B-8-3

Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp1014-1015

Leakage Reduction by Thermal Annealing of NiPtSi Silicided Junctions and Anomalous Spider-Web of In-Layer Pt Network

Masakatsu Tsuchiaki and Akira Nishiyama
Corporate Research & Development Center, Toshiba Corporation.
c/o 8 Shinsugita-cho, Isogo-ku, Yokohama 235-0032, Japan
Phone:+81-45-776-5941 Fax:+81-45-776-4113 E-mail:masakatsu.tsuchiaki@toshiba.co.jp

1. Introduction

For sheet resistance reduction of ever shallowing S/D junctions, NiSi is now utilized as a primary SALICIDE material owing to its small Si consumption and low formation temperature. Recently, however, an in-depth study of thin NiSi films has revealed thermal instability and associated substantial leakage generation on shallow junctions even during thermal processing at 500°C [1]. Since such low-temperature intolerance significantly impairs device manufacturability, a way must be devised to stabilize NiSi films against heat stimulus. Among various means of such thermal stabilization, today, growing attention is directed to Pt addition as an efficient method of improving its physical integrity [2]. Nevertheless, with respect to reduction of the thermally induced leakage, a sensitive, intensive and conclusive investigation of Pt's effectiveness has never been conducted. Moreover, the physical origin of the Pt-induced thermal stabilization is not yet fully understood. Hence, using highly reliable damage-free junctions, we herein report on a basic and systematic study of Pt's effects on thermally induced leakage. For the first time, two distinct sources of the leakage generation are isolated and their physical and practical implications are clarified. An anomalous spider-web of in-layer Pt network is also identified.

2. Experimental

The details of the junction formation are the same as those found in ref. [1], except for BSG used to form p+/n junctions. After formation of a virtually flat n-well over 12-inch, n-type, CZ, Si(100) wafers, a junction region is delineated by RIE-etching a SiN film and wet-etching an underlying TEOS film, avoiding plasma damage to the substrate (Fig.1-a). Subsequently deposited BSG film is then annealed to form a p+ region by solid-phase diffusion into the opening defined above (Fig.1-b). By adjusting the annealing time and temperature, p+/n junctions with various depths, x_j can be readily obtained. After BSG removal by wet etching, SiN sidewalls are formed to guard the periphery (Fig.1-c). Next, Ni film, alloyed with Pt by up to 10 atomic %, is sputter-deposited. The following salicidation process forms about 30-nm-thick silicide layer to complete the silicided junction structure (Fig.1-d).

3. Results and Discussion

Effectiveness of Pt Addition: In order to assess effectiveness of Pt addition for junction leakage, the above junctions are annealed in N_2 at 500 °C for 90min. Fig.2 compares leakage-depth profiles between pure NiSi and NiPt(5%)Si. Evidently, Pt addition is quite effective at this temperature, virtually eliminating all the thermally induced leakage, which is otherwise saliently visible without Pt. However, already at 550 °C, small but unmistakable ingression of the leakage-depth profiles is in evidence even with Pt addition (Fig.3). No difference in this inward movement is observed between 5% and 10% Pt addition. Also, the temporal evolutions of the leakage depths (at I_R=10^{-7}A/cm^2) are found to be describable with fast initial ingression and subsequent slower diffusion (Fig.4), as formulated in ref. [1]. The fact indicates a common origin of the thermally induced leakage irrespective of Pt addition, (i.e., burst of atomic Ni and its rapid coalescence into leakage -generating clusters)[1]. Thus, Fig.5 and Fig.6 specifically express the advantage of Pt addition in terms of these phenomenological parameters (i.e., the effective diffusion coefficient and the amount of the initial burst). The major advantage of Pt addition is found to stem from its resistance to the initial burst, although the benefit of the slower diffusion is also appreciable. Now, the effectiveness and limitation of Pt addition against the thermally induced leakage is clearly and accurately quantified here.

