GaN transistors for power and RF electronics

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Outline

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  - ➢ Semiconductors comparison
  - ➢ The High Electron Mobility Transistor
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  - ➢ Space applications
  - ➢ UNIPD research activities
- Power applications
  - ➢ Power HEMTs state of the art
  - ➢ The little box challenge
- Conclusions

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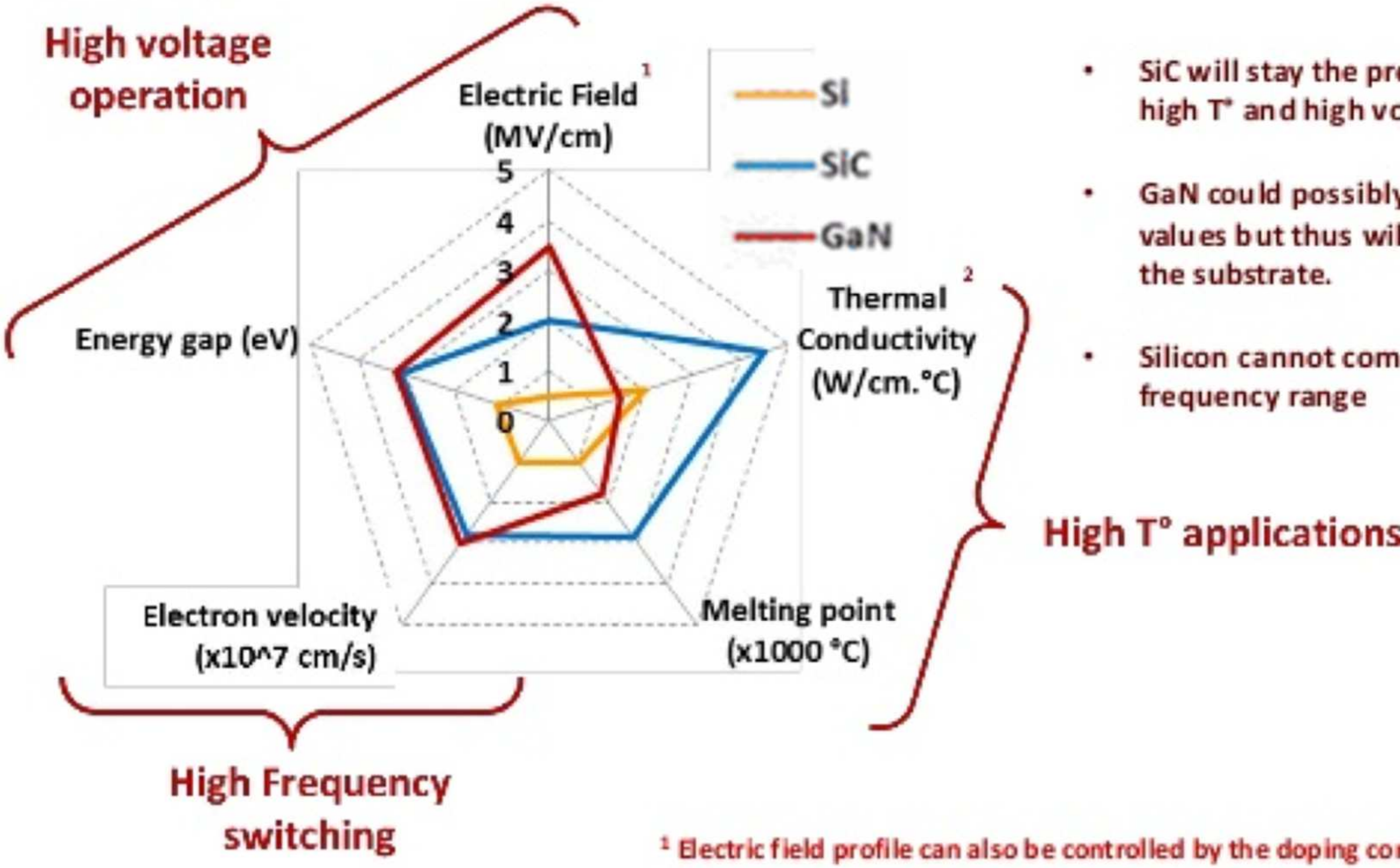
Introduction: semiconductors comparison

