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APPLICATION NOTE

A TEM-based Materials Analysis Study into 22nm FinFET Technology

INTRODUCTION

Fin field-effect-transistor (FinFET) is the basis for modern nanoelectronic semiconductor device fabrication. Figure 1 schematically shows its 3D structure design. The gate wraps around the channel on the raised Silicon fin, in which charge current flows between SiGe source and drain. Compared to traditional planar transistors, FinFET provides greater surface area between gate and channel and thus better control of the electric field and leakage reduction in the "off" state [1].

In this application note, we present a study into the structure, elemental distribution and crystal orientation of a 22nm FinFET structure, using Nanolab Technologies' state-of-art TEM instruments and other TEM-based analysis techniques including EELS and PED.

TEM lamella of ~50 nm thickness was prepared at Fin location as labeled in figure 1, by in-situ FIB lift-out technique. Figure 2 shows STEM images of the lamella, taken with a Cs probe-corrected Thermofisher Titan TEM. From the low-mag overview, one 8-fin array and one 2-fin array are seen, in contact with metal gate and then M0 and M1 metal layers separated by dielectric inter-layer. Si atom dumbbells with 0.12 nm distance between the two Si atoms are clearly seen once we zoom in at the Fin tip region, as shown in the high-resolution STEM image. This is achieved with the assistance of Cs probe-corrector that enables ultra-high spatial resolution up to 0.07 nm. One can also easily observe and measure the sub-nanometer high-k metal gate and gate oxide layers from this zoom-in image.

We were able to analyze elemental distributions in the sub-nanometer layers near the fin structure, as shown by EELS (Electron Energy Loss Spectroscopy) elemental color maps in figure 3. It is concluded that from Fin tip to metal contact, the constituent layers are: SiOx – HfOx – TiN – TaNO – TiN – TiAlOC – TiN. The metal contact is W.

EELS was also used to analyze low-k dielectric inter-layers between metal layers, as shown in figure 4. Compared to other TEM-based elemental analysis techniques such as EDS, EELS possesses higher sensitivity to light elements such as Li, B, C, N, O, and therefore provides more accurate quantitative analysis for relative compositions of non-stoichiometric oxides such as SiOx, SiCOx, etc. From below line scan, we were able to extract elements' relative ratio with accuracy up to 1 at.%.

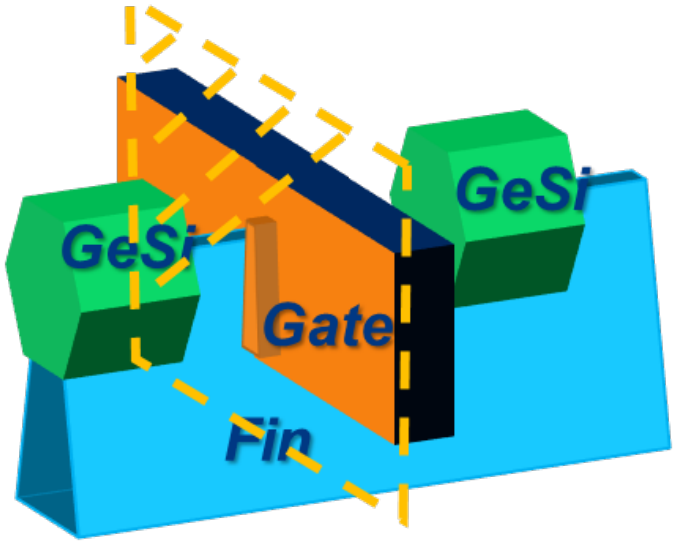
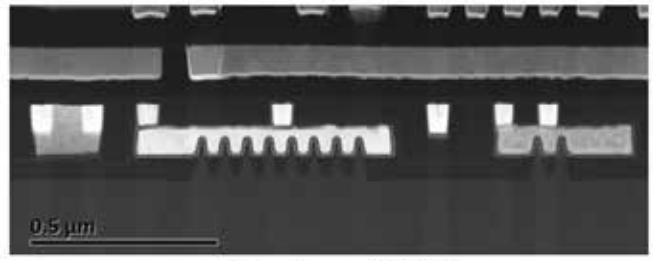
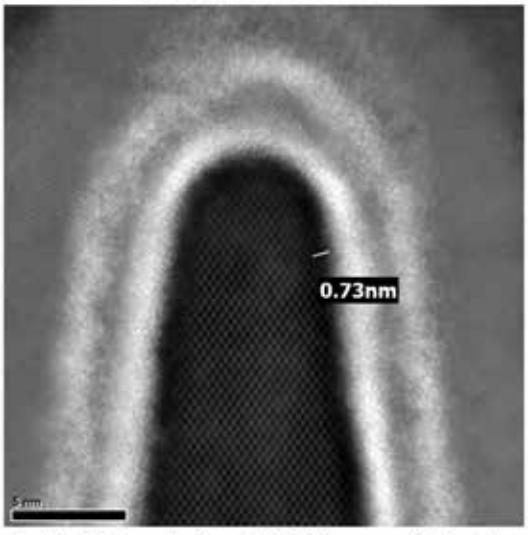


