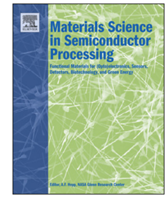
Materials Science in Semiconductor Processing 44 (2016) 8–12

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp



Structural and electrical characterization of platinum (~15 at%) doped nickel silicides on Si(100) and SiGe/Si(100) substrates

Mohammad Faheem*, Aditya Kumar, Yifan Liang, Paul van Der Heide

GLOBALFOUNDRIES Inc., 400 Stone Break Extensions, NY 12020, Malta

ARTICLE INFO

Article history:
Received 3 November 2015
Received in revised form
2 January 2016
Accepted 4 January 2016
Available online 7 January 2016

Keywords:
NiSi
NiSiGe
XRD
Phase formation
Sheet resistance

ABSTRACT

Ni(Pt~15 at%)Si/Si(100) and Ni(Pt~15 at%)SiGe/SiGe/Si(100) films corresponding to rapid thermal annealing (RTA1) temperatures of 220, 230 and 240 °C with constant RTA2 (at 420 °C) have been investigated for sub 20 nm devices. X-ray reflectometry (XRR), X-ray diffraction (XRD), four point probe, and atomic force microscopy (AFM) techniques were employed for the characterization of NiSi and NiSiGe films. XRR results indicated that NiSi and NiSiGe film thicknesses increased with RTA1 temperatures. NiSi films densities increased with layer thickness but NiSiGe films displayed an opposite trend. The diffractograms revealed that NiSi and NiSiGe layers contain identical phases and possessed fiber texture at 220 °C. Whereas, the peaks shift were observed for NiSi (211) and NiSi (021) at higher RTA1 temperatures which appear due to Pt diffusion (hexagonal structures of larger grain size were noted). NiSiGe crystallites self-alignment was observed because of strained SiGe/Si(100) substrate. At 240 °C, NiSiGe layer showed the smallest crystallites. This is believed to be due to Pt distributed along the silicide grain boundaries which obstructs silicide grain growth. NiSi and NiSiGe sheet resistance decreased significantly with increase in RTA1 temperatures and found to correlate with multiple grain orientation. AFM revealed a smooth-stable surface morphology for all films.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

For nanometer scale devices, ultra-thin silicides displaying low contact resistivity, low processing temperatures and good mechanical strength are crucial [1,2]. For these and other reasons (such as etch selectivity and stress), nickel slicides are widely used in CMOS ohmic contacts, interconnects and to reduce the gate and source/drain regions [3,4]. The main disadvantage of the nickel silicide is its low thermal stability. Several studies have been conducted to improve thermal stability of NiSi by doping different materials such as platinum, cobalt, tantalum, titanium, zirconium etc. [5–9]. In addition, thin nickel silicides layers have a severe tendency to agglomerate which causes an increase in electrical resistance and high mobility of nickel [10,11]. Nickel silicide can be formed by various methods such as solid state-reaction of Si and thin nickel film on Si substrate, explosive solidification, ion implantation, reactive deposition and stacked hot plate [12–18]. Each nickel silicide phase has a different crystalline structure. A stoichiometric NiSi phase provides the lowest resistivity among the many nickel silicide phases. It is reported that nickel silicide phases are temperature dependent and Ni_2Si and NiSi phases are formed in the temperature range of 220–350 and 350–750 °C [13–16].

Nickel silicides grown on $Si_{1-x}Ge_x$ substrates has drawn attention due to the high performance and prevention of the formation of $NiSi_2$ [19,20]. The germanosilicidation between metal and SiGe becomes important since the $Si_{1-x}Ge_x$ substrate can provide compressive strain which enhances the hole mobility. In addition, these allow the formation of tensile strained Si channels which improve both the electron and hole mobility. These germanides are, however, reported being less stable than the corresponding silicides of the same atomic composition [21]. The relatively low melting points of the germanide phases indicate a relatively high reactive diffusion as compared to the similar diffusion in the corresponding silicide phases. Furthermore, increasing the annealing temperature of Ge rich $Ni(Pt)Si_{1-x}Ge_x$ film causes morphological instability which has the adverse effect of increasing sheet resistance [22]. The use of Ni(Pt) has, however, been shown to improve the stability of Ni(Pt) on $Si_{1-x}Ge_x$ by retarding the formation of high resistivity phases [23].

