論文の内容の要旨

Abstract of Dissertation

Title: Study on Growth of InAs Quantum Dots on Si-based Substrates by Metal Organic Chemical Vapor Deposition for Silicon Photonics Application

（シリコンフォトニクス応用に向けた有機金属気相成長法によるシリコン系基板上のインジウム砒素量子ドットの結晶成長に関する研究）

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There has been continued interest in the development of III-V light sources on Si substrate that can be integrated with Si-based electronics for silicon photonics application. However, direct growth of III-V on Si is particularly challenging due to large lattice-mismatch, and the polar/non polar nature of III-V/IV system, which generates a high density of threading dislocation and Anti-Phase Domains (APD) respectively. These defects in the epitaxial layers limit the optical and/or electronic quality of the III-V components on Si. On the other hand, Ge is an ideal intermediate material between GaAs and Si because it is both lattice matched to GaAs and

compatible to Si technology and has drawn considerable attention recently for direct growth of III-V-on-Si

For the optical source, quantum dots (QD) due to their three dimensional carrier confinement properties have been predicted to produce lasers with lower threshold current and higher temperature stability than their quantum well counterparts. QD laser on GaAs substrate at telecommunication wavelength of 1.3 μm has been commercialized. However, so far there is no report on the growth of InAs QD laser at 1.3 μm on silicon substrate. There is thus a great interest in the fabrication of QD lasers at 1.3 μm on silicon substrate. This study is aimed at growing high density InAs QD with high optical quality by MOCVD emitting in the 1.3 μm band on silicon-based substrate for silicon photonics application. Various Si-based substrates that were investigated for their suitability for the growth of InAs QD for laser application were Si, Ge/Si and germanium-on-insulator-on-silicon (GeOI) substrates.

Firstly, the growth of GaAs buffer layer on Si substrate was extensively studied. The beneficial effect of off-cut substrate in suppressing APDs in GaAs layers was confirmed. Various growth methods to obtain high structural quality GaAs buffer layer with low surface roughness on Si substrate were investigated. GaAs/Si substrate was further used to grow InAs QDs. InAs QDs were grown according to surfactant-mediated growth technique. We obtained arrays of QDs with high density (above 10^{10} cm^{-2}). These QDs yielded ground state emission in the 1.3 μm band at RT, when capped by InGaAs strain-reducing layer with a broad line-width (57 meV). The PL intensity of QDs grown on GaAs/Si substrate is one order of magnitude lower than that obtained on reference GaAs substrate. The low PL

intensity of QDs grown on GaAs/Si substrate is attributed to high density of dislocations in the GaAs buffer, which act as non-radiative centers. In the following Si substrate with Ge intermediate layer is discussed.

Si-based substrates with Ge intermediate layer that were studied in the present work were Ge/Si and GeOI substrate. GaAs buffer layer on Ge/Si and GeOI substrate was grown by three-step growth method. High structural quality GaAs layer with low surface roughness was obtained on both Ge/Si and GeOI substrates. The XRD FWHM and surface roughness of GaAs grown GeOI (Ge/Si) substrates were 42 (61) arcsec and 1 (1.2) nm. These values are less than or comparable to those reported in literature for GaAs layers grown on Ge based Si substrates. The GaAs/Ge/Si and GaAs/GeOI substrates were further used to grow InAs QDs. For QD laser application, high density of QDs (ideally 10^{11} cm^{-2}) is required. However, conventional InAs/GaAs QDs yield density in the range of (1-3) x 10^{10} cm^{-2} because of long surface migration of In adatoms. We have shown that the use of Sb allows the growth of high density (above 6 x $10^{10}cm^{-2}$) InAs/Sb:GaAs QDs on GaAs/Si, GaAs/Ge/Si and GaAs/GeOI substrate, with enhanced PL intensity at RT compared to that of InAs/GaAs QDs. In spite of high QD density, coalescence dots are suppressed. This is the first report to study the effect of surfactant on InAs QDs grown on the respective substrates

With the further optimization of the QD growth parameters such as growth temperature, growth rate, V-III ratio and coverage, we obtained arrays of QDs with high density (above 8 x 10^{10} cm^{-2}) on GaAs/Si, GaAs/Ge/Si and GaAs/GeOI substrate with ground state emission in the 1.3 μm band at RT with a narrow line-width (~27 meV, on GaAs/GeOI). The PL intensity of QDs grown on GaAs/GeSi

substrate was lower than that obtained on GaAs/GeOI substrate, while higher than that on GaAs/Si substrate. The improved PL intensity compared to that obtained on Si substrate is related to the lower density of dislocations due to lattice matched nature of GaAs/Ge system, while higher PL intensity obtained on GeOI substrate compared to that from Ge/Si substrate results from the combination of crystallographic quality of Ge layer transferred on Si substrate by smart-cut technique. The above results demonstrate the better suitability of GeOI versus Ge/Si and Si substrate for the growth of GaAs layers and InAs QDs for silicon photonics application.