Figure 1: Schematic 3D figure showing FinFET structure. Orange dotted plane shows current cut location.



a. Overview of FinFET



b. High Resolution STEM image of Fin tip

Figure 2: STEM images of 22nm FinFET

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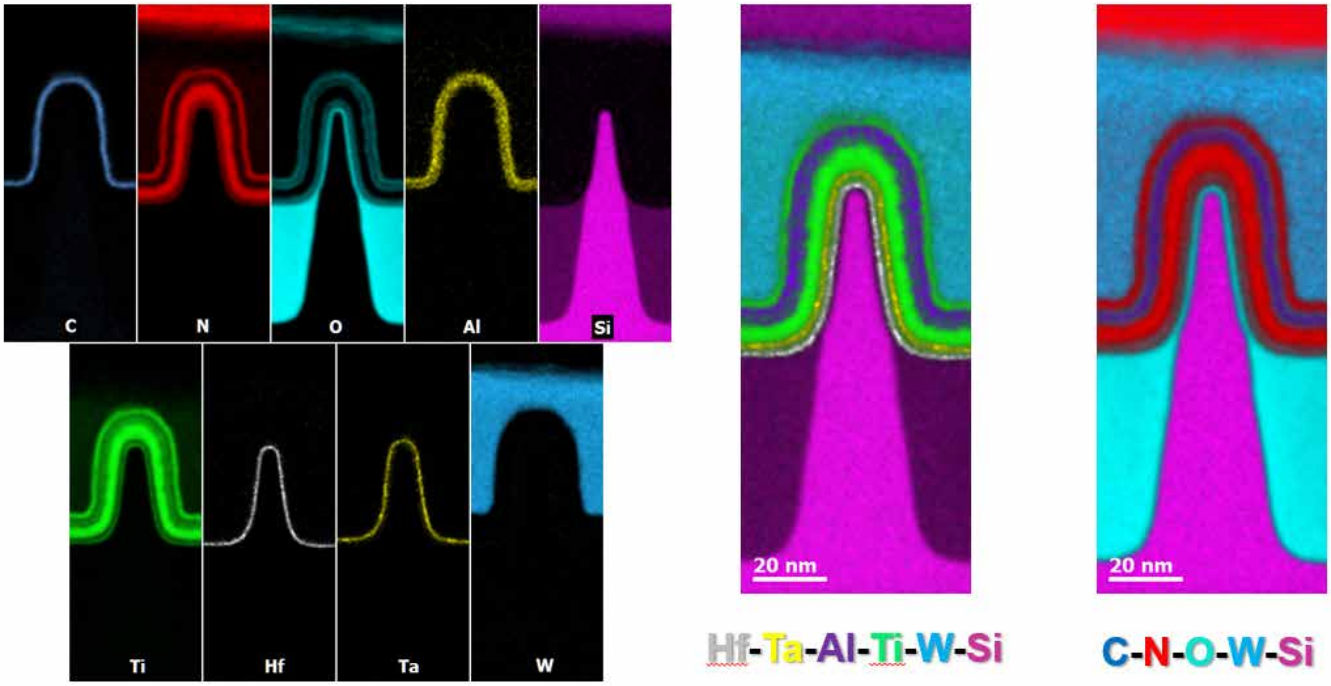

