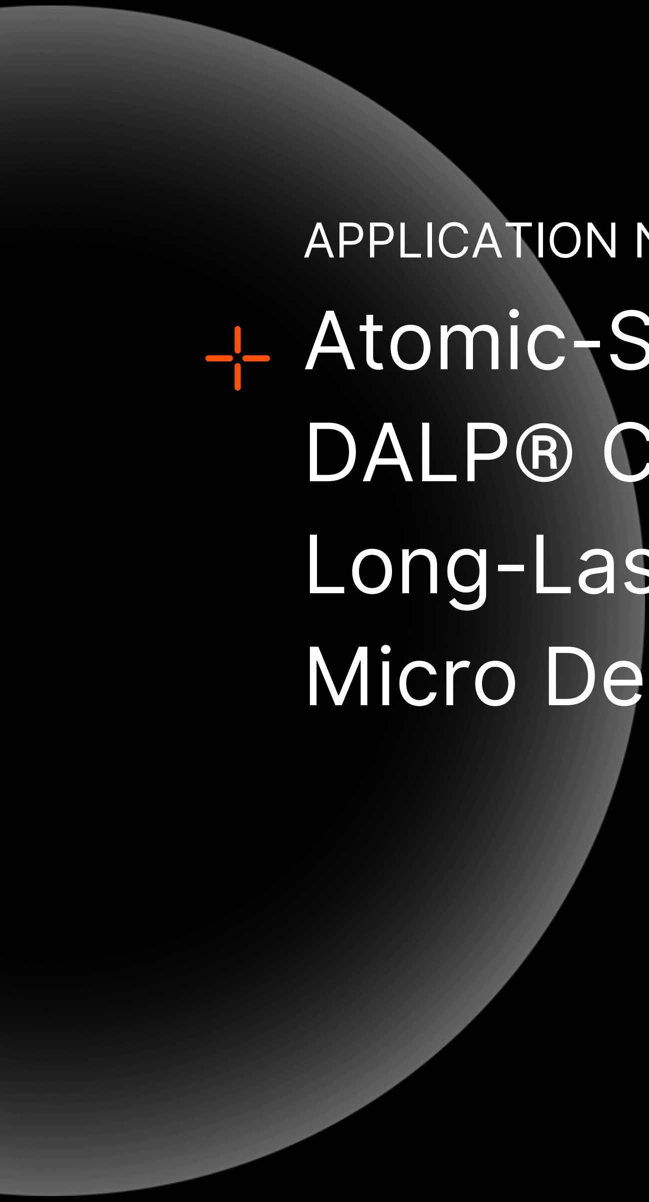


APPLICATION NOTE

Atomic-Scale Efficiency: DALP® Coating Innovations for Long-Lasting, Cost-Optimized Micro Devices

