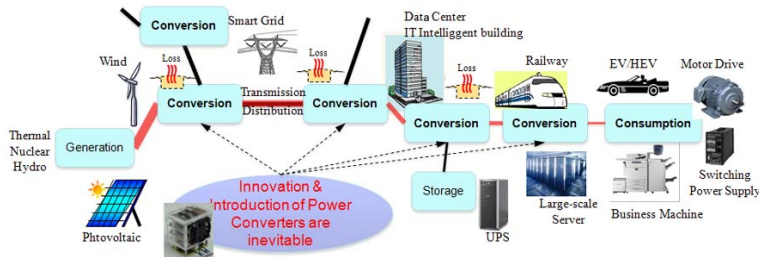


Gallium Nitride power devices

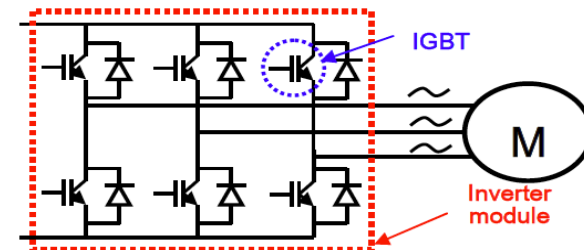
Frédéric Morancho

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- > **Energy** may be the most important factor that will influence the shape of society in the 21st century
- > Strong societal demand on the environment and renewable energies
(Grenelle laws, H2020, COP21,...)
- > **Power electronics is a key field** to address this demand
→ *Innovation and introduction of power converters are inevitable*



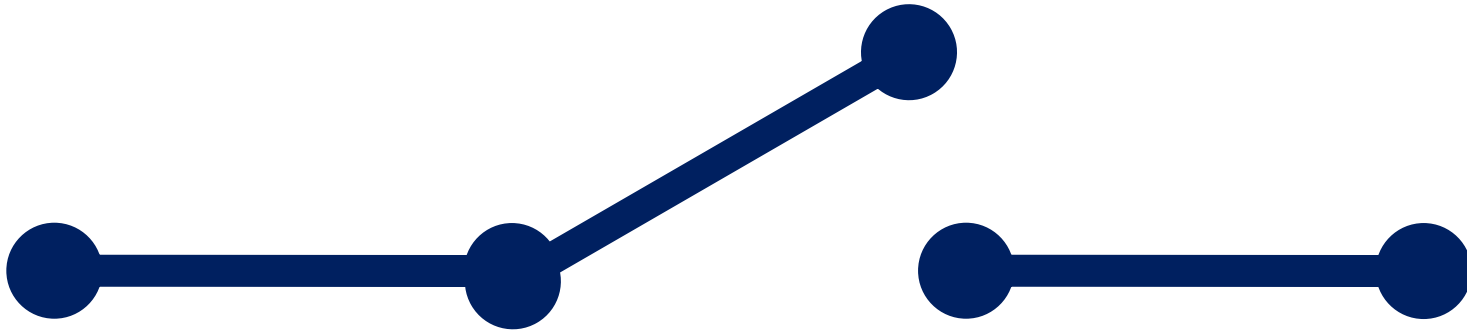
from <https://unit.aist.go.jp/adperc/cie/research/research1.html>, ADPERC of the National Institute of Advanced Industrial Science and Technology (AIST)



Example of a three phase inverter module

- ➔ High power, high frequency, high temperature and low losses power switches are mandatory for an optimal power management
- ➔ **Gallium Nitride (GaN) power switch** seems to be the **perfect switch** in terms of energy savings, cost, yield, size, weight and cooling

The perfect power switch



OFF-state

Attains infinite resistance = zero leakage current
Sustains unlimited voltages = no breakdown

The perfect power switch



OFF-state

Attains infinite resistance = zero leakage current
Sustains unlimited voltages = no breakdown

ON-state

Zero voltage drop = no ON-state resistance
High current carried during the ON-state