	GaN	InN	AlN	Si
Bandgap (eV)	3.4 eV	0.6 eV	6.4 eV	1.1 eV
Mobility ($cm^2V^{-1}s^{-1}$)	1500	3000	300	1000
Breakdown Field (MV/cm)	3	Low	11	0.3
Effective Mass	$0.21\ m_e$	$0.09\ m_e$	$0.4\ m_e$	$0.19\ m_e$
Velocity (cm/s)	2×10^7	2×10^8	-	1.0×10^7
Polarization	High charge, carrier confinement			

[1] U. K. Mishra, P. Parikh, Y.F. Wu, "AlGaN/GaN HEMTs—An Overview of Device Operation and Applications" IEEE Proc. Vol. 90, No. 6, p. 1022, June 2002.
[2] U. K. Mishra, L. Shen, T. E. Kazior, Y. F. Wu, "GaN-Based RF Power Devices and Amplifiers" IEEE Proceedings, Vol. 96, No. 2, p. 287, February 2008.

Introduction: semiconductors comparison

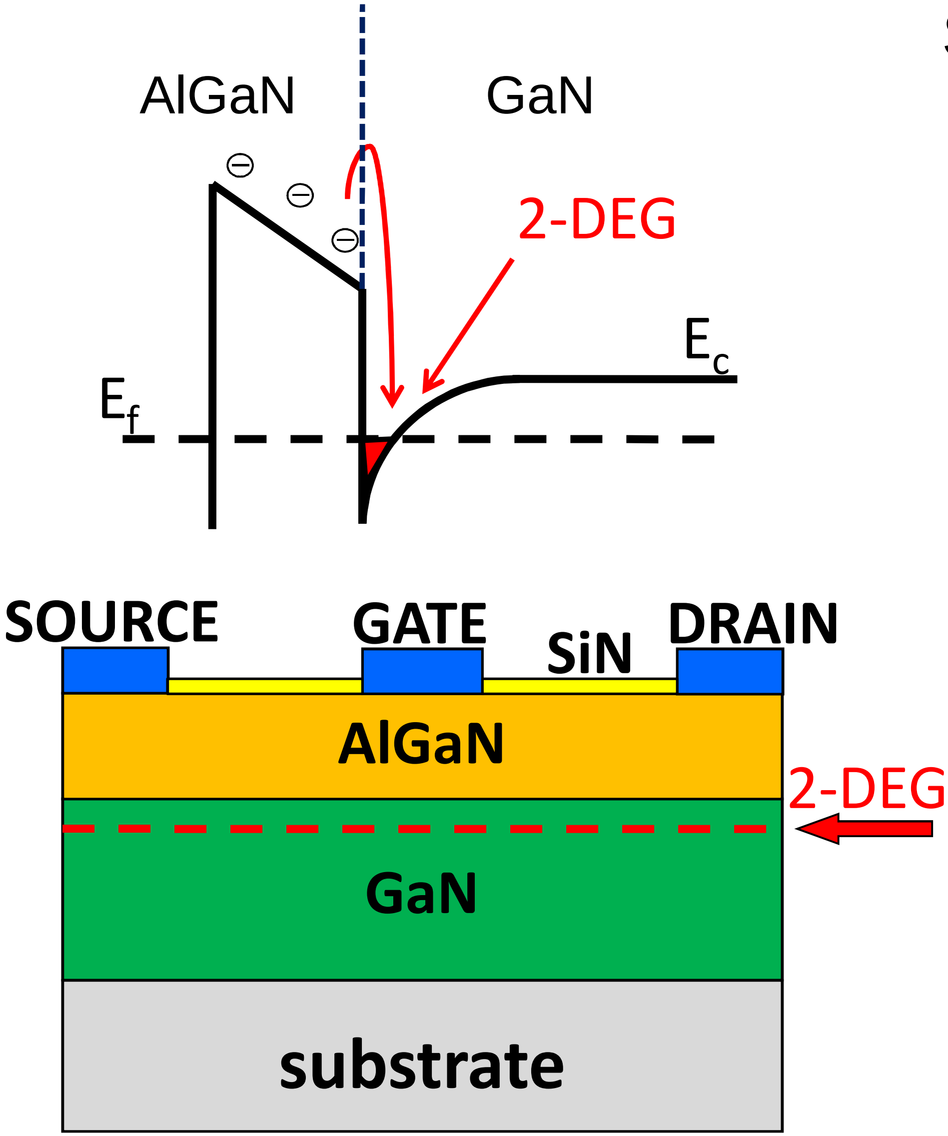


- SiC will stay the preferred choice for high T° and high voltage applications.
- GaN could possibly reach high-voltage values but thus will require bulk-GaN as the substrate.
- Silicon cannot compete at the high-frequency range

