Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp694-695

Nickel Compound and Alloy Contacts to Nanoscale Si, Ge, and InGaAs Channels

Renjie Chen[1], Binh-Minh Nguyen[1,2], Wei Tang[2,3], and Shadi A. Dayeh[1]

[1]Integrated Electronics and Bio-interfaces Laboratory
Department of Electrical and Computer Engineering
University of California San Diego
9500 Gilman Dr. MC 0407, La Jolla, CA, 92093, United States
Phone: +1-858-534-5171 E-mail: sdayeh@ece.ucsd.edu
[2] Center for Integrated Nanotechnologies, Los Alamos National Laboratory
P.O. Box 1663, K771, Los Alamos, NM, 87545, United States
[3]Department of Materials Science and Engineering
University of California, Los Angeles, Los Angeles, California 90024

Abstract

Contact metallurgy for advanced geometries of current and future CMOS channel materials is vital to achieve ultra-short channel devices and desired performances. We utilize in-situ and ex-situ microscopy coupled with transport characterization to establish key kinetic, thermodynamic and structural behaviors of Ni contact alloys to Si and Ge/Si core/shell nanowires and InGaAs FinFETs. Significant size and channel orientation dependencies for the Nickelide/InGaAs FinFET reactions are reported.

1. Introduction

Nickel Silicide has been the contact of choice for CMOS devices due to its low resistivity, compatible temperature of formation, and the etch selectivity with respect to nickel enabling self-aligned technologies that have fueled transistor scaling to sub-20 nm [1]. For sub-10 nm high mobility channels such as InGaAs, nickelide (Ni-InGaAs) contacts have been recently explored as suitable self-aligned contacts [2]. At nanoscale geometries, size relevant thermodynamic barriers, surface and interfaces, and confined directionality in specific crystal orientations can significantly influence the Ni-semiconductor compound and alloy nucleation, mass transport, and growth rate and morphology, respectively, for both the SiGe and InGaAs material systems. [3] This paper overviews nanoscale size effects on Ni silicide/germanide and nickelide contact formations, their structural properties and morphology, and their kinetic coefficients for different crystal orientations.

2. Silicide Contacts to Si Nanowires

For in-situ TEM studies, our platform for studying metal-semiconductor reactions consists of a 30–50 nm silicon nitride membrane suspended over a Si frame carrier suitable for transmission electron microscopy studies with temperature control. This enables observation of the dynamic behavior of solid-state reactions with excellent temperature and reaction rate control, and at an atomic scale resolution. Fig. 1 shows typical reaction fronts for of Ni with Si nanowires (NWs) grown in [112] and [111] orientations but exhibiting a fixed {111} interfacial plane for $NiSi_2$/Si at an annealing temperature of 400°C [3]. Atomically abrupt type-A interfaces were obtained facilitating the reproducible fabrication of ultra-short Schottky barrier field-effect transistors (SB-FETs) down to 17 nm channel lengths [4]. The small reaction cross-section enforces a single homogeneous nucleation site, and as such, the reaction proceeds in a layer-by-layer fashion. The presence of a defect or a heterointerface can switch the nucleation to heterogeneous type and accelerate the reaction kinetics [5].

3. Germanide/Silicide Contacts to Ge/Si Core/Shell Nanowires

Higher hole mobility Ge channels confined and passivated with thin crystalline Si shells [6] exhibit significantly different reaction dynamics from that of pure Ge and Si channels. The presence of the heterointerface in Ge/Si core/shell NWs leads to the metallide nucleation at the heterointerface on the silicon side resulting in a $NiSi_x$ leading interface and Ni_2Ge lagging interface [7]. By selective etching of the Si shell underneath the Ni contact, a proportionate $Ni_2Ge/NiSi_x$ abrupt interaface with Ge/Si core shell NWs was attained allowing precise control over the channel morphology down to a 2 nm channel length (Fig. 2).

4. Nickelide Contacts to InGaAs FinFETs

The interaction between Ni and InGaAs has recently been studied on ultrathin InGaAs films. [1] However, to reveal orientation and size effects and kinetic, thermodynamic and structural properties as a function of these, Fin channels fabricated on TEM frames is ideal. We have recently developed an approach to integrate InGaAs Fins on insulator on Si substrates in a Fab compatible process [8] and utilize it here to reveal the aforementioned effects. We found that the nickelide segment is longer for smaller Fin widths in both [110] and [100] orientations, as discussed below, with a relatively flat interface for [110] as opposed to a rough interface for [100] oriented Fins (Fig. 3). We also observed that the Nickelide reacted region expands anisotropically along the free surface in the [001] orientation by ~ 28±5% with minimal or negligible expansion along other directions lateral to the Fin sidewalls.

Our time dependent studies reveal a $t^{1/2}$ dependence with slightly larger effective diffusion coefficients for smaller Fin widths than larger ones, and for [110] than

[100] oriented Fins, as seen in Fig. 4. The insets in Fig. 4 also illustrate that there is no incubation time for planar films (volume diffusion) whereas Fins (surface diffusion) have as a result smaller incubation times that reduces with Fin width (surface collection/cross-section deposition). Our cumulative Fin width dependent study is shown in Fig. 5 which demonstrates $(1/w+1/h)^{1/2}$ dependence for smaller Fins where w is the Fin width and h is the Fin height. The larger slope at larger Fin widths, i.e. smaller $(1/w+1/h)^{1/2}$ is likely due to variation in the volume of nickelide region and slightly smaller diffusion coefficients and interface diffusion layer thickness. Detailed studies are currently ongoing to elucidate these effects.

