

## Emerging Materials and Processes

### Room Tampa Bay Salons 1-2 - Session EM1-WeM

#### Conductive ALD Films

**Moderators:** Jean-François de Marneffe, IMEC, Henrik Sønsteby, University of Oslo

8:00am **EM1-WeM-1 Platinum Growth on Li-Based Thin Films Using Thermal ALD**, *Manon LETICHE, Sylvain POULET, Nicolas MASSONI, Violaine SALVADOR, Hélène COURDERT-ALTEIRAC, Nicolas GAUTHIER, Messaoud BEDJAQUI, CEA-LETI, France*

Lithium-based layers are key players in developing nanostructured energy storage systems. As such, ultrathin lithium phosphorous oxynitride LiPON deposited by Atomic Layers Deposition (ALD) is incorporated as solid-electrolyte between two electrodes for on-chip microsupercapacitors<sup>1,2</sup>. To avoid battery-like behavior it is crucial to select electrode material that doesn't interact with Lithium while providing efficient capacitive behavior and high electrical conductivity. To that purpose, using thermal ALD, noble metals are very good candidates but suffer from low nucleation<sup>3</sup>. This study aims to evaluate the implementation of ultrathin noble metals (such as platinum) deposited by ALD as electrodes for lithium-based capacitances.

Pt thin film was obtained by thermal ALD using Trimethyl(methylcyclopentadienyl)platinum(IV) and O<sub>2</sub> reactants. Pt nucleation on LiPON layers (20 nm thin) has been studied in comparison to lithium free substrates. In order to promote Pt nucleation surface treatment like TriMethylAluminium (TMA) pre-pulsing or TiN interfacial layer were used. Pt growth was morphologically, structurally and electrically characterized on SiO<sub>2</sub> and LiPON substrates using AFM, SEM, TOF-SIMS and spectroscopic ellipsometry.

Primarily, more than 300 cycles were required to obtain viable and continuous Pt film of 8nm on LiPON without any surface treatment. It was found that, whether using TMA pre-pulsing or a TiN interfacial layer, the nucleation delay could be reduced to 200 cycles on LiPON and 85 on SiO<sub>2</sub> substrate to achieve continuous Pt of 8 with a uniformity <3% and low resistivity (20 μΩ.cm) at 200mm wafer scale. Top view imaging and AFM characterizations show island growth without surface treatment on SiO<sub>2</sub> and LiPON substrates with high roughness. Same characterizations when TMA or TiN surface treatment is used evidence a high surface coverage with very low surface roughness on both substrates.

Focusing on the interface LiPON/Pt using TMA pre-pulsing, a thickness evaluation of LiPON with and without Pt capping under air exposure was performed using spectroscopic ellipsometry. Surprisingly, same behavior was observed in both cases. Ongoing interfacial characterizations are expected to assess the compatibility of these materials and Li diffusion through Pt.

(1) Göhlert, T. *Nano Energy* **2017**, *33*, 387–392.

(2) Ghandari, I. *Dalton Trans.* **2026**, *55* (3), 1149–1163.

(3) Hämäläinen, J. *Chem. Mater.* **2014**, *26* (1), 786–801.

8:15am **EM1-WeM-2 The Stability Study of ITO Film Deposited by Thermal Atomic Layer Deposition**, *Yongqing Shen, Zhengying Jiao, Liguo Chai, Fengbin Tian, Kaiqiang Zhao, libin Jia, Jie Shen, Jianqi Chen, Jinjuan Xiang, Beijing Superstring Academy of Memory Technology, China; Weihai Fan, Beijing Superstring Academy of Memory Technology, Taiwan; Hongbo Sun, Guilei Wang, Chao Zhao, Beijing Superstring Academy of Memory Technology, China*

Metal oxide thin-film transistors (TFTs), especially InGaZnO TFTs have attracted considerable attention for 3D dynamic random access memory (DRAM) applications, owing to their lower off-state leakage and suitable carrier mobility. A thin Tin-doped In<sub>2</sub>O<sub>3</sub> (ITO) has been employed as an inserting layer at contact region to reduce the Schottky barrier from IGZO channel, so as to get higher on-current. [1] Given the promising potential of ALD-grown ITO thin film for 3D DRAM applications, investigating its thermal stability and the impact of contact materials on its performance are critical for back-end-of-line (BEOL) compatibility evaluation. In this work, the thermal stability of ALD-grown ITO film was systematically evaluated via annealing experiments. The film is stable after annealing in an N<sub>2</sub> atmosphere at 600 °C, and has a mixed polycrystalline–amorphous phase structure. Prolonged annealing time, however, induced a significant increase in oxygen-related defects. When the annealing temperature was elevated to 800 °C, the ITO films became rough and initiated decomposition. Considering that ITO may come into contact with

interconnect materials (e.g., TiN and W) during subsequent process integration, the effect of TiN deposition on ITO property was also investigated. Deposition of TiN at 530 °C in a hydrogen-containing ambient caused partial damage to the ITO film. In contrast, no obvious changes in ITO properties were observed after annealing in N<sub>2</sub> at 600 °C, indicating that reducing gases (e.g., H<sub>2</sub>) can degrade ITO stability. At 400 °C (without H<sub>2</sub>), TiN deposition did not cause significant ITO damage; nevertheless, a slight reduction in ITO thickness was detected. This thickness loss is speculated to result from reactions between the byproduct HCl and the ITO surface, as well as the breaking of In–O and Sn–O bonds due to oxygen scavenging by TiN. Collectively, the results demonstrate that the temperature, atmosphere, and process byproducts of subsequent steps all contribute to ITO film damage or thickness loss. This study provides reliable experimental data to guide the integration of ITO for advanced 3D DRAM applications.