[1] Electric field profile can also be controlled by the doping concentration

[2] Tc for GaN is given here for typical GaN-on-Si. It has been demonstrated that Tc of bulk GaN could reach 4 W/cm.°C

HEMT: High Electron Mobility Transistor



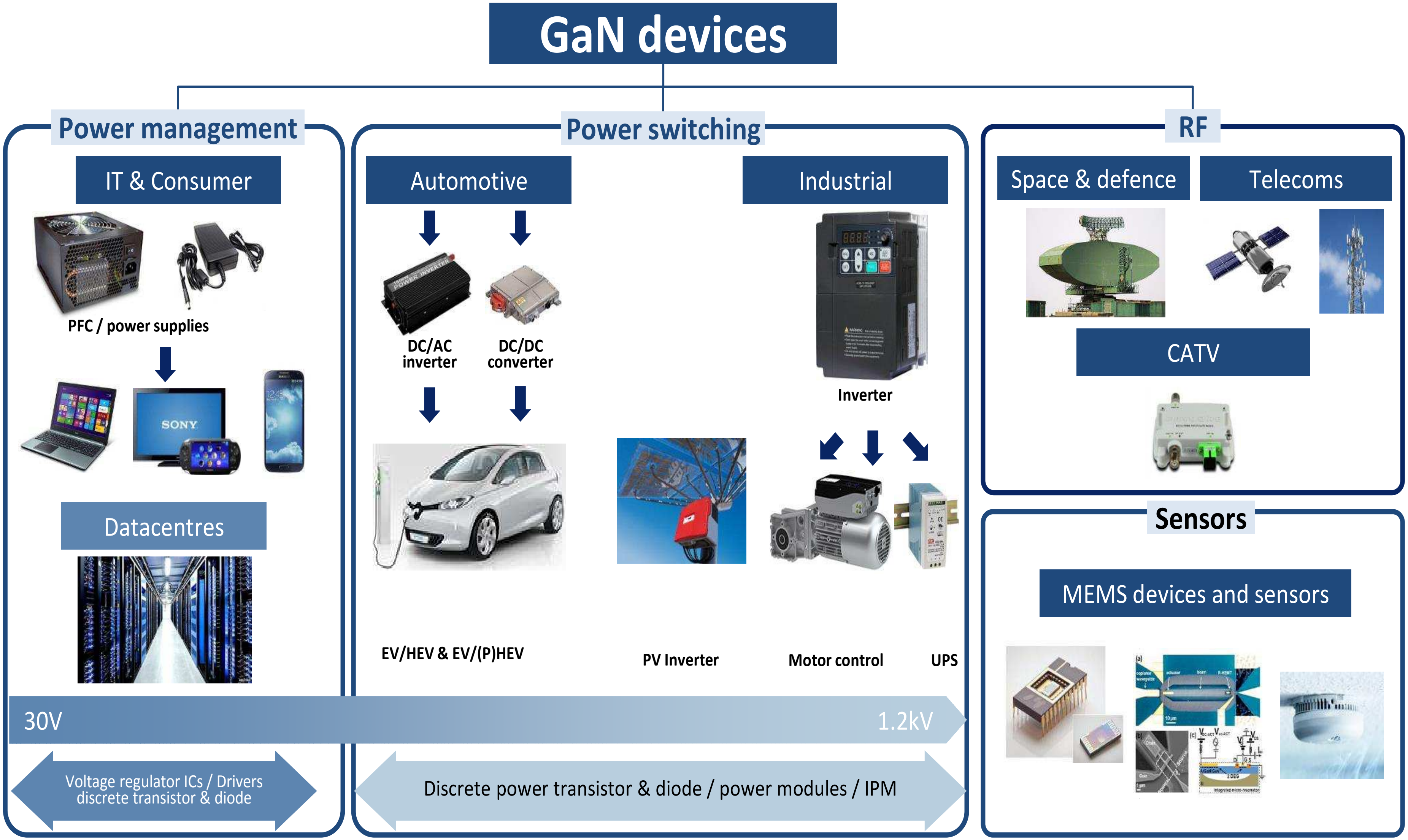
Spontaneous + piezoelectric polarization

