Key pieces of modern day technology such as the dynamic random-access memory (DRAM) keep following the trend of down-sizing. This requires the dielectric layer that is a crucial component in these structures to reduce its thickness [1]. As downscaling continues the thickness of dielectric components reaches a limit where electrons can tunnel through the dielectric. To overcome this limitation high-k dielectrics such as HfO$_2$ [2], TiO$_2$ or BaTiO$_3$ are investigated. Coating high aspect ratio substrates with a dielectric increases the capacitance of DRAMs by the factor of the aspect ratio. Morphology and conformity of this coating layer play a crucial role for the quality and functionality of a DRAM. We report on a transmission electron microscopy (TEM) study of thin TiO$_2$ layers deposited on a high aspect ratio trench-like substrate.

The key enabling technique to coat high aspect ratio surfaces pinhole-free is atomic layer deposition (ALD) [3]. Two self-limiting reactions of precursors with the surface ensure good uniformity of layers with precise control of the thickness. In addition, a variant of ALD based on O$_2$ plasma as oxidant rather than water vapour is used. This plasma-enhanced ALD (PEALD) has the advantage of lowering the temperatures that are necessary for the precursor ligands to react with the surface. Both, ALD and PEALD were applied to coat an amorphous Si substrate that features a trench-like structure with TiO$_2$ using TDMA-Ti precursor at 75°C at a chamber temperature of 240°C.

Fig. 1 shows TEM micrographs of the trench structure (in a cross-sectional view) covered with 100 cycles of TiO$_2$ using ALD and PEALD, respectively. The micrograph (e) gives an overview of the trench substrate. (a) and (b) show the top part while (c) and (d) show the lower part of the trenches. For (a) and (c) ALD was applied whereas for (b) and (d) PEALD was used for the deposition. PEALD yields better step coverage (bottom thickness divided by top thickness) of 88% compared to 79% for ALD.

In the HRTEM micrograph in Fig. 2 the atomic structure of TiO$_2$ is resolved revealing that PEALD unlike ALD induces crystallization at the same chamber and precursor temperature. In the inlay image of Fig. 2 the simulated diffraction pattern of the anatase phase of TiO$_2$ is compared to the SAD pattern yielding good agreement. Diffraction spots indicated by an arrow correspond to the brookite phase. Both phases have been observed in HRTEM as well. It is planned to investigate how the parameters during PEALD (temperature, plasma power and purging times) influence crystallization.

Fig. 1: TEM of high aspect ratio trenches are shown in cross-sectional view. (a) and (b) show top end of trenches coated with TiO$_2$ using thermal ALD and PEALD, respectively. (c) and (d) show bottom end of trenches coated with TiO$_2$ using ALD and PEALD, respectively. (e) TEM at lower magnification illustrates the high aspect ratio.

Fig. 2: HRTEM confirming crystalline structure of TiO$_2$ deposited with PEALD on top end of the trench structure (cf. Fig. 1 (b)). Inlay shows SAD spots compared to the simulated diffraction rings of the anatase phase of TiO$_2$. Diffraction spots corresponding to the brookite phase are indicated by arrows.