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Germanium-induced Modulation of Work Function and Impurity Segregation Effect in Fully-Ni-germanosilicide ($Ni(Si_{1-x}Ge_x)$) Gate

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1. Introduction

It has been recognized that reduction of sheet resistance of gate electrode and suppression of gate depletion are key factors for achieving high-performance MOSFETs in deep sub-50 nm gate regime. Metal gate technology is the solution for these issues. The most difficult challenge is work function control to maintain low Vth of less than 0.4 V. Fully-silicide gate is one of the promising candidates for realizing dual work function by segregating impurities at silicide gate electrode/gate insulator interface [1,2]. However, the maximum modulation range ever reported is only 0.32 eV, obtained by Sb, which is insufficient for CMOS application to achieve a low Vth.

In this paper, a new method for modulating flatband voltage (Vfb) is reported. The effect of Ge incorporation into fully-Ni silicide gate is investigated. It is demonstrated that $Ni(Si_{1-x}Ge_x)$ changes Vfb according to Ge fraction: x. In addition, the Ge incorporation modulates the Vfb shift effect of B impurity to the opposite direction, compared to the previous report [2]. As a result, the controllable range can be expanded to 0.47 eV near the midgap.

2. Experimental

$Ni(Si_{1-x}Ge_x)$ gated capacitors were fabricated on lightly-doped p-type (100) Si substrates. Following the growth of 10 nm thermally grown SiO_2 dielectric, 50 nm poly-Si or poly-SiGe (Ge≤30%) layers were deposited. Then poly-Si and poly-SiGe were doped with various amounts of B, As and P, and were activated with a 1015°C, 10s anneal. After patterning gate electrode, the gates were silicided with Ni at 450°C or 550°C for 60s in N_2 atmosphere. The CV characteristics were measured at 100 kHz. These samples were analyzed by XRD, TEM, and SIMS.

3. Results and Discussion

A. Effect of Ge incorporation

As shown in Fig. 1, the CV curve shifts to the positive direction, and the work function changes from 4.73 eV to 4.86 eV with increasing Ni thickness. It is identified from the XRD analysis that NiSi is formed in the case of 30 nm Ni sputtered sample, and Ni_2Si is formed in the case of 50 nm Ni sputtered sample (not shown). Therefore, the Vfb difference is caused by the phase change from NiSi to Ni_2Si with an increase in Ni-sputtered thickness [3].

In the 30 nm Ni-sputtered sample, a constant Vfb value (-0.46 V) is obtained, independent of the Ge fraction (Fig. 2). On the other hand, the Vfb values vary with Ge fraction in the case of 50 nm Ni sputtered sample; Vfb shifts to the negative direction (-0.42 V) with 5% Ge incorporated, and is fixed until Ge fraction increases to 25%. Then the Vfb value shifts to the opposite (positive) direction with 30% Ge incorporated (Fig. 2). As shown in Fig. 3, only in the 50 nm Ni sputtered sample (Fig3. (b)), Ni_2Si is formed near the surface region. Near the SiO_2 interface, on the other hand, Ni(SiGe) is formed in both cases. Therefore, the negative shift in the case of Ge=5-25 % can be caused by the phase change from Ni_2Si to Ni(SiGe) at the SiO_2 interface. From the TEM-EDX analysis, it is identified that Ge can be solved only in the Ni(SiGe) phase. As shown in Fig. 4, in the 50 nm Ni sputtered case, the Ge fraction in the Ni(SiGe) is twice as high as that of poly-SiGe before forming Ni(SiGe), while they are linear in the 30 nm Ni sputtered sample. This is because drive out of Ge from the surface Ni_2Si region results in the Ge condensation in the Ni(SiGe) grain near the SiO_2 interface (Fig. 5). Final Ge fraction in the Ni(SiGe) is about 60% in the 50 nm Ni sputtered sample with an initial Ge fraction of 30%. The positive Vfb shift in that highest Ge condensation (60%) (Fig. 2) equivalently agrees with the direction to the work function of NiGe, which is reported as 5.2 eV [4]. This result suggests that higher Ge fraction is required to control the work function between the NiSi and NiGe values.

