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Pt interlayer effects on Ni germanosilicide formation and contact properties

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ABSTRACT

Ni and Ni(Pt) germanosilicide formation and their contact properties on n-type epitaxial $Si_{0.84}Ge_{0.16}$ have been studied in this work. It is revealed that compared to NiSi, NiSiGe has enhanced phase stability but worse morphology stability. It is also found that Pt incorporation in germanosilicidation improves the morphology of the germanosilicide film. The Schottky contact characteristics of NiSiGe and Ni(Pt)SiGe on n-SiGe were evaluated by current–voltage (*I–V*) technique at room temperature. NiSiGe/n-SiGe contact shows a Schottky barrier height (SBH) of 0.65 eV with little difference from that of NiSi/n-Si contact. However, the contact shows a reduced SBH with a markedly increased ideality factor and leakage current when annealing temperature increases to 650 °C, indicating thermal degradation of the contact quality. Pt incorporation increases the SBH to 0.73 eV. In addition, its diode parameters such as SBH, ideality factor, and reverse leakage show better conformity during the whole annealing temperature range (from 450 to 650 °C). Therefore, it is concluded that Pt interlayer between Ni and SiGe can modulate the barrier height of Ni germanosilicide and improve its contact properties.

1. Introduction

Recently, SiGe has found various applications in high performance metal-oxide-semiconductor field effect transistors (MOSFETs). By incorporating SiGe to the source/drain (S/D) of p-MOSFETs, compressive strain can be induced in the p-channel which enhances the effective hole mobility thus the device performance [1–3]. Moreover, introducing B in epitaxial SiGe allows for a higher concentration than in Si, therefore lower contact resistance can be achieved when SiGe is applied in the S/D region of p-MOSFETs [4]. In bipolar devices, SiGe can also be used as a narrow bandgap base in heterojunction bipolar transistors [5,6].

Contact formation between germanosilicide/SiGe with good thermal stability, electrical behavior and contact integrity is a key challenge to the successful application of SiGe to those novel devices. As complementary MOS (CMOS) technology entered sub-100 nm node, NiSi has replaced $CoSi_2$ as the S/D contact material owing to its low resistivity, low formation temperature, low silicon consumption, and little narrow line effect [7,8]. According to previous studies, Ni is still considered as the most attractive metallization candidate for SiGe [9,10]. Thus, the influence of Ge incorporation needs to be considered in the Ni based self-aligned silicide (salicide) technology. There were some studies on Ni germanosilicide formed on SiGe [11–15]. However, most of them were focused on NiSiGe formation and material properties. Very limited number was reported on germanosilicide/SiGe contact properties [16–18], which may be of crucial importance to the performance of ultra-scaled devices. In addition, it was found that the Pt incorporation in Ni/SiGe reaction has beneficial effects on thermal stability of the low resistive germanosilicide films [19–21], which has been widely adopted in Ni salicide process. However, the influence of Pt on electrical characteristics of NiSiGe/SiGe contact was rarely reported [18].

In this work, material as well as contact properties of Ni and Pt-alloyed Ni germanosilicide formed with different thermal budgets were studied, with emphasis on the effect of Pt alloying.

2. Experimental

Epitaxial SiGe films were prepared by ultra-high vacuum chemical vapor deposition. 23 nm unintentionally doped (n-type) and heavily boron doped ($\sim 5 \times 10^{20}$ cm^{-3}) SiGe films were grown on n-Si(100) substrate (2–8 Ω cm). The Ge composition determined by spectroscopic ellipsometry is 16%.

Patterned samples on n-SiGe for Schottky diode fabrication were prepared by plasma enhanced chemical vapor depositing SiO_2 and lithography to form circular contact holes with a diameter of 600 μm. After standard RCA cleaning and diluted-HF dip to remove native oxide, all the samples were immediately loaded into a vacuum chamber with a base pressure of 5×10^{-5} Pa. Different

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metal layer structures, Ni(10 nm), Pt(1 nm)/Ni(9 nm), and Pt(10 nm) were deposited by ion beam sputtering at a working pressure of 5×10^{-3} Pa.

All the as-deposited samples were immediately annealed by rapid thermal annealing (RTA) in N_2 ambient after removal from the vacuum chamber. The annealing temperature ranges from 450 to 650 °C for the patterned samples and from 300 to 800 °C for the others. For RTA process, the temperature ramp rate is about 50 °C/s and the duration time is 60 s.

For the patterned samples, unreacted metals were selectively etched in a boiling solution H_2O:HCl:HNO_3 = 16:8:1 for 2 min. (Ni/Pt/SiGe samples) or in a boiling H_2SO_4:H_2O_2 = 3:1 solution for 1 min. (Ni/SiGe samples). 1 μm Al was deposited onto the back side of the wafer to make an ohmic contact. Circular Al electrodes were formed on the front side by lift off to ensure reliable contact.

X-ray diffractometry (XRD) was utilized to detect the phase formation. The sheet resistance (R_{sh}) of the samples was measured by a four-point probe (FPP). Scanning electron microscopy (SEM) was employed to demonstrate the film morphology. The electrical characteristics of the diodes were measured by current–voltage (*I–V*) technique using a Keithley 2400 source/meter.