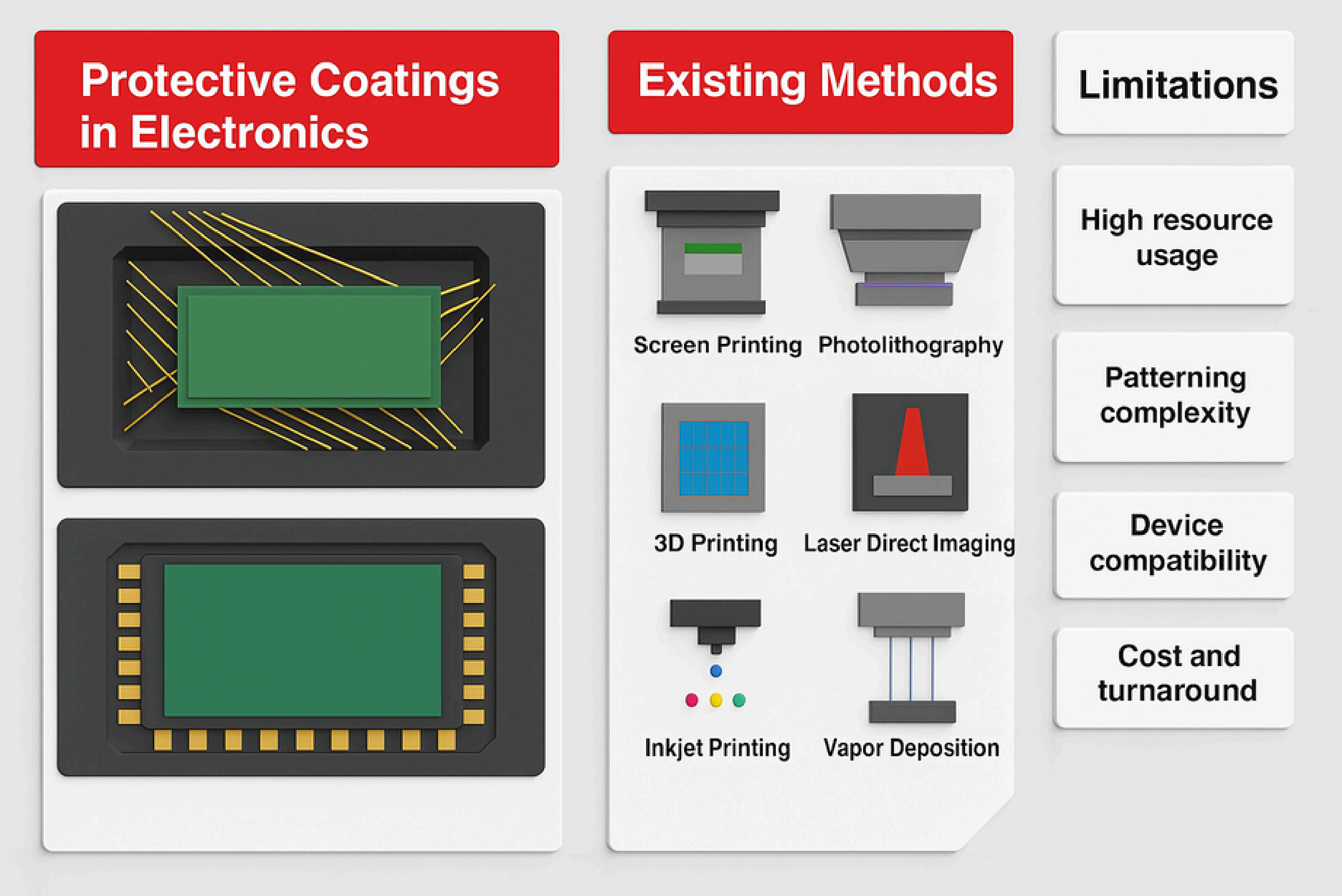
ATLANT 3D®

Atomic-Scale Efficiency: DALP® Coating Innovations for Long-Lasting, Cost-Optimized Micro Devices

Background

Protective coatings are essential in MEMS, sensors, solar cells, and microelectronics, preventing degradation from moisture, chemicals, and mechanical stress. They enhance the reliability of devices like pressure sensors, biosensors, microactuators, and photovoltaic modules.

Common methods include ALD, CVD, and spin coating. However, these techniques often require high temperatures, offer limited material compatibility, and struggle with 3D coverage and precision. This limits their use in flexible electronics, bio-sensors, and next-gen solar cells, where low-temperature, conformal, and selective coatings are vital.



Current Challenges

Standard deposition techniques typically coat entire substrates, requiring additional etch steps to remove unwanted material. This not only wastes chemicals and materials but also introduces extra handling and process steps that increase costs and extend development timelines. Vacuum-based methods and high-temperature processing can damage fragile MEMS structures, limiting their use in applications demanding precise and localized coatings.

DALP® Offerings

ATLANT 3D's proprietary Direct Atomic Layer Processing (DALP®) offers a transformative alternative. By employing a microreactor to directly deposit thin films atom by atom, DALP® enables maskless, localized coating precisely where needed. This avoids the need for photoresists or sacrificial masks, allowing for accurate protection of intricate or sensitive regions, such as bond pads or optical surfaces, which would otherwise be exposed during blanket deposition.