Initial Leakage and Its Reduction by Post-Annealing: In order to illuminate the origin of the thermally induced leakage, Ni backside SIMS data are correlated with the leakage-depth profiles of NiPtSi junctions (Fig,7). The excellent matching between these profiles unequivocally proves that Ni-induced GR centers remain to be the root cause of the thermal leakage even with Pt addition. Strikingly however, for junctions without post-annealing, dramatic incongruity develops between these profiles (Fig.8). Notably, before post-annealing, the presence of "initial leakage", which is in no way attributable to Ni, is now exposed here for the first time. Since the initial leakage is similarly witnessed in NiSi junctions (Fig.9), Pt's involvement in this just-after-silicidation leakage can be ruled out. On the other hand, the absence of such initial leakage in n+/p junctions [1] implicates B's involvement in the leakage. Without direct involvement of the metallic components, B's interaction with silicidation-induced primary defects (i.e., Si interstitials or vacancies) is suspected. In fact, B is known to form gap-states with interstitials (i.e., boron interstitial cluster, BIC)[3]. It is speculated the initial leakage is generated by some forms of BICs. Remarkably, yet, this initial leakage can be eliminated by annealing the NiPtSi junctions at 500°C, without invoking the thermal leakage, thanks to the Pt-induced thermal stability (Fig.10). Practically, it means, with Pt-addition, a critical process window just opens to realize an ultimate minimum leakage by beneficial post-annealing at about 500°C, so that BICs are electrically deactivated, at the very same time, by avoiding excessive annealing above 550°C, so that Ni-induced leakage generation can be prevented (Fig.11).

Origin of Pt-Induced Thermal Stability: In order to probe the origin of the Pt-induced thermal stability, the silicide layers are also diagnosed with various physical analyses. First, a profound impact of Pt addition is found in the reorientation of silicide grains to highly oriented and possibly off-axiotaxy states (Fig.12). By plan-view TEM, grains are also found to become fine and compact with Pt addition, whereas they are large and elongated without Pt (Fig.13-a,b). Further, plan-view HAADF and EDX identified the presence of Pt network (i.e., bright contours), in contrast to the pure NiSi grains surrounded by darker (i.e., thin and poor) perimeters (Fig.13-c,d). Surprisingly, yet, this Pt network doesn't conform to the physical grain boundaries (GBs) at all and concentrates around the mid-layer (Fig.14-a,b). It forms an anomalous spider-web of in-layer Pt network extending even within a single grain! This tightly localized Pt presence warrants outright rejection of mixing-entropy as a principal source of the thermal stability. Also, the absence of monolithic PtSi phase at the interface is inconsistent with obstruction of Ni burst by seamless blanket interfacial barriers. Conceivably, this anomalous Pt network is a remnant of Pt-stuffing into GBs of some earlier metal-rich silicide phase (e.g., Ni_2Si), incorporated and left intact in the final phase (i.e., NiSi). Such intermediate-phase Pt-stuffing may well interfere with the phase transition and induce final grain reorientation to constitute a crystallographically stable (i.e., off axiotaxy) [2] and thermally robust interface structure, thus, resulting in the effective stabilization by Pt addition as observed here against Ni burst and thermal leakage generation (Fig.15).

4. Summary and Conclusion

Using highly reliable damage-free junctions, the effectiveness and limitation of Pt addition against the thermally induced leakage is accurately specified. In addition, the emergence and evanescence of the silicidation-induced initial leakage is successfully witnessed and their physical and practical implications are clarified. The root cause of the Pt-induced thermal stabilization is also identified.