2-DEG channel

High carrier concentration
+
High mobility

Ready for power and RF applications

GaN electronics applications



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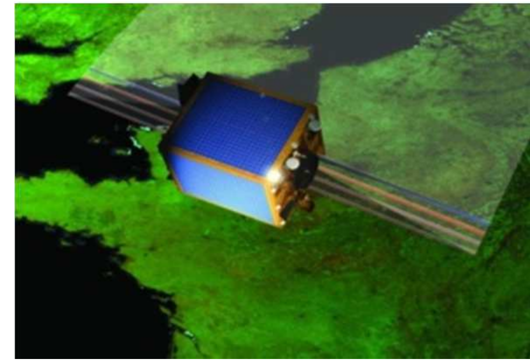
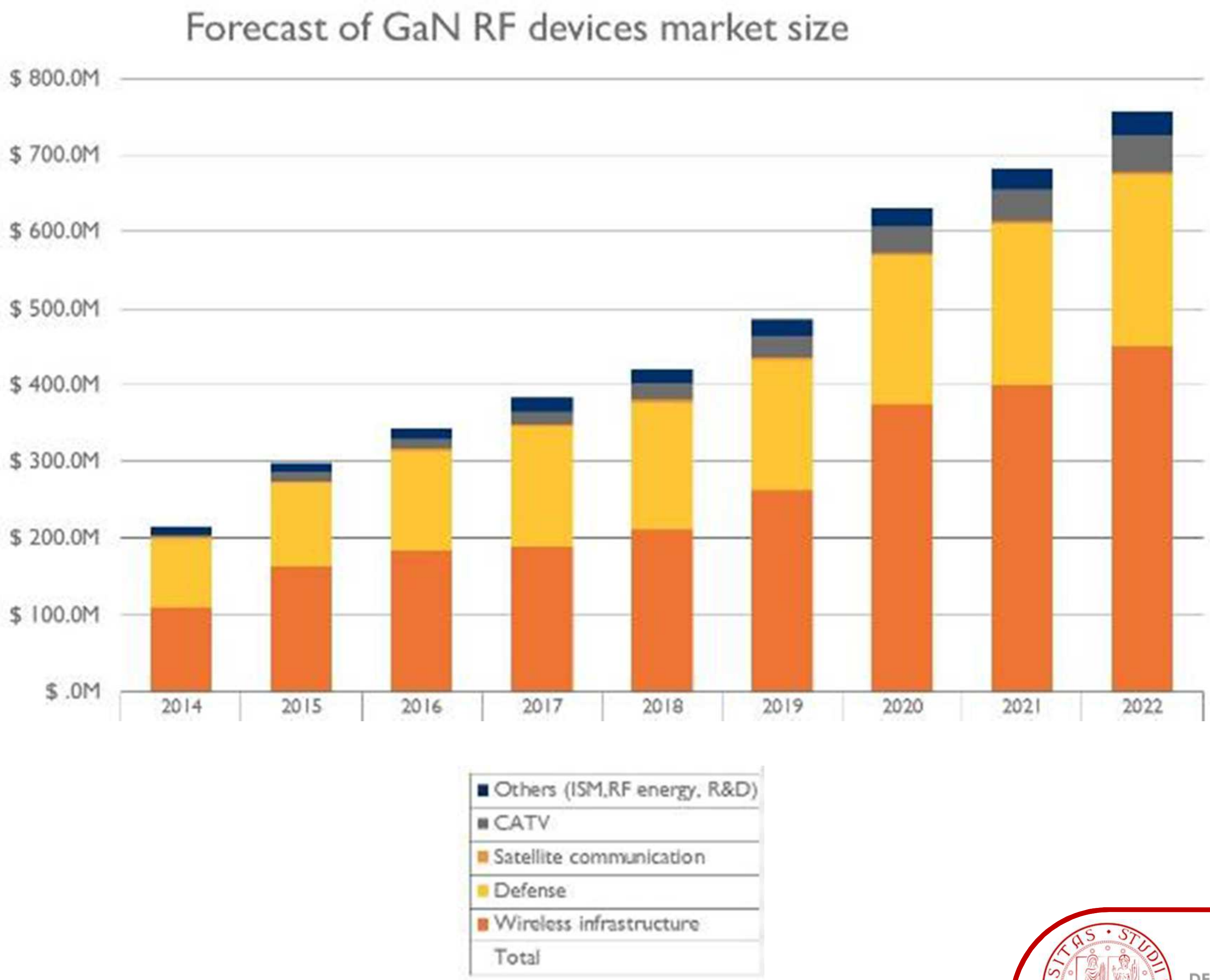
GaN RF applications

The main applications of GaN HEMT RF devices are:

