Effect of Ni on the formation of Co silicides from Co-Ni alloy.

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In microelectronics, especially in Complementary Metal Oxide Semiconductor (CMOS) technology, metal silicides such as Titanium disilicide ($TiSi_2$), Nickel monosilicide (NiSi), and Cobalt disilicide ($CoSi_2$) have been widely used as contacts (i.e., to form source, drain and gate contacts) [1]. Although NiSi is mainly used for sub-65 nm CMOS technology, it is interesting to use the low resistivity of $CoSi_2$ for 65 nm CMOS technology, especially in 200 mm fabs [2]. However, the formation of $CoSi_2$ is difficult in small devices, especially with sizes below 65 nm and lower formation temperatures are required for the actual process. Several studies have demonstrated that adding/alloying Ni (i.e., ternary $Co_{1-x}Ni_xSi_2$) significantly reduces the formation temperature of the $CoSi_2$ phase [3,4]. Moreover, the alloyed films are morphologically more stable and offer a smaller lattice mismatch to Si than non-alloyed films ($NiSi_2$ and $CoSi_2$). Hence, understanding the impact of Ni incorporation on the formation of $CoSi_2$ is needed.

Therefore, in this work, we systematically investigated the effect of different Ni concentrations (i.e., 0 at.%, 8 at.%, 15 at.% and 35 at.%) on the formation of Co disilicides. After cleaning the substrate (i.e., Si_{100}), Co(Ni) films were deposited using simultaneous magnetron co-sputtering of Co and Ni targets. During this co-deposition, the substrate was not rotated in order to obtain a gradient of Ni concentration in the Co film. The powers applied on the Co (P = 150 W) and Ni (P = 30 W) targets during the co-sputtering were optimized in order to obtain Ni concentration varying between 2 and 45% and thicknesses between 30 and 90 nm by comparing simulation (Fig. 1a) and experimental measurements of the thickness by XRR (Fig. 1b) and Ni content by SEM/EDX. Later, a 30 nm SiO_x protective layer was deposited in order to carry out the in-situ XRD measurement (Fig. 2), and the results show that the same formation sequence (i.e., Co_2Si, CoSi and $CoSi_2$) is obtained for all different Ni concentrations. Noticeably, the texture of the films varied with respect to the Ni concentrations, mainly the preferential orientation of the $CoSi_2$ phase (i.e., 220, $2\theta = 47.8°$) intensity is highly enhanced with 8 at.% and 15 at.% of Ni films than the pure one (0 at.%). However, the presence of the NiSi phase (i.e., $2\theta = 31.6°$ & $35.7°$) is noticed for a higher Ni concentration (i.e., 35%, see Fig. 2d) than other concentrations. This NiSi phase formation (below 350 °C) for the initial concentration of 35% Ni is related to the solubility limit of Ni in CoSi (about 30 at.% of Ni at 400 °C). Indeed if the concentration is higher than the solubility (i.e., 35 at.% Ni instead of 30 at.%), it does not allow the incorporation of all Ni within the CoSi phase, leading to formation of the NiSi phase (Fig. 3). Furthermore, the evaluation of the $CoSi_2$ phase formation temperature is spotted with various Ni concentrations (Fig. 4), for example, 515 °C (0 at.% Ni), 470 °C (8 at.% Ni), 445 °C (15 at.% Ni), 490 °C (35 at.% Ni). As a result, adding a small Ni concentration that favors the $CoSi_2$ phase formation at a lower temperature, even for the larger Ni quantity (35 at.%), is still below the temperature range than pure Co one (i.e., 0 at.% Ni). These results may be explained using the ternary phase diagram (Fig. 3). Hence, this study is beneficial to understanding the impact of Ni on the Co silicide formation and to the integration of Co(Ni) alloys for contact formation in microelectronics.

References

[1] C. Lavoie, P. Adusumilli, A. V Carr, J. S. J. Sweet, A. S. Ozcan, E. Levrau, N. Breil, and E. Alptekin, ECS Trans. **77**, 59 (2017).
[2] A. Newman, A. Campos, D. Pujol, P. Fornara, M. Gregoire, and D. Mangelinck, Mater. Sci. Semicond. Process. **162**, 107488 (2023).
[3] Y. Piao, Z. Zhu, X. Gao, A. Karabko, C. Hu, Z. Qiu, J. Luo, Z.-B. Zhang, S.-L. Zhang, and D. Wu, J. Vac. Sci. Technol. A Vacuum, Surfaces, Film. **30**, (2012).
[4] D. Smeets, J. Demeulemeester, K. De Keyser, D. Deduytsche, C. Detavernier, C. M. Comrie, C. C. Theron, C. Lavoie, and A. Vantomme, J. Appl. Phys. **104**, (2008).

