論文の内容の要旨

論文題目

Thermal oxidation kinetics of SiGe layer epitaxially grown on Si substrate
（Si基板上にエピタキシャル成長されたSiGe層における熱酸化機構の研究）

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Recent metal-oxide-semiconductor field-effect transistor (MOSFET) technologies pay attention to the impact of strain on the mobility enhancement. As a *p*-type component, compressively strained high-Ge-content SiGe *p*MOSFETs have become a promising candidate for the next-generation devices. For SiGe-based MOSFETs, there are two interfaces (oxide/SiGe, and SiGe/Si) to be considered. As Ge content increases, the control of the oxide/SiGe interface becomes difficult, and the impedance caused by the SiGe/Si heterojunction interface becomes significant. However, there has been no systematic study on the understanding on these issues so far.

The main objective of this thesis is to understand the Ge reaction kinetics in preferential Si oxidation on SiGe substrate and thus to propose a way how to suppress degradation of the oxide/SiGe interface quality. This thesis proposes the thermodynamic method to achieve stable SiO_2/SiGe interface structure, and discusses the reaction mechanisms of Ge atoms at the interface. In addition, analyses of impedance properties of SiGe/Si heterojunction interface and the deposited gate dielectric film are also discussed.

In Chapter 1, necessities of SiGe oxidation study for the high-performance SiGe devices were introduced. The thermodynamics of SiGe oxidation was also discussed. In Chapter 2, basic principles of instruments employed in this thesis were briefly introduced. The accuracy issue of several measurement techniques, such as x-ray photoemission spectroscopy (XPS), x-ray diffraction (XRD), Raman spectroscopy and secondary-ion mass spectroscopy (SIMS), for the estimate of Ge concentration in SiGe substrates was discussed in detail. In Chapter 3, preferential Si oxidation of SiGe substrate based on the thermodynamic guideline was discussed. The aim of this chapter was to make thermodynamically stable SiO_2/SiGe stacks by thermal oxidation, but the Ge reaction was not discussed. Since the preferential Si oxidation was essentially the oxygen exchange process between GeO_2 and Si, the efficiency of this process is to be

examined in detail. Therefore, in Chapter 4, we discussed how well the Si atoms could take oxygen from GeO_2. To observe this process directly, GeO_2/Si stacks were designed and annealed it in UHV ambient. From the UHV annealing of these stacks, the oxygen-taking process by Si within the limited GeO_2 thickness range could be directly observed, and then the kinetics of metallic Ge atoms was conjectured. Through the GeO_2/Si stacks, each reaction path of Ge atoms was examined, and its qualitative meaning for SiGe gate stacks was discussed. The movement of Ge atoms at the oxide/Si (or /SiGe) interface was also analyzed by limited-source diffusion model. In Chapter 5, the understanding on the Ge reaction kinetics in the previous chapter was applied in the fabrication of SiGe MOS gate stacks, and its validity was verified. In this chapter, the relationship between the interface oxide growth and increase of interface state density was discussed. In Chapter 6, the impedance analysis of SiGe/Si heterojunction interface were discussed. This chapter adopted the concept of constant-phase element (CPE) for the impedance analysis, and discuss how the CPE-containing equivalent circuit should be understood. In Chapter 7, the discussion points of previous chapters (Chapter 3, Chapter 4, Chapter 5, Chapter 6) were summarized, and the future outlook of the SiGe oxidation were presented.