Atomic Level Solutions® for Advanced Microelectronic Applications

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1. Abstract

Atomic Layer Deposition (ALD) has successfully been applied to advanced microelectronic applications importantly for conformal coatings on high aspect ratio devices. However, traditional ALD is limited in deposition rate because the ability to bring precursors rapidly to the surface. In this paper we review recent results for *precursor delivery* using advanced vaporization (Trijet) as well as recent advances in *Pulsed CVD* (AVD®) using art elements held in common with ALD technology. These and other advances - such as Multiple Single Wafer configurations allow ALD application for continued scaling under conditions of improved process control and higher productivity. Key applications include: capacitors (dielectrics and electrodes), transistors and contacts. This paper reviews these technological advances in the context of their applications.

2. Introduction

ALD is a sequential self-limiting surface reacted CVD process. [1,2,3] This leads to outstanding conformal coating capability in 50:1 aspect ratio features used in advanced DRAM technology with design rules <100nm. [4] Today DRAM capacitors as well as gates at 45nm, and films for data storage devices are in production.

3. Chemical Deposition Processes

3.1 Advanced Source for ALD and Pulsed CVD

In thermal ALD, a first metal containing chemical precursor is pulsed to the wafer followed by a second pulsed chemical precursor such as oxygen or nitrogen, both undergo a self-limiting reaction with purges in between.

In Pulsed CVD or (Atomic Vapor Deposition, (AVD), a non-metallic reactant gas (e.g. NH_3, O_3...) continuously flows to the substrate, while the metallic MO precursor is pulsed.[5] Injection is achieved with a pulsed liquid injector. (Trijet®) See Figure 1. The advanced source may be used for ALD as well.

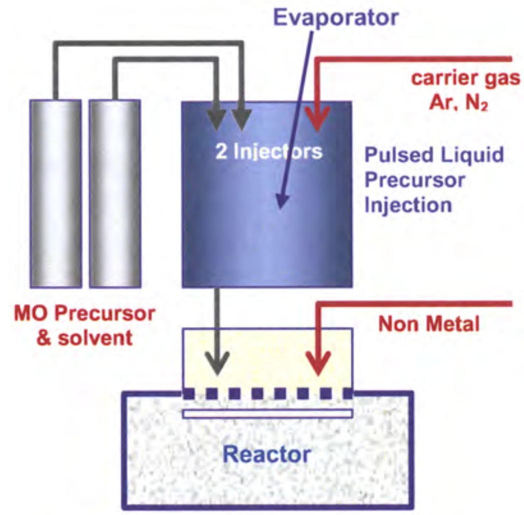

Figure 1 Trijet® source has been used for Pulsed CVD (AVD) and ALD. More injectors may be used for multi-element compounds.

3.2 High Productivity Thermal ALD and AVD Enabled by Advanced Vaporizer (Trijet)

At ICSICT 06 we presented a summary of an advanced, single wafer high productivity ALD system with ~1sec cycle time using TMA/O_3 on planar 300mm wafers. [1] A single wafer 300mm reactor with vertical, area-distributed gas injects is used. It is important to note that high system performance is achieved by optimization of many elements: chemical source delivery, gas distribution (showerhead), chamber design, ALD controller and factory automation.
In this paper we introduce the results of additional enhancements achieved by use of advanced liquid injection source, optimized processes, and multi-single wafer capabilities.

3.2.1 Advanced Trijet Vaporizer

CFD (Computational Fluid Dynamics) is used to support the TriJet design. The modelling is based on solving the time-dependent two-phase flow of droplet spray levitated in the gas flow inside the vaporizer volume including the mass and heat transfer involved in the vaporization of the precursor liquid.

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The example shown in Figure 2 elucidates the processes inside the vaporizer for pure TEMAZ precursor, a low volatility liquid injected at room temperature into the 200° C hot vaporizer.

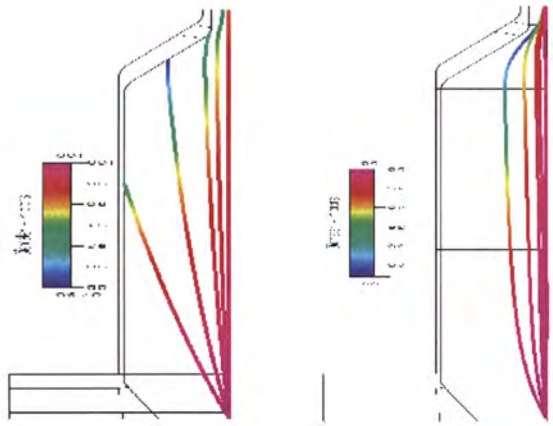

Figure 2. Computed trajectories for two distinct droplet sizes (50 μm and 100 μm) as a function of the injection angle.

