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AES and Related Techniques for Yield Improvement, Metrology and Development Support of ULSI Circuits Manufactured in ≤ 28nm CMOS Technology

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In semiconductor industry, the common surface analysis techniques AES, XPS and TOF-SIMS became widely used and are well established analytical methods for the characterization of thin films. Especially AES (Auger Electron Spectroscopy) plays an important role in the daily routine analysis work in a surface analysis lab, which supports semiconductor fabrication. Also, the superior spot size in state of the art field emission Auger instruments down to 7 nm allows the identification of very small defects. This property is indispensable, because the size of killer defects, which makes an IC chip nonfunctional, decreases with shrinking dimensions in technology nodes ≤ 28nm. Defect sizes of only 10 nm already can cause excursions. More often such tiny features will only be noticed later in the process, after decoration with masking films.

As an example, polycorn defects, which occasionally occure after Poly-Si deposition, are investigated by AES. It is known from TEM Brightfield images that tiny globuli of 2—5 nm size are formed, subsequently cause a distortion of the Poly-Si growth and finally lead to corn formation. AES analysis combined with in situ Focused Ion Beam (FIB) allows the preparation of a cross section and immediate high resolution AES analysis on the cut surface. The inclusions were found to consist of metal oxide. As an example, Al oxide agglomerations are shown in **Figure 1.**

Spacer nodules occured as bridges between transistor gates after spacer Silicon Nitride deposition, produced by very small particles which remain on the Poly-Si gates after final plasma strip. SiN deposition acts as a decoration film and enlarges the defects, here from 10 nm to some hundred nm size. Because the original particles are so small, it is almost impossible to accomplish a conclusive TEM, because particle size and the thickness of the TEM lamella are much different. The accomplishing investigation was carried out by high resolution AES mapping of the Carbon KVV Auger peak. The carbon distribution reflects an enrichment at the place of the defect, indicating organic based residues. **Figure 2.** [1]

With the transition to ≤ 28 nm CMOS technology, the analytical challenges with regard to steadily decreasing dimensions and a still growing materials palette cause a demand for additional techniques. In order to characterize ultrathin films and multiple film stack systems, especially in a high-k metal gate stack, LEIS (Low Energy Ion Scattering Spectroscopy) is a useful supplement. With its monolayer sensitivity of ≤ 1 Å it fills a gap, since AES and XPS with an information depth between 10…50 Å applied on ultrathin films reach their limit. Questions regarding film formation, nucleation, film coverage, diffusion as materials properties from huge importance, finally can be answered by the smart combination of above mentioned techniques.

As example studies of ALD grown HfO_2 on treated base SiO_2 are shown. Using LEIS, the film closure as well as the film growth are determined from surface spectra. The LEIS results are compared with AES, XPS, TEM cross sectional analysis and ellipsometric thickness measurements (VASE). **Figure 3.** [2] [3]

Ultra thin PVD Aluminum on TiN acts as nucleation promoter for the subsequent Poly-Si deposition. The film formation and closure of the Al was analysed by LEIS. Even the longest deposition time, which results in nominal 8Å thick Al did not form a complete cover of the TiN underlayer. Whereas the following 3D Atomprobe (LEAP) investigation could not show that in the nm scale, LEIS as integrating method over a larger scale (up to mm^2) is able to detect the non closure. **Figure 4.**

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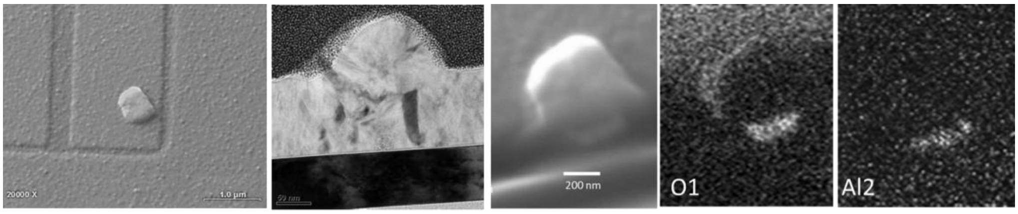

Figure 1. SE image of a polycorn defect in the AES spectrometer PHI SMART II Defect Review Tool at 20kV. TEM bright field image (2^{nd} left) , defocused, shows tiny globuli on the Si substrate. The in-situ cut through a corn with subsequent high resolution AES mapping reveals the presence of Al_2O_3.

