Power electronics

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3rd February 2026,
The Faculty, Brussels

Outline

- Introduction
- Technological Developments in WBG/UWBG Power Devices
- Trends, Challenges, and Opportunities
- Recommendations for European Cooperation
- Importance of International Cooperation

Introduction

Why Power Electronics Matter for European Resilience

- Power conversion efficiency is a key enabler for electrification and climate goals
- Silicon reaches physical limits at high voltage, temperature and switching speed
- WBG and UWBG technologies shift performance limits at device and system level
  - System-level efficiency gains up to ~10%
  - Reduced TCO* via smaller converters and lower cooling
  - Relevance for data centers and AI power

- At least 50 % of the electricity used in the world is controlled by Power Devices.

Key message: WBG/UWBG devices address silicon limits and unlock higher-efficiency electrification.

*) TCO : Total Cost of Ownership

Technological Developments in WBG/UWBG Power Devices

Advanced Semiconductor Materials for Power Applications

- WBG platforms: Silicon Carbide (SiC), Gallium Nitride (GaN)
- UWBG candidates: Gallium Oxide (Ga_2O_3), Aluminum Nitride (AlN), amd Diamond
- Key scaling parameters: bandgap, critical electric field, thermal conductivity

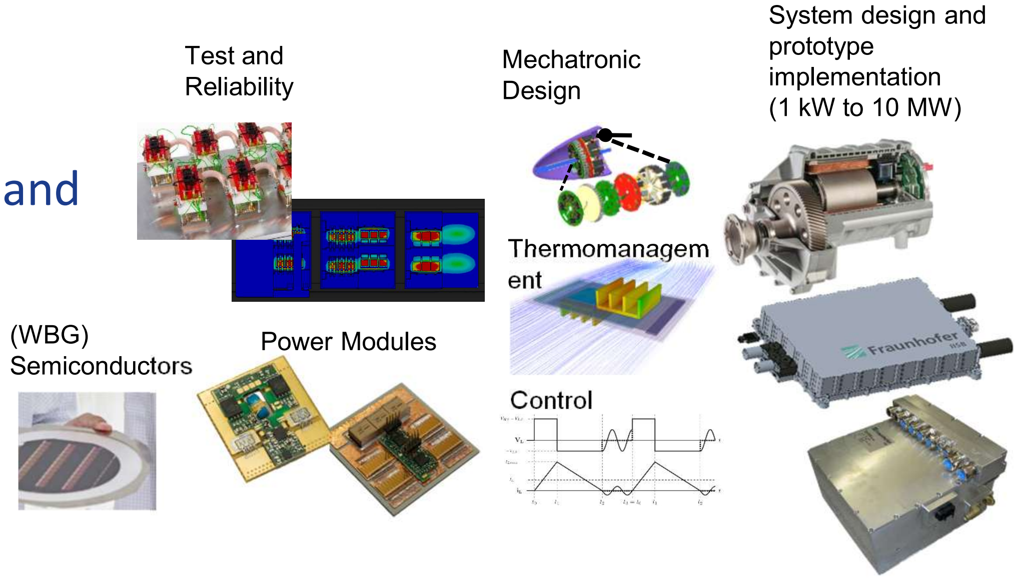
		WBGs		Ultra WBGs		
	Silicon	4H-SiC	GaN	Ga2O3	Diamond	AlN
Bandgap E_g [eV]	1.1	**3.26**	**3.45**	4.85	5.47	6.2
Melting Point [°C]	1420	-	-	1795	-	-
Electron Mobility μ_n [cm^2/Vs]	1350	900	1000	150	4000 (th.)	500
Dielectric constant ε	11.8	9.7	9.5	9.9	5.5	9.1
Thermal Conductivity k [W/cmK]	1.56	**3.7**	1.5	0.1	25	3
Critical Electrical Field E_{cr} [10^6V/cm]	0.2	**3.2**	**3.3**	8	10	16.6

Key message: Material properties translate directly into higher voltage, temperature and frequency capability.

Trends, Challenges, and Opportunities

From Devices to Energy-Efficient Systems

- Higher breakdown voltages at reduced material volume
- Lower conduction and switching losses across operating range
- Higher power density through reduced passives and cooling demand
- Co-optimization across device, package and control is essential



Key message: System gains require co-design across device, package and control - materials alone are insufficient.

