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APPLICATION NOTE

ALD for Power Devices

INTRODUCTION

- **Picosun's Atomic Layer Deposition (ALD) technology offers a superior way to improve the performance of power electronic components.**
- **ALD produces ultra-thin, defect-free coatings with the highest conformality and uniformity, digitally repeatable thickness control and sharp interfaces.**
- **Picosun provides a selection of turn-key manufacturing ALD solutions specifically designed for 100-200 mm (4-8 inch) wafer production lines such as compound semiconductor based power components.**

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BACKGROUND

- GaN and SiC have been unanimously recognized as the best materials for next generation power electronic devices with applications in consumer electronics, transportation, and energy production and distribution, including renewable energy such as wind and solar power.

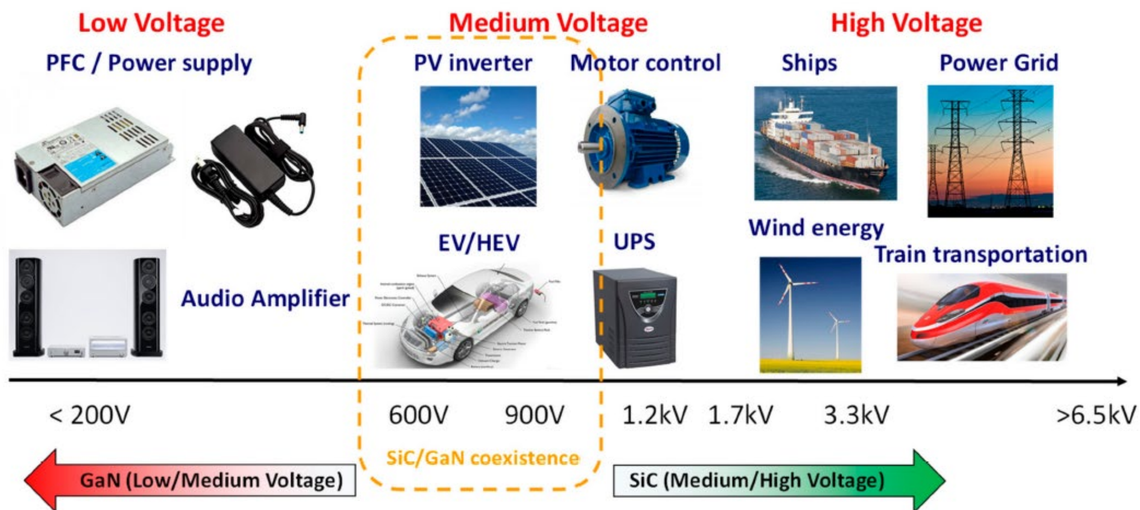

Fig 1. *Examples of applications of GaN and SiC power devices as a function of voltage [1].*

- This is due to the superior material properties of GaN and SiC, compared to conventional silicon, such as wider bandgap, higher critical electric field, and higher saturation velocity. This enables higher power handling capability, higher operating temperatures, higher conversion efficiency, and higher electron mobility compared to silicon-based devices.

- Despite the obvious benefits of GaN and SiC -based power components, challenges still do exist, some key issues being:
  - High interface trap density → "current collapse" phenomenon (GaN), low inversion channel mobility (SiC)
  - Gate leakage current (GaN)
  - Poor threshold voltage stability (both GaN and SiC)
  - Gate insulation and surface passivation (GaN)

ADVANTAGES OF PICOSUN'S ALD SOLUTIONS FOR POWER DEVICES MANUFACTURING

- Deposition of defect-free high-*k* dielectric layer is the key requirement for reducing gate leakage current, increasing inversion channel mobility, and improving threshold voltage stability [2]. ALD technology stands superior here compared to other methods such as PECVD. With ALD, the highest quality ultra-thin, defect-free coatings of superior conformality, sharp interfaces, digitally repeatable thickness control and exact chemical composition can be produced. ALD process runs at moderate temperatures and from gaseous precursors so it is gentle also on sensitive substrates. Several ALD materials such as Al_2O_3, AlN [3], and ZrO_2 have been shown to significantly improve the properties of power electronic components.