In this work, phase formation, surface morphology, and electrical characterization of nickel silicides formed due to the reaction of thin Ni(P~15 at%) film on Si (100) and $Si_{1-x}Ge_x$/Si (100) substrates are reported for sub-20 nm devices. Layer densities, grain formation, resistivity and surface morphology of NiSi and $NiSi_{1-x}Ge_x$ films are of specific interest. The International

* Corresponding author.
E-mail address: faheem2001@gmail.com (M. Faheem).

http://dx.doi.org/10.1016/j.mssp.2016.01.002
1369-8001/© 2016 Elsevier Ltd. All rights reserved.

Technology Roadmap for Semiconductors (IRTS) indicates the thickness of silicides should decrease below 15 nm for sub-20 nm devices. This requires the need for uniform-smooth $Ni_nSi_{1-x}Ge_x$ films with low specific resistance and good surface morphology.

2. Experiment

Six samples were prepared. Among them, three samples have Si(100) substrates while the other three have $Si_{1-x}Ge_x$/Si(100) substrates. For $Si_{1-x}Ge_x$/Si(100) substrates, a single $Si_{1-x}Ge_x$ layer of 55 ± 2 nm thickness and 17 ± 0.5 Ge at% was epitaxial grown on the Si(100) substrates. All Si and $Si_{1-x}Ge_x$ surfaces were in-situ pre-cleaned by standard SiCoNi process prior to Ni(Pt ~ 15 at%) sputtering deposition. A thin film of Ni(Pt ~ 15 at%) of 15 ± 1 nm was deposited on Si (100) and $Si_{1-x}Ge_x$/Si (100) substrates using commercial physical vapor deposition (PVD) method. After Ni (Pt ~ 15 at%) deposition, two steps rapid thermal anneal (RTA) processes were used to form nickel silicides. For RTA1 process, samples were annealed for 60 s at 220 °C, 230 °C, and 240 °C. Following this, all wafers were chemically stripped to remove unreacted Ni (Pt ~ 15 at%). After stripping, 2nd anneal known as RTA2 was performed at 420 °C for 10 s. RTA1 and RTA2 temperatures stability were within 2.5°. Finally, the samples were stripped using Aqua Regia (HNO_3:HCl, 1:3) to remove unreacted Pt. For the sake of simplicity the terms NiSi and NiSiGe will henceforth be used in place of Ni(Pt ~ 15 at%)Si/Si(100) and Ni(Pt ~ 15 at%)SiGe/SiGe/Si(100), respectively. All measurements presented in this paper were taken after RTA2.

SiGe film thicknesses and Ge concentrations were ascertained using high resolution X-ray diffraction (HXRD) on a Bruker D8 Fabline. NiSi and NiSiGe film densities and crystalline structure were examined using X-ray reflectometry (XRR) and grazing incident X-ray diffraction (GIXRD) on a Bruker D8 discover (Cu Kα source used). GIXRD results were acquired in the 2theta interval from 10° to 60°. The raw data were fitted with simulations derived using laptops to achieve the lowest cost function. Sheet resistance values were provided via four probe method on Capres microRSM. The surface morphology of the NiSi and NiSiGe films were examined by atomic force microscopy (AFM) on a Bruker ICON.

3. Results and discussion

Representative HXRD patterns following RTA2 are shown in Fig. 1. HXRD patterns revealed a change in the SiGe thickness that decreased with increasing RTA1 temperatures. As temperature increases, Ni(Pt) reacts faster with the SiGe layer to form NiSiGe. This process reduces the SiGe layer thickness. Ge concentration on the other hand remains same (approximate). A strained surface is important since it provides higher mobility leading to improve current drive. The requirements for a strained epitaxial layer are controlled over layer thickness, Ge concentration and lower regrowth interface contamination. All three samples fulfill these requirements and have strained SiGe layers after RTA2 as shown in Fig. 1.