European Commission

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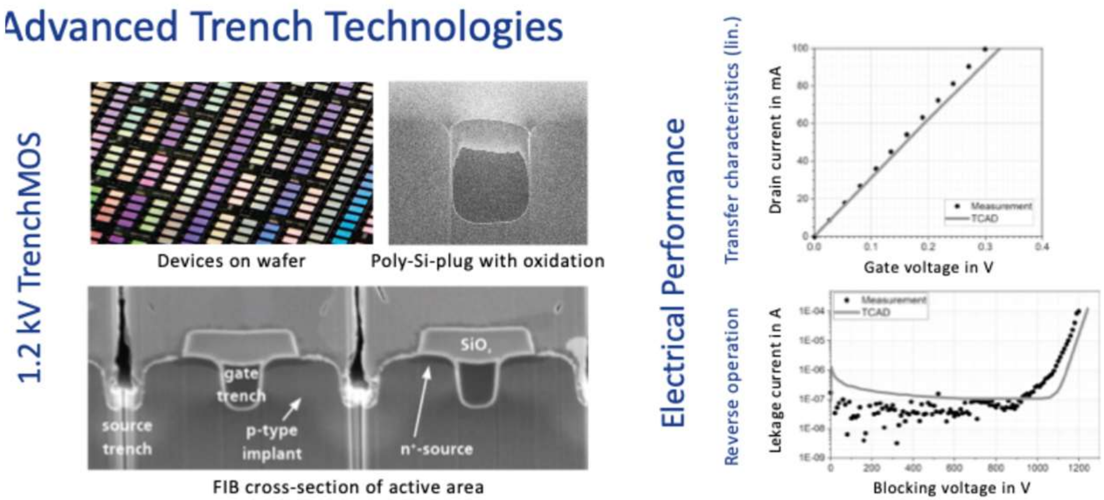
SiC: Research and Scale-Up Priorities

- Large-diameter substrates as a cost/yield enabler (8-inch transition), 12-inch substrates announced
- Interface engineering to reduce traps and improve channel mobility
- Qualification under high-field and high-temperature stress conditions
- Cost reduction driven by wafer diameter and process maturity is accelerating industrial adoption

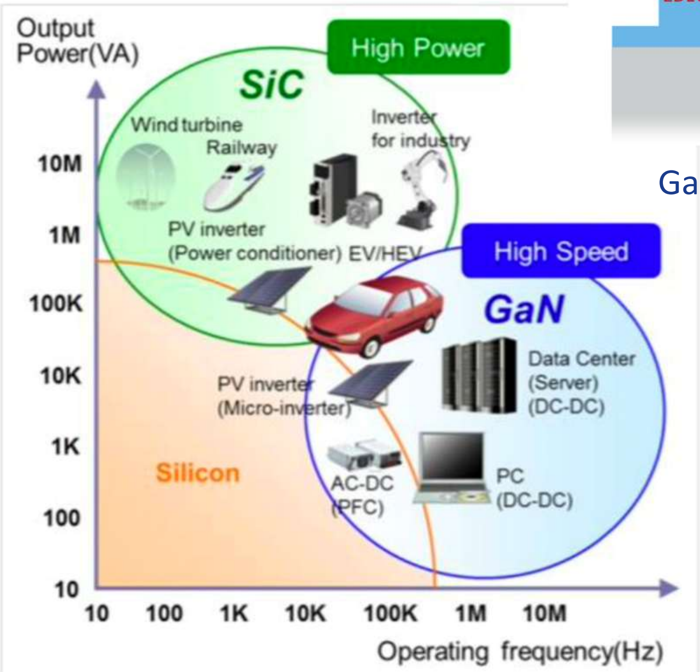
200 mm and 150 mm SiC substrates



Key message: SiC progress depends on substrates and robust MOS interfaces with proven reliability.

GaN: High-Frequency Power Conversion and Voltage Scaling

- High-frequency operation enables compact, high-density converters
- GaN dominates high-frequency applications, while thermal robustness remains a key challenge
- Thermal path engineering for GaN-on-Si and GaN-on-SiC
- Research pathways toward higher voltage classes (≥1200 V)



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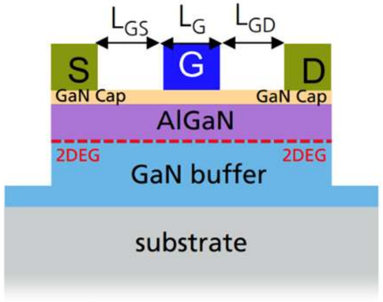

GaN HEMT schematic

Key message: GaN leads in switching speed; extending voltage range requires reliability & thermal breakthroughs.