The perfect power switch



OFF-state

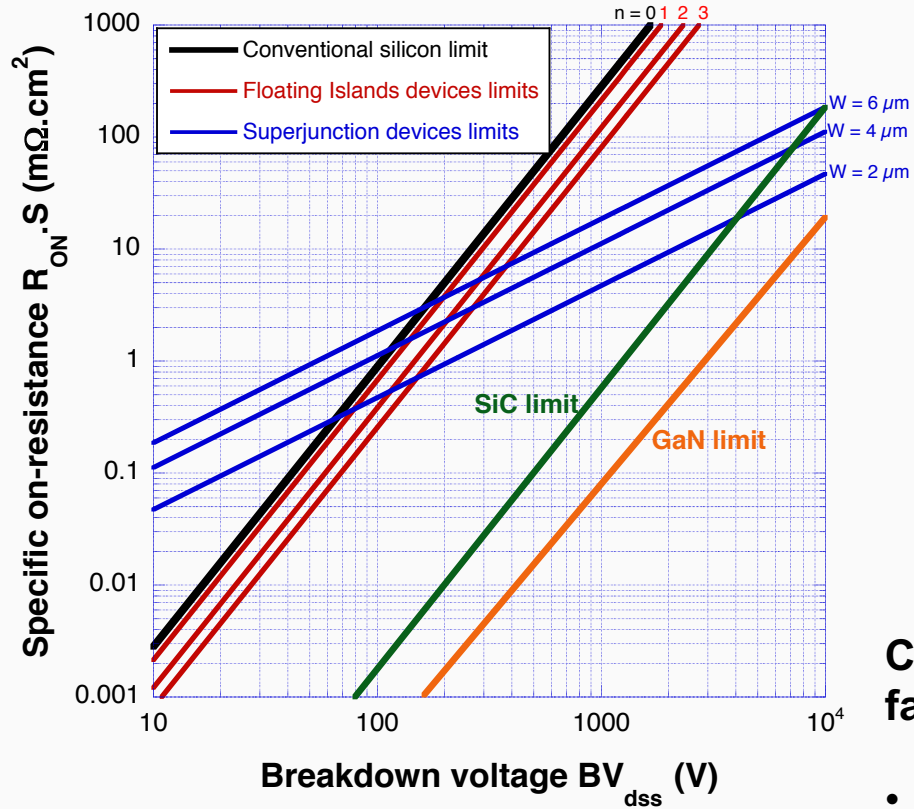
Attains infinite resistance = zero leakage current
Sustains unlimited voltages = no breakdown

ON-state

Zero voltage drop = no ON-state resistance
High current carried during the ON-state

The time to switch between the ON and OFF-state is zero

Si, SiC, GaN: limits of performance

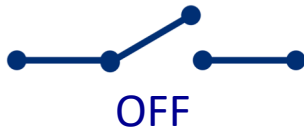


Baliga's FOM:
$$R_{ON} \cdot S = \frac{4 \cdot BV_{dss}^2}{\epsilon \cdot \mu_n \cdot E_C^3}$$

(limit for conventional unipolar devices)

Compared to the silicon limit, the improvement factor of the static performance seems to be huge:

- $R_{ON} \cdot S$: 3 decades for SiC and 4 decades for GaN
- BV_{dss} : more than 1 decade



HEMT = High Electron Mobility Transistor

e^- mobility ≈ 1500 à $2000 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$

