Projet-ANR-17-ASTR-0007 SMART MODEL

INSTITUT DE RECHERCHE xlim

# Thermal characterization of AlGaN/GaN HEMTs using thermoreflectance and 3omega methods

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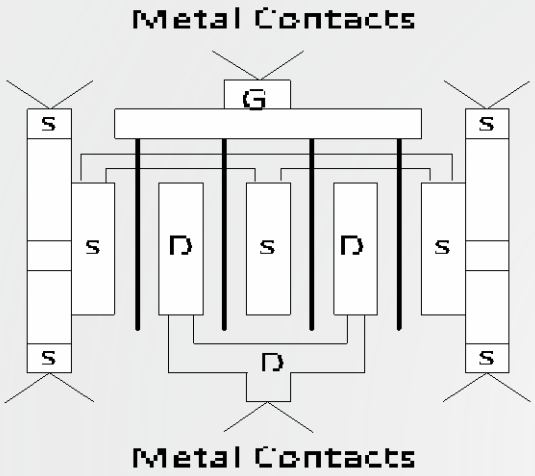
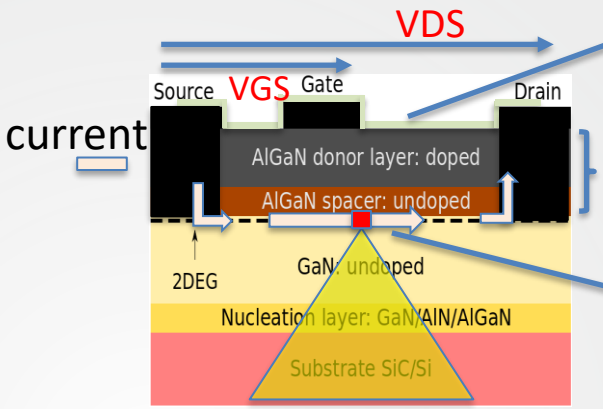
# Outline

- Introduction
  - The AlGaN/GaN HEMTs
- Thermoreflectance setup
  - Presentation of the principles
  - Measurement results on GaN HEMTs
- 3omega setup
  - Presentation of the principles
  - Some results on GaN HEMTs
- Conclusion et future works

# The AlGaN/GaN High Electron Mobility Transistor (HEMT)

High Power Applications, High power density (**10GW/cm3!**)




Schematic cross section of conventional AlGaN/GaN HEMT.

Si3N4 (20nm)

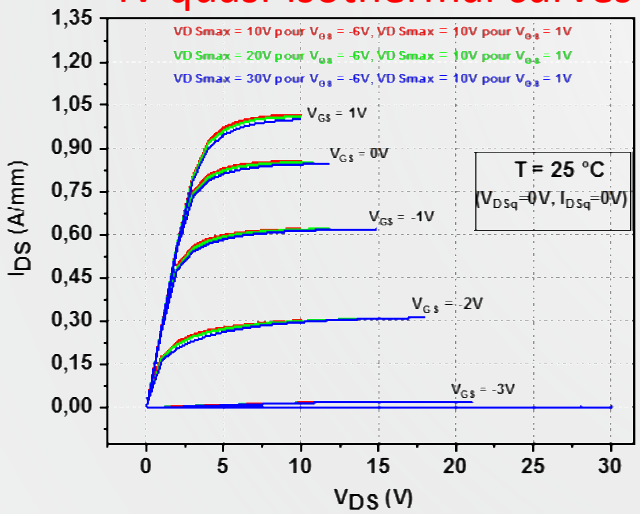
Few nanometers

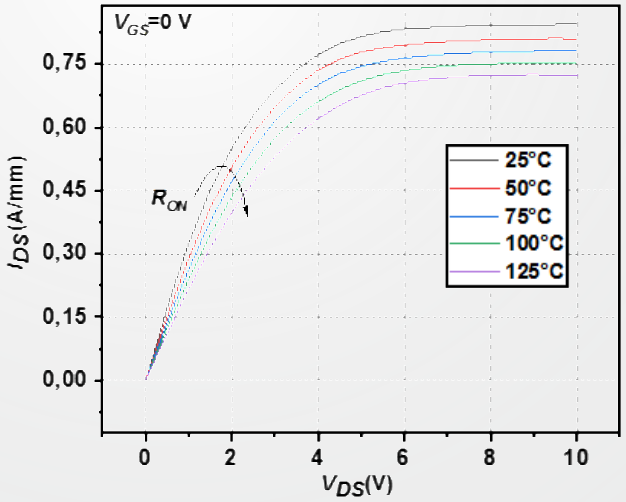
Hot area

Tbaseplate

Thermal dissipation

## IV quasi-isothermal curves




Variation with Tbaseplate

# Introduction : How to determine a thermal model?

- Measurements techniques

  • infrared, **thermoreflectance**, Raman spectroscopy, **3 omega,** electrical method, …

  • spatial and time resolution are not always suited to the size and the use of the device

  • the measured temperature may be not the temperature of the active electrical area (thermal shunt)

