IMPACT OF THE SENSOR TEMPERATURE ON LOW ACETONE CONCENTRATION DETECTION USING AlGaN/GaN HEMTs

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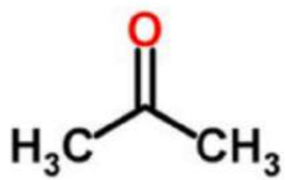
Outline

I. Context and Introduction: Why Acetone?

Biomarker Compounds [1]	Chemical Structure	Associated Diseases/ Disorders/Conditions [2]	References
		ARDS	[48,49]
		Lung cancer	[50]
		CIP	[48]
		CPD	[51]
		Cystic fibrosis	[52]
		Diabetes mellitus	[41,53]
		Hepatic cirrhosis	[54]
		Ketosis, starvation	[55]
		PLC	[43]

- Acetone a biomarker
- VOCs
- Sensing at low level

Need of highly sensitive sensors for this VOC detection

metabolites
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Review

Advances in Electronic-Nose Technologies for the Detection of Volatile Biomarker Metabolites in the Human Breath

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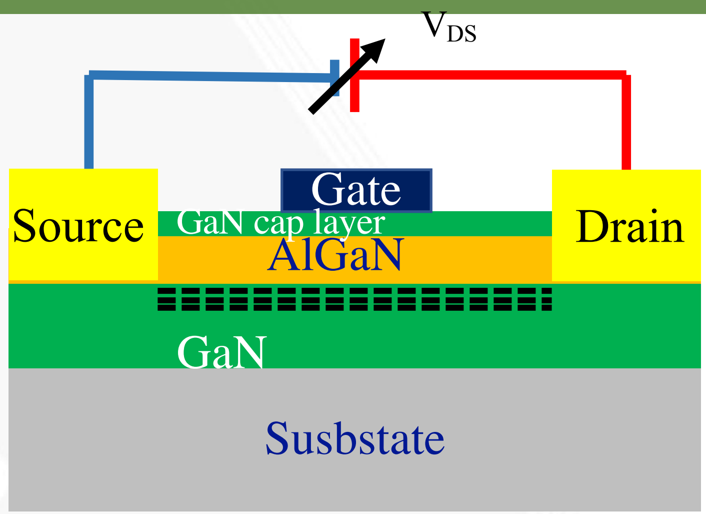
I. Context and Introduction: which sensor?



- **2D gas:** du to the AlGaN/GaN barrier
- **High stabily:** Chemical, and high temperature operating
- **High drain current:** May be modulated by the applied voltage easily
- **High electrons mobilty:**

phys. stat. sol. (a) **185**, No. 1, 85–89 (2001)

High-Electron-Mobility AlGaN/GaN Transistors (H for Fluid Monitoring Applications

R. Neuberger[1]) (a), G. Müller (a), O. Ambacher (b), and M. Stutzm

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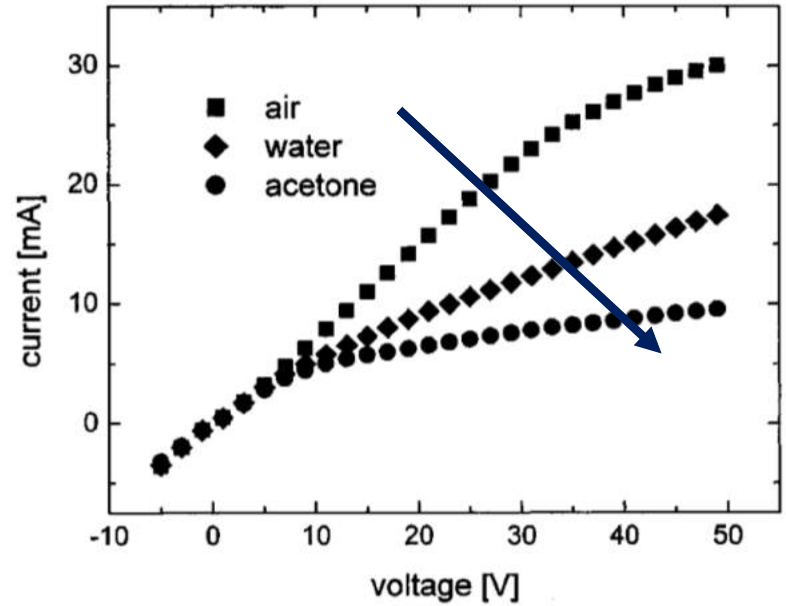

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I. Context and Introduction: which sensor?