e^- concentration $\approx 2 \cdot 10^{13} \text{ cm}^{-2}$

→ very low specific ON-resistance between drain and source

AlGaN/GaN power HEMTs are grown on Si substrate

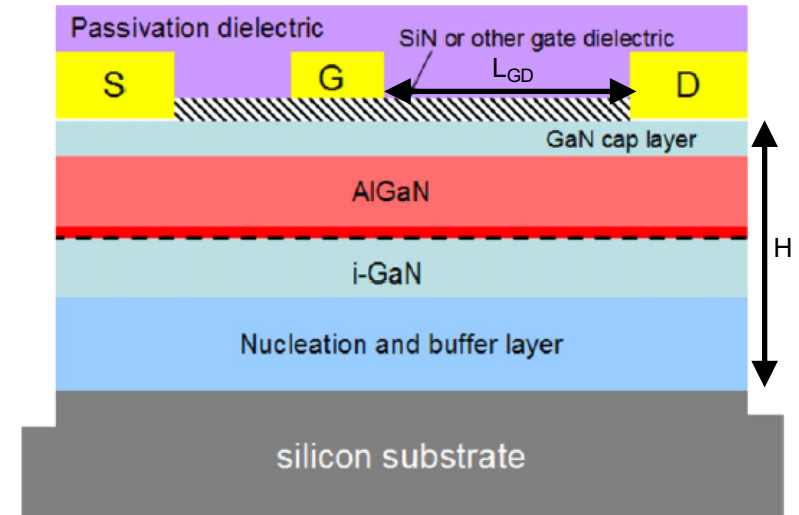
→ the production cost is reduced

→ possible combination of GaN devices and Si technology

The GaN HEMT is normally-ON

→ the switch is in the ON-state when $V_{GS} = 0 \text{ V}$

→ in other words: $V_{TH} < 0 \text{ V}$ for conventional GaN HEMTs



Example of an AlGaN/GaN HEMT cross-section with a gate dielectric

Power GaN HEMT: main challenges

✓ **High Voltage capability**

- 600 V node & 1200 V nodes

✓ **Normally-OFF behaviour**

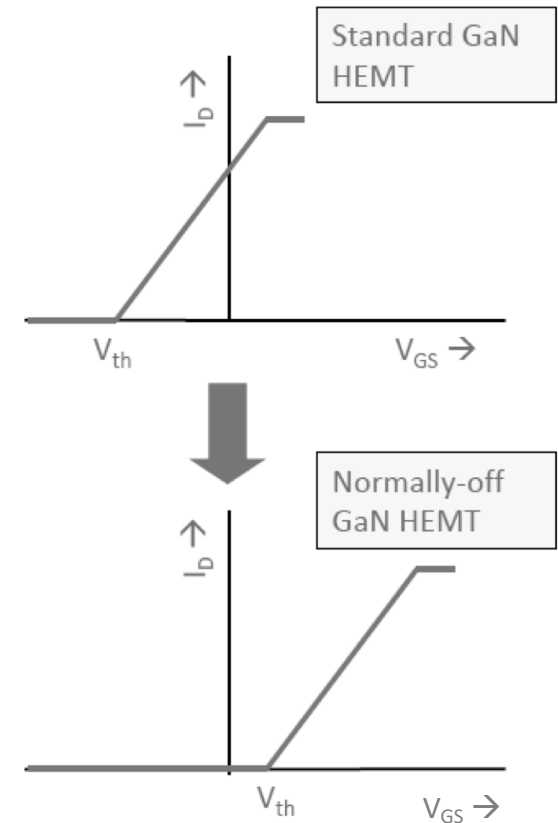
- Threshold voltage $V_{TH} > 2\text{ V}$

✓ **Low ON-state resistance**

- Lower than other device competitors (Si MOSFETs, Si IGBTs, SiC MOSFETs, ...)