The DALP® process streamlines fabrication by eliminating unnecessary steps and minimizing resource usage. Its precision reduces CO_2 emissions, water and chemical consumption, and material waste by over 90% compared to traditional methods. Additionally, its software-driven design flexibility allows rapid iteration and customization, making it ideal for both prototyping and production. This application note highlights how DALP® enables advanced protective coatings using HfO2, Al2O3 and TiO2, demonstrating improvements in device performance, environmental impact, and fabrication speed.

DALP® Materials

ATLANT 3D's DALP® enables precise control film morphology, transitioning surfaces from porous to dense and flat structures.

The ellipsometry data demonstrates that increasing the deposition temperature using DALP® technology significantly improves film density and quality, transitioning TiO_2 from a porous to a compact structure at thicknesses larger than 15 nm.

This was further supported by SEM and AFM characterization of thick TiO_2 lines (250–300 nm) deposited on SiO_2/Si substrates which reveal a dense microstructure with a smooth surface profile. AFM vertical line scans yield low roughness (0.693–0.769 nm), demonstrating excellent surface uniformity. Compared to the Si substrate's 1.4 nm roughness, DALP®-processed TiO_2 offers superior planarization, making it ideal for advanced microfabrication.

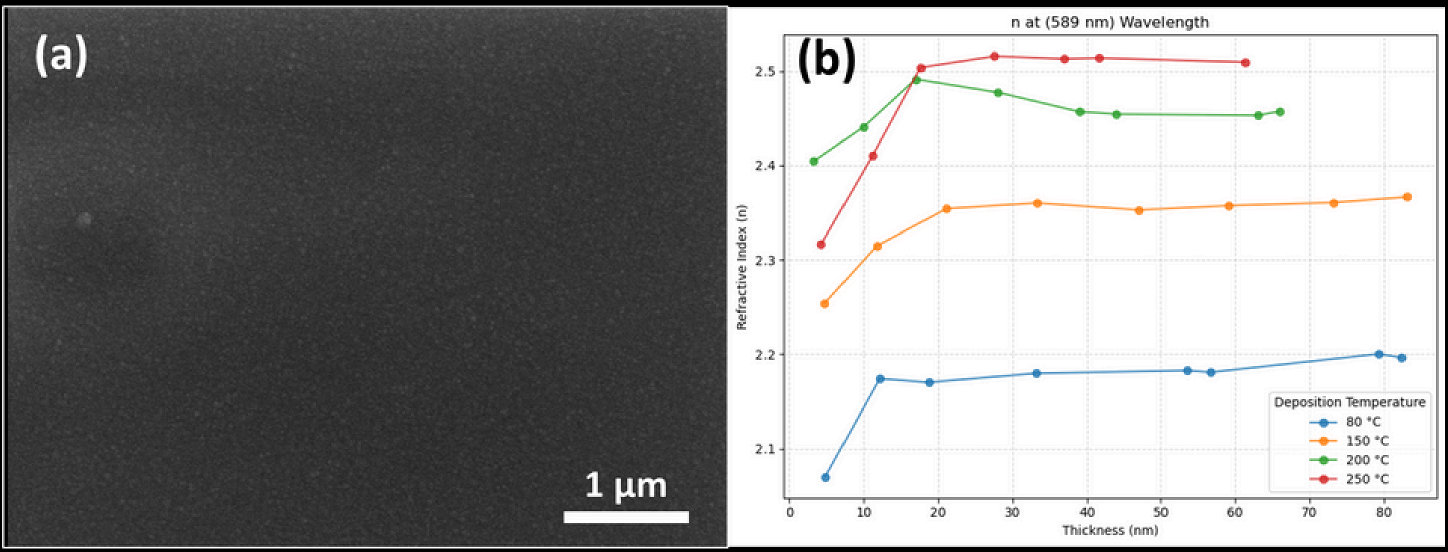
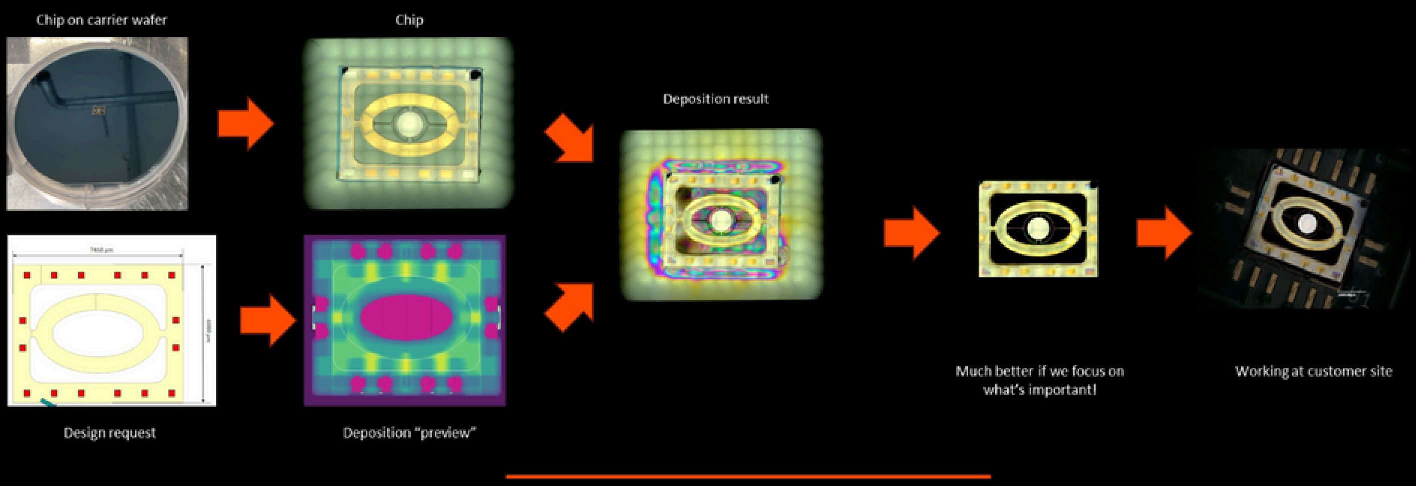