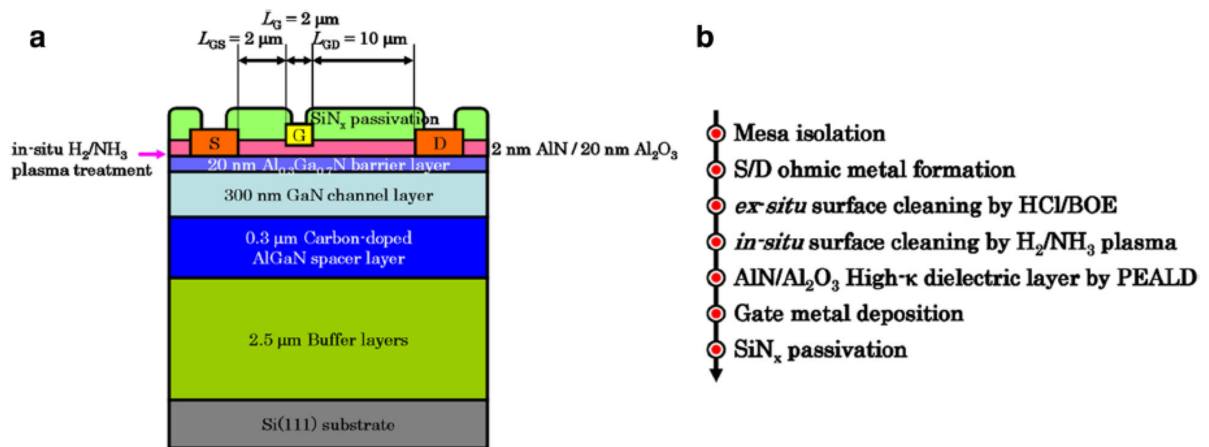

Fig 2. *GaN-based HEMT with high-k dielectric deposited in a PICOSUN® ALD tool. Schematic cross section and dimensions of the HEMTs (a); device fabrication process flow (b) [3].*

- ALD deposited, high permittivity, large bandgap insulators such as Al_2O_3, HfO_2, and SiO_2 decrease interface trap density and improve the performance of both GaN- and SiC-based power components. A wide range of other ALD materials such as CeO_2, BeO, AlON, LaON etc., which are not possible to deposit with other techniques such as PECVD, have also been utilized in this application.

- With ALD, near stoichiometric epitaxial GaN can be deposited directly on SiC [4], Si, AlN and AlGaN. This opens up interesting possibilities in transistor design as direct deposition of GaN decreases the number of material interfaces in the device and thus simplifies the overall process.

- Normally-off HEMT devices with positive threshold voltage (e.g. recessed hybrid MISHEMTs and p-GaN gate devices) are important for the large scale adoption of the promising GaN material in practical applications. In these devices, efficient gate insulation and surface passivation are particularly critical in achieving optimal performance. ALD materials such as Al_2O_3, AlN, and HfSiO have excellent conformality and properties to make normally-off HEMT devices a viable technology for large scale utilization.

- Also metals and other conductive materials can be deposited with ALD. In normally-off p-GaN HEMT devices, Schottky metal gates have shown superior performance compared to Ohmic gates in terms of higher threshold voltage and lower leakage current.