8:30am **EM1-WeM-3 Atomic Layer Deposition of TiN layer in Interposer Chip for Superconducting Quantum Processor Unit**, *Kestutis Grigoras, Harshad Mishra, Jukka-Pekka Kaikkonen, Joel Häntinen, Elsa Mannila, Wisa Förbom, Rishabh Upadhyay, Mikael Kervinen, Isabel Gueissaz-Mattelmäki, Marco Marin Suarez, Jorden Senior, VTT Technical Research Centre of Finland, Ltd, Finland*

The increasing complexity of interconnects on a chip and the potential for crosstalk between qubits present significant challenges for scaling up a superconducting quantum processor unit (QPU). The commonly adopted solution is 3D integration, where a QPU interposer chip is employed to reduce parasitic capacitance and inductance, as well as to facilitate signal routing between qubits and control electronics. For higher levels of integration, the interposer typically incorporates through-silicon vias (TSVs). The purpose of TSVs is to minimize the so-called chip resonance mode and to route signals between qubits and control electronics. Due to the growing density of interconnects, the diameter of superconducting TSVs must be as small as possible, on the order of several tens of micrometers. The most reliable method for conformally coating the sidewalls of such high-aspect-ratio structures is the atomic layer deposition (ALD) technique. There are only a few material candidates suitable for superconducting coatings, with titanium nitride (TiN) being one of them.

In this work, we have fabricated and tested silicon interposer chips with coplanar waveguide (CPW) type signal lines and resonators formed by patterned TiN/Ta or Nb layers. These structures were prepared by sputtering [1]. Several types of TSVs were etched using deep reactive ion etching (DRIE) and then coated with a TiN layer using either thermal or plasma ALD. The performance of these structures was measured and compared to reference chips without TSVs. We also compared different characteristics of TiN layers obtained by sputtering and by thermal or plasma ALD. We found that both the microstructure and the critical temperature (T<sub>c</sub>) of TiN films prepared by different methods were quite similar. On the other hand, the film stress and selectivity in wet or dry etchants depended on the preparation method, with differences reaching even an order of magnitude. Depending on the fabrication step, these differences could either complicate or, conversely, simplify chip fabrication.

K. Grigoras et al., “Qubit-compatible substrates with superconducting through-silicon vias”, *IEEE Trans Quant Eng*, 3 2022, doi:10.1109/TQE.2022.3209881  
[https://doi.org/10.1109/TQE.2022.3209881]

8:45am **EM1-WeM-4 Achieving Ultra-Low Resistivity in TiN Thin Films via Supercycle PEALD: The Critical Role of Ti:N Stoichiometry over Impurity Content**, *Van Long Nguyen, Christophe Vallee, Natalya Tokranova, Bryant Colwill, University at Albany-SUNY*

Titanium nitride (TiN) has attracted significant interest in microelectronics due to its excellent chemical resistance, thermal stability, and low resistivity. Low-resistivity, stoichiometric TiN films are essential for realizing high-performance interconnects, diffusion barriers, and electrodes in next-generation microelectronic and quantum devices. While Atomic Layer Deposition (ALD) offers superior conformality, conventional low-temperature processes often yield nitrogen- or titanium-deficient films with high electrical resistivity due to poor stoichiometry and excessive impurity incorporation. We introduce a supercycle PEALD approach that periodically alternates two distinct plasma chemistries (TMSDMA + Ar plasma and TMSDMA + N<sub>2</sub>/H<sub>2</sub>/Ar plasma with bias to play with energetic ions) (**Figure 1Sa and 1Sb**) to precisely control the TiN film composition and structure. The resulting TiN supercycle film demonstrates a significantly lower electrical resistivity than its constituent films (**Figure 1Sc**). Surprisingly, this performance gain is achieved even with relatively high residual

# Wednesday Morning, July 1, 2026

concentrations of C and O impurities. XPS analysis confirms that the resistivity minimum directly correlates with an approximately stoichiometric Ti:N  $\approx$  1:1 ratio derived from the relative populations of TiN-related Ti2p and N1s chemical states (**Figure 1Sc**). This result indicates that precise Ti:N stoichiometry, rather than impurity concentration, is the dominant factor governing the electrical performance of TiN films. This supercycle strategy provides a scalable, low-temperature method for fabricating high-conductivity TiN suitable for advanced nanodevice integration.