- 3D thermal Simulation

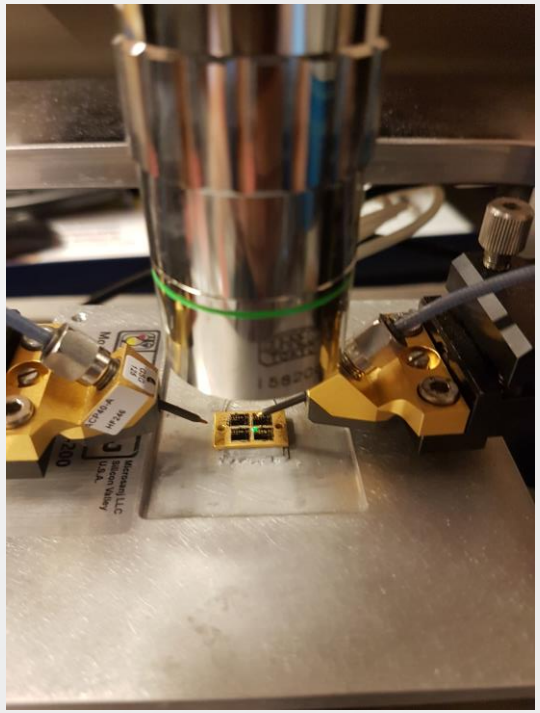
  • need the knowledge of thermal properties of materials

  • need the device structure

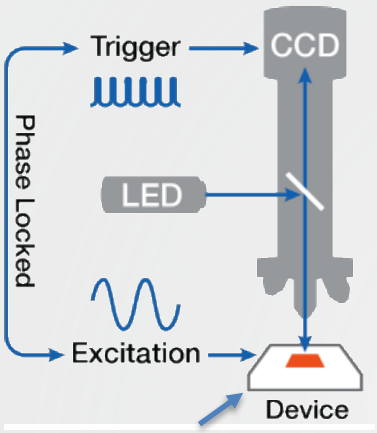
  • give temperature distribution of the whole device

# Thermoreflectance setup (1/2)


MICROSANJ : NT 220C special
- 4MP Camera
- 4 light sources 365nm, 470nm, 530nm, 780nm
- spatial resolution 0.29um
- transient resolution 50ns
- thermal resolution on Au : 0.5°C (5min)



# Thermoreflectance setup (2/2)




Peltier stage+ Piezo

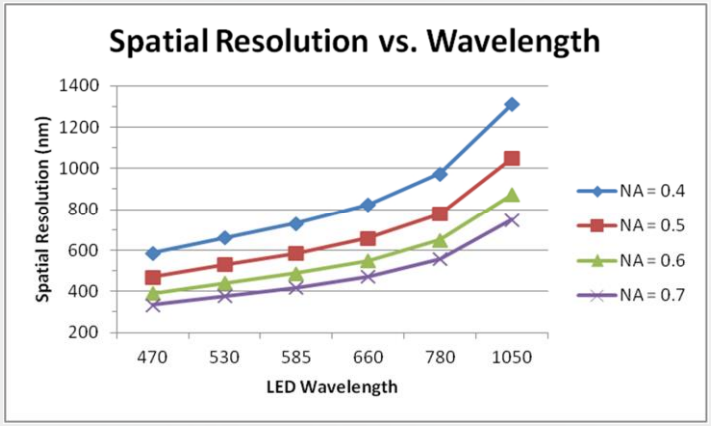
The complex **refractive index** of a material changes with temperature, and the thermoreflectance coefficient Cth simply represents the linear change in optical reflectance of a surface due to a change in temperature

**measurements**

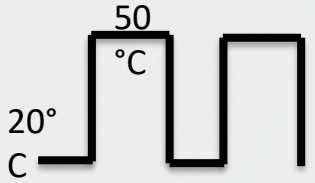
$$\frac{\Delta R}{R_0} = C_{th}(\lambda)\Delta T$$

- Device material properties
- Illumination Wavelength
- Microscope Numerical Aperture

**Temperature determination**

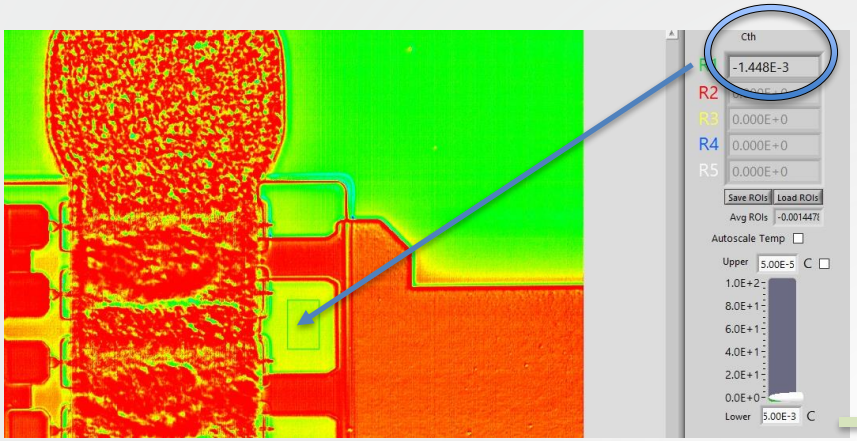



For a given wavelength :
- Calibration of Cth on a Peltier heating stage,
- Using a 3D piezo stage to ensure alignement of pixels with temperature increase

