Annealing Reaction for Ni Silicidation of Si Nanowire

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Abstract: Silicidation for Si Nanowires (Si NWs) has been investigated. Ni silicides were formed by the reaction of Si NW and Ni layer during low temperature Rapid Thermal Annealing (RTA) processes. The time dependence of the encroachment length revealed that this phenomenon is governed by the diffusion of species. Activation energy of the Ni diffusion for NW width ranging from 10nm to 23nm was estimated. We also investigate Ni silicidation of Si NW using two step annealing process. The encroachment length of Ni silicide was dramatically suppressed by the two step annealing process.

Introduction: Si Nanowire FET is one of promising candidates for enhancing MOSFET performance in the future. Conventionally, silicidation of source /drain is perfomed in the MOS fabrication processes in order to reduce parasitic resistance [1]. For that purpose, Ni silicide is used owing to its low resistivity as well as relatively small Si consumption during the reaction [2]. Therefore, it is very reasonable that Ni silicidation has been applied to many Si NW performance studies so far [3-5]. But Si Nanowire can be thought that it has different solid state properties from bulk Si. We researched Ni silicidation into Si Nanowire by reacting 6nm Ni films and approximately 10nm to 23nm Si Nanowire and observation by SEM images.

Experiments: Si NWs have been fabricated by lithography, dry etching and thermal oxidation (at 1000^{o}C for 45min) using 30-nm-thick SOI substrate. Oxide around Si NW was partially removed by buffered HF solution. 6-nm-thick Ni film was deposited by magnetron sputtering in an Ar ambient. RTA at various temperatures ranging from 400^{o}C to 600^{o}C was performed. Unreacted Ni films were removed by SPM (mixed H_2SO_4 and H_2O_2). Fig.1 shows fabrication process flow. For some samples, two step silicidation process was performed. The first annealing of the two step process was performed at 300^{o}C for 30sec, followed by the unreacted Ni removal and the second annealing at 400^{o}C for 30sec (Fig.2).

Results: Fig.3 shows fabricated Si NW after Ni silicidation process. Ni silicide encroachment into Si NW was observed by SEM and the encroachment length was measured. Fig.4 shows the time dependence of the encroachment length λ of Ni silicide formed by RTA at 400 ^{o}C. Fig.5 shows similar exponential dependence of encroachment length on temperature for three NWs width experimented. Fig.6 shows Arrhenius plots. The results in difference from NW width W_{nw} using orientation <110> NWs. Calculated activation energy of W_{nw} = 10, 17 and 23nm were 1.48eV, 1.52eV and 1.60eV, respectively. In fig.7 and 8, results of single step annealing process and two step annealing process are compared. The error bar indicates the standard deviation of the encroachment length $1\sigma\lambda$. This figure says that the encroachment length of Ni silicide on two step annealing process becomes shorter than that on single step annealing process for all NW width experimented.

Conclusions: Silicidation of Si NWs was investigated in terms of the encroachment length of Ni silicide from the edge of exposed Si NWs. The time dependence of the encroachment length revealed that this phenomenon is governed by the diffusion of species. Activation energy of the diffusion on changing NW width from 10nm to 23nm was estimated to be 1.48-1.60 eV. It is thought that Ni_2Si is formed [6]. We also investigate Ni silicidation of Si NW using two step annealing process. The encroachment length of Ni silicide is dramatically suppressed for the two step annealing process.

Acknowledgement: This work supported by NEDO.

References: [1] H. Iwai, T. Ohguro, and S. Ohmi, *Microelectron. Eng.* **60**, 157(2002). [2] T. Morimoto, et al., *IEEE Trans. Electron Devices*. **42**, 915, (1995). [3] E. J. Tan et al, *IEEE Electron Device Letters*. **29**, No. 8, August (2008). [4] E. J. Tan et al, *IEEE Electron Device Letters*. **29**, No.10, October (2008). [5] Y. Jiang et al, *VLSI Tech. Symp*, p. 34 (2008). [6] K. N. Tu, W. K. Chu, J. W. Mayer, *Thin Solid Film*., **25** (1975) 403-413

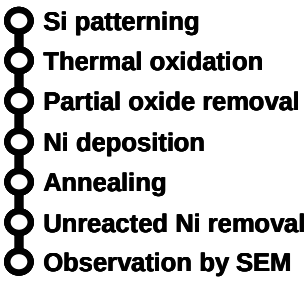

Fig.1: Fabrication process flow.