Figure 3. Elemental color maps of 22nm FinFET

Figure 5 reveals grain orientation analysis of MO Cu line and metal gate W, acquired by PED (Precession Electron Diffraction) technique. PED is a nano-beam diffraction analysis technique integrated with TEM. It provides crystal orientation, grain size, texture and strain analyses at nanometer scale. From the Cu grain orientation map in figure 5a, one can obtain a statistical understanding of the grain size distribution in the Cu metal line, as well as the Cu grain orientation preference as shown in figure 5c. <111> direction is observed to be the preferred growth direction on the vertical direction.

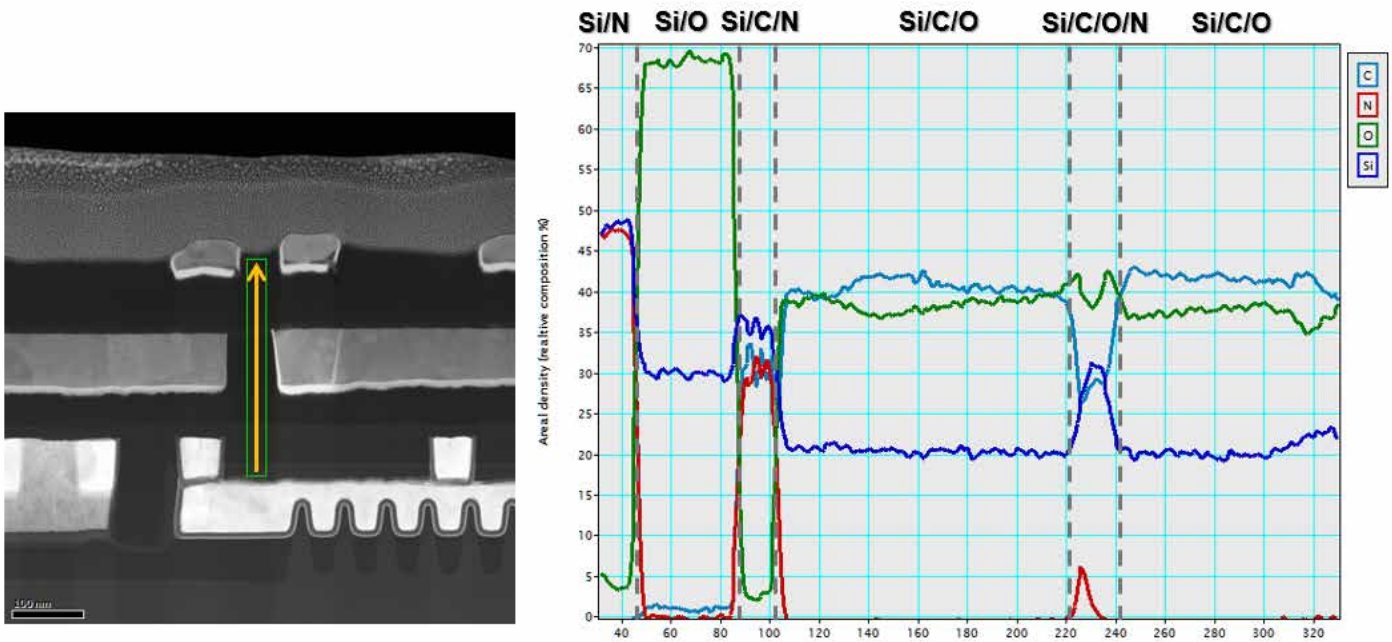

Figure 4: Semi-quantitative line scan of low-k dielectric inter-layers

