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P-2-6 Enhanced Thermal Stability of Nickel Germanide with Ultrathin Ti Layer

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I. Introduction

Germanium is an attractive material both for being MOSFET channel material for its high carrier mobility [1] and being photodetector's absorbing layer for λ = 1.3 - 1.55 μm due to its small direct energy bandgap of 0.8 eV [2]. As in the conventional Si technology where self-aligned metal silicide is used for source/drain contact and local interconnect, self-aligned metal germanide may be also necessary for Ge technology. Monogermanide NiGe is one of the most promising candidates due to its low resistivity, low formation temperature and capability for self-aligned process [3-4]. However, one major drawback of NiGe is its low thermal stability. Its surface condition is severely degraded as being roughened for temperature higher than 400^{o}C due to agglomeration, and thus loses the film continuity at 600^{o}C from isolated island formation [4-5]. On the other hand, thin Ge on Si substrate is more promising than bulk-Ge substrate. High quality hetero-epitaxial Ge on Si has been realized recently using molecular beam epitaxy (MBE) or ultrahigh vacuum chemical vapor deposition (UVCVD) in spite of ~4% lattice mismatch between Ge and Si [6]. For NiGe on polycrystalline Ge on Si, the degradation temperature is even lower [7].

In this study, we found that incorporation of an ultrathin Ti (1 nm), either as a capping layer or as an intermediate layer, can significantly suppress agglomeration of thin NiGe film on epitaxial Ge on Si substrates, thus widen the process window of Ge technology.

II. Experimental

The strain-relaxed Ge epilayer on Si was fabricated using a recently developed two-step UVCVD epitaxial technology [6]. At the first step, ~30 nm Ge buffer layer was deposited at 250 - 350^{o}C using diluted GeH_4 source, and at the second step, ~100 nm Ge was deposited at 600 - 700^{o}C. No cycling annealing was carried out. The as-formed Ge film has been confirmed to have high quality with smooth surface (rms ~1.0 for scan area of 10 × 10 μm^2) and threading dislocation density of < 10^7 cm^2 [6]. Ni and Ti were deposited sequentially in a PVD system immediately after removing the native oxide by dipping in DHF solution. The metal-deposited wafers were rapid thermal annealed (RTA) at 350^{o}C for 30 s, followed by selectively etching in diluted HNO_3 solution. Then second RTA was performed for 30 s at various temperatures ranging from 350 to 700^{o}C to assess the thermal stability. The films were characterized by sheet resistance, SEM, and AFM measurements.

III. Results and discussion

Three sets of samples were compared, i.e., pure ~9 nm Ni, ~9 nm Ni with ~1 nm Ti bottom layer, and ~9 nm Ni with ~1 nm Ti capping layer. After the first 350^{o}C RTA and selectively etching, all samples showed smooth surface, as that of the initial Ge epilayer. The rms roughness increases when the second RTA temperature becomes higher than 450^{o}C, as shown in **Fig. 1**, where the rms data were obtained from scan area of 5 × 5 μm^2 area in AFM measurement. The pure Ni samples degraded more rapidly than the samples with ~1 nm Ti incorporation. It is evident that the surface morphologies are different for samples with and without Ti insertion. **Fig. 2** shows AFM surface morphologies of samples of pure Ni annealed at 550^{o}C, Ti/Ni annealed at 600^{o}C, and Ni/Ti annealed at 650^{o}C. For the NiGe film formed from pure Ni, the film contains regularly distributed islands and the film seems discontinuous, whereas the NiGe films formed with ultrathin Ti incorporation are still continuous even after 650^{o}C annealing but with irregularly distributed hills and grooves. SEM images shown in **Fig. 3** reveal those differences clearly, where the surface morphologies of pure Ni samples annealed at 450 and 500^{o}C, Ni/Ti and Ti/Ni samples annealed at 500 and 600^{o}C are compared. The NiGe film formed from pure Ni is clearly agglomerated after 500^{o}C anneal, forming islands with the size of about 130 nm. The formation of NiGe islands is confirmed by the energy dispersive x-ray fluorescence spectroscopy (EDX), as both Ni and Ge signals are detected within the island area whereas no Ni signal is detected outside the island area. For the NiGe films formed from Ni/Ti or Ti/Ni after 600^{o}C anneal, both Ni and Ge signals can be detected at any location of the surface, indicating remaining of the film continuity. However, for all samples after 700^{o}C anneal, no Ni signal (only Ge and Si) can be detected by EDX at the surface, probably due to Ge migration to the surface.

