Influence of annealing schemes on the formation and stability of Ni(Pt)Si thin films: partial, laser, total, and unique anneals

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Silicide thin films are used as contacts to improve electrical conductivity in microelectronics technologies [1]. For advanced technologies (starting from the 65 nm-node), the choice of silicide material has converged towards nickel-based silicide: Ni(Pt)Si thin films. Compared to the previously popular cobalt-based silicides, Ni(Pt)Si presents the advantage of a lower formation temperature, and a diffusion-controlled growth, preventing formation issues in narrow active lines [1]. However, one of the major drawbacks of Ni(Pt)Si films is their low stability at high temperatures *i.e.,* morphological degradation due to the agglomeration phenomenon. With the downscaling trend of the transistors, the current thickness of Ni(Pt)Si films is reduced to 10 nm resulting in a high sensitivity to agglomerate. Such degradations represent a serious limitation particularly in recent imagers technologies dealing with the co-integration of both Ni(Pt)Si and $TiSi_x$-based contacts [2]. In addition, due to the reduction of final Ni(Pt)Si thickness obtained through laser anneal, Dynamic Surface Annealing (DSA) has been introduced for the 28 nm-FDSOI technologies instead of the classical Rapid Thermal Annealing [3].

In a previous work, we demonstrated that the annealing schemes (partial, total, and unique anneal) used during the formation of Ni(Pt)Si thin film impact the final silicide thickness, microstructures and agglomeration temperature [4]. Previous findings indicated that a potential impact of the silicide film texture might explain the results discrepancy.

In this study, the impact of various annealing schemes (partial, DSA, total, and unique anneal) on the formation and agglomeration of ultra-thin Ni(Pt)Si films is investigated. In this way, similar Ni(Pt)Si thickness (10 nm) has been achieved on 300 mm Si(100) wafers. After complete formation, the silicide films are then submitted to an additional anneal, between 500 and 800 °C, to evaluate their stability at high temperatures (Fig. 1). To this extent, a combinatorial approach of several ex-situ techniques (Rs, ellipsometry, TEM-EDX, SEM, and EBSD) is performed.

Fig. 2 illustrates that the degradation of Rs appears to shift to higher or lower temperatures depending on the annealing type. One might consider that this result could not be assigned to a discrepancy in final silicide thickness. Moreover, on Fig. 3, top-view SEM inspections performed after the additional annealing at 500 °C for 30 s demonstrates a change in silicide microstructures, and confirms the previous Rs results indicating that DSA anneal allows to delay the degradation to high temperatures (Figs. 2 and 3). Our findings suggest that the pink-NiSi(013) grains, in Fig. 4, present a more favourable interface energy with the Si(100) substrate as compared to the blue-NiSi(100). The pole figures presented in Fig. 5 explicit an axiotaxy-like texture in the particular case of DSA annealing. Texture comparisons for ultra-thin films (10 nm) give deeper insights into the role of the orientations of NiSi(010) and NiSi(013) in the agglomeration phenomenon. Depending on the annealing schemes used during the formation of the silicide, there is a strong correlation between the initial microstructures of Ni(Pt)Si films and the agglomeration. Indeed, cross-analyses of these different key parameters indicates that the presence of very fine grains (40 nm) in DSA-laser anneal, and high ratio of Ni(Pt)Si grains oriented towards the (013) direction (or pink-indexed grains) appear to be more efficient in delaying the agglomeration to higher temperatures. These results will be discussed in terms of grain size distribution by combination of SEM and TEM analyses, elements redistributions by STEM-EDX profile scans, and texture evolutions during agglomeration by pole figure and EBSD analyses.

References

[1] C. Lavoie et al., Microelectronic Engineering 70, 144 (2003).
[2] F. Guyader et al., 2022 International Electron Devices Meeting (IEDM) (2022), p. 37.4.1-37.4.4.
[3] C. Feautrier et al., J. Appl. Phys. 10 (2017).
[4] M. Grégoire et al., Microelectronic Engineering 271–272, 111937 (2023).

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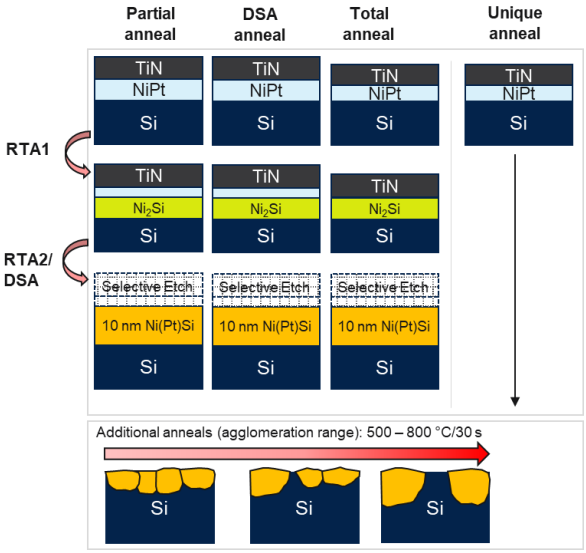

Fig. 1: Schematics of the different annealing schemes used during the formation process of 10 nm Ni(Pt)Si films followed by an additional high temperature-anneals between 500 – 800 °C/30 s.