AlGaN/GaN HEMT based liquid sensors

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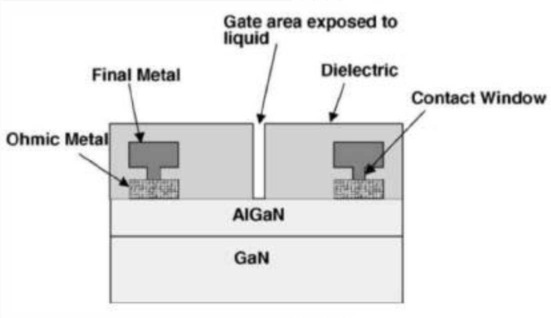
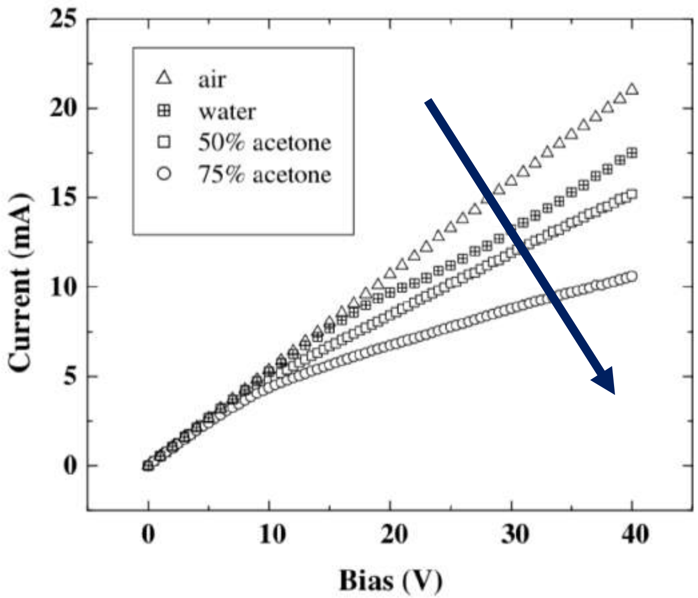




Liquid solutions

I. Context and Introduction: which sensor?

IEEE TRANSACTIONS ON ELECTRON DEVICES

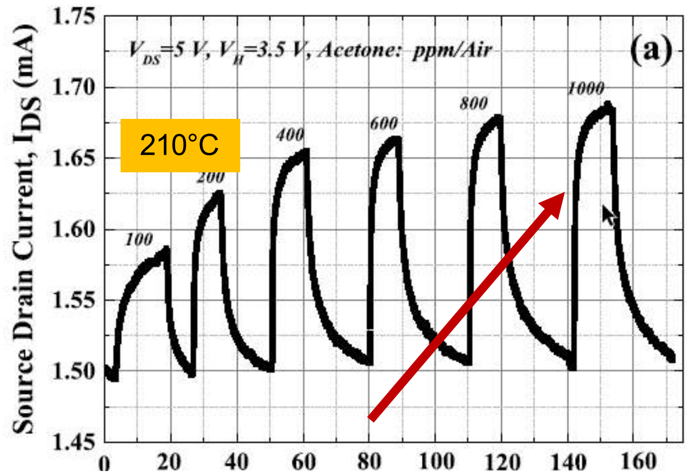
Characterization of an Acetone Detector Based on a Suspended WO_3-Gate AlGaN/GaN HEMT Integrated With Microheater