Fig. 4 plots the sheet resistances ($R_{sq.}$) as a function of annealing temperature for the above three sets of samples. $R_{sq.}$ is stable up to 450^{o}C for NiGe film formed from pure Ni, and the stable range extends to 500^{o}C with ultrathin Ti incorporation. The abrupt $R_{sq.}$ increase for pure Ni sample is believed to be mainly due to formation of isolated islands. However, the $R_{sq.}$ increase for samples with ultrathin Ti incorporation may be caused by other mechanism besides the surface roughness, such as Ge migration, because the NiGe film is still continuous after 600^{o}C anneal. In this sense, the NiGe film with Ti incorporation may extend its thermal stability to 550^{o}C.

For thinner film, the thermal stability would be even lower for pure Ni samples [5], whereas the stability for Ni/Ti samples remains. Thus the stability enhancement by ultrathin Ti incorporation is more significant. **Fig. 5** compares AFM morphologies of 500^{o}C annealed NiGe films formed from 5 nm pure Ni and 3 nm Ni + 1 nm Ti. The former has totally islanded with rms of 5.95 nm whereas the latter (rms = 0.85 nm) is still as smooth as the initial Ge film.

The driving force for NiGe agglomeration is believed to be the reduction of the interfacial energy of the grain boundaries [7]. In Ti/Ni or Ni/Ti systems, we speculate that Ti is incorporated into the NiGe film to form ternary $Ni_{1-x}Ti_xGe$ phase, which may have lower Gibbs energy, thus higher thermal stability than NiGe. The formation of NiTiGe is partly confirmed by the lower $R_{sq.}$ of the Ti/Ni sample in **Fig. 4**, as it may also imply thicker germanide.

However, Ti signal is not detected by EDX probably due to its content being lower than the measurement limit. More characterization and analysis are ongoing to gain understanding.

IV. Conclusion

In brief, the thermal stability of NiGe films formed on epitaxial Ge on Si can be significantly improved by ultrathin Ti incorporation mainly due to suppression of NiGe agglomeration.

References

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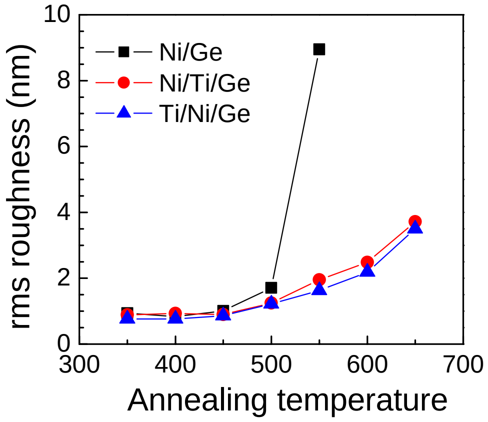

Fig. 1 Roughness (rms) obtained from AFM scan area of 5 × 5 μm^2 as a function temperature of the second RTA for three sets of samples.

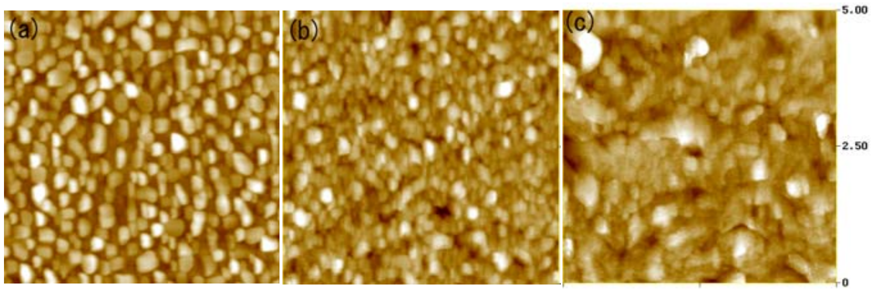

Fig. 2 AFM surface morphologies with scan area of 5 × 5 μm^2 for samples of (a) Ni(9nm)/Ge after 550^{o}C anneal, rms = 8.9 nm; (b) Ti(1nm)/Ni(9nm)/Ge after 600^{o}C anneal, rms = 2.5 nm; and (c) Ni(9nm)/Ti(1nm)/Ge after 650^{o}C anneal, rms = 3.7 nm.

