Innovative correlative study based on NBD and EDS analyses for nanoscale characterizations of cobalt silicide film

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New RF technologies are being developed for various applications, including satellite, and automotive [1]. One of interesting options for 65 nm RF technology is to integrate an innovative Co silicide process. In the past decades, the development of 65 nm node dealt with the replacement of Co disilicide by Ni mono-silicide integrations [2]. The change was motivated by two main problems relative to Co silicide formation: the narrow-line effect and the Co disilicide formation temperature [2]. In that way, new approaches have been studied to form Co disilicide in small dimensions by introducing between the Co layer and Si substrate a Ti interlayer. Such process is known as TIME for Ti Interlayer-Mediated Epitaxy [3]. Indeed, the targeted microstructure for Co silicide layer generates an hetero-epitaxy with the Si(100) substrate, what could be an enabler for Co disilicide films in critical dimensions. This ternary system is complex to integrate in microelectronics but reveals clear challenges in terms of characterizations.

To investigate the influence of TIME process on the final Co-silicide microstructure, several samples were prepared. A stack formed of Ti, Co and TiN layers is deposited by PVD (Physical Vapor Deposition). The samples will be referred as A, B and C dealing with the subsequent deposition thicknesses for each layer: A Ti 5 nm/Co 7.2 nm/ TiN 10nm, B and C are identical: Ti 3nm/Co 7.2nm/ TiN 10nm. The annealing temperatures will be different from those 3 layers. The standard silicide process flow starts with a first anneal at 500 °C for 30 s, and a second anneal at 800 °C for 20 s to form the less-resistive $CoSi_2$ phase.

In this study, the primary objective is to observe the influence of titanium during the silicidation process and evaluate the presence of any identified parasitic phases like CoTi, TiSi, and Ti. To achieve these goals, EDS (Energy Dispersive X-ray Diffraction Spectroscopy) and NBD (NanoBeam diffraction) TEM techniques are combined to investigate the local microstructure in detail. TEM- EDS is used to validate the stoichiometry of the sample using cliff and lorimer quantification [4]. NBD, with Automated Crystal Orientation and Phase Mappings (ACOM-TEM) [5], uses electron diffraction to study phases presence and crystalline orientation at a nanometer scale. Diffraction analysis is performed using the NanoMEGAS ASTAR system implemented on a JEOL NeoARM TEM with 1.5 nm step size resolution.

The STEM-HAADF images comparison shows the impact of the couple thickness/temperature on silicidation (fig 1). As the films grow thicker the layers are more homogeneous. The correlation of those HAADF maps with elemental EDS maps (fig.2) enables to highlight the presence of titanium inside CoSi grains. The quantification of different regions on those samples with or without titanium is summarized in table 1. The quantification results on the three samples A indicate a stoichiometry close to $CoSi_2$ structure. These results information will be implemented on further crystal orientation analysis.

Figure 3 shows the virtual bright field image and the orientation map for the 3 samples. The indexing of diffraction patterns mainly revealed the presence of the $CoSi_2$ phase for all 3 samples. This phase corresponds to a face-centered cubic phase with lattice parameters close to those of the Si substrate phase. Therefore, the orientation mapping overestimates the presence of $CoSi_2$ in the substrate. Moreover, the orientation map correlated with the $CoSi_2$ index map point out the presence of 2 preferential orientations. One is along the (001) plane, which is the growth plane of Si, and the second is along the (-122) plane. Finally, the titanium inclusions do not affect the crystal structure of the different cobalt silicides, and thus, no CoTi or $TiSi_x$ grains were detected. The NBD analysis also did not reveal the presence of residual cobalt grains. To summarize, a simple TEM-EDS analysis is not sufficient to deeply study such a complex silicidation process. But its combination with NBD allows for a more in-depth analysis for the detection of phases and the organization of the silicide matrix in the presence of a thin initial Ti layer. The alliance of both technique enables to get complete sets of characterization allowing to better understand complex material implemented in microelectronics applications.

References

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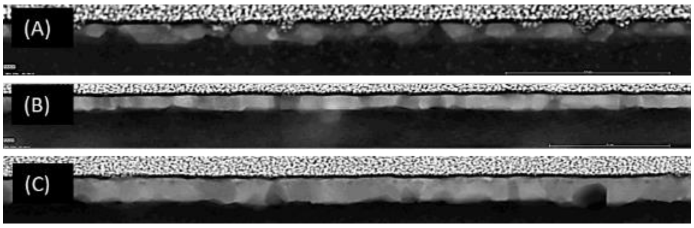

Figure 1: STEM HAADF images of $CoSi_x$ layers for (A), (B) and (C).

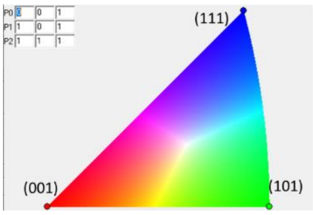

Figure 4: Index map of $CoSi_2$ cubic phase

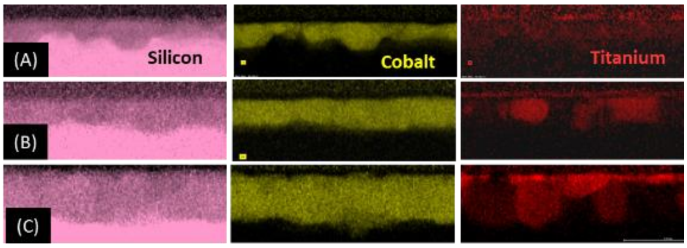

Figure 2: EDS quantified maps of $CoSi_x$ layers of samples (A),(B) and (C)

	Sample A		Sample B		Sample C	
Co	35 at.%	/	25 at.%	23 at.%	35 at.%	29 at.%
Si	64 at .%	/	74 at.%	67 at.%	64 at.%	60 at.%
Ti	>1 at.%	/	1 at%	10%	1 at.%	11 at.%

Table 1: EDS quantification on different area of the 3 samples without or with Titanium content

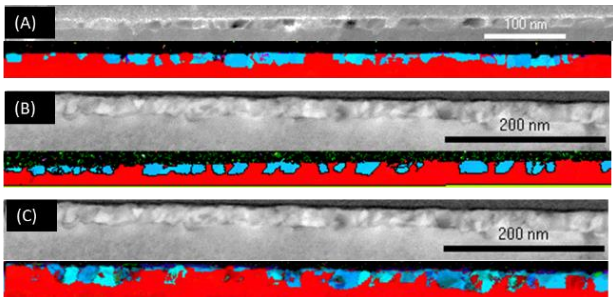

Figure 3: Virtual Bright Field and NBD orientation maps for $CoSi_2$ indexation phase for samples (A), (B) and (C)