論文の内容の要旨

Study on Silicon/InGaAsP Integrated Photonic Devices by Ar/O_2 Plasma Assisted Direct Bonding
（Ar/O_2 プラズマ直接接合法によるシリコン・InGaAsP 集積フォトニクスデバイスに関する研究）

李　凌瀚

SILICON-on-insulator (SOI)-based photonic devices have been attracting much research interest because of their potential for optical and electrical monolithic integration as well as for realizing compact photonic devices. However, because of the inefficient light generation in silicon, heterointegration of III-V materials to silicon is always considered as a very promising and necessary solution. Since the lattice mismatch between silicon and III-V active materials introduces large dislocations and initial stress, making the direct growth of a high quality III-V material layer on silicon very difficult, the direct bonding method attracted great research interest as a practical technology. As a result, several breakthroughs in silicon active devices have been achieved. However, technical challenges such as direct current injection from silicon to III-V material for light emission, excessive coupling loss caused by the mode size mismatch among interconnection still remains.

In this work, The Ar/O_2 plasma assisted direct bonding technology for silicon and InGaAsP material heterointegration was first introduced. The effective direct current injection from silicon to III-V materials was realized by Ar/O_2 plasma assisted direct bonding. The $In_{0.75}Ga_{0.25}As_{0.45}P_{0.55}$ interlayer between silicon and InGaAsP materials and the proportion of argon and oxygen in plasma treatment plays an important role among others in the improvement of efficient current injection.

Later a direct-current-pump silcion/InGaAsP spontaneous light emission was further demonstrated by plasma assisted direct bonding, demonstrating with a threshold current of 780mA/mm^2 at 15 °C.

The silicon/InGaAsP hybrid waveguide was simulated and analyzed using effective index method and FDMBPM simulation. The prototype of the hybrid waveguide was fabricated by Ar/O_2 plasma assisted direct bonding. With p doped and n doped silicon micro rib of 10^{19} atom/cm^3, the propagation loss of the waveguides is 3.04dB/mm and 2.9dB/mm, respectively. The direct-current-pumped silicon/InGaAsP Fabry-Perot laser was then demonstrated under 5^0C with 75mA threshold current. The central peak of the lasing was around 1556nm with 0.2nm linewidth. The silicon/InGaAsP vertical PIN photodiode was also realized. The photodiode shows around 50% quantum efficiency at 1550nm and TE polarization.

Finally, the novel technology basing on two quite robust processes: sub-micron loading effect in the ICP dry etching and oxidation for constructing 3D microstructures was developed. The 3D SSC has been fabricated. It is capable of converting the optical beam from a 4.6-μm-high, 3.1-μm-wide single-mode rib waveguide to a 280-nm-high, 500-nm-wide wire waveguide with a coupling loss of 1.96 dB.

This dissertation has demonstrated the potential of realizing silicon based photonic heterointegration by MEMS technology and Ar/O_2 plasma assisted direct bonding. The achievement opens a new area of realizing silicon based hybrid photonic circuit by demonstrating the basic optical active component such as laser and photo detector. Furthermore, the realization of the silicon 3D spot size convertor and relative fabrication method for 3D silicon structure reveals the possibility of low coupling loss optical interconnection.