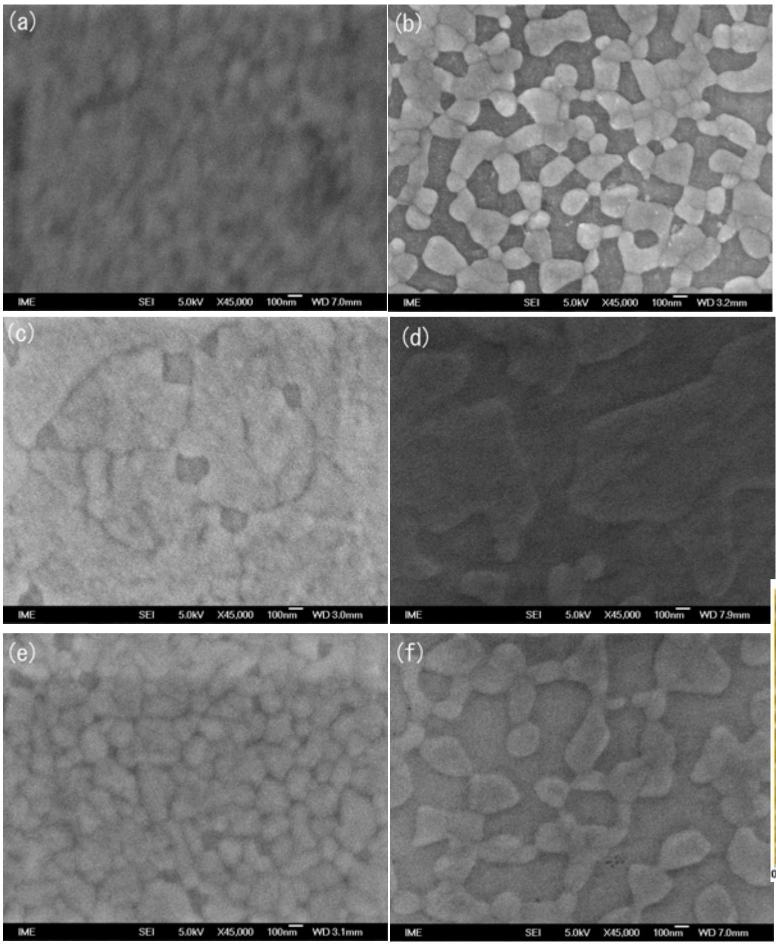

Fig. 3 SEM images of samples of (a) Ni(9nm)/Ge after 450^{o}C anneal; (b) Ni(9nm)/Ge after 500^{o}C anneal; (c) Ni(9nm)/Ti(1nm)/Ge after 500^{o}C anneal; (d) Ni(9nm)/Ti(1nm)/Ge after 600^{o}C anneal; (e) Ti(1nm)/Ni(9nm)/Ge after 500^{o}C anneal; and (f) Ti(1nm)/Ni(9nm)/Ge after 600^{o}C anneal. EDX was also performed to identify the components.

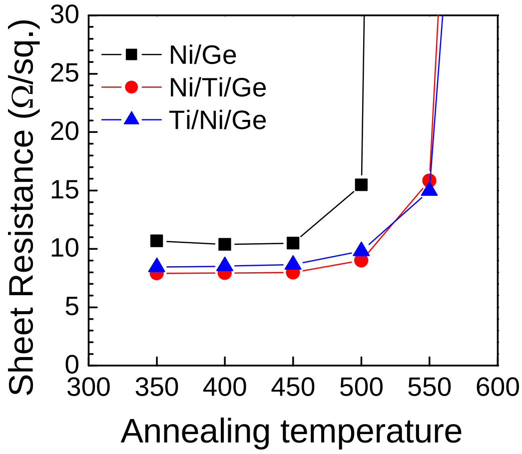

Fig. 4 Sheet resistance as a function of temperature of the second RTA for three series samples.

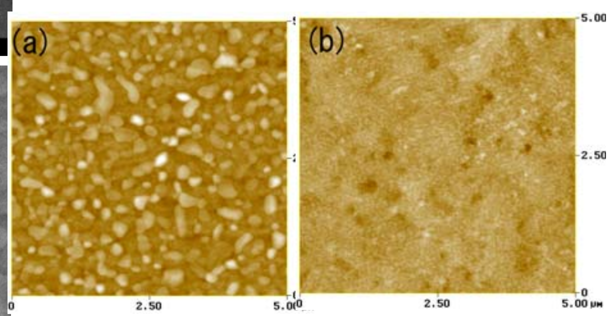

Fig. 5 AFM surface morphologies with scan area of 5 × 5 μm^2 for samples of (a) Ni(5nm) after 500^{o}C anneal, rms = 5.95 nm; (b) Ni(3nm)/Ti(1nm)/Ge after 500^{o}C anneal, rms = 0.85 nm.