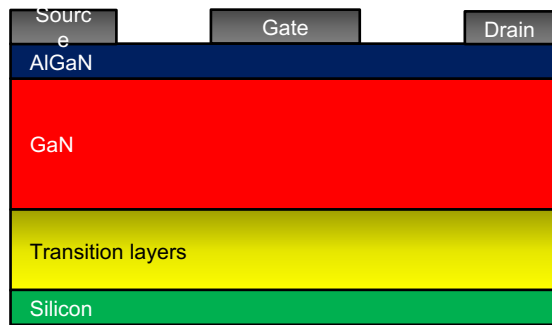
✓ **Fast and efficient switching**

- Low dynamic ON-resistance

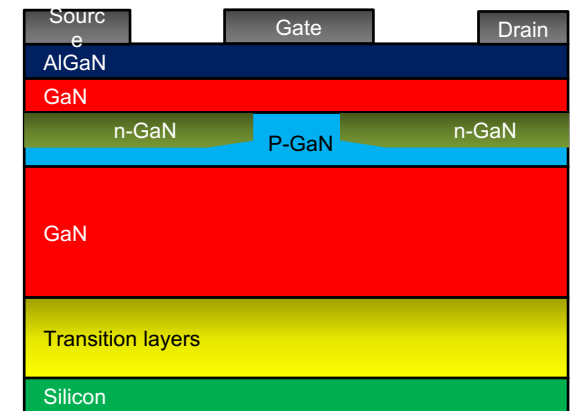
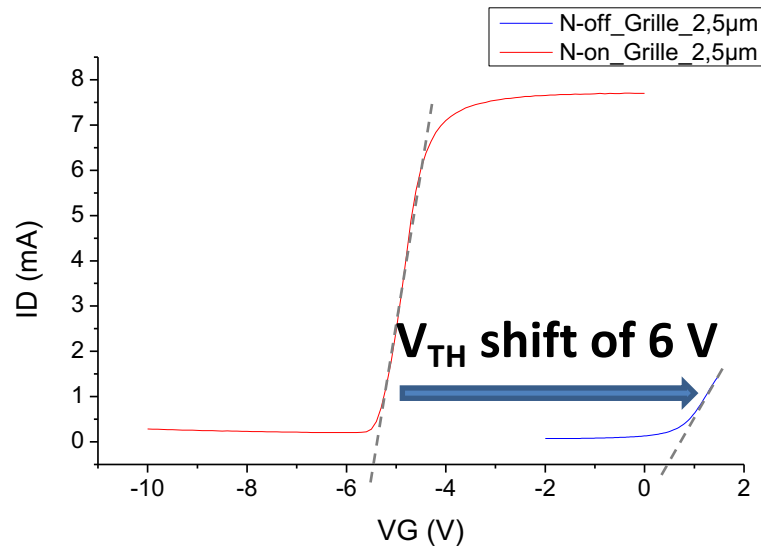


Normally-off GaN HEMT

A new normally-off power GaN switch realized in the micro and nanotechnologies platform of the LAAS-CNRS



Conventional normally-on GaN HEMT



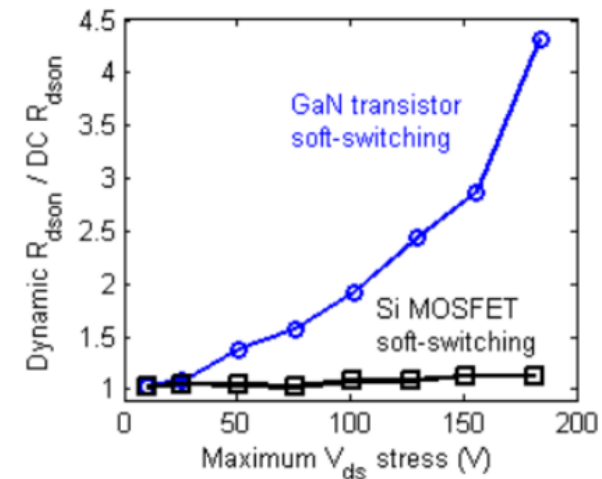
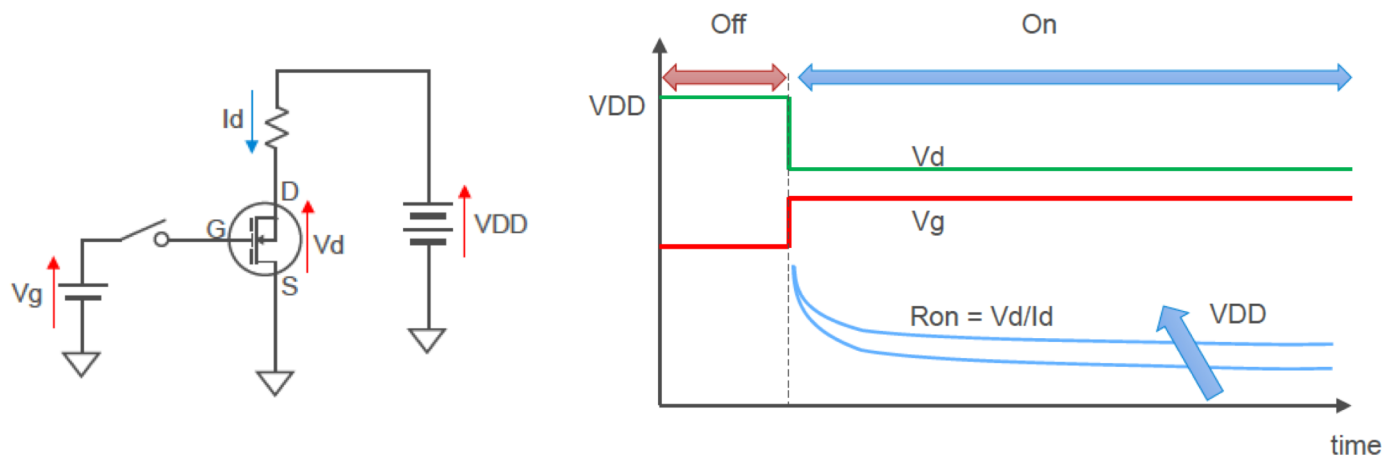
New normally-off GaN HEMT

A significant shift of 6 V in the threshold voltage was demonstrated with the new GaN HEMT compared to the conventional one: the new GaN HEMT is actually normally-off

Dynamic ON-resistance

What is dynamic ON-resistance?