- Satellite communications
- Mobile base stations
- Military
- Cable-TV
- Wi-Fi connections for IoT



GaN RF applications



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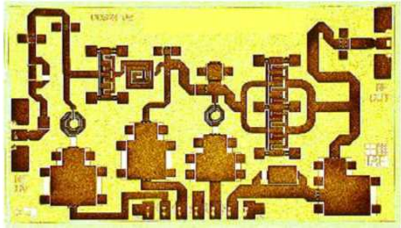
GaN RF space applications

- The European Space Agency has launched the Proba-V satellite on May 2013. It is an Earth Observation satellite used to map global vegetation.
- The GaN-based amplifier transmits data in X-band (8 GHz) with a bitrate of 100 Mb/s and output power of 8 W.

The Proba-V satellite

- ESA will launch in 2020 another observation satellite: BIOMASS.
- It is designed to monitor global forest biomass by means of a SAR radar.
- The 435 MHz radar works with a GaN-based High Power Amplifier.



GaN MMIC amplifier

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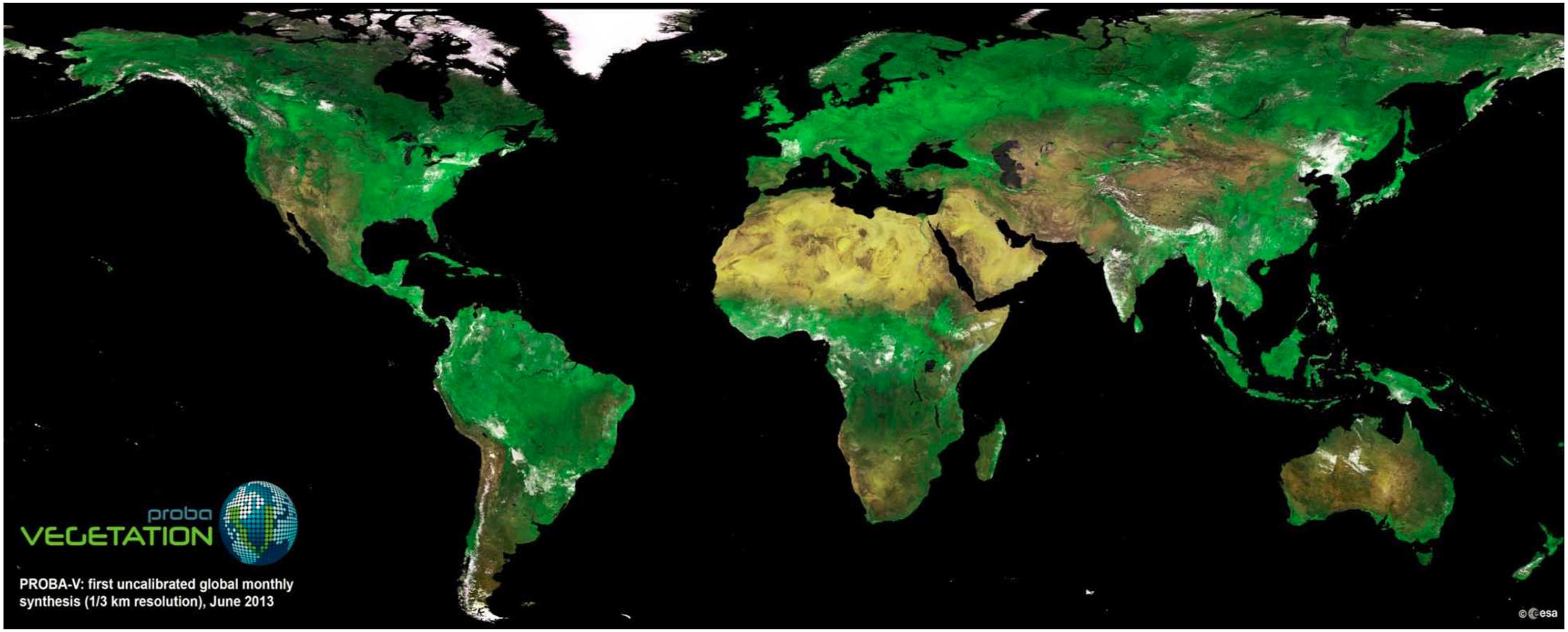
GaN RF space applications