References

[1] M. Tsuchiaki et al., Jpn. J. Appl. Phys., 43, 5166 (2004)
[2] C. Detavernier et al., Appl. Phys. Lett., 84, 3549 (2004)
[3] P. Deak et al., J. Phys. Cond. Matter S2141 (2005)

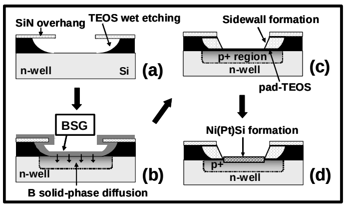

Fig.1 p+/n junction formation procedure. (a) Isolation is achieved by wet etching of TEOS. (b) Solid-phase diffusion from BSG is used for creating p+ region. (c) Sidewall seals junction edges. (d) Ni(Pt)Si is formed.

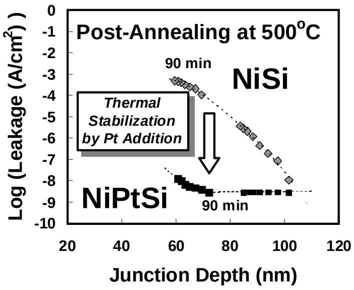

Fig.2 Leakage-depth profiles of NiSi and NiPt(5%)Si junctions after 500°C annealing.

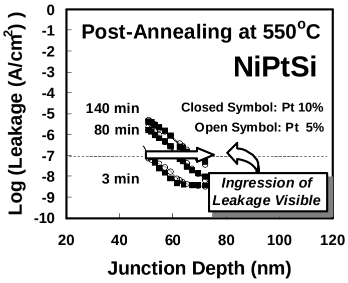

Fig.3 Leakage-depth profiles of 5% and 10% NiPtSi junctions after 550°C annealing.

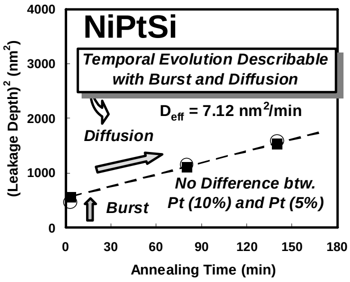

Fig.4 Temporal evolution of leakage depth of NiPtSi junctions during 550°C post-annealing.

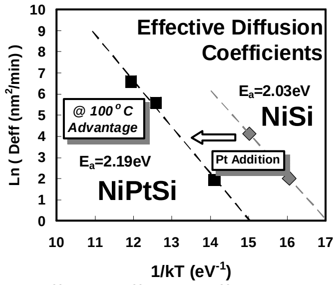

Fig.5 Effective diffusion coefficients plotted as functions of temperature for both NiSi and NiPtSi.

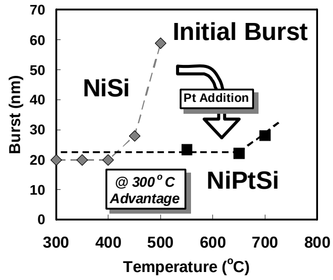

Fig.6 Amounts of initial burst plotted as functions of temperature for both NiSi and NiPtSi.

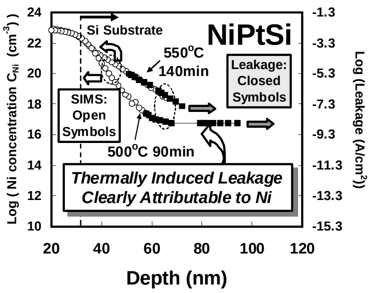

Fig.7 Comparison between Ni SIMS profiles (open symbols) and leakage-depth profiles (closed symbols) of NiPtSi junctions after post-annealing.

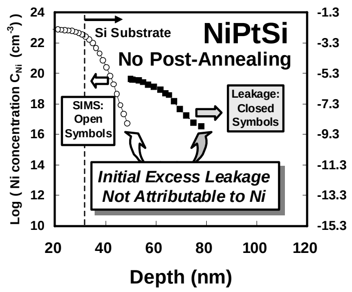

Fig.8 Comparison between Ni SIMS profiles and leakage-depth profiles of NiPtSi junctions without post-annealing.

