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Enhanced thermal and morphological stability of $Ni(Si_{1-x}Ge_x)$ growth on BF_2^+-preamorphized $Si_{0.8}Ge_{0.2}$ substrate

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Abstract

The stability of nickel germanosilicide formed on Ni thin films on $Si_{0.8}Ge_{0.2}$ was found to be enhanced by the BF_2^+-preamorphization of the epitaxial Si–Ge layer. Agglomeration of polycrystalline $Ni(Si_{1-x}Ge_x)$ is retarded by 100 °C in the BF_2^+-implanted samples. The growth of laterally uniform $Ni(Si_{1-x}Ge_x)$ and resistance to agglomeration at high temperature in the BF_2^+-implanted samples are attributed to the retardation of the growth of $Ni(Si_{1-x}Ge_x)$ grains by the presence of fluorine bubbles. Sheet resistance measurement was found to correlate well with the transmission electron microscope observation.

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1. Introduction

$Si_{1-x}Ge_x$ heterostructures are attractive for high-speed electronic and optoelectronic devices due to their high mobility and band-gap engineering possibilities, while maintaining compatibility with the widely used Si process technology. Silicide/$Si_{1-x}Ge_x$/Si heterostructures are promising for using in devices such as the heterojunction bipolar transistor and infrared detectors with high cutoff wavelengths [1,2].

The self-aligned-silicide (salicide) technique, which provides low-resistance silicide films on gate and source/drain regions, is one of most important technologies in reducing the parasitic resistance in metal-oxide-semiconductor field-effect-transistors (MOSFETs) [3,4]. NiSi is being considered as a potential candidate for ultra-shallow junction

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technologies because the same sheet resistance can be obtained with less Si consumption as compared to $CoSi_2$. NiSi is the only silicide left with comparable resistivity with $TiSi_2$ and $CoSi_2$ for the next generation of deep submicron Si based integrated circuits. On the other hand, intensive efforts have been made to extend the IC devices to other substrate frames, such as Si–Ge [5–7].

Metal germanosilicides can be used in the gate (polycrystalline) and source/drain (single crystal) areas of MOSFETs, and knowledge about the formation and stability of thin metal germanosilicide films is essential for such applications. The thermally induced metal/$Si_{1-x}Ge_x$ reaction has previously been studied for many metals, including Ti, Cu, Co, Pt, Pd and Ni [1,8–13]. Various degrees of germanium segregation and/or the formation of segregated layered structures were observed in the reactions of these metal/$Si_{1-x}Ge_x$ systems. The difference in the heats of formation for silicide and germanide offers the driving force for the segregation of Ge-rich Si–Ge alloys [7,14].

Two major concerns with NiSi are its poor phase and morphological stability under thermal process in Ni/Si system. For the Ni on blank silicon, high-resistivity $NiSi_2$ was found to form in 700 °C annealed sample [15]. Direct deposition of Ni thin films onto $Si_{1-x}Ge_x$in a self-aligned silicide (salicide) process would be an efficient technique and would take advantage of established technologies. In Ni/$Si_{1-u}Ge_u$ systems, the formation temperature of high-resistivity $NiSi_2$ is increased from 700 °C to above 900 °C as a result of the formation of a ternary Ni($Si_{1-x}Ge_x$) solid solution. However, the morphological stability of $NiSi_{1-x}Ge_x$/$Si_{1-u}Ge_u$ system is considerably worse than that of a NiSi/Si system. The undesirable characteristics lead to Ge segregation, deterioration of the $Si_{1-x}Ge_x$ layer, degradation of junction integrity, and film agglomeration at low temperatures, resulting in poor thermal stability and high-resistivity contacts [15,16].

Ion implantation has become a standard technique for ultra-shallow junctions in microelectronics devices processing. Since the presence of metal films on preamorphizied silicon may alter the defect structure and cause dopant redistribution to affect shallow junction properties, it has been of great interest to investigate the interactions of metal thin films with preamorphized silicon system [17–23]. Moreover, with an added sacrificial amorphous Si, silicidation grown on SiGe alloy was shown to improve the interfacial roughness [24]. As a result, the use of BF_2^+-preamorphized salicide process on Ni/$Si_{1-u}Ge_u$/Si system is envisioned to be a possible scheme to prevent Ge segregation, improve the NiSi film uniformity and thermal stability, and maintain good quality of $Si_{1-u}Ge_u$ layer in the reaction process. In this study, we report the successful formation of high-quality NiSi on BF_2^+-preamorphized epitaxial $Si_{0.8}Ge_{0.2}$ on silicon.

2. Experimental procedures

Single crystal, 3–5 Ω cm, phosphorous-doped (001)Si wafers were used in the present study. 200-nm-thick low-temperature Si buffer layer and 700-nm-thick $Si_{0.8}Ge_{0.2}$ layer were grown on (001)Si wafers consecutively by ultra-high vacuum chemical vapor deposition (UHV/CVD). The silicon wafers were cleaned chemically by a standard RCA cleaning process. The cleaning procedures of $Si_{0.8}Ge_{0.2}$/Si wafers are slightly different from the standard cleaning procedures of silicon wafers. Surface oxide layers were removed by etching instead of boiling in acid solutions. The acid solution was composed of H_2SO_4:H_2O_2 = 5:3 [9]. The concentrations of acid solutions need to be carefully controlled to prevent the surface of the wafers from serious pitting. The wafers were dipped in a dilute HF solution (HF:H_2O = 1:50) for 2 min immediately before loading into a medium current implanter and an ultra-high vacuum electron beam evaporation system. $Si_{0.8}Ge_{0.2}$ wafers were implanted with 20 keV BF_2^+ to a dose of 5×10^{15} cm^{-2} for preamorphization. The wafers were oriented 7° off the incident beam direction to minimize the channeling effect. From the TRIM-98 simulation [25], the projected range (R_p) of the implanted boron ions and fluorine ions dissociated from 20 keV BF_2^+ ions are 18.2 nm and 18.3 nm, respectively. A 20-nm-thick Ni layer was then deposited onto preamorphized $Si_{0.8}Ge_{0.2}$ substrate by e-beam evaporation. The vacuum was better than 5×10^{-6} Torr during the thin film deposition.