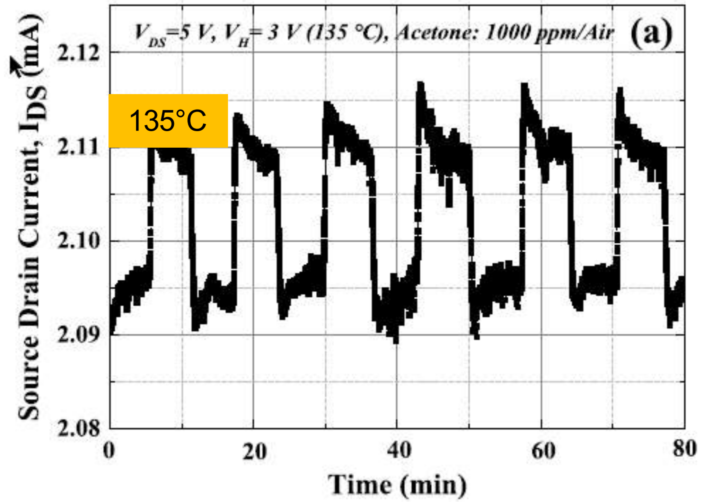
Jianwen Sun, Robert Sokolovskij, Elina Iervolino, Fabio Santagata, Zewen Liu, Pasqualina M. Sarro, *Fellow, IEEE*, and Guoqi Zhang, *Fellow, IEEE*

?

1. Should we use High or Room Temperature?
2. How to annihilate temperature effect?
3. What is the industrially more appropriated method for measurements?

Acetone in air





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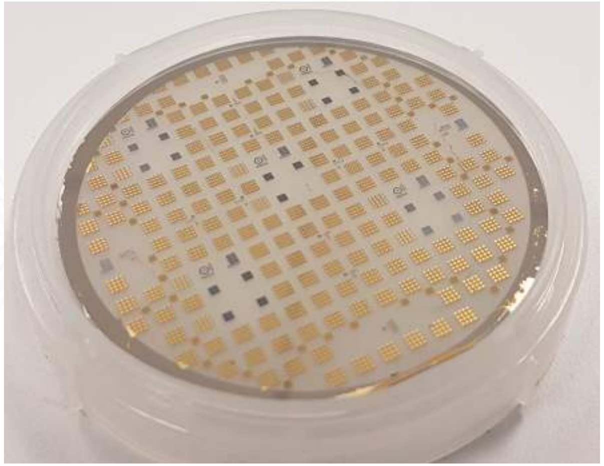
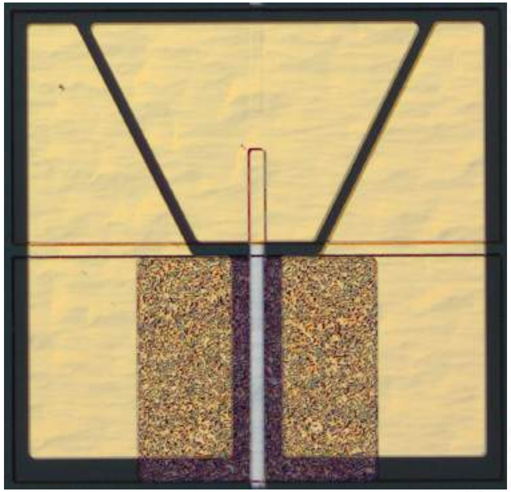
II. Experimental results: Our HEMT

HEMT Structure

MOVPE



Wafer of manufactured HEMTs



Microscopic view of one HEMT

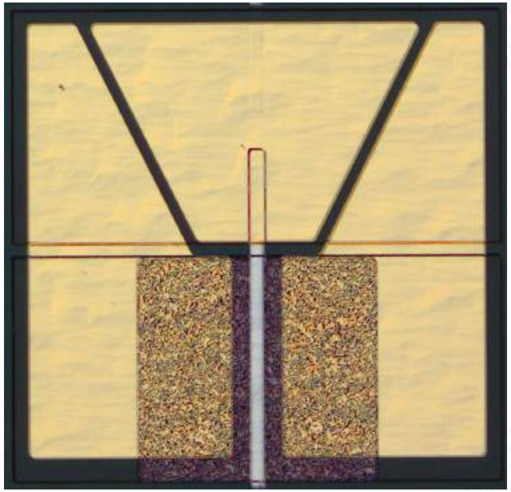
II. Experimental results: Our HEMT

HEMT Structure

MOVPE

- **Ohmic contact**: multilayer 12/200/40/100 nm of Ti/Al/Ni/Au
- **Followed by a RTA** 870°C
- **Gate contact**: Pt (15nm)

