Applications of electron tomography to advanced CMOS process technology

Abstract

As semiconductor device dimensions continue to shrink, the transistors themselves are becoming smaller than the thickness of a transmission electron microscopy (TEM) lamella. If lamellae cannot be made smaller, electron tomography may soon be needed to resolve features that change within the thickness of the lamellae. We report on tomography results from three popular CMOS device challenges. In the first sample, an e-SiGe epitaxial S/D region is resolved in three dimensions. In the second sample, NiSi growth morphology is resolved in three dimensions, on both a S/D region and a gate. And in the third sample, tungsten contacting NiSi is reconstructed in three dimensions, suggesting the total 3D contact area between the two metals.

Hugh L. Porter*, Jeremy D. Russell**

SEMATECH and GLOBALFOUNDRIES*, GLOBALFOUNDRIES**

Albany, New York, United States, hugh.porter@sematech.org

GLOBALFOUNDRIES 28 NM PROCESS TECHNOLOGY

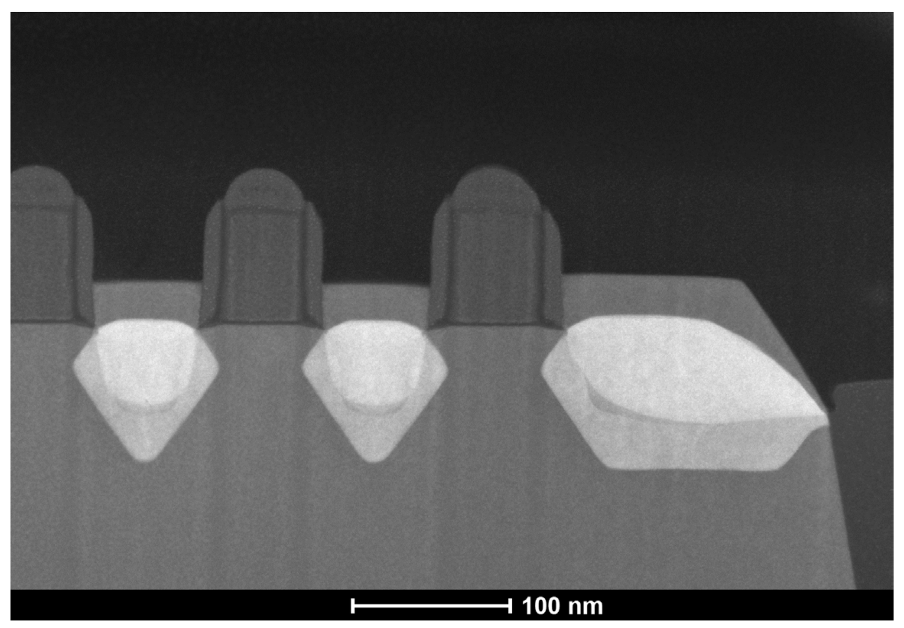
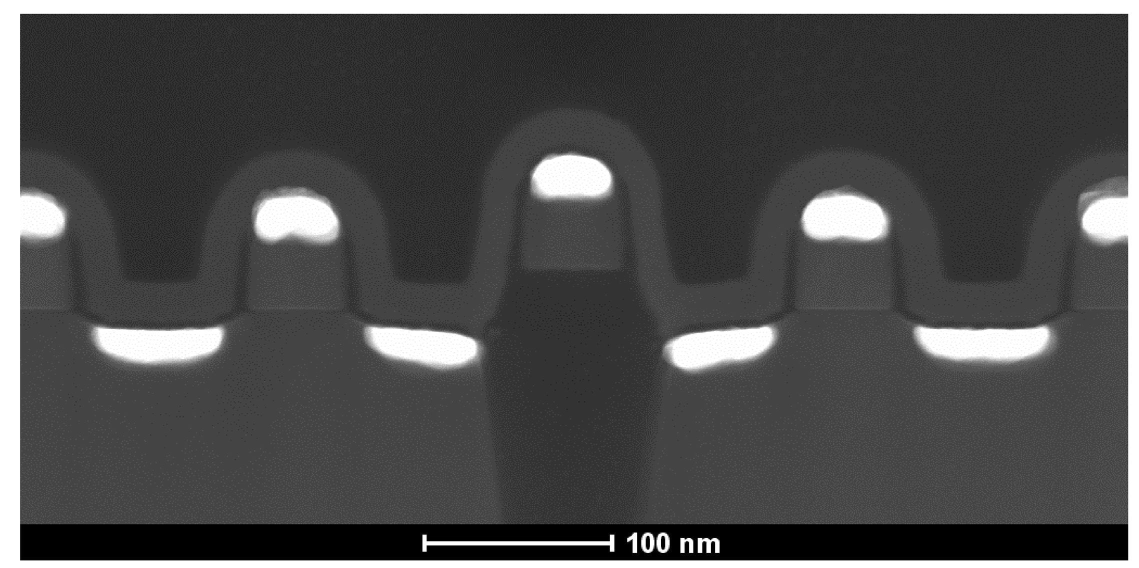
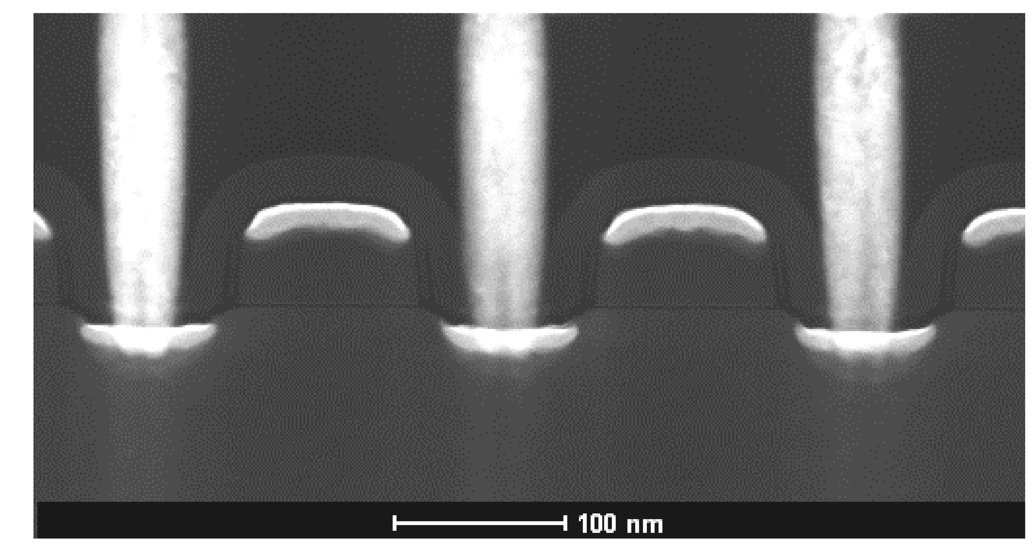
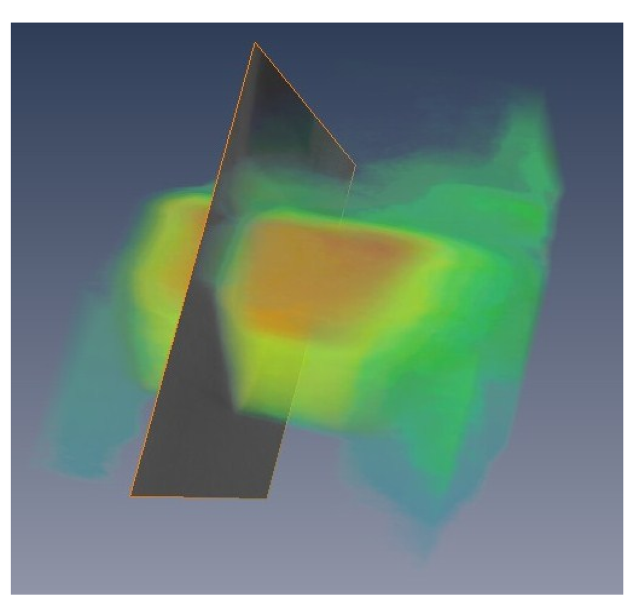
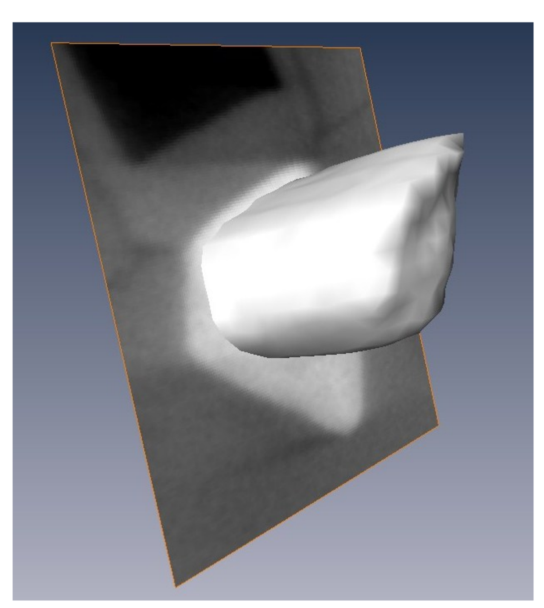