Fig.1: Structural and surface characterization of thick films. a) SEM image of TiO2 film. b) Refractive Index n at 589 nm wavelength, versus the thickness.

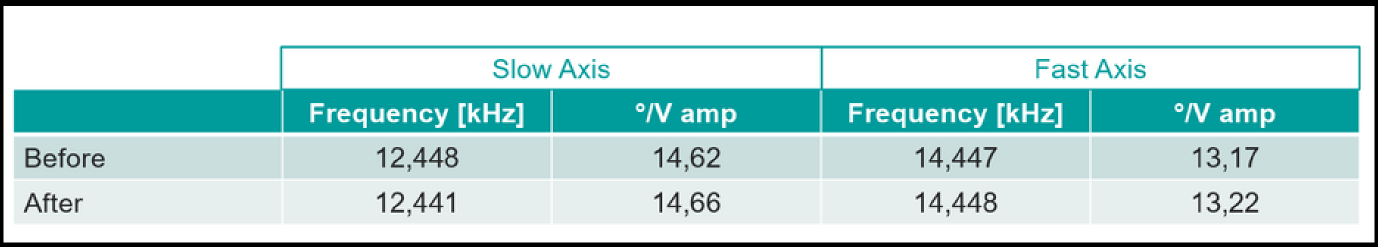
1 Localized Coating of Sensitive MEMS Micromirrors

ATLANT 3D applied its DALP® technology to selectively deposit protective dielectric films on MEMS micromirror arrays, avoiding sensitive areas like mirror plates and bond pads. Post coating tests confirmed that with with no performance degradation observed as seen in Fig. 3.



- Coating present
- Depositing over the edge leads to CVD artifacts outside of the chip

Fig. 2: MEMS micromirror device with DALP® -Deposited protective coating (transparent layer) on the frame and support structure, excluding the central mirrors and band pad areas (which remain uncoated and fully functional)



	Slow Axis		Fast Axis	
	Frequency [kHz]	**°/V amp**	**Frequency [kHz]**	**°/V amp**
Before	12,448	14,62	14,447	13,17
After	12,441	14,66	14,448	13,22

Fig. 3: Characterization of Micromirrors performances before and after local protective coatings.