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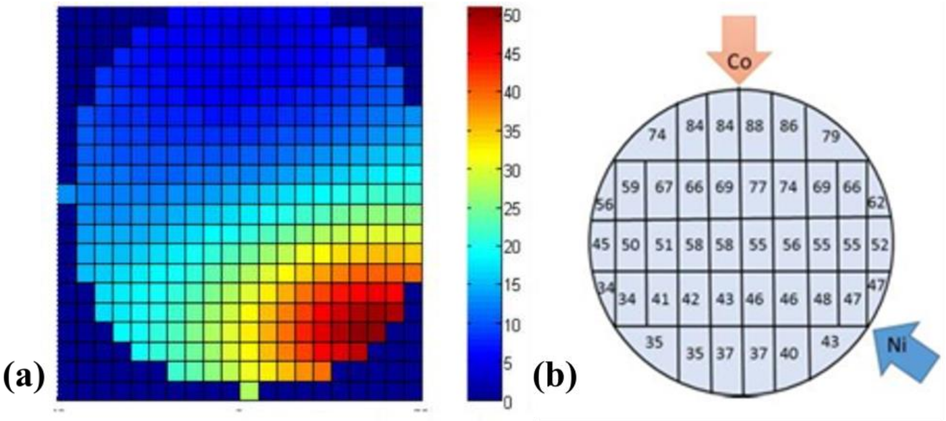

Fig. 1: Co-deposition of Co & Ni: (a) Simulated gradient of Ni percentage and (b) Thicknesses measured by XXR.

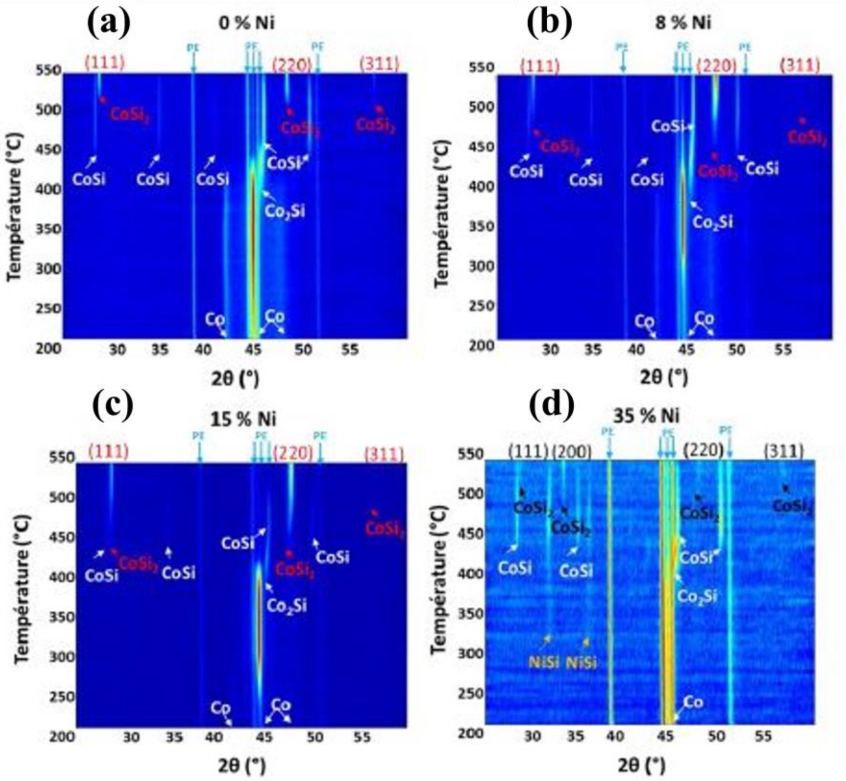

Fig. 2: In-situ XRD patterns for different Ni concentrations (a) 0 at.%, (b) 8 at.%, (c) 15 at.%, and (d) 35 at.%.

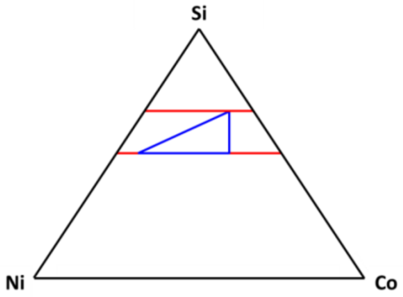

Fig. 3: Co-Ni-Si ternary diagram at 450 °C showing the equilibrium between CoSi, NiSi and $CoSi_2$.

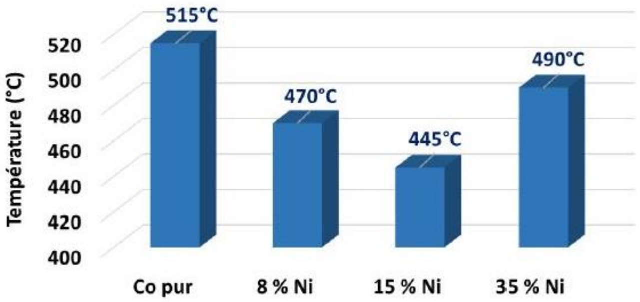

Fig. 4: Formation temperature of $CoSi_2$ phase using different Ni concentrations (0 at.%, 8 at.%, 15 at.%, and 35 at.%).