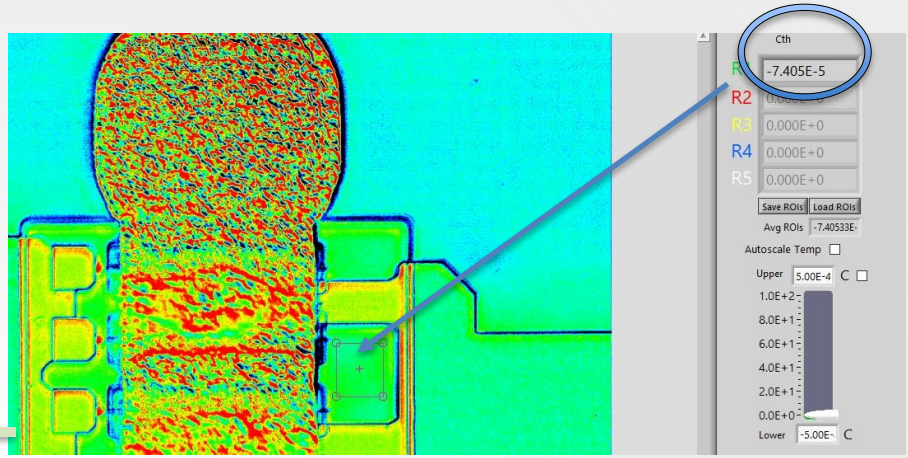


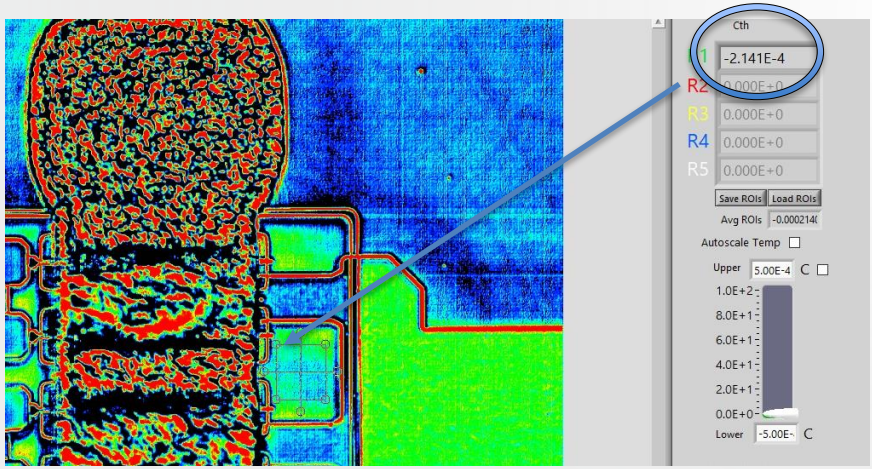
# Choice of wavelength

**Near UV 365nm** **Best sensitivity**



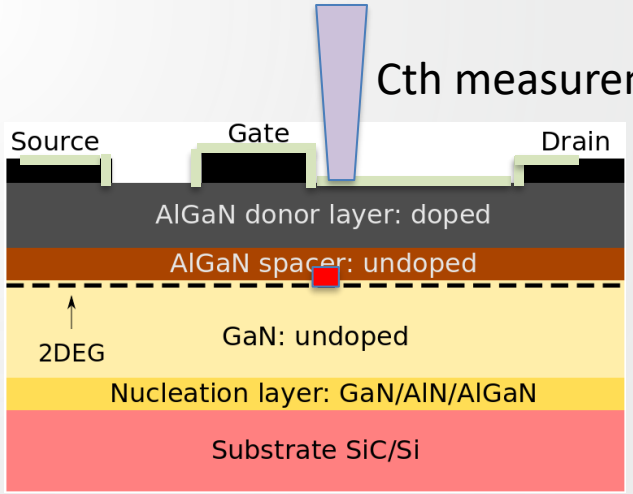

Blue 470nm




Green 530nm