2 TiO_2 Masking for Selective Electroless Plating

ATLANT 3D's Direct Atomic Layer Processing (DALP®) enables precise, maskless deposition of TiO2 films as plating inhibitors. Tests on silicon substrates with pre-patterned seed layers showed that 35–50 nm thick DALP®-deposited TiO_2 films effectively prevented copper deposition in protected areas during electroless plating, while thinner films (~15 nm) offered partial inhibition.

The TiO2 masks remained intact throughout the plating process, with no signs of dissolution or detachment, and energy-dispersive X-ray spectroscopy confirmed the absence of copper on masked regions. This approach eliminates the need for traditional blanket masking and etching steps, offering a streamlined, lithography-free method for selective metallization.

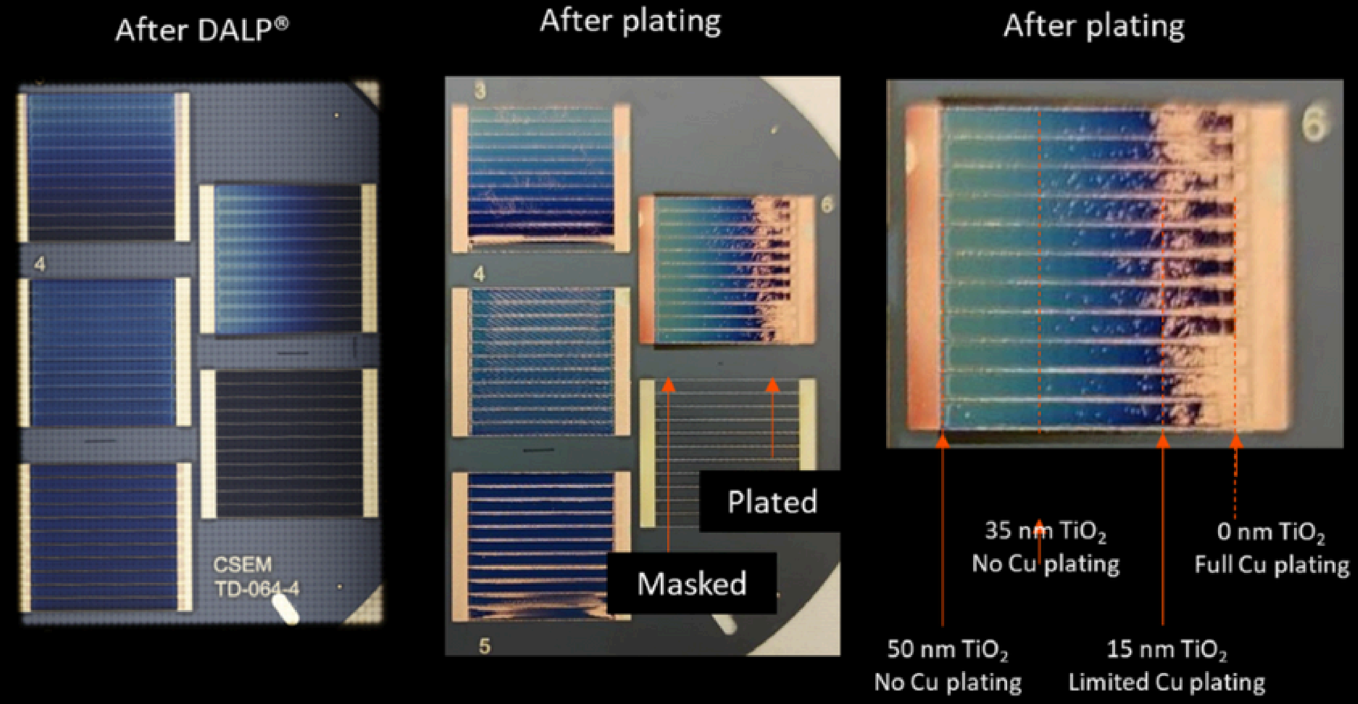


Fig.4: TiO_2 Masking for Selective Electroless Plating.

