論文 / 著書情報
Article / Book Information

題目(和文)	プラズマ活性化接合を用いた III-V/Siハイブリッド光アクティブデバイスの研究
Title(English)	Study of III-V/Si Hybrid Photonic Active Devices using Plasma Activated Bonding
著者(和文)	林侑介
Author(English)	Yuusuke Hayashi
出典(和文)	学位:博士(学術), 学位授与機関:東京工業大学, 報告番号:甲第10563号, 授与年月日:2017年3月26日, 学位の種別:課程博士, 審査員:西山 伸彦,荒井 滋久,水本 哲弥,宮本 恭幸,庄司 雄哉,田辺 克明
Citation(English)	Degree:Doctor (Academic), Conferring organization: Tokyo Institute of Technology, Report number:甲第10563号, Conferred date:2017/3/26, Degree Type:Course doctor, Examiner:,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

Study of III-V/Si Hybrid Photonic Active Devices using Plasma Activated Bonding

(プラズマ活性化接合を用いた

III-V/Si ハイブリッドアクティブデバイスの研究)

Summary of Doctoral Dissertation
(論文要約)

February 22nd, 2017

Directed by:
Prof. Nobuhiko NISHIYAMA
Prof. Shigehisa ARAI

Yusuke HAYASHI

Department of Electrical and Electronic Engineering
Graduate School of Science and Engineering
Tokyo Institute of Technology

In this thesis, III-V/Si hybrid active devices fabricated by N_2 plasma activated bonding (PAB) were investigated for the realization of photonics- electronics convergence routers (PECR).

In chapter 1, history and current situation of optical communications, photonic integrated circuits, silicon photonics, and III-V/Si hybrid integration are explained. Based on these background, research goals, research methods and structure of the thesis are explained.

In chapter 2, design of III-V/Si hybrid devices are discussed. Wavelength-unable laser is one of key components to realize PECR. On the assumption of using Si ring resonators as reflective mirrors, filtering performance is investigated. By using Vernier effect, cascaded ring resonators can exhibit high mode selectivity as well as wide free spectral range beyond C-band.

Based on these ring resonator characteristics, laser performance was numerically calculated. Assuming final goals are laser performance such as threshold current (I_{th}) < 20 mA, external differential quantum efficiency (η_d) > 30%, and sub-mode suppression ratio (SMSR) > 30dB, design of ring resonators satisfying these three conditions was clarified by numerical calculations. Structure of III-V/Si tapers was also investigated to adiabatically connect optical mode between Si waveguide and III-V/Si waveguide. Numerical calculation based on finite difference method (FDM) and eigen mode expansion method (EME) revealed that a coupling efficiency of -1dB (79%) can be achieved at a taper length of 140 μm.

In chapter 3, low temperature direct bonding technique using N_2 plasma activated bonding is discussed. In III-V/Si direct bonding process, annealing process basically causes thermal stress due to the thermal expansion coefficient difference between InP and Si. Compared with conventional bonding method using annealing temperature of more than 250°C, N_2 PAB is expected to enable tighter bonding strength even with bonding temperature as low as 150°C. We have been investing this bonding technique by using the vacuum chamber that can maintain high vacuum state of 10^{-4} Pa during bonding process. By investing cleaning process of sample surface, bonded area was successfully widened from 2 x 2 cm^2 die to a 2-inch wafer. From TEM measurement of cross section, III-V and Si was found to be bonded rigidly, without any exfoliation. When introducing Si waveguide patterns on a silicon-on-insulator (SOI) surface, bonded area was found to be decreased greatly because of air voids appeared along waveguide patterns. To solve this problem, hydrophobization of SOI surface was carried out by introducing N_2 annealing process and rib waveguide structure. 86% bonded area on a patterned SOI wafer was finally achieved due to these improvements.

In chapter 4, fabrication techniques for III-V/Si hybrid devices are described. Basic fabrication and evaluation of Si ring resonators and III-V/Si tapers are mainly discussed here. As for ring resonators, peak wavelength control of ring resonators was demonstrated because it is important to control lasing wavelength of a hybrid laser. Because refractive index of Si can be varied by thermos-optic effect, resonant wavelength can be controlled by heating ring resonators with a microheater. Analytical calculation clarified temperature rise by 45°C is enough for achieving phase shift of 2π. This means entire FSR of a ring resonator can be covered with the temperature rise. From calculation of thermal distribution based on 2D finite element method, injection power of 24 mW was found to be enough to cause temperature rise of 45°C. This estimation was experimentally examined. When using 142-μm long resonator, sweeping of entire FSR of 4.1 nm was confirmed at injection power of 40 mW. Additionally cascading of two rings was demonstrated to get wider FSR by Vernier effect. FSR of 50 nm was achieved by independently controlling dissipated power at microheaters put on each ring.

In chapter 5, Fabrication and characterization of III-V/Si hybrid devices are described. Several types of GaInAsP/SOI hybrid lasers using N_2 PAB are demonstrated, and their details are explained here. The first demonstration of hybrid laser was fabricated on a bare SOI wafer to see the effect of N_2 PAB on III-V layer structure. Lasing operation was obtained under pulsed current pumping, and relatively low threshold current density (J_{th}) of 850 A/cm^{-2} was achieved. This can be explained by reduction of thermal stress due to the introduction of N_2 PAB. Additionally, room-temperature continuous-wave (RT-CW) operation was achieved by introducing a Si waveguide and current confinement structure. 100-μm wide mesa and 2-μm high Au electrode successfully decreased thermal resistance to 32 K/W, which also contributed to the RT-CW operation. Based on these basic characteristics, a hybrid laser using Si ring resonators as reflective mirrors was demonstrated. From the measurement of lasing wavelength, intensity peak derived from cascaded two ring resonators was confirmed. Thus, lasing operation not using facet cleaving was realized on a III-V/Si hybrid chip.

As a summary, III-V/Si hybrid active devices fabricated by N_2 PAB were investigated in this thesis. By using N_2 PAB, relatively low J_{th} of 850 A/cm^{-2} was achieved. Furthermore, RT-CW operation of hybrid lasers were achieved by introduction of current confinement structure and reduction of thermal resistance. Finally, based on these basic characteristics, a hybrid laser using Si ring resonators as reflective mirrors was demonstrated.