Immediately after a switching from a High Voltage OFF-state to a Low Voltage ON-state, R_{ON} remains high for a period of time that can vary from ns (ideal case) to ms or even longer (deleterious case)



- The dynamic ON-resistance (R_{ON-dyn}) depends on both V_{DD} and the duration of the OFF-state

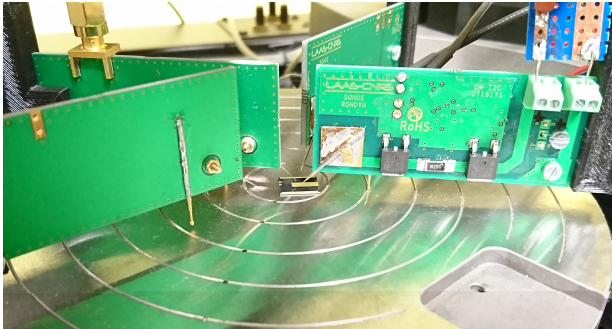
The higher V_{DD} is and/or the higher t_{OFF} is \rightarrow the more R_{ON-dyn} increases

- This mechanism is due to surface and bulk traps

To restore the drain current, all trapped charge must be released

Dynamic ON-resistance

A state-of-the-art characterization bench for R_{ON-dyn} extraction created and realized at LAAS-CNRS

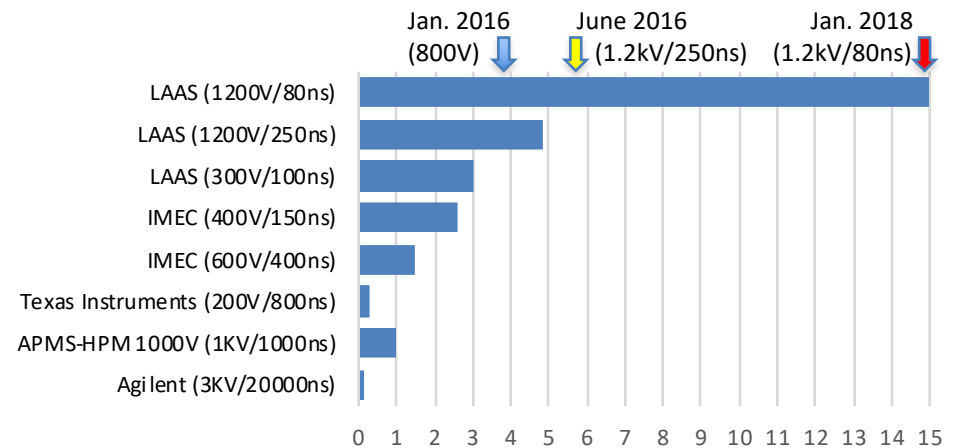


Solution based on a **very fast voltage clamp** circuit

Better resolution with the difficult switching conditions

Analysis of electrical parameters as a function of time

Figure of merit: $V_{MAX}(V) / \text{time before accurate measurement (ns)}$



- **Best test setup in the world in terms of ' V_{MAX} / time ' figure of merit (to our knowledge)**
- **An exceptional tool to understand device physics and electrical behavior of GaN HEMT**

> Many projects:

- 1 PhD and 1 post-doc within the frame of OPGAN (Région Occitanie / FEDER) project
- 1 PhD and 1 exploratory project within the frame of the « GANEX » LABEX
- 1 post-doc within the frame of DESTINEE (ANR) project
- 1 direct research collaboration with EXAGAN company

> Many partners:



> Some dreams:

- More energy efficient and faster converters, smaller and low-weight (with smaller inductors and capacitors)
- GaN bidirectional power switch → GaN power ASIC
- GaN power nanowires