the waveguide is 50º with respect to the (001) plane. Modulators can be also fabricated on p-InGaAsP(001) wafer by using the carrier depletion effect.