Eectrical contact



Microscopic view of one HEMTS

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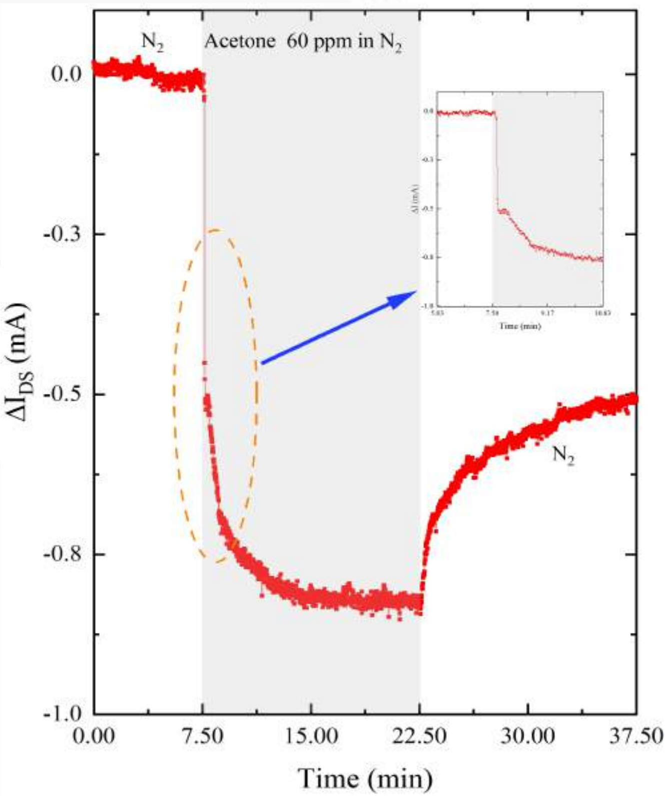
II. Experimental results: Acetone @ RT



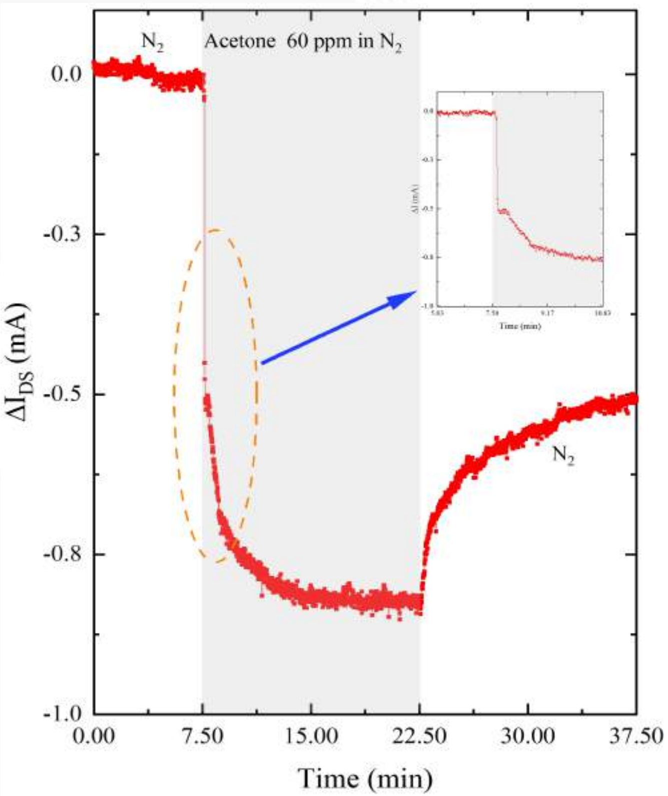
Under acetone:

1. **Sharp** decrease of the current is observed just after the acetone switching
2. **Current stabilizes** for a few seconds and starts again to decrease with a smaller slope
3. **Finally saturates** to reach a constant value

Going back under Nitrogen:

1. **Slow increase** of the current followed by a saturation without recovering the initial state
2. **Initial state** Recovred after several hours

II. Experimental results: Acetone @ RT



1. **Sensitivity:** 15µA/ppm
2. **Relative variation:** 2.4%
3. **Time response:** 131s

II. Experimental results: Acetone @ RT

N_2 flow (cm^3/s)	Acetone concentration (ppm)	Sensitivity (µA/ppm)	Relative variation (%)	Response time (s)
100	30	33.3	2.7	70
200	60	15	2.4	131
300	90	7	1.7	166
400	120	6	1.9	150