5. Conclusions

In conclusion, this work demonstrated excellent control over the morphology of compound contacts to Ge, and Si/Ge nanostructures and alloyed contacts to InGaAs Fins. The orientation and size dependence has been examined and shown to influence the reaction kinetics and thermodynamics.

Acknowledgments

We would like to acknowledge discussions with Profs. K.-N. Tu, S. S. Lau, and S. T. Picraux and Dr. X. Dai.

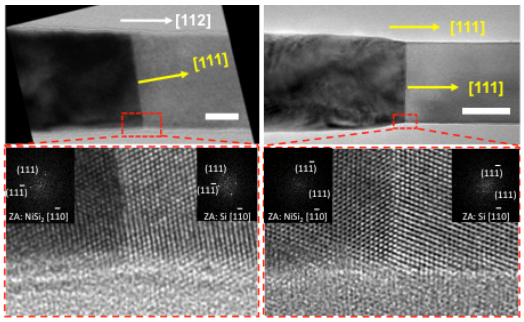

Fig. 1 Ni reaction with Si NWs at 400°C demonstrating typical {111} interfacial plane for $NiSi_2$/Si type-A interface for both [112] and [111] oriented Si NWs.

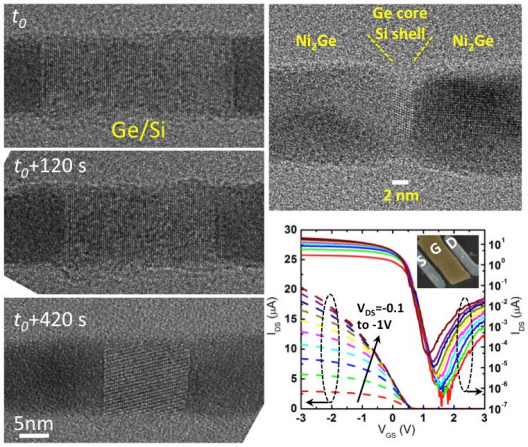

Fig. 2 Ni reaction with Ge/Si NWs at 300°C with atomically abrupt $Ni_2Ge/NiSi_x$-Ge/Si core/shell NW interface down to 2 nm channel. Transfer curves for a 17.2 nm diameter, ~250 nm channel length Ge/Si core/shell NW with compound contact.

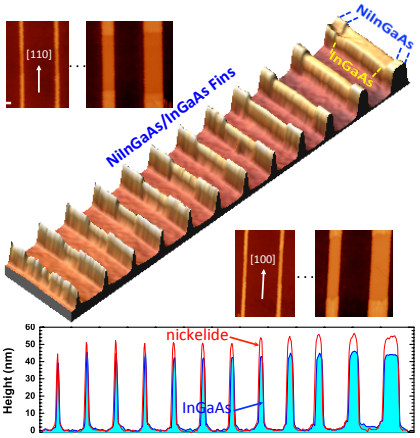

Fig. 3. Atomic Force Microscope images showing flat nickelide/InGaAs interface for [110] and rough interface for [100] Fins. The nickelide expands anisotropically in the [001] orientation.

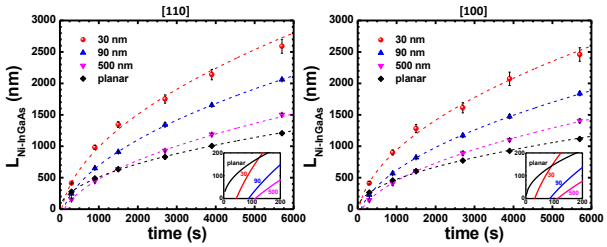

Fig. 4. Time dependent growth rate of the nickelide segment in planar, [110] and [100]. Insets highlight the small incubation times for narrow Fins (surface diffusion) and no incubation time for planar film.

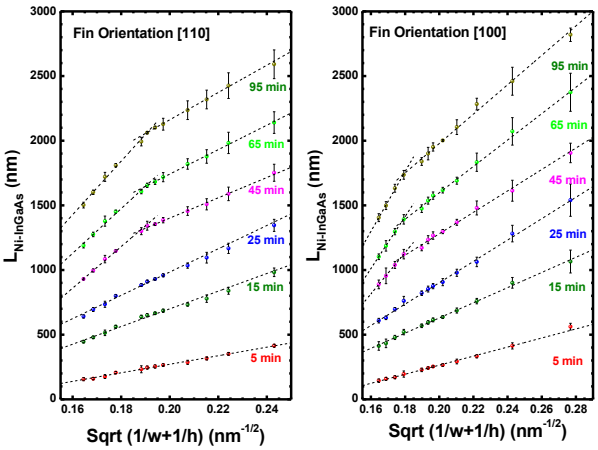

Fig. 5. Nickelide length as a function of inverse Fin width w and height h for different annealing times and at [110] and [100] orientations.

References

[1] L. J. Shen, *Silicide Technology for Integrated Circuits*, London, Institute for Electrical Engineers, 2004.

[2] S. Kim et al. Applied Physics Express **4** (2011) 114201.

[3] W. Tang et al. Semi. Sci. Tech. **29** (2014) 054004.

[4] W. Tang et al. Nano Lett. **12** (2012) 3979.

[5] W. Tang et al. Nano Lett. **13** (2013) 3947.

[6] B.-M. Nguyen et al. Nano Lett. **14** (2014), 585.

[7] S. A. Dayeh et al. ECS Trans. **58** (2013) 115.

[8] X. Dai et al. Adv. Func. Mat. doi:10.1002/adfm.201400105, (2014).