# Atomic layer deposition into ultra-high aspect ratio structures with a stop-flow ALD reactor

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December 30, 2016

The structures requiring conformal thin films are continuously becoming more demanding. New technical solutions are needed to meet the requirements. Here the growth of ALD $Al_2O_3$ and $TiO_2$ in ultra-high aspect ratio structures is shown with a Beneq TFS 200 ALD reactor equipped with a high aspect ratio stop-flow module. The highest achieved aspect ratios for ALD $Al_2O_3$ and $TiO_2$ films were 1:3000 and 1:2000.

## 1 Introduction

There is a strong drive for conformal deposition into structures with increasingly demanding aspect ratios (AR) in several technologies. [1] Atomic layer deposition (ALD), as a versatile surface reaction controlled deposition technique, has provided the solution for many technologies. However, even the limits of ALD can be reached when conformality is required in ultra-high AR in the order of >1:1000. New technical solutions are needed to push these boundaries.

The rate of ALD film growth on a surface is the sum of the time it takes for the precursors to diffuse onto the reactive sites and the time it takes for the precursors to react. The diffusion rate is dependent on the precursor properties and morphological dimensions of the sample. The reaction rate is dependent on the sticking coefficient of the precursors, i.e. the probability of the precursor reacting with an unreacted surface site upon contact. For systems with diffusional control, the exposure, Pt, required to uniformly coat a surface can be estimated based on Equation (1). [2]

$$Pt = 2.3 \times 10^{-7} m^{1/2} \Gamma \left(\frac{L}{d}\right)^2, \qquad (1)$$

where

P = precursor partial pressure (Torr)

t = dosing time (s)

m = molecular mass (amu)

$\Gamma$ = density of reactive sites in $10^{15}$ $cm^{-2}$

L = tube length

d = tube diameter.

Thus the main factors influencing the highest achievable conformally coated AR are the substrate morphology, density of reactive sites, precursor partial pressure, molecular mass and sticking coefficient, and the exposure time. The substrate properties and precursor molecular mass and sticking coefficient cannot be changed, and the precursor partial pressure can be influenced only to a limit. Therefore, the exposure time is the main tool available for achieving uniform films on ultra-high AR.

There are three types of pulsing systems available for temporal ALD. In continuous flow the precursor is introduced into the reactor continuously during the pulse time and the reaction space is simultaneously pumped. When coating high AR structures long pulses are required and a vast majority of the precursor is wasted. In reduced flow the gas flow in the pump line is restricted during the precursor pulse increasing the residence time of the precursor in the reaction chamber. As the precursor in-flow remains unchanged, the total pressure in the reaction chamber increases. With long pulse times this can lead to precursor backflow to the source side.

Furthermore, as the restriction is usually positioned in the pump line outside the hot zone, cold-spots and condensation may be an issue. In stop-flow all the gas inlets and the pump line can be closed after the precursor is introduced into the reactor. The precursor diffusion and the ALD reaction can be given theoretically an indefinite time to proceed to conclusion. This enables uniform coating of ultra-high AR structures without unnecessarily large precursor consumption and risk of backflow or condensation problems.

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## 2 Results

ALD $Al_2O_3$ and $TiO_2$ films were grown from trimethyl aluminium, titanium tetrachloride and water with a Beneq TFS-200 ALD reactor equipped with a stop-flow module. The diffusion length of $Al_2O_3$ and $TiO_2$ on an in-house built test structure with a 62.6 × 1000 µm opening and approximately 100 mm total length was observed to linearly increase with increasing residence time (Figure 1). For $TiO_2$ the length appeared to level off at the highest residence times. Rather than being an indication of an actual process related phenomenon, this is most probably due to inadequate precursor dosing. [2] With a residence time of 8 s an AR of 1:860 and 1:1200 were reached for $Al_2O_3$ and $TiO_2$, respectively.

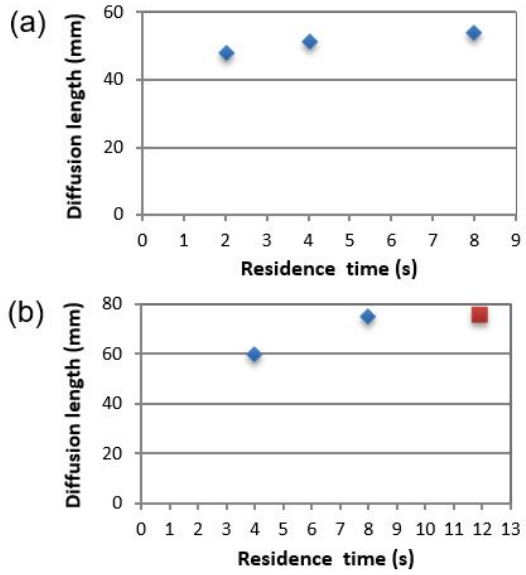


Figure 1: Influence of residence time on the diffusion length of stop-flow ALD grown $Al_2O_3$ (a) and $TiO_2$ (b) into a high AR lateral hole.

The conformality of $Al_2O_3$ and $TiO_2$ films in commercial lateral high-aspect ratio (LHAR) [3] structures was also studied (Figure 2). The test ship had features with AR ranging from 1:5000 to 1:20. All but the most demanding structure were conformally coated with both materials. In the most demanding structure $Al_2O_3$ growth was observed up to 3000 m and $TiO_2$ up to 2000 m length into the channel (Figure 2b). This corresponded to ARs of 1:3000 and 1:2000 for $Al_2O_3$ and $TiO_2$, respectively.

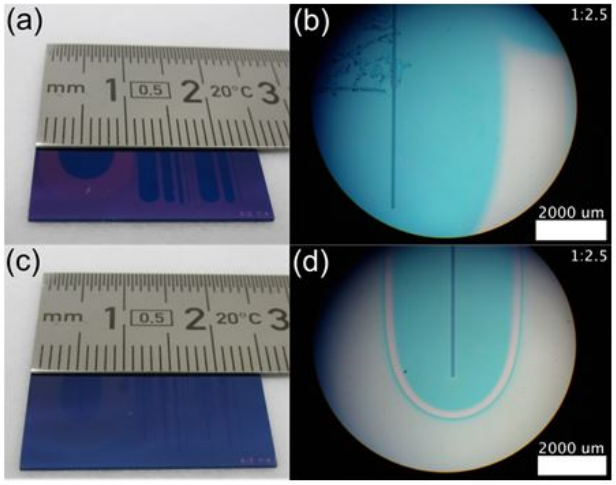


Figure 2: ALD $Al_2O_3$ (a-b) and $TiO_2$ (c-d) growth into LHAR structures with a maximum AR of 1:5000.

## 3 Conclusions

ALD film growth of $Al_2O_3$ and $TiO_2$ was demonstrated into ultra-high AR structures with a Beneq TFS 200 reactor equipped with a HAR stop-flow module. The highest achieved AR was 1:3000 for $Al_2O_3$ and 1:2000 for $TiO_2$.

## References

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