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Characterization of a FinFET 6T-SRAM cell by tomography

O Richard, S Demuynck, A Veloso, P Van Maree and H Bender
IMEC, Kapeldreef 75, B-3001 Leuven, Belgium
E-mail: olivier.richard@imec.be

Abstract. A 0.186µm² 6T-SRAM cell composed of FinFETs is analysed by high-angle annular dark field scanning transmission electron microscopy (HAADF-STEM) tomography. It allows to reveal features that are not observed in the conventional (S)TEM images due to the overlap of different materials over the thickness of the TEM specimen. The influence of the specimen thickness on the quality of the obtained tomograms is studied.

1. Introduction
Due to its good short channel characteristics and the possibility to control the channel potential without heavy doping the fin field effect transistor (FinFET) is considered one of the most promising structures in order to continue the scaling of the 6 transistors static random access memory (6T-SRAM) device beyond the 32nm node [1,2].

In this study, a 6T-SRAM cell with an area of 0.186µm² with ~20nm wide fins (pitch 124nm) and ~60nm wide metal/polysilicon gate lines (pitch 150nm) crossing in the orthogonal direction is characterized. Contact vias with a diameter of ~60nm and boomerang-shaped vias are patterned with full-field extreme ultra-violet (EUV) lithography. The process flow is stopped before the tungsten metallization and after the deposition of a Ti/TiN contrast layers stack in the contact and boomerang-shaped vias. Due to the complex geometry of this device (figure 1) and the small dimensions of the different structures (less than the thickness of the TEM specimen), it is not possible to avoid the overlap of different materials (metal/polysilicon gate, silicided fin, Si fin, high-k dielectric, nitride spacers, contact and boomerang-shaped vias, Ti/TiN contrast layers, residues…) over the thickness of the TEM specimen in conventional (S)TEM images. Moreover, the preparation of such specimens at the exact position of interest is difficult and one loses the 3D overview of the full cell in thin specimens. In order to overcome these problems, this device is analysed by STEM tomography.

2. Experimental
Different specimens with different thicknesses and at different positions from similar 6T-SRAM cells are prepared by FIB milling. In order to protect the specimen during the FIB milling a CVD glass layer and a sputtered Pt layer are deposited beforehand on the area of interest. The CVD glass layer is ~85nm thick for the thin specimens and ~350nm thick for the thicker TEM specimens in order to avoid the overlap of the device with the Pt layer during the image acquisition at high tilt angle.

The TEM specimens are mounted on a single tilt tomographic holder (Fischione) with the tilt axis parallel to the oxide/silicon interface (figure 2).

The device is composed of different (poly)crystalline materials (silicide/polysilicon gate, silicided fin, Si fin, Si substrate, Ti/TiN contrast layers) inducing diffraction contrasts in the conventional TEM
image series and breaking the projection criterion needed for tomography. The HAADF-STEM mode where the contrast is proportional to the TEM specimen thickness and to $\sim<Z>_2^2$ where $Z$ is the atomic number is used in order to overcome this problem.

An FEI Tecnai (F30) FEG transmission microscope operating at 300kV equipped with the Xplore3D software (FEI) is used in order to acquire the tilt image series. The tilt range is taken for each series as large as possible till the structure is shadowed by the silicon substrate or/and by the protective Pt layer, with $1^\circ$ tilt increment. The image series alignment is performed using 10nm gold beads as fiducial markers and the 3D reconstructions are carried out with the Inspect3D (FEI) software. Two 3D reconstruction schemes, the weighted back projection (WBP) and the simultaneous iterative reconstruction technique with 20 iterations are applied [3,4]. The obtained volumes (3D reconstruction) are then sliced using the Amira software.

**Figure 1.** Layout of the 6T-SRAM device. The vertical black lines are the fins, the horizontal grey lines are the high-k/TiN/polysilicon gate lines running over the fins, the white squares and boomerang shapes are the contacts. The arrows mark the position of the different TEM specimens.

3. Results and discussion

3.1 Thin specimens (specimens # 1a and 1b)

Even with thin specimens (~100nm thick), the correct interpretation of conventional (S)TEM images is not possible due to projection overlaps. Figures 2a and b show two examples for specimens prepared at different positions through the cell. HAADF-STEM tomography is performed with both specimens. Different slices of the 3D reconstruction (tilt range: -69°, +70°) obtained with the specimen of figure 2a are shown in figure 3. As can be seen on the slices taken along the fins (figure 3b-d); the contact vias are not in the middle of the TEM specimen thickness.