Fig. 2 demonstrates the thicknesses and densities of all samples. All samples showed the clear interference fringes that could be resolved and modeled. From the fit, NiSi film annealed at 220 °C appears to be ~7.14 nm in thickness. The layer thickness is increased to ~12.87 nm and 14.56 nm for the samples annealed at 230 °C and 240 °C. SiGe layer thicknesses are estimated at 44.66, 42.02, and 39.40 nm which is about ~1–2 nm differences as measured by HXRD. On the other hand, NiSiGe thicknesses are estimated to be 8.93, 13.47 and 15.81 nm, i.e. these show the same general trend as observed for NiSi grown on Si.

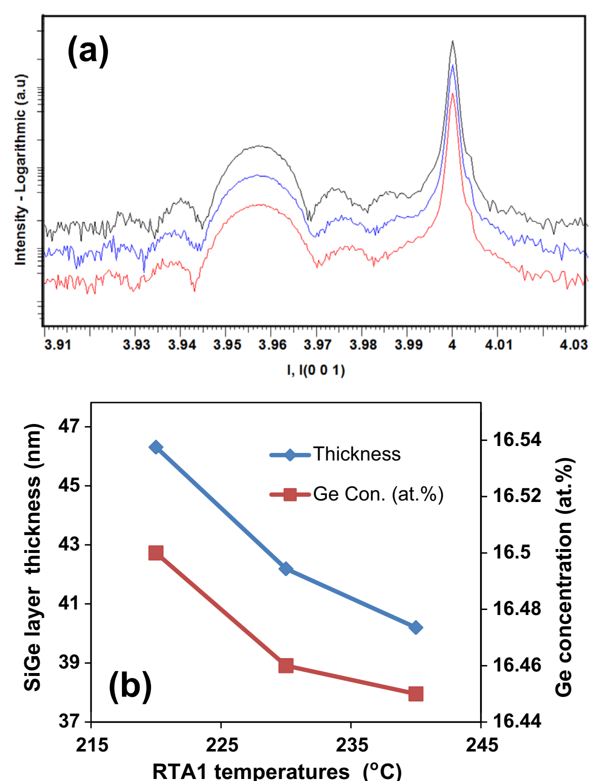


Fig. 1. (a) HXRD measurements on SiGe/Si(100) substrates using 004 reflections after RTA2 –bottom to top with increase in RTA1 temperatures (b) plots of SiGe layer thickness and concentration versus RTA1 temperatures.

As shown in Fig. 3, the density increased with annealing temperatures (RTA1) for NiSi samples. The value 4.43 g/cm^3 for the sample annealed at 220 °C is somewhat lower that can attribute to the growth temperature (RTA1). Higher annealing temperatures lead to improve grain growth which can cause density increases. An opposite tendency was, however, observed in the NiSiGe films, i.e. a higher density was noted at lower temperatures with the density further decreasing as the annealing temperature increases. This can be explained by the fact that as the annealing temperature increases Ni and Pt react faster with the Si present within the SiGe film. This can cause increase in unit cell and corresponding decrease in density.

GIXRD of NiSi and NiSiGe samples after RTA2 are shown in Fig. 4. The notations used to index the intensity peak in diffractograms refer to NiSi (*hkl*) for simplification, though Ge is present in the solid solution of NiSiGe. Fig. 4(a) demonstrates that NiSi phase observed in all samples deposited on Si substrates. At 220 °C, NiSi peaks indicative of the (110), (101), (210), (120), (021), (211), (310), and (301) planes are observed. These results signify that the crystallites are randomly distributed along different planes with most aligned along (021) and (211) planes. A clear NiSi (121) peak is noted. There is, however, a significant difference in the diffraction patterns between the samples annealed at 220 °C and that annealed at 230 °C and 240 °C, i.e. an enhancement of the NiSi (021) peak and the disappearance of NiSi (121) peak is noted along with a notable enhancement of NiSi (211) plane at 240 °C.

The diffractogram also reveal a peak shift at higher temperatures of 230 °C and 240 °C. The fact that this peak shift is towards larger 2θ value corresponds to the decrease in plane spacing. Due to higher Pt doping and the underlying Si planes could cause the NiSi unit cell to distort. The distorted unit cell can produce stresses in the NiSi films which would result in the peak shift and change in lattice parameters. Previously it was reported [24] that a small change in the lattice parameter and atom positions caused by

Download English Version:

https://daneshyari.com/en/article/727803

Download Persian Version:

https://daneshyari.com/article/727803

Daneshyari.com