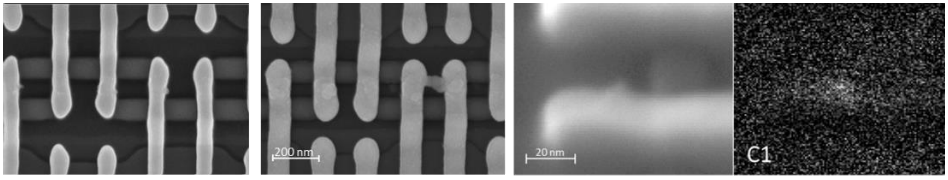

Figure 2. SE images before (left) and after Poly-Si deposition (2^{nd} left) show the enlargement and bridge formation caused by the tiny defects. At 2000x magnification in the AES spectrometer the mapping of Carbon KVV of the gates before Poly-Si deposition was carried out and proved the organic nature of the defect material.

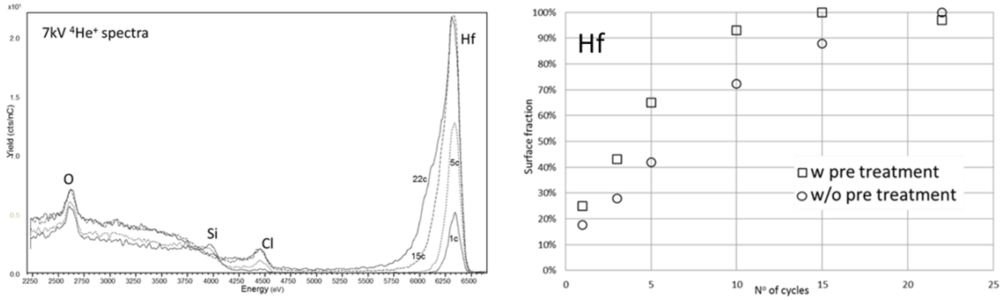

Figure 3. Overlay of LEIS Spectra (left) of ALD HfO_2 layer after 1, 5, 15 and 22 deposition cycles: growing Hf peak intensity reflects the Hf cover on the underlying SiO_2 film. From the peak areas of film (Hf) and substrate peaks (Si) the surface fractions of the top film were drawn, see right graph. The Hf oxide film reaches 100% film closure earlier if the SiO2 was pre-treated.

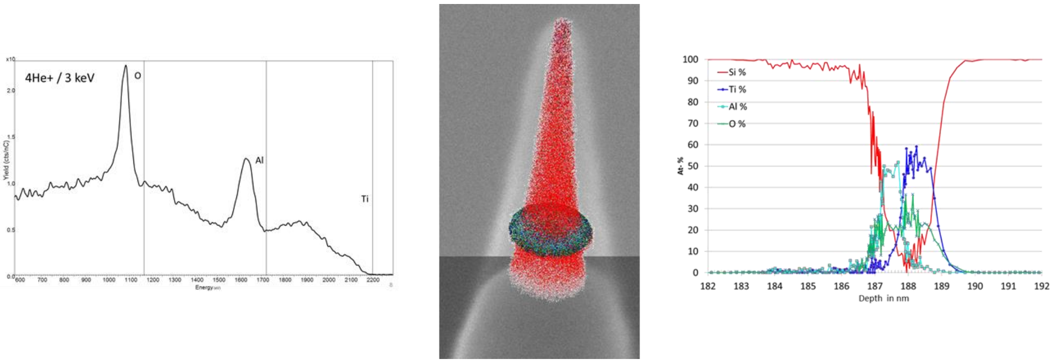

Figure 4. LEIS spectrum of 8Å PVD Al on TiN (left) shows Ti on the surface, indicating incomplete closure of the film. The image 2^{nd} left shows the 3D Atomprobe cylinder of extracted ions, with reconstructed depth profile (right) of the Al/TiN film stack.

References:
[1] K.Dittmar *et al*, ECASIA 2011
[2] K.Dittmar et al, LEIS Workshop 2012

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