Global image of vegetation taken with Proba-V



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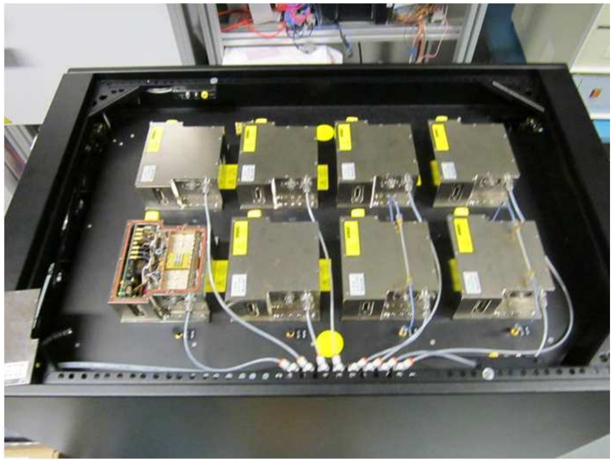
GaN RF research activities at UNIPD

The main activity of our research group are:

- Analysis of the performance of the devices (on-wafer)
- Feedback to the companies to improve the process
- Study of the reliability and the life-time



Accel-RF - top view of the fixtures

Accel-RF Automated Accelerated Reliability Test Station

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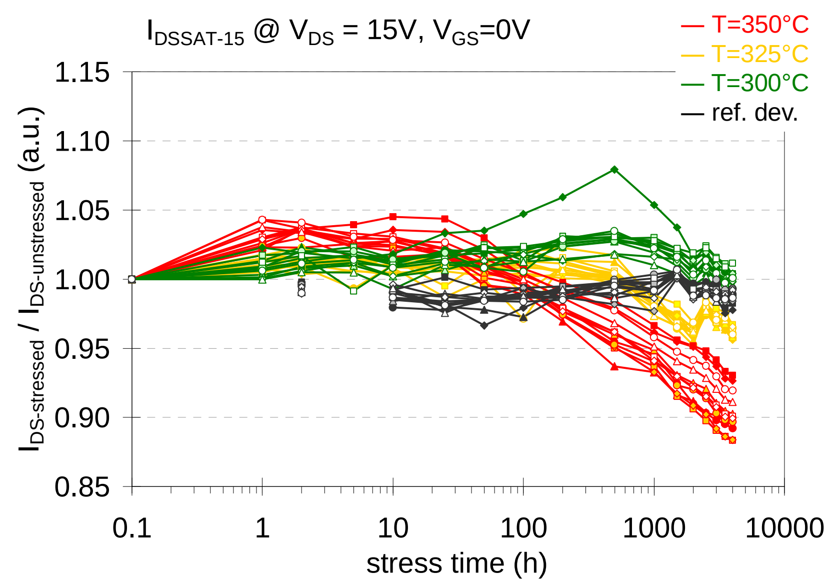
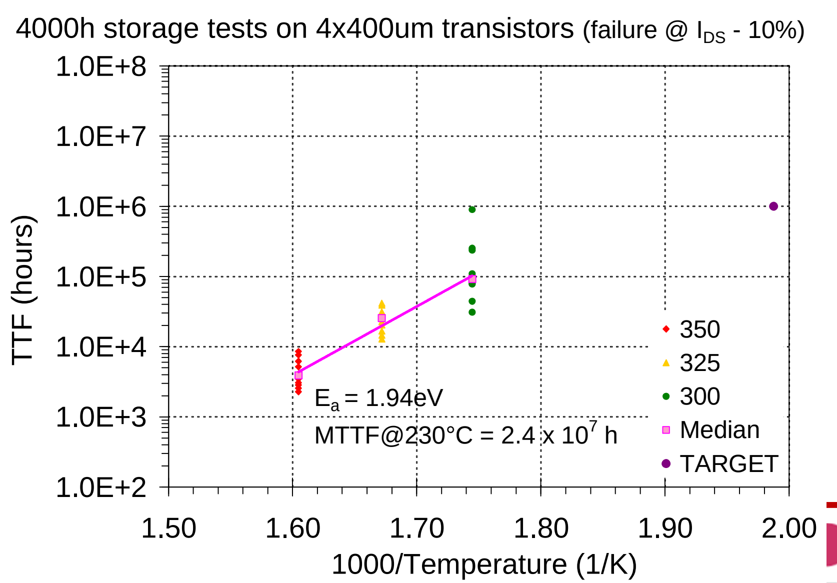
GaN RF research activities at UNIPD

Estimation of the device life-time by means of 4000h accelerated life tests:

- The devices are placed in a oven at three different temperatures: 300°C, 325C and 350°C.
- The device parameters are monitored during the thermal storage stopping it at fixed intervals with a complete characterization
- An exponential degradation law allow us to estimate the device lifetime at a certain operative temperature.