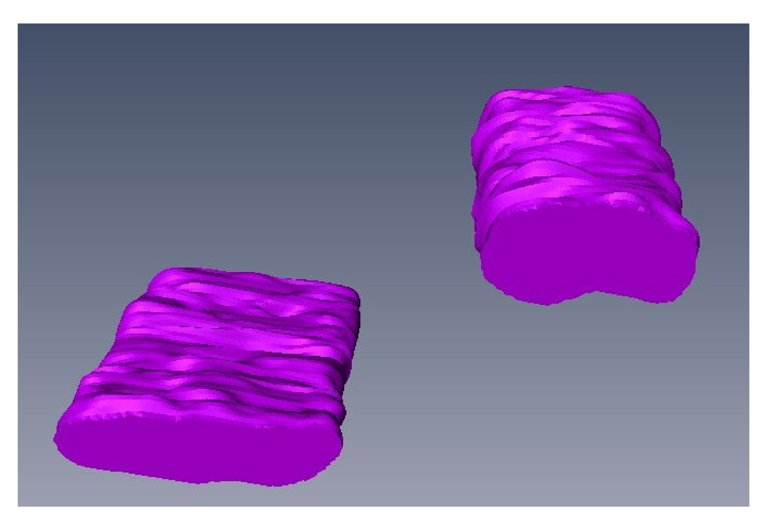
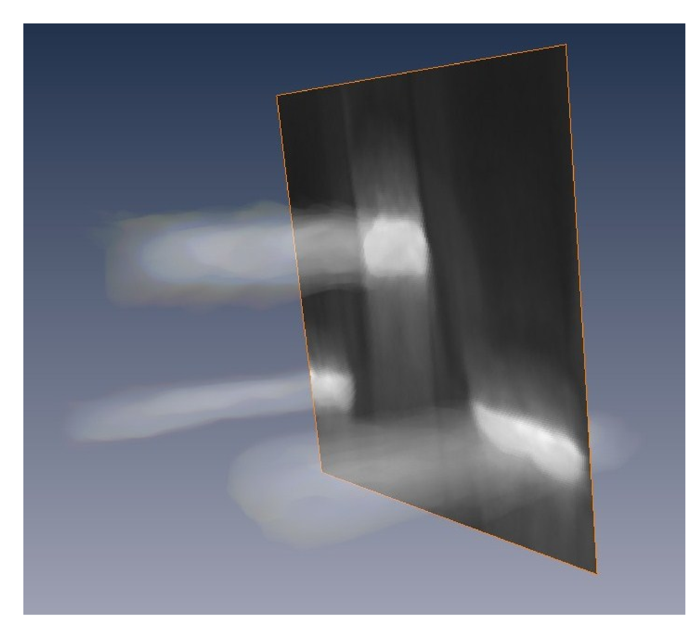
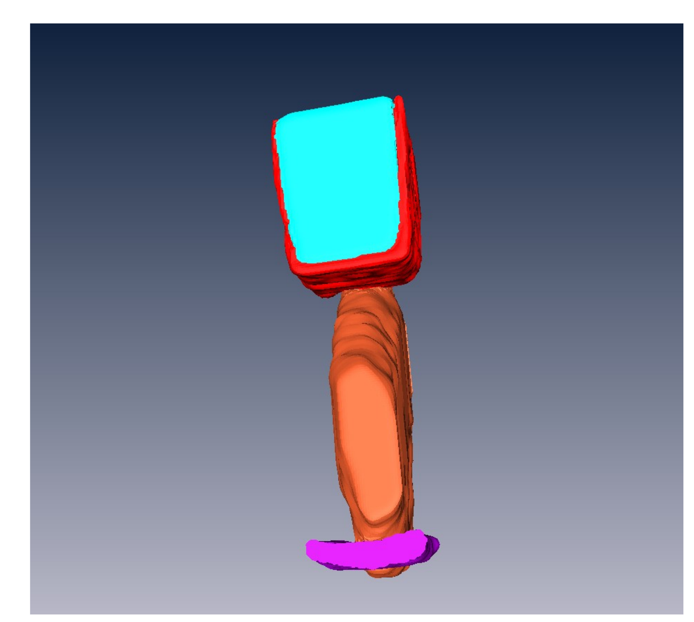
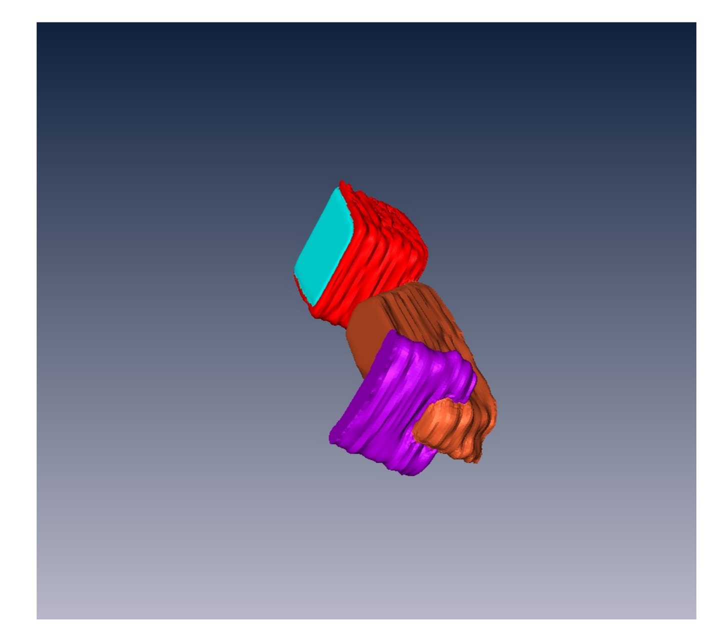
The samples analyzed for this study were taken from the GLOBALFOUNDRIES 28 nm process technology, and were fabricated at GLOBALFOUNDRIES Fab 8 in Malta, NY. The 28nm technologies are based on bulk silicon substrates, and are designed for a wide variety of applications from high performance such as graphics and wired networking to mobile computing and digital consumer to low power wireless mobile applications that require long battery lifetime.