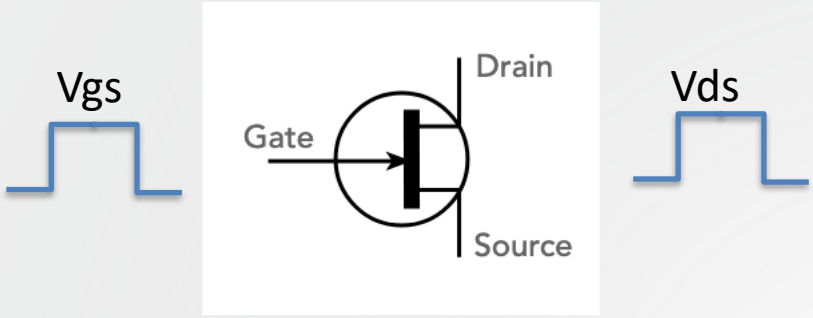
Cth measurements

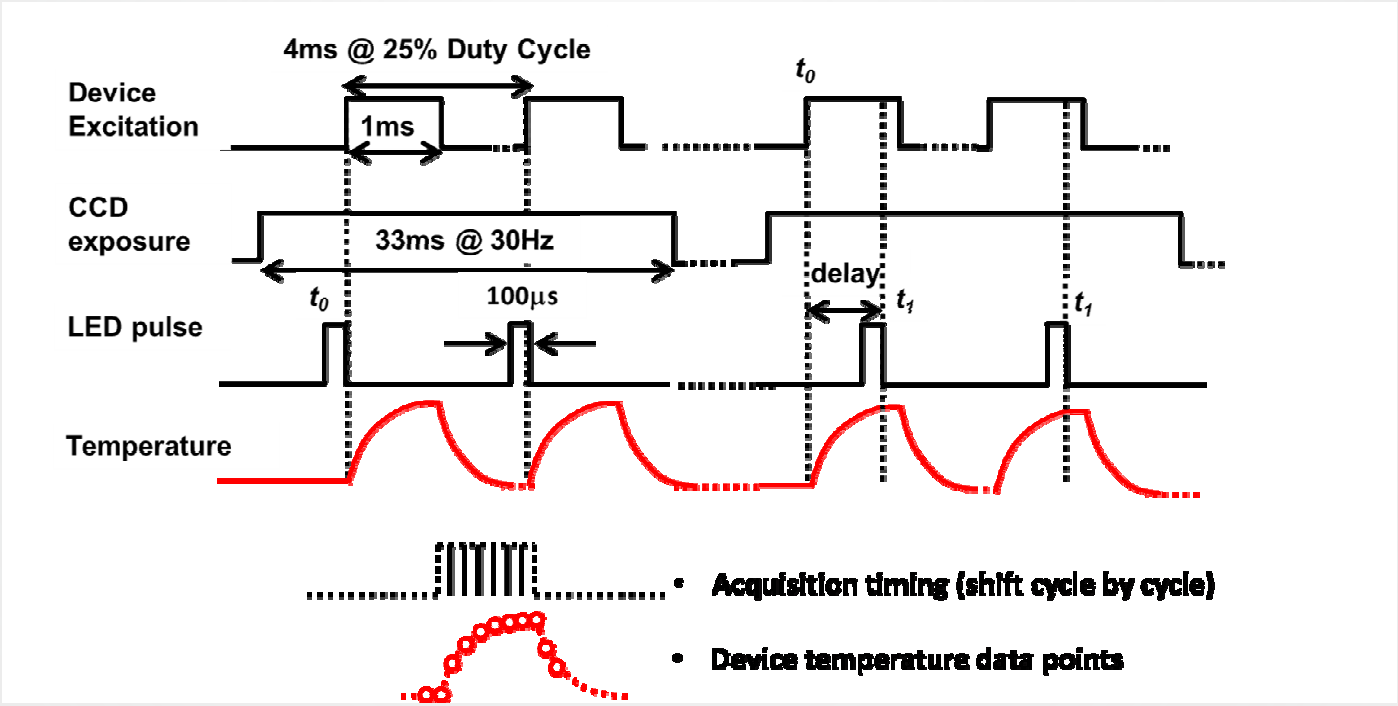



Si3N4 (20nm)

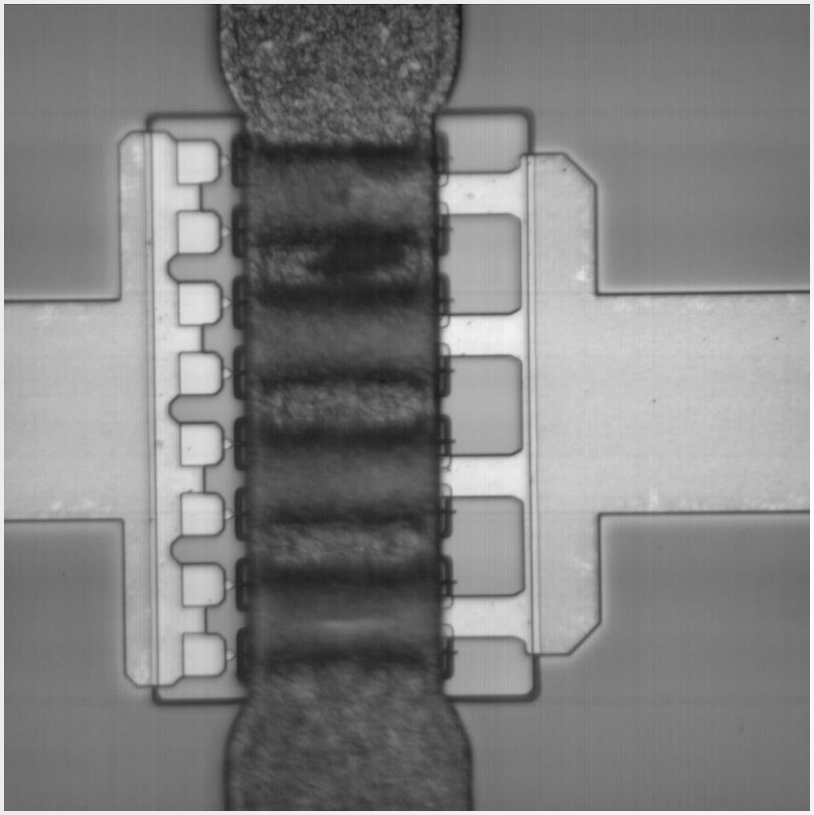
Schematic cross section of conventional AlGaN/GaN HEMT.