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GaN power applications

The main applications of GaN HEMT power devices are:

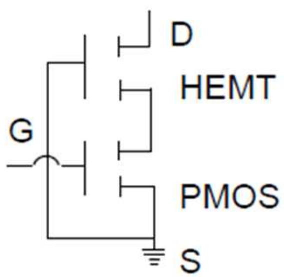
- Power supplies for smartphones, laptops and consumer electronics
- Automotive converters
- Inverters for renewable resources
- Industrial converters and inverters

GaN power HEMT solutions

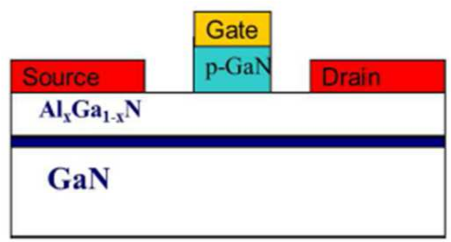
E-Mode by cascode configuration

P Gate

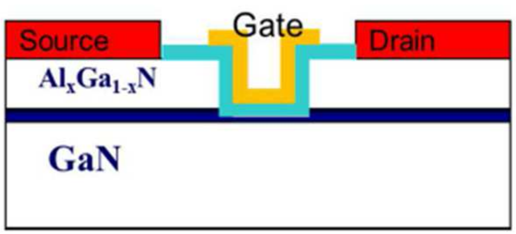
Recessed gate



- ✓ No intrinsic normally-off
- ✓ Needs a Si device
- ✓ Best mobility and charge
- ✓ Stable gate structure



- ✓ High sheet resistance out of the gate
- ✓ Cannot tolerate Vg>6V
- ✓ Normally-off
- ✓ No insulator reliability issues



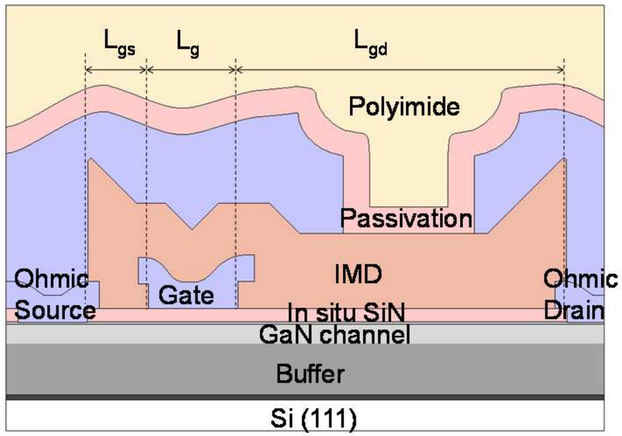
- ✓ Poor mobility under gate
- ✓ Insulator reliability issues
- ✓ Normally-off
- ✓ Low resistance in the access region and tolerate high VG value

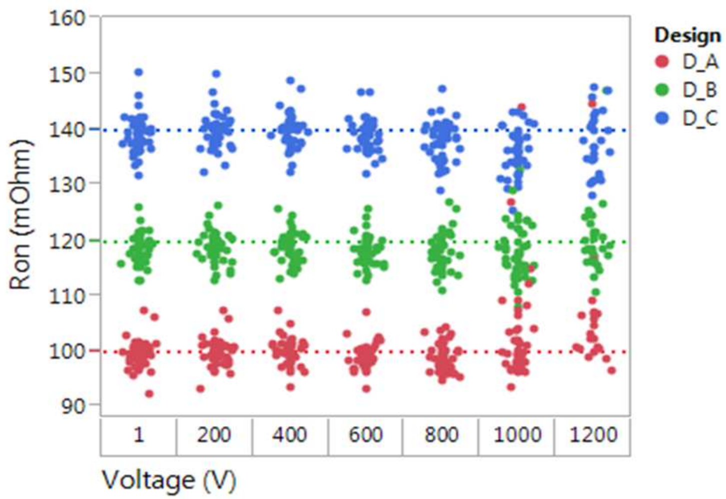
GaN Power D-mode HEMTs

- For low conduction loss is fundamental to achieve low R_{DSON} values
- In the last year outstanding results were obtained with 600V rated devices
- The next step is to achieve the 1200V range