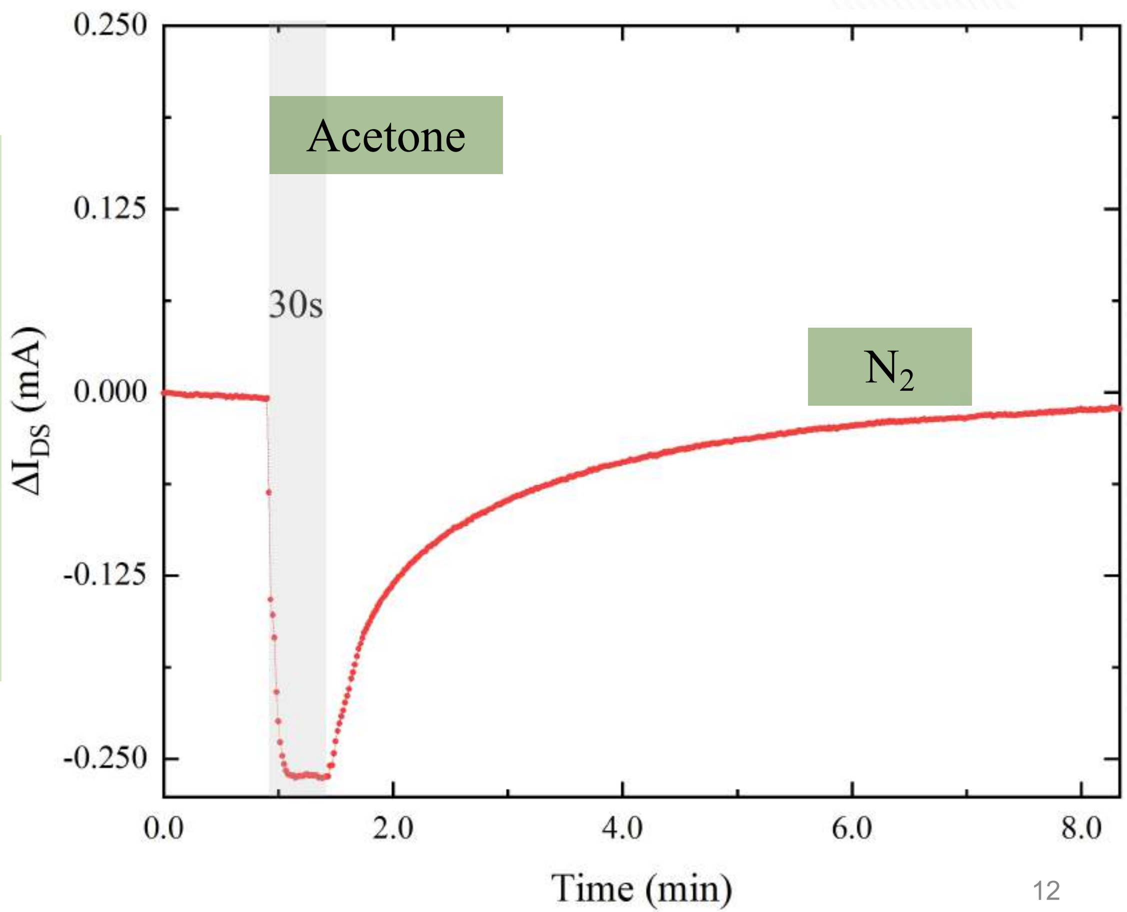
- $\begin{cases} S \searrow \text{ when } [Acetone] \nearrow \\ \tau_r \nearrow \end{cases}$ $\Rightarrow$ Temperature effect (cooling of the sample)
- τ_{rc}, not measured it takes hours!