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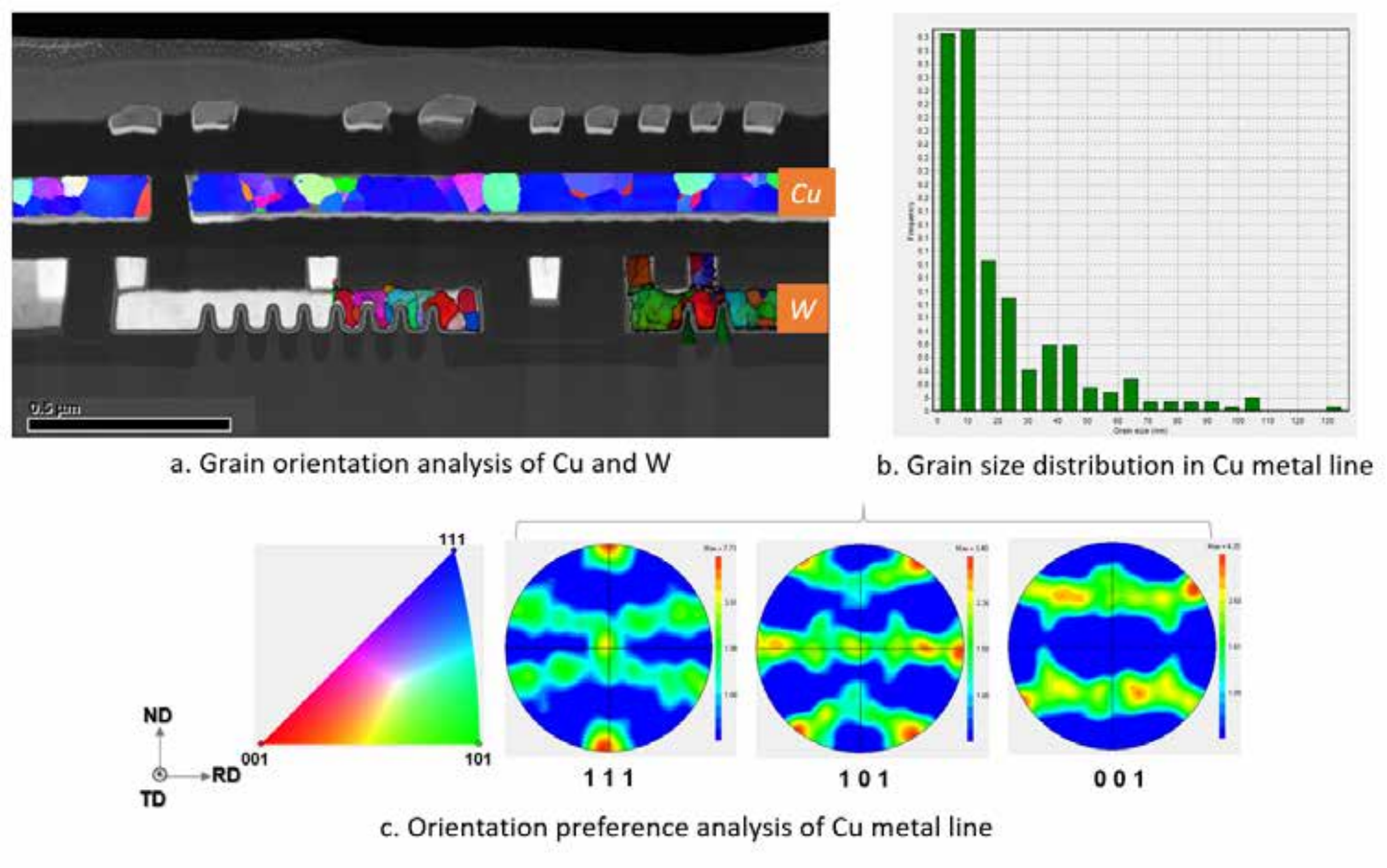

Figure 5: Grain orientation analysis of W and Cu metal layers

SUMMARY

Nanolab Technologies, a Eurofins company, has extensive experience in electron microscopy-based materials analysis of semiconductor devices. We have shown in this application note our capability to apply various TEM-based techniques to analyze the structure, materials and crystal orientations of a 22nm FinFET, all at nanometer or sub-nanometer scale. These analyses can also be applied to investigations on other complex devices including 7 nm FinFET, nanosheet transistor, 3D NAND, MRAM, etc…

REFERENCES

[1]. https://blog.lamresearch.com/tech-brief-finfet-fundamentals/