UWBG Materials: Longer-Term Opportunities and Barriers

- Extremely high breakdown fields enable new device concepts
- Open challenges: bulk crystal quality, doping control, stable contacts
- Packaging compatibility and thermal management remain limiting factors

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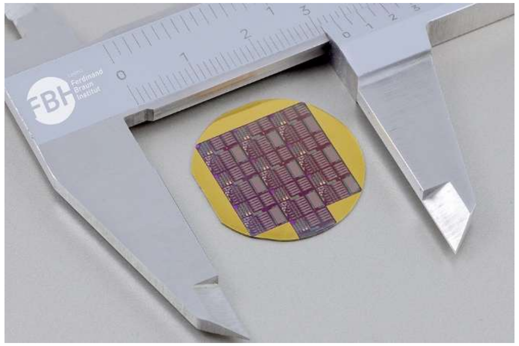

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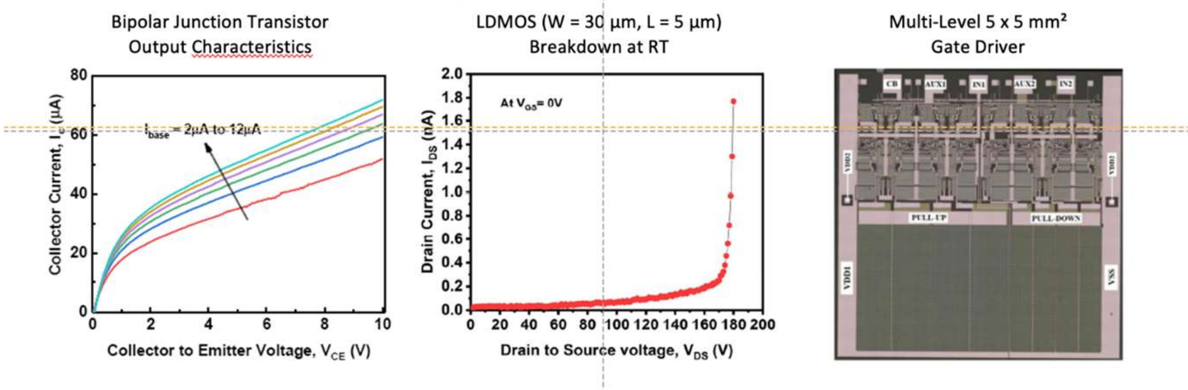
Aluminum nitride-based value chain: First generation of AlN/GaN transistors produced at FBH with Fraunhofer IISB Aluminum nitride crystal show promising properties, i.a. a power density that is superior to that of SiC or GaN devices.

Key message: UWBG promises step-change voltage performance, but bottleneck of materials and contacts.

Heterogeneous Integration as a System-Level Performance Multiplier

- Co-integration of power devices with drivers, control and sensing reduces parasitics
- Integration modalities: 2.5D interposers, 3D stacks, embedded die, co-packaging
- Trade-offs between electrical performance, thermal paths, mechanical stress and yield
- Multiphysics co-design mandatory



Key message: Integration reduces parasitics and unlocks higher speed, but thermal design and reliability are key.

WBG / UWBG Power Electronics – Research & Technology Roadmap

Near Term (1–3 yrs)

- 8-inch SiC substrates
- SiC MOSFET reliability & interfaces
- GaN adoption in data centers

Mid Term (3–6 yrs)

- High-voltage GaN (≈ 1200 V)
- Advanced heterogeneous integration
- Pilot-line scale-up & qualification

Long Term (6–10 yrs)

- UWBG materials (Ga_2O_3, AlN)
- Integrated power subsystems
- Full multiphysics co-design & lifetime models

Key message: Near-, mid- and long-term priorities align materials maturity with integration and validation needs.

Recommendations for European Cooperation

Recommendations for European Cooperation (1/2)

- Secure access to manufacturing infrastructures, manufacturing tools, EDA software, materials and consumables
  → **Impact: technology sovereignty and supply-chain resilience**
- Coordinate end-to-end pilot-line capabilities (crystal → devices → packaging → test) to de-risk scale-up towards production-relevant devices and volumes
  → **Impact: reduced time-to-market and manufacturing readiness**
- Harmonize qualification and accelerated reliability tests for high-field, high-temperature and fast-switching stresses
  → **Impact: faster industrial adoption and reduced qualification costs**

Recommendations for European Cooperation (2/2)

- Establish shared, pre-competitive datasets and models for defects, interfaces, lifetime and multiphysics behavior
  - → **Impact: improved predictability, reliability and design efficiency**
- Strengthen ecosystem linkages across materials suppliers, fabs, packaging houses and OEM integrators
  - → **Impact: accelerated innovation transfer and value-chain alignment**
- Invest in integration-ready packaging and co-design toolchains to reduce parasitics while ensuring thermal/mechanical robustness
  - → **Impact: higher power density and system-level performance**
- Develop skills and training spanning materials, device physics, packaging, EMC/EMI and system design
  - → **Impact: sustainable talent base and long-term industrial competitiveness**

Key message: Coordinated pilots, standards and shared models accelerate European readiness for power.

Overall conclusion for Europe:

Coordinated technology development, integration and pilot-line validation are critical to translate WBG and UWBG innovations into robust, competitive power-electronic systems for future energy and computing infrastructures.