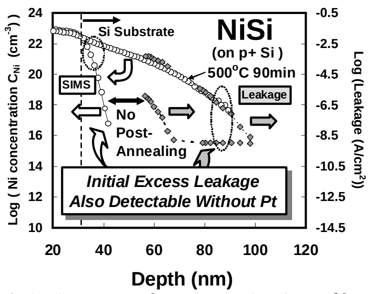

Fig.9 Comparison between Ni SIMS profiles and leakage-depth profiles of NiSi junctions with and without post-annealing.

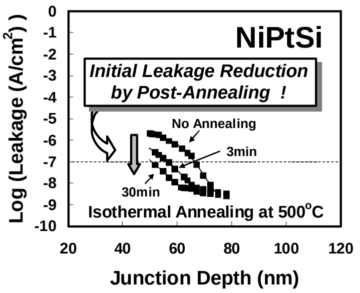

Fig.10 Evolution of leakage-depth profiles of NiPtSi junctions during post-annealing at 500°C.

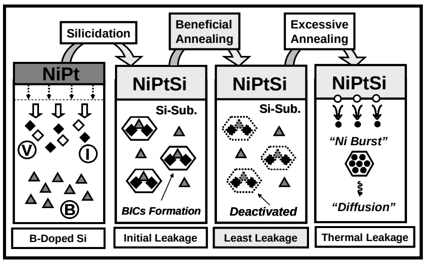

Fig.11 Schematic diagram explaining origins of initial and thermal leakages and concepts of beneficial and excessive annealing.

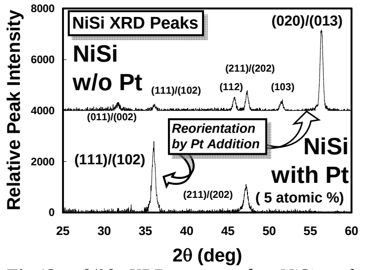

Fig.12 θ/2θ XRD spectra for NiSi and NiPt(5%)Si films.

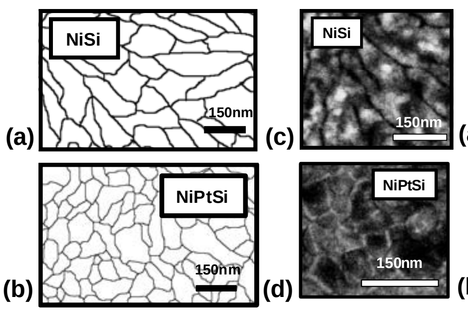

Fig.13 Outlines of grains: (a) NiSi, (b) NiPt(5%)Si. Plan-view HAADF images: (c) NiSi. (d) NiPt(5%)Si. EDX detects 10 atomic % Pt on white network in (d).

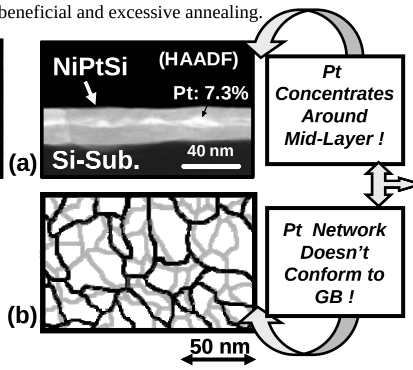

Fig.14 (a): X-HAADF image of NiPt(5%)Si. (b): Plan-view correlation between grain boundary (black) and Pt network (gray)

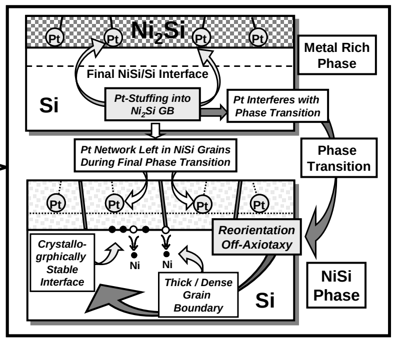

Fig.15 Schematic diagram explaining a model of Pt-induced reorientation and associated thermal stabilization.