FEI Titan 80/300 Electron Tomography

The tilt series were carried out on a probe-corrected FEI Titan 80-300 TEM, using FEI Automated Tomography software. The microscope was operated in STEM mode at 300 kV. A high angle annular dark field (HAADF) detector with a relatively short camera length of about 70 mm was used to reduce diffraction contrast and allow Z-contrast to dominate the image .

Conclusions

For tomography to become standard practice, certain technical challenges need to be addressed. Sample throughput needs to improve, for example. But most importantly, the nature of tomography needs to be understood by both TEM engineers and internal requestors, and technical transparency should be maintained between the two groups. Leaving noise in the images so that all stakeholders have an equal chance to see the raw data and draw their own conclusions would be a good practice. The need to tune a semiconductor process requires speed of data and transparency and integrity of the technique. Based on our preliminary results showing tomographic images of advanced CMOS technology, it is our finding that tomography can add value to process development.

	PMOS e-SiGe	NMOS NiSi	W contact to NiSi
STEM cross sections			
Sample information	The STEM image above shows the e-SiGe (in bright) for PMOS devices. It is deposited in more than one concentration, and integration engineers would like to know the shape of the SiGe crystals in 3 dimensions. Below image "a" shows a semitransparent tomographic reconstruction of one of the SiGe crystals. The false colors show the higher concentration in orange, and the lower concentration in yellow. The image "b" shows the same thing only with an opaque reconstruction of just the higher concentration SiGe. Both reconstructions show an interface between the two concentrations at an angle.	The STEM above shows a row of partially processed NMOS transistors. We see NiSi, but we do not see tungsten contacts. This is so we can analyze the surface roughness and coverage of NiSi, without the tungsten confounding the tomography. In the opaque reconstruction, below image "a", we see a rough NiSi surface, however, very uniform coverage. The semitransparent reconstruction, below image "b", is less informative, but much easier to create.	The STEM image above shows a row of NMOS transistors with both NiSi and tungsten contacts. Sometimes it is hard to determine the quality of the contact between these two metals based on the STEM image alone. The reconstructions below show that the NiSi and W are in contact through some amount of area between the metals. However, we also see that the tungsten contact is not exactly in the center of the lamella. This can be useful to know when doing TEM on contacts and trying to capture them in the lamella.
Tomographic reconstructions	a)  b) 	a)  b) 	a)  b) 

GLOBALFOUNDRIES® SEMATECH