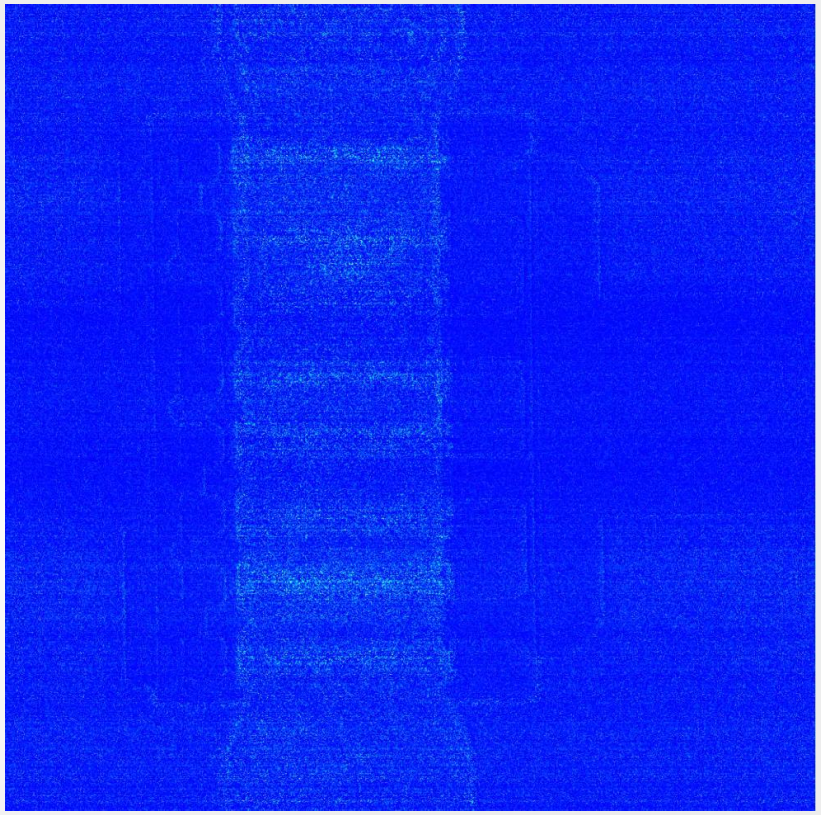
# Using thermoreflectance with HEMTs



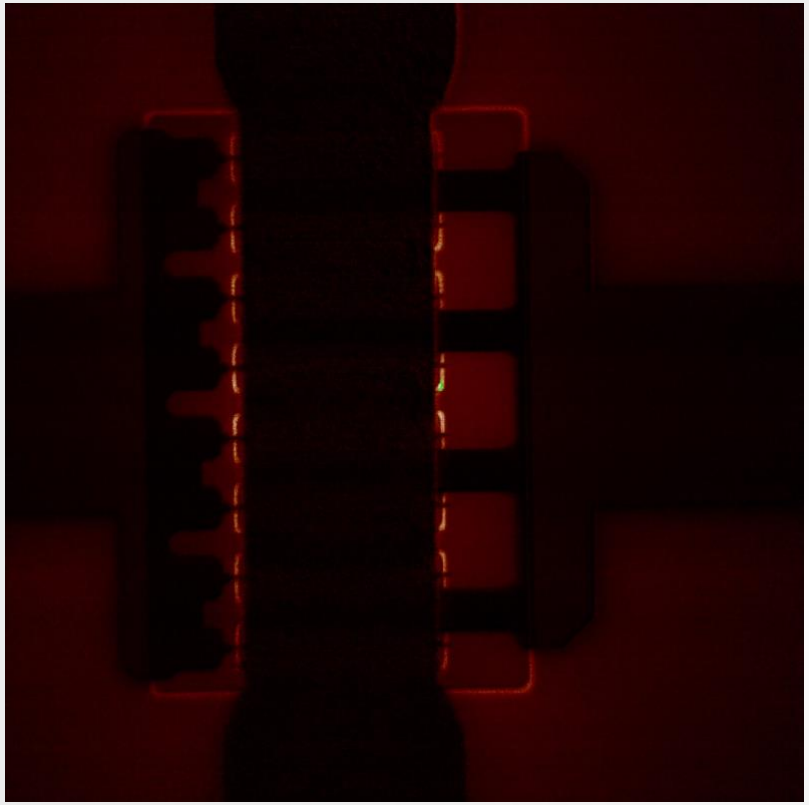
# Thermoreflectance measurements on GaN HEMT