9:00am **EM1-WeM-5 Characterization of Superconducting Niobium Nitride Thin Films Grown by Thermal Atomic Layer Deposition**, *Annika Häkkinen, Oona Turpeinen, Jaakko Julin*, University of Jyväskylä, Finland; *Mikko Laitinen*, University Of Jyväskylä, Finland; *Timo Sajavaara*, University of Jyväskylä, Finland

Metal nitrides are a promising group of superconducting materials for a wide range of quantum technologies and advanced electronic applications. In applications requiring superconducting functionality, such as quantum computing, thin-film quality plays an essential role in device performance. Among metal nitrides, niobium nitride (NbN) is especially interesting due to its relatively high theoretical critical temperature (17 K) and compatibility with thermal ALD processes, which provide a straightforward implementation without added process complexity. [1]

In this work, superconducting NbN thin films were grown with TFS-200 ALD system from Beneq Oy operated in thermal mode at 400–500 °C using NbCl<sub>5</sub> and NH<sub>3</sub> as precursors. Film thicknesses varied between 25 and 100 nm and the depositions were done on silicon and sapphire substrates. The effects of film thickness, deposition temperature, substrate choice, and post-deposition annealing (650–1000 °C) on the superconducting and structural properties were investigated. Film characterization was carried out using electrical resistivity and critical temperature measurements, Atomic Force Microscopy (AFM), X-Ray Diffraction (XRD), and Time-of-Flight Elastic Recoil Detection (ToF-ERD).

Deposited films exhibited promising superconducting properties with critical temperatures up to 13.6 K after post deposition annealing. Films were slightly nitrogen rich and contained low concentrations of impurities such as O (< 4.6 at.%), Cl (< 3.6 at.%), C (< 3.8 at.%) and H (< 4.7 at.%). Superconducting critical temperature was dependent on the film thickness but even the thinnest films (25 nm) had a transition temperature of 10.6 K. These results highlight thermal ALD as a viable method for producing high-quality superconducting NbN thin films.

[1] G. K. Deyu et al.” Recent advances in atomic layer deposition of superconducting thin films: a review” *Mater. Horiz.* **12**(15):5594-5626 (2025)

## Author Index

### **Bold page numbers indicate presenter**

#### — B —

BEDJAOUI, Messaoud: EM1-WeM-1, 1

#### — C —

Chai, Liguo: EM1-WeM-2, 1

Chen, Jianqi: EM1-WeM-2, 1

Colwill, Bryant: EM1-WeM-4, 1

COURDERT-ALTEIRAC, H el ene: EM1-WeM-1,

1

#### — F —

Fan, Weihan: EM1-WeM-2, 1

F orbom, Wisa: EM1-WeM-3, 1

#### — G —

GAUTHIER, Nicolas: EM1-WeM-1, 1

Grigoras, Kestutis: EM1-WeM-3, 1

Gueissaz-Mattelm aki, Isabel: EM1-WeM-3, 1

#### — H —

H akkinen, Annika: EM1-WeM-5, 2

H atinen, Joel: EM1-WeM-3, 1

#### — J —

Jia, libin: EM1-WeM-2, 1

Jiao, Zhengying: EM1-WeM-2, 1

Julin, Jaakko: EM1-WeM-5, 2

#### — K —

Kaikkonen, Jukka-Pekka: EM1-WeM-3, 1

Kervinen, Mikael: EM1-WeM-3, 1

#### — L —

Laitinen, Mikko: EM1-WeM-5, 2

LETICHE, Manon: EM1-WeM-1, 1

#### — M —

Mannila, Elsa: EM1-WeM-3, 1

Marin Suarez, Marco: EM1-WeM-3, 1

MASSONI, Nicolas: EM1-WeM-1, 1

Mishra, Harshad: EM1-WeM-3, 1

#### — N —

Nguyen, Van Long: EM1-WeM-4, 1

#### — P —

POULET, Sylvain: EM1-WeM-1, 1

#### — S —

Sajavaara, Timo: EM1-WeM-5, 2

SALVADOR, Violaine: EM1-WeM-1, 1

Senior, Jorden: EM1-WeM-3, 1

Shen, Jie: EM1-WeM-2, 1

Shen, Yongqing: EM1-WeM-2, 1

Sun, Hongbo: EM1-WeM-2, 1

#### — T —

Tian, Fengbin: EM1-WeM-2, 1

Tokranova, Natalya: EM1-WeM-4, 1

Turpeinen, Oona: EM1-WeM-5, 2

#### — U —

Upadhyay, Rishabh: EM1-WeM-3, 1

#### — V —

Vallee, Christophe: EM1-WeM-4, 1

#### — W —

Wang, Guilei: EM1-WeM-2, 1

#### — X —

Xiang, Jinjuan: EM1-WeM-2, 1

#### — Z —

Zhao, Chao: EM1-WeM-2, 1

Zhao, Kaiqiang: EM1-WeM-2, 1