The color coding (blue is smaller) describes the decreasing droplet size due to the progress of vaporization. Trajectories of droplets of pure TEMAZ precursor depend on injection angle and droplet size. Conclusions derived from the analysis: i) the required size to obtain (almost complete) vaporization inside the vaporizer < 50 μm becomes a design criteria for injector. ii) droplets smaller than 50 μm do not hit the wall because they follow the flow stream lines due to their small size. As a conclusion of the analysis the optimal droplet size and maximum injection angle can be determined for each kind of precursor (different volatility) and injector design criteria can be derived to obtain complete vaporization.

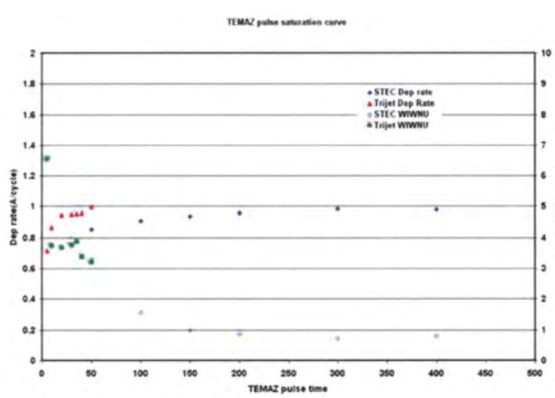

Figure 3 ALD saturation characteristics of TEMAZ using Advanced Vaporizer Trijet compared with previous standard vaporizer.

Figure 3 illustrates the reduction in time to reach saturation for TEMAZ precursor. Saturation is reached in times of approximately 50msec.

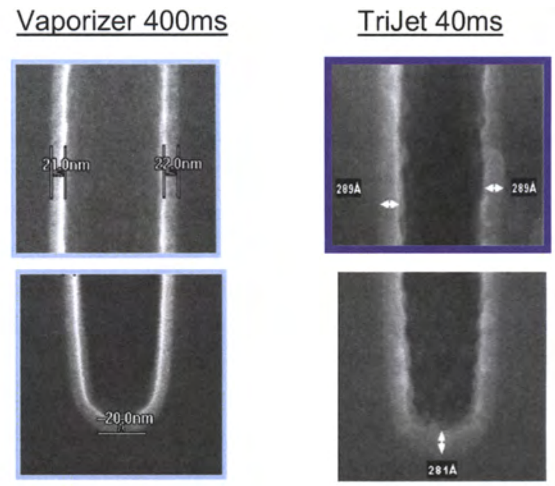

Figure 4 Step coverage results for ZrO_2 with 40msec using Trijet in comparison to 400msec using a standard vaporizer.

In the theory of step coverage [6] of high aspect ratio structures, the partial pressure of injected precursor is a key to achieving step coverage with shorter exposure times. Fig. 4 illustrates a 10 fold reduction in exposure time for achieving nominally 100% step coverage in 50:1 DRAM structures.

3.2.2 Advanced Atomic Level Process Solutions

The advanced ALD system developed using $TiCl_4/NH_3$ chemistries achieve excellent conformality as shown in Figure 5.

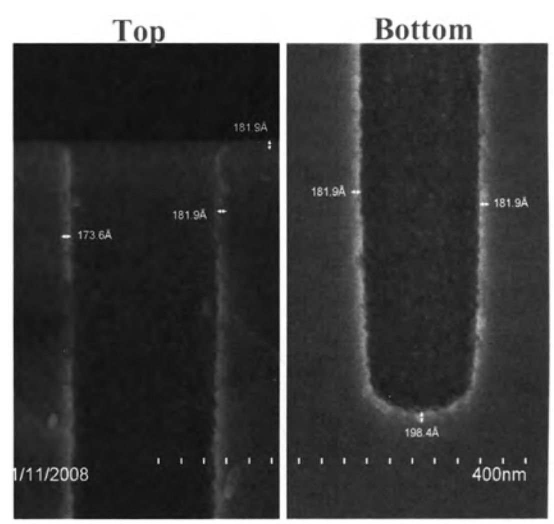

Figure 5 TiN ~100% conformal coatings on 50:1 high aspect ratio structures. These results were achieved

concurrently with high throughput when combined with optimized process as shown in Figure 6. [7]