II. Experimental results: Acetone @ 300°C

- **Acetone concentration:** 60ppm
- **Exposure time:** 30, 60, 90, 120s

30s

- ➢ Sharp decrease of the current
- ➢ With N_2, recovery of the initial level
- ➢ Time response (6s) faster than RT
- ➢ Sensitivity (4.2µA/ppm, 1.9%) smaller, may be acetone cooling



II. Experimental results: Acetone @ 300°C

- **Acetone concentration:** 60ppm
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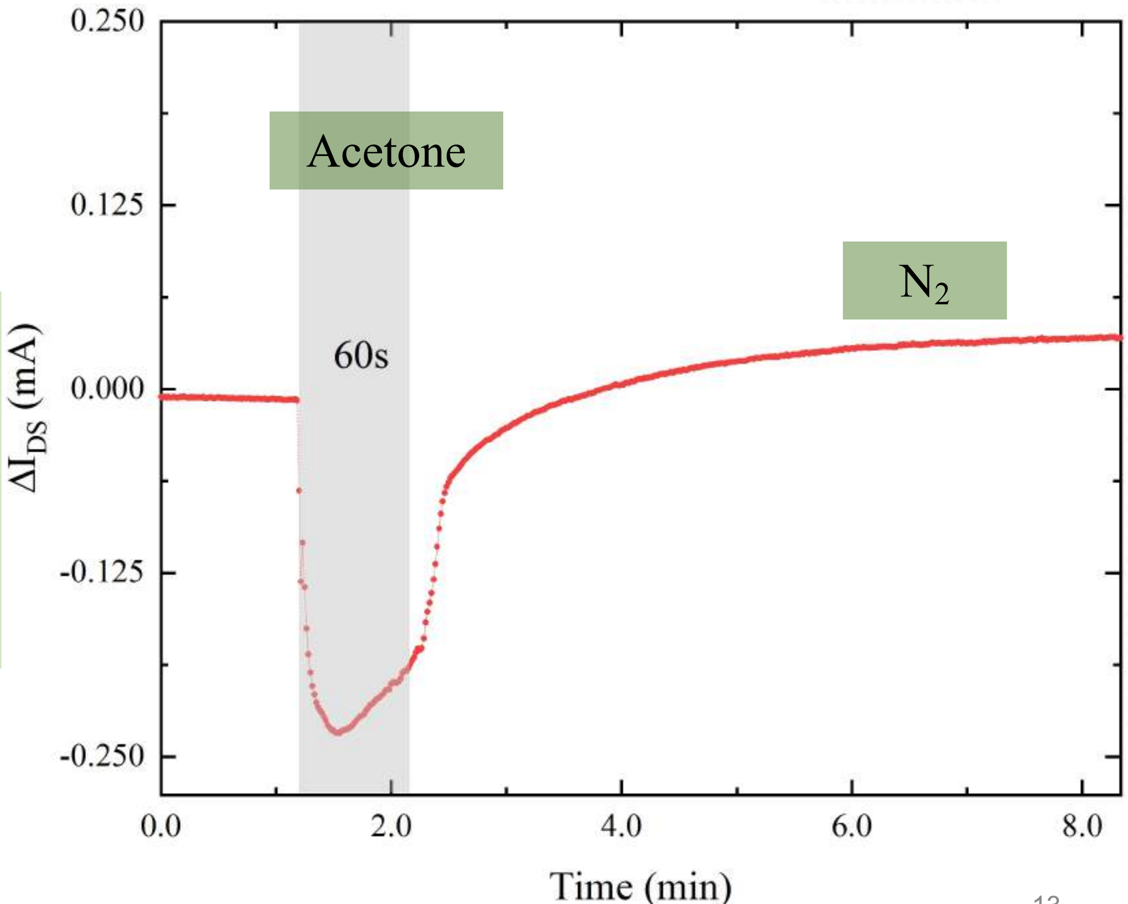
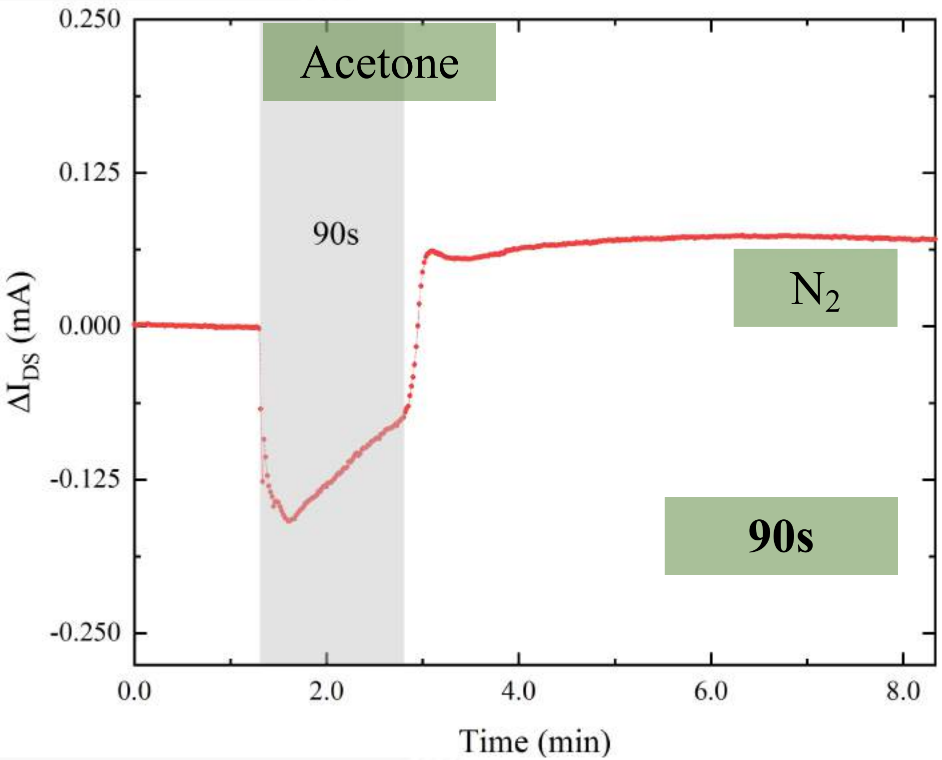