P. Moens et al.
(On-Semiconductor) ISPSD 2016:

- ➢ 6mΩ in 100A, 650V
- ➢ 100mΩ, 20A, 1.2kV with leakage current ~100nA





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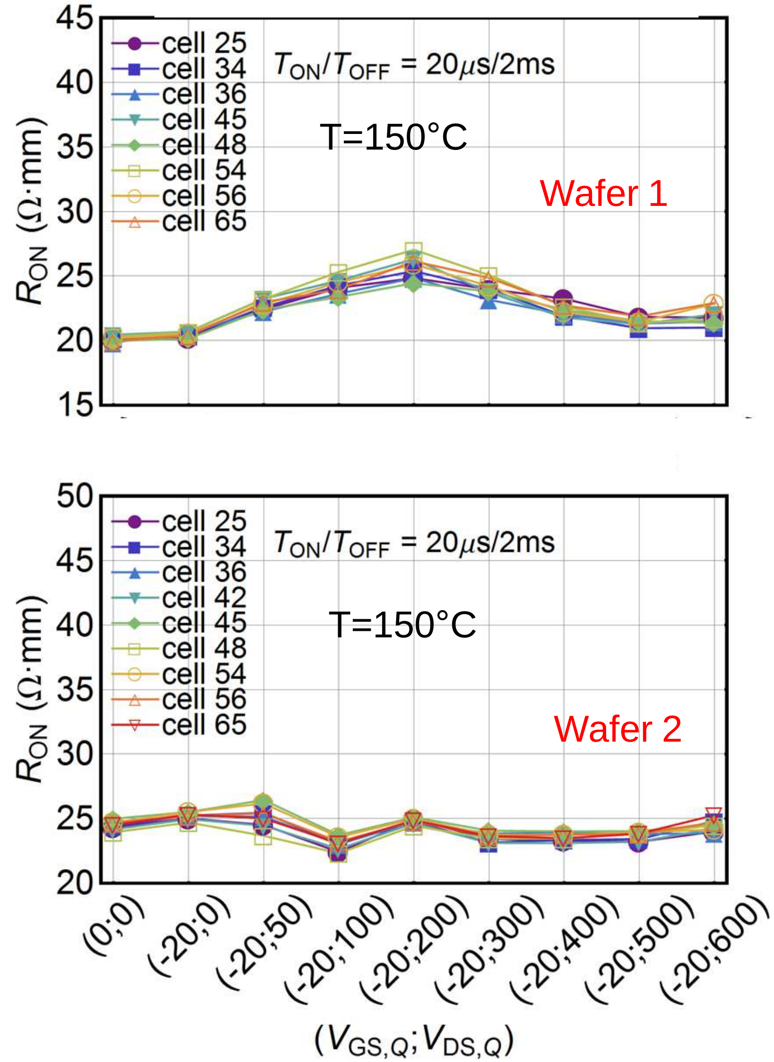
GaN Power research at UNIPD

- During the switching operations of a transistor the R_{DSON} could increase due to trapping phenomena
- One of the main activities in our research group is the analysis of the dynamic behaviour of the devices
- There is a trade-off between the performance of the device and the reliability



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The little box challenge

INTRODUCING THE LITTLE BOX CHALLENGE

An open competition to build a (much) smaller power inverter, with a $1,000,000 prize.

Design and build a kW-scale inverter with the highest power density (at least 50 Watts per cubic inch).

Know what that means? Have a healthy disregard for the perceived limits of engineering?
Then you're exactly who we're looking for.

Google | IEEE

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The little box challenge

The Belgian company CE+T won the competition with an amazing inverter based on a GaN HEMT

Parameter	Realised	Requested
Maximum Power Tested	2062 VA	2000VA
Volume of enclosure	225 cm³	655 cm³
Power density	8850 W/litre	3050W/litre
DC voltage range	300 to 450VDC	399.5 V
AC voltage (RMS) output	240 Vac	240V +/- 12Vac
Efficiency (CEC Method)	95.4 %	Min 95 %
Max Temp of Enclosure	48 °C	60 °C
Ambient T° of test	29 °C	30 °C
EMI compliance	FCC Part 15 B	FCC Part 15 B

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The little box challenge

Commercial 2 kW Inverter

Target size of the challenge

CE+T GaN inverter

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Conclusions

- GaN HEMT are ready for RF space applications
- GaN devices have now improved reliability, that was a problem in the first transistors
- GaN devices for power applications allow to shrink the size of the systems
- GaN HEMT have higher efficiency for energy saving
- In the future GaN could be a key technology both for RF and power electronics.

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Thank you for your attention

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