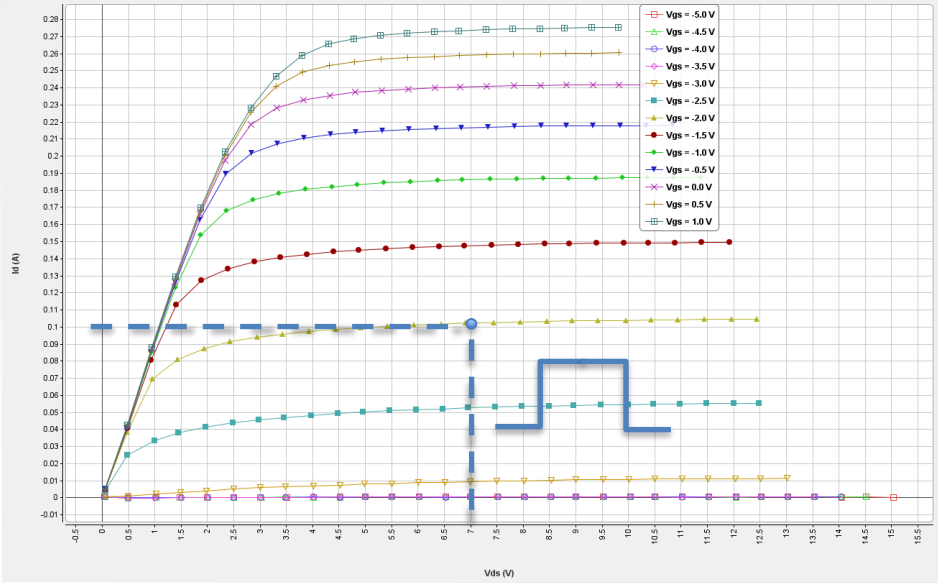


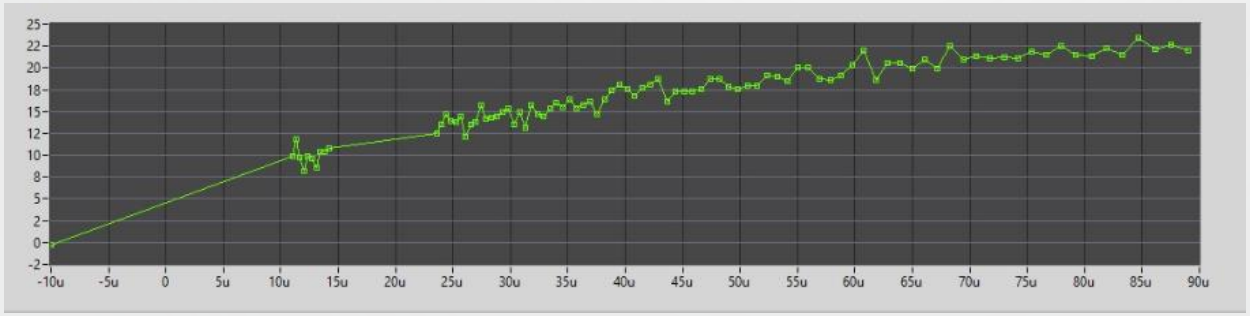


UMS GH15 GaN HEMT 8x50

# Thermoreflectance measurements on GaN HEMT GH15 8X50





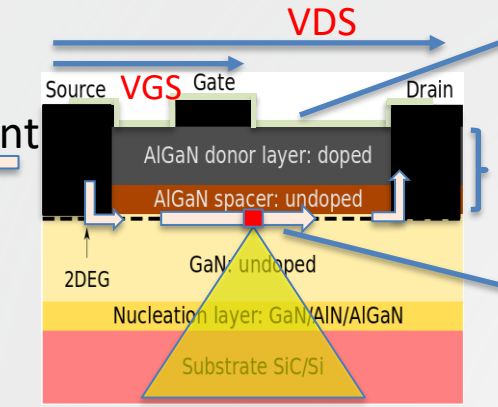



Transient image measurement
Width = 100µs
Period = 1ms.
Vd = 7V , Ids = 100 mA
Pdiss = 0,7 W ($\Delta T$ = 22 °C)