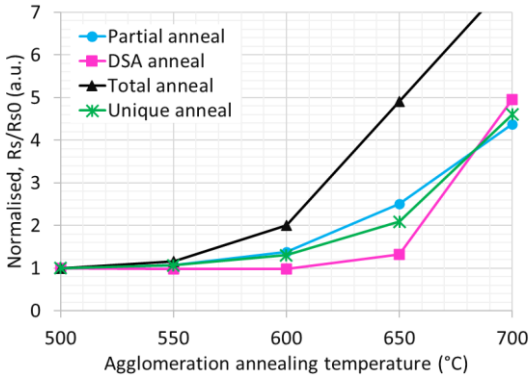

Fig. 2: Normalized sheet resistance, Rs, of 10 nm Ni(Pt)Si formed by different annealing schemes post-high temperature anneals showing drastic Rs increase due to film degradation.

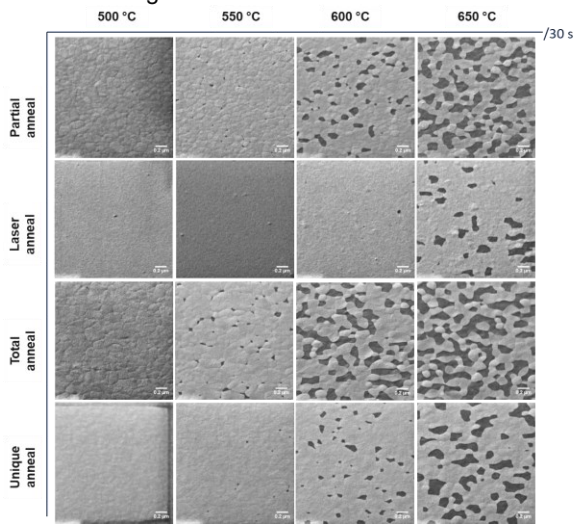

Fig. 3: Top-view tilted-SEM images of 10 nm Ni(Pt)Si illustrating morphology evolution during agglomeration phenomenon for annealing between 500-650 °C/30 s. Light gray contrast represents Ni(Pt)Si thin film, dark gray contrast represents exposed Si substrate.

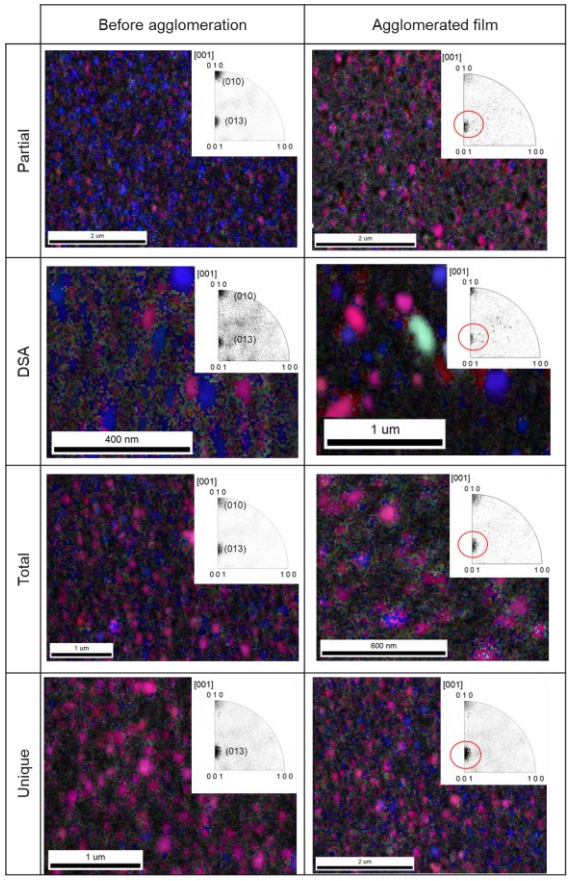

Fig. 4: EBSD cartography mappings and inverse pole figures (IPF) for grains spatial distribution and texture analysis of Ni(Pt)Si on Si(100) substrate. Pink colour represents Ni(Pt)Si(013)/Si direction, blue represent Ni(Pt)Si(010)/Si(100) direction and dark areas represents unindexable and/or fine grains. Texture evolves principally towards pink grains after agglomeration as seen in IPF where intensity of Ni(Pt)Si(010) is reduced while Ni(Pt)Si(013) remained.

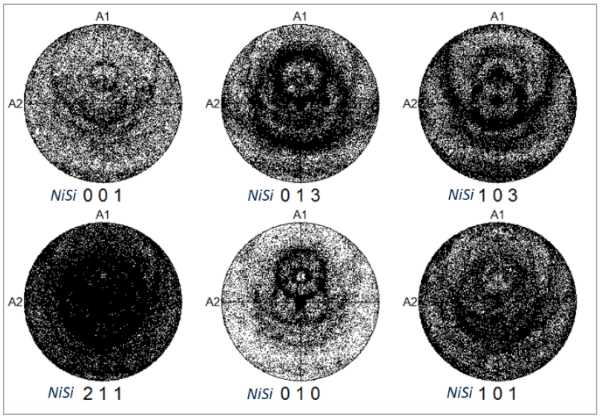

Fig. 5: EBSD extracted pole figures (PF) of 10 nm Ni(Pt)Si film on Si(100) substrate formed by DSA after annealing at 550 °C/30 s. Axiotaxy-like texture is detected in the typical axiotaxy direction *i.e.,* NiSi(013), NiSi(211), and NiSi(202).