A toolbox for characterization of film penetration depth in high aspect ratio structures

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3D semiconductor devices have often dry etched vertical high aspect ratio holes, with 20 -200 nm critical dimensions. Conformality of the ALD/CVD thin film process in those high aspect ratio (HAR) structures is important for the functionality of the devices. HAR structures can be either lateral (LHAR) or vertical (VHAR). In this study, we focused on two less known factors of ALD growth in HAR structures, namely difference between vertical and lateral HAR geometries as well as the effect of the surface roughness. The PillarHall® lateral high aspect ratio (LHAR) test structure and measurement method is an effective way for fast and easy conformality characterization of the thin film processes [1]. PillarHall LHAR is a wide trench with nominal gap height 500 nm. The unique feature of PillarHall LHAR-method is an accurate and repeatable film penetration depth (PD) profile that allows to quantify step coverage for any aspect ratio as well as to characterize reaction kinetics in the sub-micrometre dimensions and molecular diffusion conditions. The compared HAR structures (Fig.1) were on commercial test chips VHAR1 (vertical holes) and PillarHall LHAR4 (lateral trenches) by Chipmetrics Ltd, as well as a modified version of LHAR chip (M-LHAR). The ALD process used in this study was TMA/H_2O Al_2O_3 at 300 °C in Beneq TFS-200. The Gordon model [2] is a useful approach to compare and predict the film PD performance in both HAR structure types. According to Gordon model, all structures had the same feature dimensions while their roughness varied. An inverse relationship between surface roughness and PD was revealed as the measured PD was highest for M-LHAR (Rq=0.17 nm) and lowest for VHAR1 (Rq=4.8 nm). The results indicate that surface roughness together with HAR geometry and gap height are the important factors that affects the model accuracy. In this study, NIR optical reflectometry was used to precisely measure the lateral trench gap height. We show also initial results from highly sensitive and PillarHall compatible measurement tools, such as contrast imaging SEM, UV-reflectometer (Fig.2) and imaging ellipsometer. They enable to measure PD of ultra-thin films with thickness < 10 nm. The presented toolkit concept is an efficient platform consisting of several well-specified test chips, measurement instruments, and modelling tools to execute highly accurate and repeatable film penetration depth analyses of ALD processes.

References

1. J. Yim and O. M. E. Ylivaara et al., Phys. Chem. Chem. Phys., 22 (2020), 23107
2. R. G. Gordon et al., Chem. Vap. Deposition, 9 (2003),73

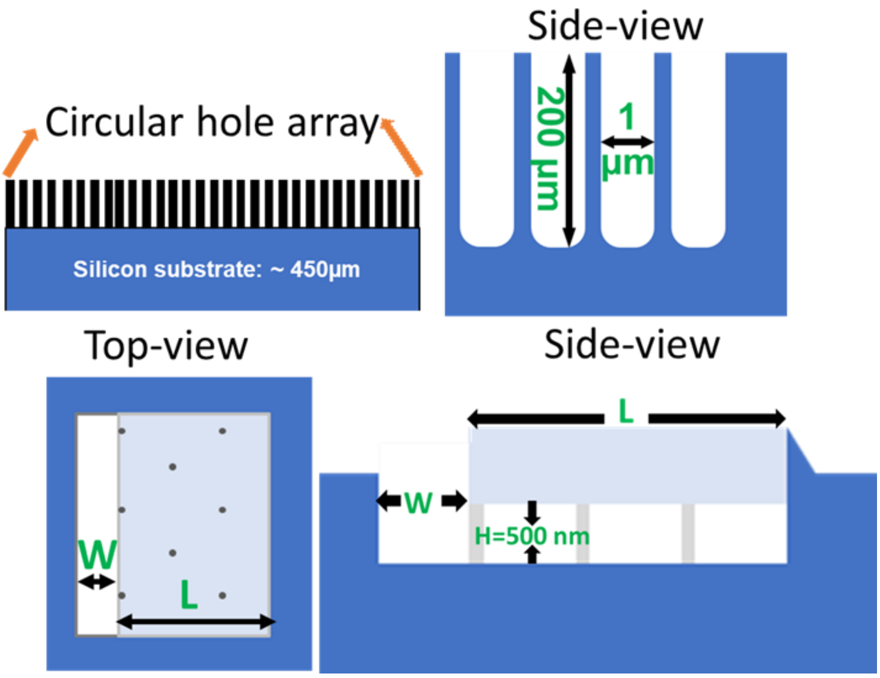

Figure 1. Schematic illustration of the HAR test structures used in the study. VHAR1 (top row) and PillarHall LHAR test structures (lower row). For LHAR test structures, lateral width (L) varies from 1 to 5024 µm and opening width (W) varies from 5 to 100 µm. H represents the gap height.

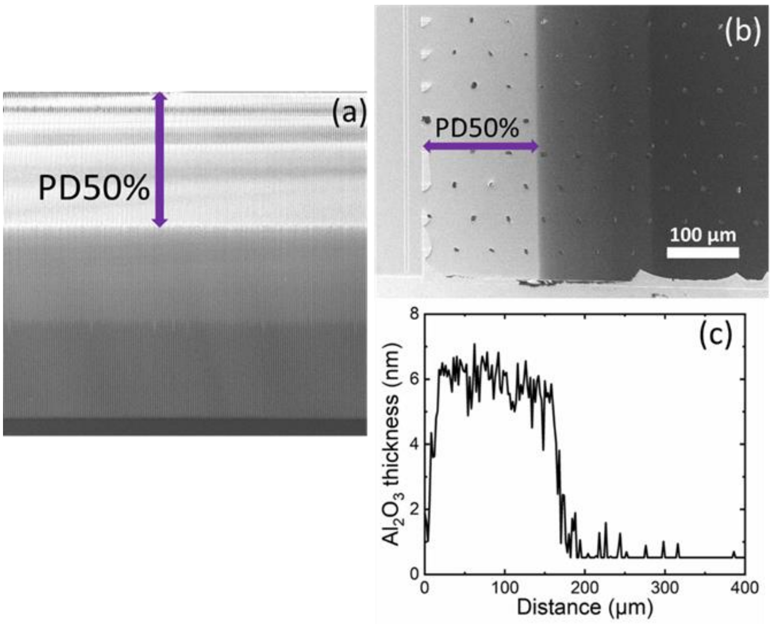

Figure 2. (a) Cross-sectional SEM from VHAR1 after 50 nm thick Al_2O_3 and (b) top-view SEM from LHAR4 after 5 nm thick Al_2O_3 deposition. (c) the film penetration depth profile of 5 nm thick Al_2O_3 film by UV-Vis reflectometer. The penetration depth (PD) measurement is indicated on SEM images.