B. Ge-induced modulation of impurity segregation effect

In the B-doped Ni_2Si samples, Vfb shifts to the positive direction, which is similar to the results in Ref. [2]. Inversely, in the B-doped Ni(SiGe) samples, Vfb shifts to the *negative* direction (Fig. 6). The modulation range increases with increasing Ge fraction. The controllable range of work function reaches 0.47eV by incorporating Ge (4.94 eV (Ge=0%) to 4.47 eV (Ge=30%)) (Fig. 7). This value is larger than that of Sb-induced work function modulation [2]. In the NiSiGe sample, Ge is segregated near the gate electrode/SiO_2 interface (Fig. 8). However, the Ge incorporation has little influence on the segregation of B at the SiO_2 interface, indicating that the impurity segregation effect on work function is affected by the presence of Ge. Although the reason is not clear at present, our experimental results provide a hint for understanding physical mechanism of work function modulation induced by the impurity segregation.

In both As and P implanted samples, Vfb shifts to the negative direction as previously reported, and the Ge incorporation expands the modulation ranges (Fig. 9). An addition of the phase change effect (Ni_2Si to Ni(SiGe)) to the impurity segregation effect results in enhanced Vfb control range.

4. Conclusion

Ge-induced Vfb modulation in fully-germanosilicide gate has been thoroughly investigated. It has been demonstrated that negative Vfb shifts, observed in the case of Ge=5-25% samples, can be caused by the phase change from Ni_2Si to Ni(SiGe). Higher Ge fraction in Ni(SiGe) (Ge≥60%) is required in order to modulate Vfb toward that of NiGe(positive shift). In addition, the Ge incorporation can expand a controllable Vfb range, and the widest range of segregated impurity modulation, which reaches 0.47 eV near the midgap, has been achieved.

Acknowledgment

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Reference

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[3] Y.J. Chang *et al.*, J. Vac. Sci Technol.**A1** (1983) 1193.
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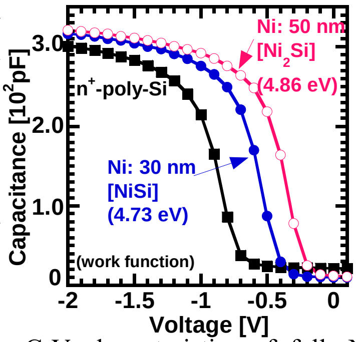


Fig. 1: C-V characteristics of fully-Ni silicide and n^+-poly Si gates. The values of work function obtained from the Vfb-Teff plot are also shown.

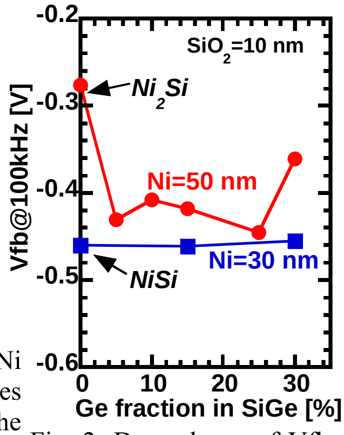


Fig. 2: Dependence of Vfb on Ge fraction in SiGe-layer before forming germanosilicide.

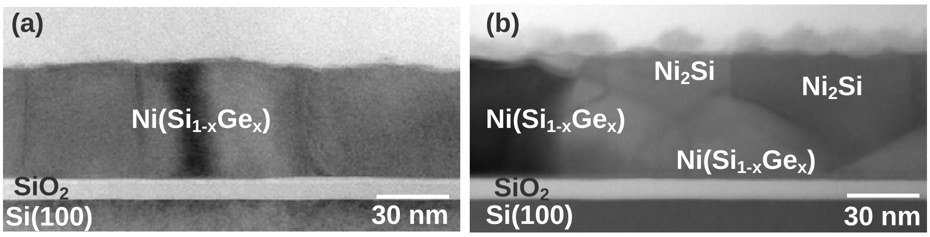


Fig. 3: Cross-sectional TEM image of 15% poly-SiGe layer after forming germanosilicide for (a) 30 nm Ni sputtered and (b) 50 nm Ni sputtered samples, respectively. Ni_2Si is formed near the surface region only in the 50 nm sputtered case.