$$R_{TH} = \frac{\Delta T}{P_{diss}}$$

$R_{TH}$ = 31,43 °C/W

# The AlGaN/GaN High Electron Mobility Transistor (HEMT)

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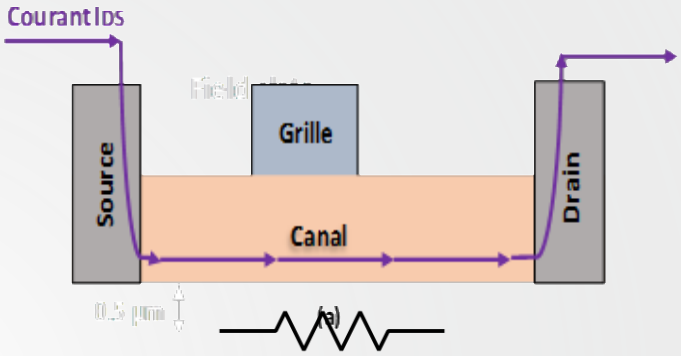
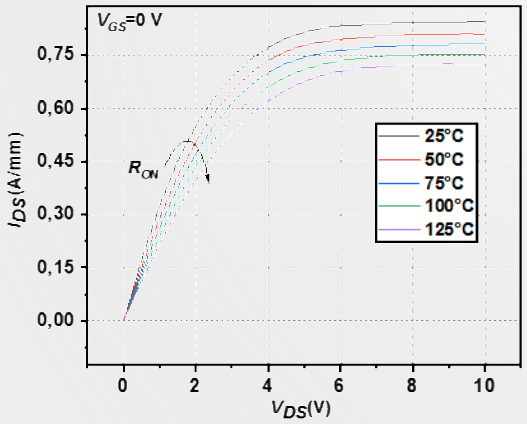
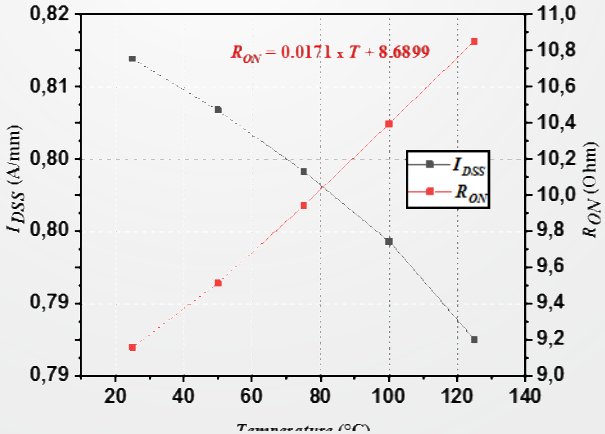


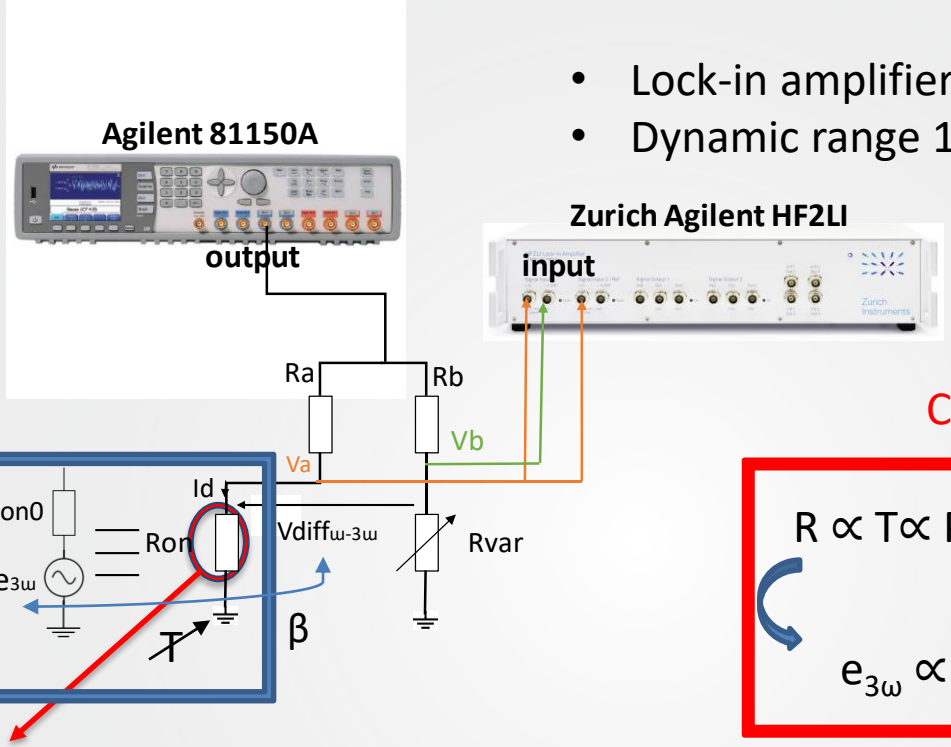

Ron(T)

## Variation with Tbaseplate



# The 3ω method: History and principles




- Lock-in amplifier Bandwidth :50 MHz
- Dynamic range 120 dB

Corbino (1912), Cahill (1990)