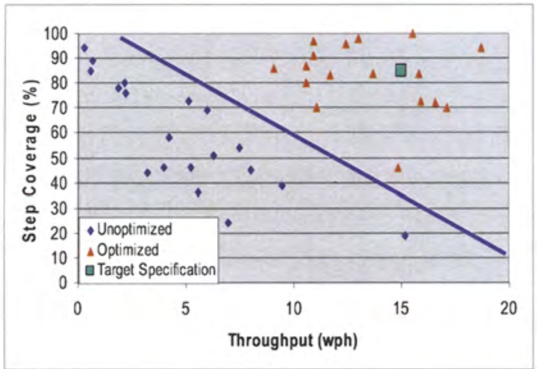

Figure 6. TiN Throughput and step coverage for different processes

3.2.3 Multi-Single Wafer Capabilities

Advanced ALD reactors are placed in a compact configuration -yet each reaction space is independent of each other and - while the chemical source and pumping is shared. Matching uniformity from such single wafer arrays is a measure of the performance of the Multi-wafer system. Figure 7 shows early matched results.

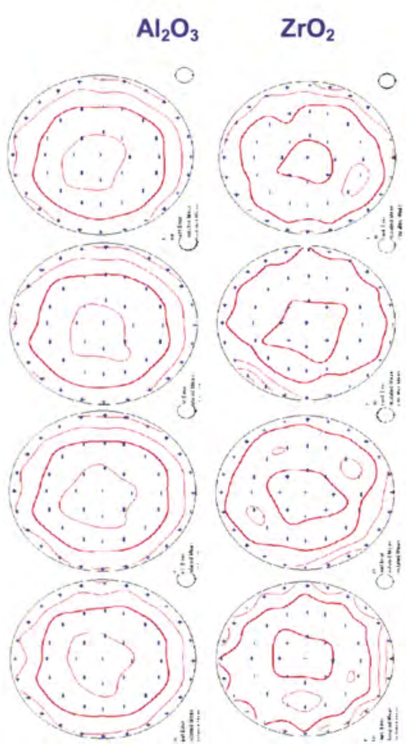

Figure 7 Within Wafer Thickness Non-uniformity for 8 wafers run in Multi Single Wafer System.

The WIWNU of Al_2O_3 and Zr_2O films are 0.91-1.11%, while both sets of films have matching WTWNU of 0.27-0.33%, one sigma. These results exhibit highly reproducible and high productivity capabilities.

4.0 Higher-k Oxide and Metal Films and Their Applications

4.1 Capacitors on Chip

The DRAM capacitor application is driven by the need to increase capacitance density under scaling.[4] Today's DRAM capacitors are MIM structures, with TiN used as lower and upper electrodes, and ZrO_2 in combination with Al_2O_3 have been used for 70nm production. There is a need to increase the effective relative dielectric constant above 35.

RF-decoupling capacitors with thicker films and metal electrodes enable the scaling of advanced communications chips. The thicker films therefore also require higher deposition rates.

Floating Gate and SONOS-type Non Volatile Memory are candidates for scaling by the introduction of new high K dielectrics.

4.2 Advanced Dielectrics and Metal Gates

The Production has been announced for HfO_2, -based HfSiO and HfSiO(N), and are being pursued in combination with metal gates for obtaining the lowest EOT. [8]

Today, advanced transistor films may be made by CVD or ALD. Since today's gate architecture is planar, there is no compelling reason to use ALD as there is in high topology capacitors. However, in the future, when transistors designs use vertical architectures, then ALD may be preferred.

4.3 *Electrodes, Interconnect and Contacts*

TiN is used for DRAM stack capacitor electrodes *and* deep trench upper electrodes. TiN has good thermal stability allowing deep trench process integration while maintaining low resistivity through 1050° C.

A case for the insertion of new film depositions / solutions in the 32-22nm nodes is made. Atomic Level Solutions for W, TaN, Cu, TiN and Ru to some degree have been achieved. Today barriers are on the order of 1-4 nm and are used in 5:1 or less aspect ratio structures.

Atomic Level Solution processes and films are being developed for barriers and Cu seeds onto which electroplated Cu may be deposited. The barriers are generally well established, being TaN for Cu. ALD W nucleation - surface activation layers are used before CVD W plugs films are deposited.

Conclusions These advances (Trijet precursor delivery, optimized ALD and AVD processes and multi wafer systems are now included in the suite of technologies within *"Atomic Level Solutions."*

Acknowledgements

5. References

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