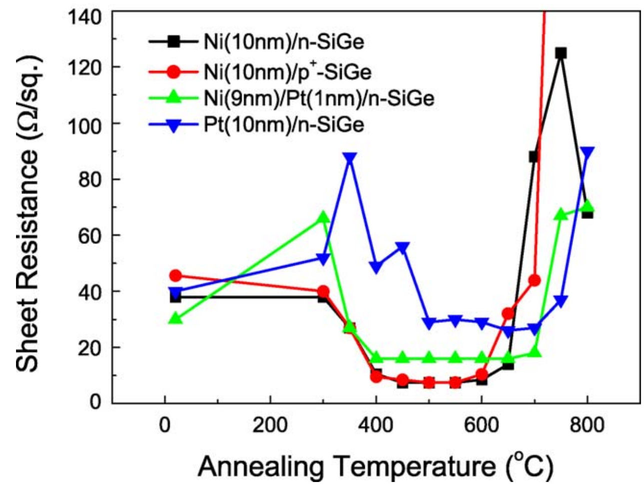

Fig. 2. Transformation curves of Ni/n-SiGe, Ni/p$^+$-SiGe, Ni/Pt/n-SiGe, Pt/n-SiGe samples after RTA at different temperatures from 300 to 800 °C.

3. Results and discussion

Fig. 1 shows the XRD spectra of Ni(10 nm)/n-SiGe(23 nm) sample annealed at different temperatures. It is observed that the peaks of NiSiGe begin to appear after 400 °C annealing and remain to 800 °C. The formation temperature of Ni germanosilicide of 400 °C is lower than Co or Ti germanosilicide, which is of great importance to preserve the SiGe-induced strain in the channel [22,23]. The germanosilicide remains in the mono-germanosilicide phase within the whole annealing temperature range, which is quite different from the Ni/Si case. The phenomenon that Ge incorporation enhances the phase stability of Ni germanosilicide was also reported by other groups [11,14–16]. The mechanism behind it was discussed by Zhang from thermodynamic considerations [9].

The sheet resistance of the germanosilicide formed from Ni/n-SiGe, Ni/p$^+$-SiGe, Ni/Pt/n-SiGe, and Pt/n-SiGe structures *versus* RTA temperature is shown in Fig. 2. For Ni(10 nm)/SiGe (n-type/p$^+$-type) structure, the R_{sh} undergoes a rapid drop and reaches a minimum at about 400 °C which could be ascribed to the NiSiGe phase formation as identified in Fig. 1. Sheet resistance degradation is observed in both samples when temperature increases to above 600 °C which is appreciably lower than that for NiSi. This indicates that Ni germanosilicide has worse thermal stability. It should be noted that previously reported improvement of thermal stability of Ni germanosilicide formed on heavily boron doped SiGe over lightly doped SiGe was not observed in this work [13,21]. For Ni(9 nm)/Pt(1 nm)/n-SiGe sample, the sheet resistance increases a little by introducing the Pt interlayer. But the R_{sh} remains the minimum until 700 °C, which is 100 °C higher than that of sample without Pt interlayer. By depositing 10 nm pure Pt on the n-SiGe substrate, R_{sh} is increased by about three times. Moreover, the formation of low resistive phase of PtSiGe is retarded although the integrity of the film can remain to the high temperature of 700 °C. Based on the above results and discussion, we can conclude that the Ni(Pt) alloy has the largest process window and acceptably low resistivity, which is highly desirable for SiGe contact technology.

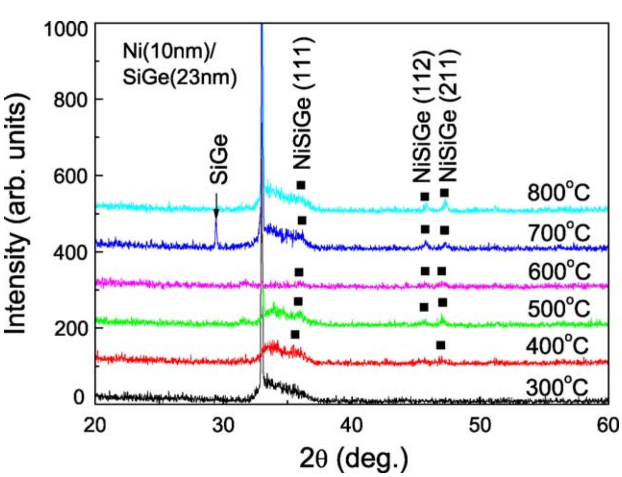

Fig. 1. XRD spectra of Ni(10 nm)/n-SiGe(23 nm) sample annealed at different temperatures from 300 to 800 °C.

SEM images reflecting the morphology properties of Ni germanosilicides formed from Ni/n-SiGe and Ni(Pt)/n-SiGe annealed at different temperatures are shown in Fig. 3 (for NiSiGe) and Fig. 4 (for Ni(Pt)SiGe). The phenomenon that Ni germanosilicide has enhanced phase stability while derogated thermal stability could be explained by morphological deterioration of the film which is well confirmed by the SEM images. The film remains flat and flawless up to 500 °C and becomes slightly rough while still remains continuous at 550 °C, which ensures that the sheet resistance stays at the minimum. However, when the temperature increases to 600 °C, corresponding to the onset of R_{sh} rise, thermal agglomeration happens, and the continuous film transforms to discrete islands. The discontinuous areas become larger as the increase of the temperature. The acceleration of film agglomeration may be accompanied or initiated by Ge segregation as observed by other groups [9,12,15], since Ni prefers to combine with Si due to the higher heat of formation of NiSi than NiGe.

For the case of NiSi, there are two possible factors influencing the thermal stability which can be manifested by the behavior of the sheet resistance of the film [13]. The phase transformation from NiSi to $NiSi_2$ accounts for the film degradation if the R_{sh} remains twice the initial one. If the R_{sh} keeps increasing with the annealing temperature, the film is related to a morphological degradation which can be also called agglomeration. Combining the XRD, R_{sh} and SEM images in Figs. 1–3, we conclude that compared to NiSi, NiSiGe triumphs in the respect of phase stability. However, NiSiGe behaves a worse thermal stability which is only attributed to the worse morphology stability.