$R \propto T \propto P \propto I^2$

$e_{3\omega} \propto I^3$

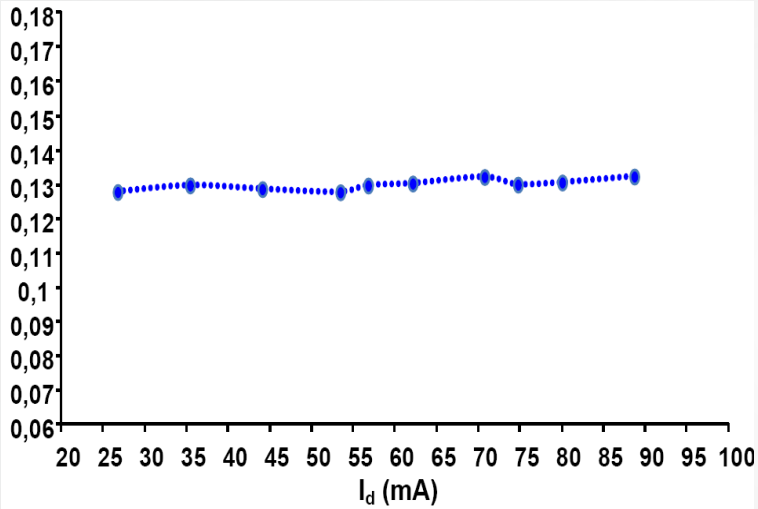
$$R_{ON}(T) = R_{ON0}.(1 + \alpha.\Delta T)$$

$$R_{TH} = \frac{4.Vdiff_{3\omega}}{\alpha.\beta.R_{ON0}^2.I_{d1}^3}$$

β is the transfer function between the "thermal source" at 3$\omega$ and Vdiff

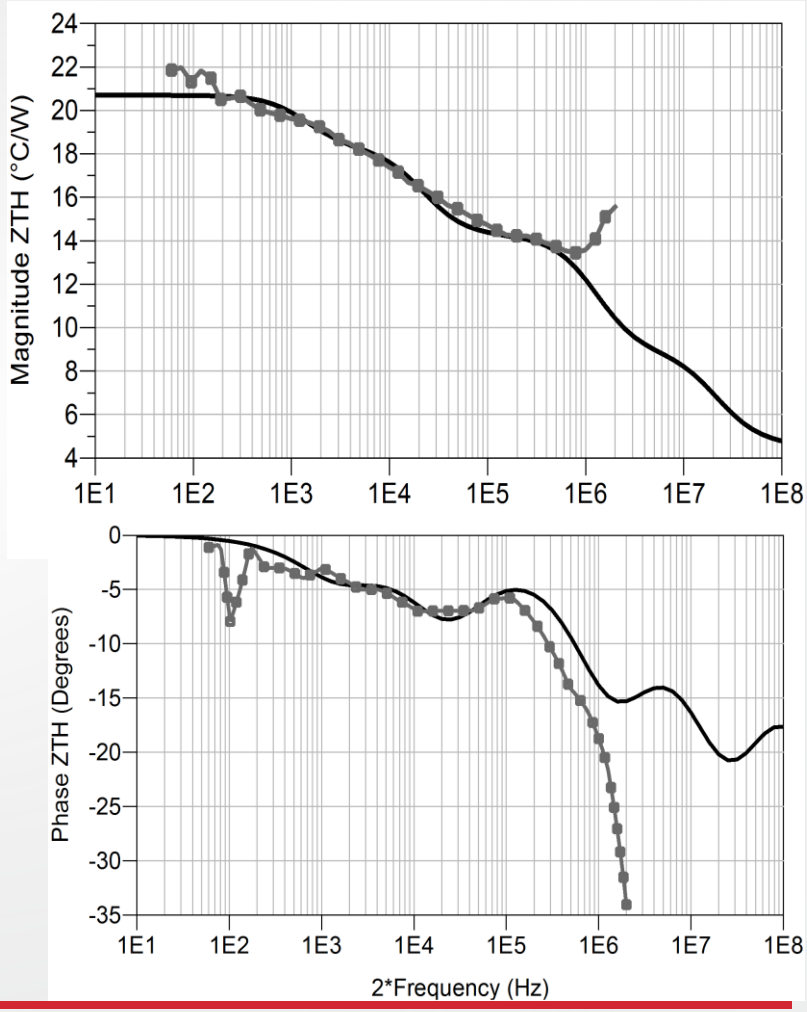
# Extraction of Rth with 3omega method

$$\frac{Vdiff_{3w}}{I_{d1}^3}$$




Ratio is constant

HEMT InAlN/GaN 8x75x0.25



# Conclusion & future works

- Thermoreflectance = surface temperature
- 3omega= channel temperature
- Coherent results between
  -thermoreflectance
  -3omega
- Validation with FEM Simulation, understanding time constants

- Future works with thermoreflectance measurement
  - Improving the measurement system
  - Hyperspectral approach, virtual test set
  - Comparison with Raman spectroscopy
- 3omega
  -improving calibration
  -using Rg(T) (Gate end to end)
- Thermal simulation at nanometric scale