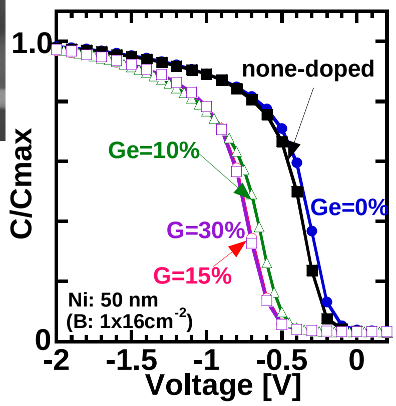
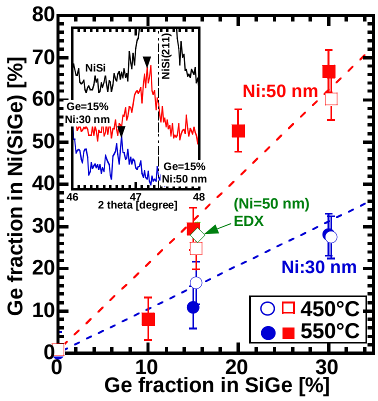


Fig. 6: C-V curves of B-doped samples. Implanted B dose is $1x10^{16}$ cm^{-2}. In the Ni(SiGe) gates, C-V curves shift to the opposite direction, compared to that in the Ni silicide gates (Ge=0%).



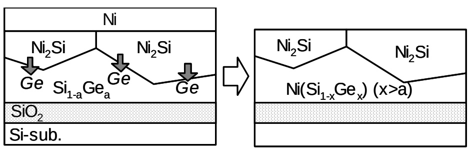
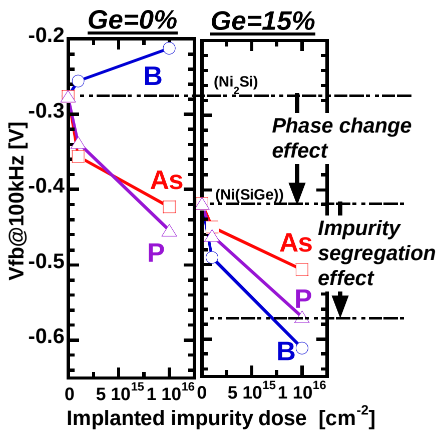
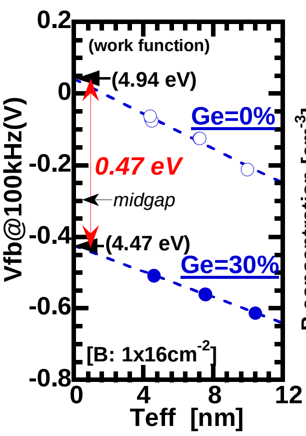


Fig. 5: Schematic of Ge condensation. Drive out of Ge from the surface Ni_2Si region results in the Ge condensation in the Ni(SiGe) grain near the SiO_2 interface.

Fig. 4: Relationship between fraction of Ge to Si in Ni(SiGe) and that in poly-SiGe before forming germanosilicide, estimated from XRD Ni(SiGe) diffraction peak shift (insert).





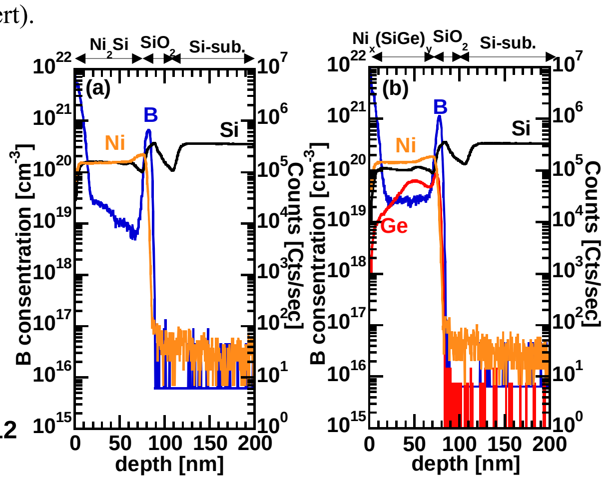


Fig. 7: Vfb-Teff plot of B-doped samples.

Fig. 8: Backside SIMS depth profile of B-doped (a) Ni_2Si gate and (b) Ni(SiGe) (poly-SiGe with 15% Ge contained) gate. Ge is gathered near the gate electrode/SiO_2 interface.

Fig. 9: Vfb vs. implanted impurity dose for B, As, and P, in different Ge fractions.