**Figure 2.** Conventional TEM images obtained with two thin specimens prepared at the level of the contact vias (a) and of the boomerang-shaped vias (b). The tomographic tilt axis is represented by the black arrow parallel to the oxide/Si substrate interface.
The process flow used for the device fabrication was not fully optimized and therefore the following process problems are clearly revealed on the tomographic slices whereas they are obscured in the TEM images.

The contact vias are slightly shifted to the left with respect to the fins (figure 3a) and, more importantly, not in contact with the fully silicided fins (figure 3a and white arrows b-d), except for the right contact via landing on the polysilicon/silicide gate which is locally in contact with the silicide.

The parts of the fins uncovered by the polysilicon gate exhibit a bright contrast over their whole height indicating that they are fully silicided and silicide is for some of them also observed slightly under the HfSiO/TiN layer stack (white triangle figure 3b).

Metallic residues exhibiting bright contrast are observed on the nitride spacers at the side of the polysilicon gate lines (white arrow figure 3a and other slices (not shown here) parallel with the slice of the figure 3a).

The cross shaped features due to the missing wedge are more visible on the slices coming from the WBP than from the SIRT 20 reconstruction but the contrast exhibited by the different materials is better for the WBP slices (compare figure 3d versus 3c).

The bright points observed in the bottom of the contact vias (e.g. white open triangle in figure 3a) are due to platinum coming from the protective layer whereas the bright features observed in the Si substrate and in the oxide layer (white solid triangles in figure 3a) are due to gold beads indicating that this slice is close to the edge of the TEM specimen.

Figure 3. Slices from the SIRT 20 3D reconstruction in the middle of the contacts (a), along fins (b) and (c). For comparison the slice (d) is taken at the same position as the slice (c) but is taken from the WBP 3D reconstruction. The bottom of the vias is marked with thick white arrows (b-d).

3.2 Thick specimen (specimen #2)
HAADF-STEM tomography (tilt range: -62°, +67°) is performed with a thick specimen (~200nm) with the central wing of the boomerangs centered in the middle of the TEM specimen and with two polysilicon gate lines in the thickness of the TEM specimen. As shown on figure 4, despite the thickness of the TEM specimen it is possible to reconstruct and observe the fins, boomerang vias and polysilicon gate lines. It is nevertheless worth noting that one of the polysilicon gate lines (figure 4a) is in focus whereas the other polysilicon gate line (figure 4b) is slightly out of focus. During the tilt acquisition series and especially for the images at high angle, it is not possible to focus the whole HAADF-STEM images. At high angle (65°), the effective thickness is ~470nm.

Spherical voids are observed in the oxide (white arrows figure 4b). These voids are also observed on the slices coming from the WBP 3D reconstruction and are therefore most likely real features of the structure and not reconstruction artifacts.
Figure 4. Slices from the SIRT 20 3D reconstruction in the middle of the polySi gate line (a), in the middle of the central wing of the boomerangs (b) and in the middle of the second polySi gate line (c).

3.3 Very thick specimen (specimen #3)
HAADF-STEM tomography (tilt range: -58º, +58º) is performed with a very thick specimen (~340nm) with the central wings of the boomerangs centered in the middle of the TEM specimen and with two rows of contact vias in the thickness of the TEM specimen. The contact vias are clearly revealed at one side of the 3D reconstruction (figure 5a) whereas at the other side the slice is not well in focus but still the main properties of the structure are revealed (figure 5b). Notice that at high angle (58º), the effective thickness is ~640nm.

Figure 5. Slices from the SIRT 20 3D reconstruction in the middle of the first row of contact vias (a) and in the middle of the second row of contact vias (b).

4. Conclusions
HAADF-STEM tomography analysis of the FinFET 6T-SRAM cell allows to reveal features which are not observed in conventional (S)TEM images due to the overlap of different materials over the TEM specimen thickness; e.g. presence of residues on the nitride spacers, silicide distribution in the fins, shape and etch depth of the contacts. Moreover in order to obtain interpretable (S)TEM images, very thin TEM specimens at accurate positions would be needed probing only a limited volume of the cell. Although the focusing problem arises for specimens thicker than ~200nm, valuable information on the structure of the device can still be obtained.

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