3 HfO_2 Protective Coating Against Aqua Regia

To evaluate DALP®-deposited films as chemical protective barriers, HfO2 was printed onto a test chip containing platinum lines. Two adjacent rectangular HfO2 areas were deposited over the Pt lines using different DALP® process parameters, resulting in thicknesses of ~21 nm and ~30 nm (verified by ellipsometry).

Fig.5: Deposited HfO2 rectangles (lighter and darker squares) on top of platinum lines before etching.

In a rigorous chemical durability test, platinum lines coated with DALP®-deposited hafnium oxide (HfO2) were exposed to aqua regia at 80 °C for 30 minutes. Aqua regia, a well-known and highly aggressive etchant for platinum, was chosen to evaluate the protective coating under extreme conditions. While uncoated control samples experienced complete platinum dissolution, the DALP®-coated regions retained significant portions of the metal, demonstrating protection.

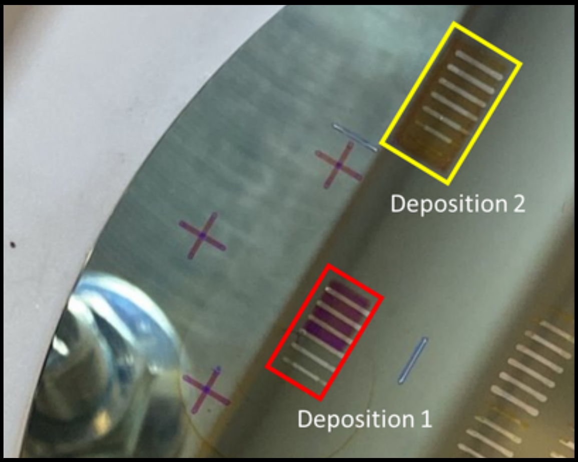


Fig.5: Deposited HfO2 rectangles (lighter and darker squares) on top of platinum lines before etching.

Fig.6: Platinum microline outcomes after aqua regia test –Pt line under TiO2 coating survived the acid attack.

This outcome suggests that even ultrathin (~20–30 nm) HfO_2 films can effectively slow down or prevent etching of underlying metals. Although some areas showed etching—likely due to factors like thermal stress-induced cracking or local particle present on the surface—the results validate the potential of DALP®-printed oxide films as robust, etch-resistant barriers.

In a rigorous chemical durability test, platinum lines coated with DALP®-deposited TiO_2 (~30 nm) remained intact after exposure to a corrosive plating solution, with EDS confirming no residual copper. Initial concerns about film thickness were resolved as the coating effectively prevented delamination. A subsequent Aqua Regia dip further validated the TiO_2 layer's protective function. Minor etching occurred only at isolated points, likely due to dust particles disrupting full encapsulation.

Efficiency and Durability Benefits

ATLANT 3D's Direct Atomic Layer Processing (DALP®) technology makes applying protective coatings faster and easier by combining everything into a single, streamlined step. Unlike traditional methods, it cuts down on equipment, processing stages, and material use; saving both time and resources. This not only reduces costs and increases yield but also minimizes environmental impact by lowering material waste and eliminating the need for complex lithography.

Conclusions

ATLANT 3D's DALP® technology revolutionizes protective coatings by enabling precise, maskless deposition of thin films on complex 3D structures.

Its applications span solar cell manufacturing—where it replaces traditional masking methods with TiO_2 layers to prevent unwanted copper plating — to optoelectronic devices, allowing for targeted anti-reflective or protective coatings without affecting active areas. DALP® also makes it easy to create multi-material, multilayer coatings in a single step, which helps improve both the durability and functionality of devices. It fits seamlessly into modern manufacturing workflows, supporting Industry 4.0 goals like rapid prototyping and sustainability. As the technology continues to evolve, DALP® is well-positioned to become a key enabler in building the next generation of advanced electronic devices.

Get in touch with our Business Development Team to discover how ATLANT 3D can transform your processes and keep you ahead of the curve, Atom by Atom®

+ Contact us here

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Innovation Fund Denmark

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CONTACT

sales@atlant3d.com
+45 22290080