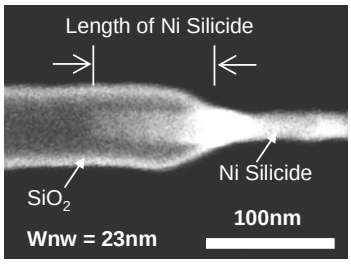

Fig.3: Si NW after Ni silicidation process.

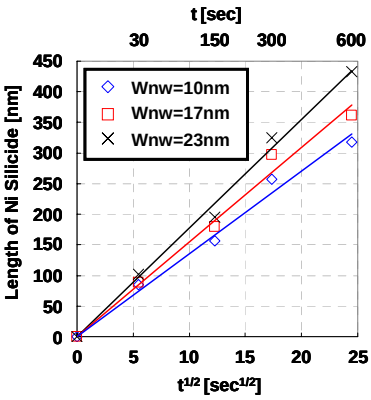

Fig.5: SEM images of Ni silicide
(a) just after 1st annealing process at 300 ºC for 30 sec and residual Ni removal and
(b) after 2nd annealing at 400 ºC for 30 sec.

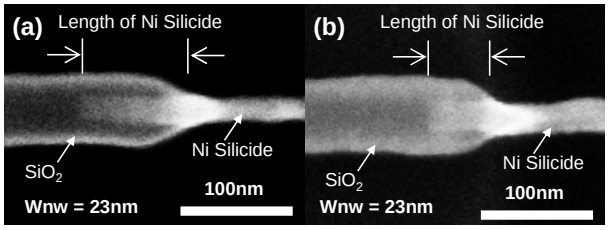

Fig.7: SEM images of Ni silicide formed by two different processes:
(a)single step annealing process at 400 oC for 30 sec.
(b) two step annealing process which consists of 1st step annealing at 300 oC for 30 sec, followed by the residual Ni removal and 2nd step annealing at 400 oC for 30 sec.

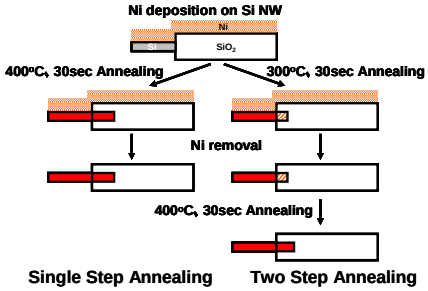

Fig.2: Schematic illustration of the single step and the two step annealing processes.

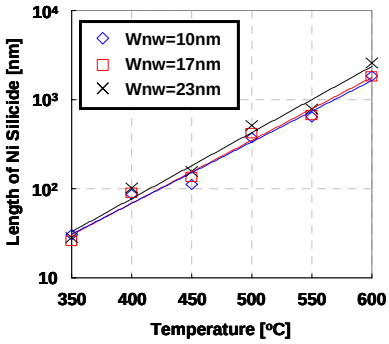

Fig.4: Time dependence of the encroachment length of Ni silicide.

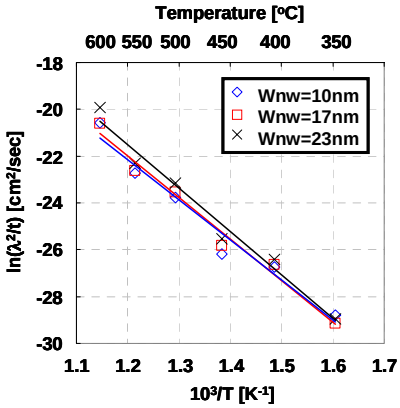

Fig.6 Arrhenius plots of NWs.

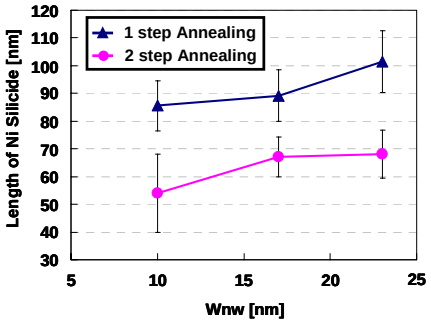

Fig.8: Encroachment length of Ni silicide on single step process, two step process.