- **Picosun provides a large library of turn-key, production-proven solutions for deposition of high quality ALD dielectrics such as Al_2O_3, AlN, HfO_2, HfAlO, SiO_2, ZrO_2, and Ta_2O_5. For metals/conductive materials processes are available for e.g. Pt, Ru, and TiN.**

- **PICOSUN® ALD equipment have the ability to deposit nanolaminates (e.g. Al_2O_3/HfO_2 multistack) in the same process run without breaks or change of equipment.**

- **PICOSUN® R&D ALD tools can combine thermal and plasma-enhanced ALD in the same process run without any hardware changes or system reconfiguration.**

- **PICOSUN® ALD systems can be clustered with other equipment such as RIE or CVD units for constant processing without vacuum breaks.**

- ***In situ* pre-clean is possible in PICOSUN® plasma ALD tools.**

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Fig 3. *PICOSUN® Morpher, fully automated production ALD platform for up to 200 mm wafer markets such as power component manufacturing.*

REFERENCES

Picosun's ALD equipment and solutions are currently in production use at several prominent power device manufacturers in Europe, USA, and Asia.

Academic references:

[1] Roccaforte *et. al.*, Materials, no. 12, p. 1599 (2019); DOI: 10.3390/ma12101599
[2] Roccaforte *et. al.*, Applied Surface Science, no. 301, p. 9 (2014); DOI: 10.1016/j.apsusc.2014.01.063
[3] Tzou *et. al.*, Nanoscale Research Letters 12:315 (2017); DOI: 10.1186/s11671-017-2082-0
[4] Rouf *et. al.*, Journal of Materials Chemistry C, no. 8, p. 8457 (2020); DOI: 10.1039/d0tc02085k

More references can be delivered on request.

ABOUT PICOSUN AND ALD

Picosun is the leading provider of AGILE ALD® thin film coating solutions for global industries and prominent research organizations. PICOSUN® ALD equipment are used in wafer-based semiconductor industries such as IC components, lighting devices, and sensor manufacturing, and coating of macroscopic 3D items such as machinery parts, medical implants and devices, watch parts and coins.

Picosun's history reaches back over four decades, to the invention of the ALD technology itself. Our exclusive dedication to ALD and the unmatched, Ph.D level expertise of our team make us your ideal partner in all your thin film coating needs!

ALD is the most sophisticated thin film coating method of today, and a key enabling technology in modern microelectronics industries. Ultra-thin ALD films have the highest conformality and uniformity down to nanometer-scale surface details and, thanks to the surface-controlled, self-limiting film growth mechanism, they are dense, crack- and pinhole-free. Several ALD materials are also intrinsically biocompatible and thus optimal for medical applications.

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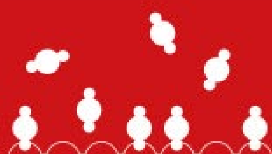
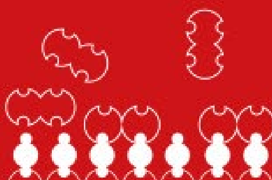
THE PRINCIPLE OF ALD



Introduction of molecules containing element A.

Adsorption of the molecules on the surface.



Introduction of molecules containing element B and reaction with element A on the surface.

Completion of one monolayer of compound AB.

Repeat cycle till desired film thickness is reached.

CONTACT INFORMATION

Main HQ

Picosun Oy
Tel. +358 50 321 1955
Fax +358 9 297 6116
info@picosun.com

European HQ

Picosun Europe GmbH
Tel. +49 1522 449 49 11 (Germany)
Tel. +33 60 785 1176 (France)
sales@picosun.com

North American HQ

Picosun USA, LLC
Tel. +1 214 790 0844
Mobile +1 972 482 1433
sales@picosun.com

Asian HQ

Picosun Asia Pte. Ltd., Singapore
Tel. +65 9830 1709
sales@picosun.com

Picosun Taiwan Co. Ltd.
Tel. +886 90 515 2985
sales@picosun.com

Picosun China Co. Ltd.
Tel. +86 139 2640 6106
sales@picosun.com

Picosun Japan Co. Ltd.
Tel. +81 3 6431 9500
sales@picosun.com

Picosun Korea Ltd.
Tel. +358 40 825 1703
sales@picosun.com

Picosun Oy - India Liaison Office
Tel. +91 96000 28593
sales@picosun.com

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