Importance of International Cooperation / Possible Partnes

Global research partners

- The USA, Japan, South Korea, Taiwan and Europe are leaders in semiconductor and power electronics research with specialised institutes and universities.

Standardisation and industry consortia

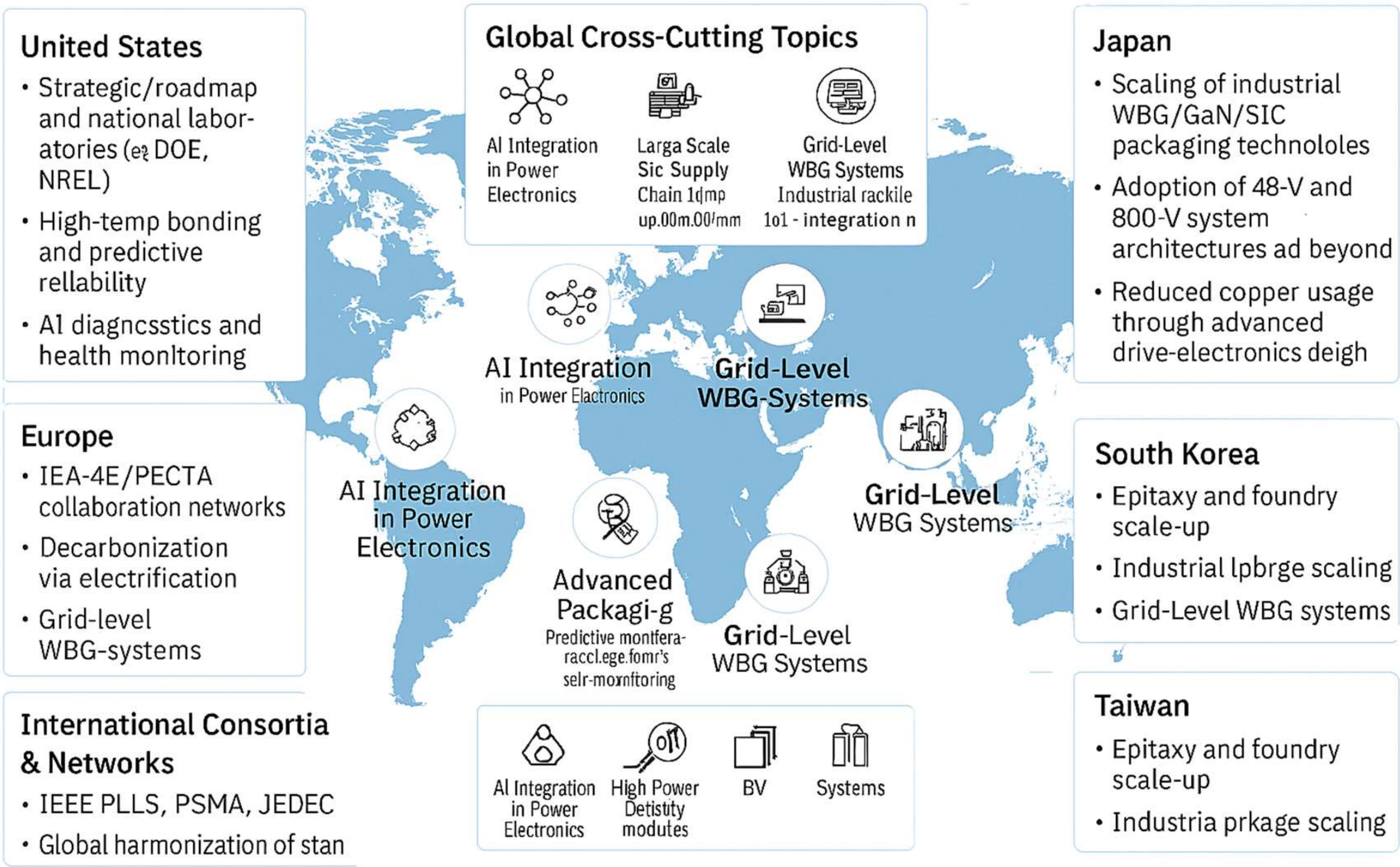
- IEEE PELS, PSMA and JEDEC promote global harmonisation of test procedures and qualification standards for new technologies.

Cooperation for innovation

- Networking enables access to modern analyses, pilot lines and manufacturing environments for rapid technology development.

Strategic importance

- Joint development strengthens competitiveness and reduces geopolitical dependencies.



International Cooperation in Power Electronics and WB/BG

THANK YOU

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This Event is associated with INPACE

Indo-Pacific-European Hub for Digital Partnerships

And is a side event of the ECS BROKERAGE EVENT 2026

This project has received funding from the European Union's Horizon Europe research and innovation programme under GA Nº 101092562

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