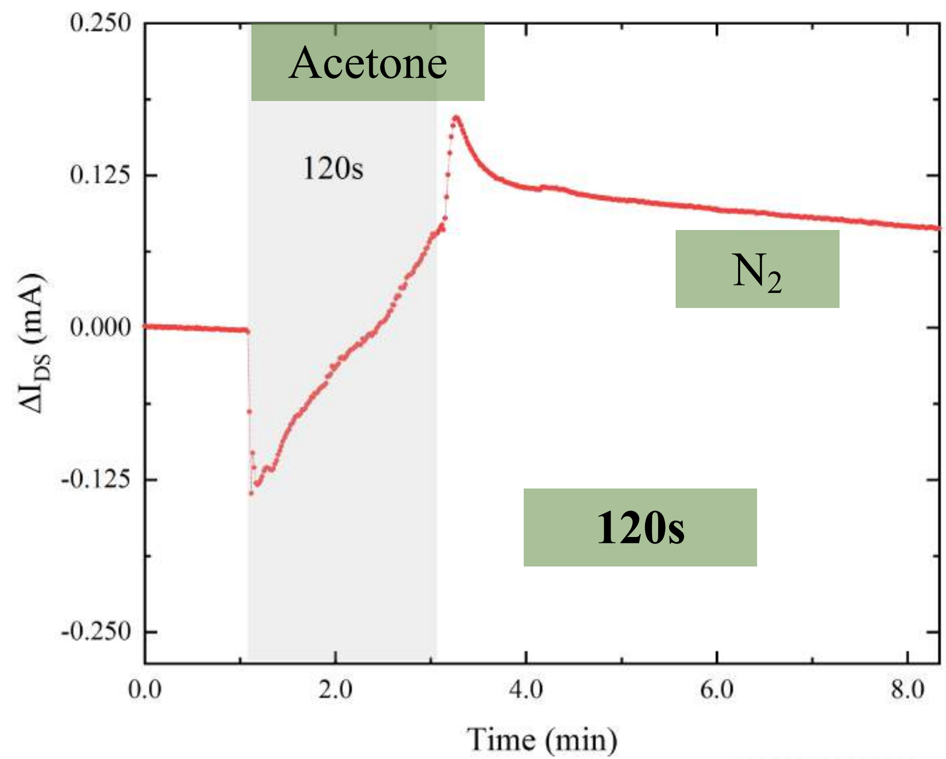
60s

- ✓ Sharp decrease of the current
- ✓ Current decreases but starts to increase, du to the temperature effect
- ✓ **Temperature effect starts to appear**

II. Experimental results: Acetone @ 300°C

- **Acetone concentration:** 60ppm
- **Exposure time:** 30, 60, 90, 120s





- ✓ Sharp decrease of the current
- ✓ **Temperature effect more proununced and**
- ✓ **Competitive effects**

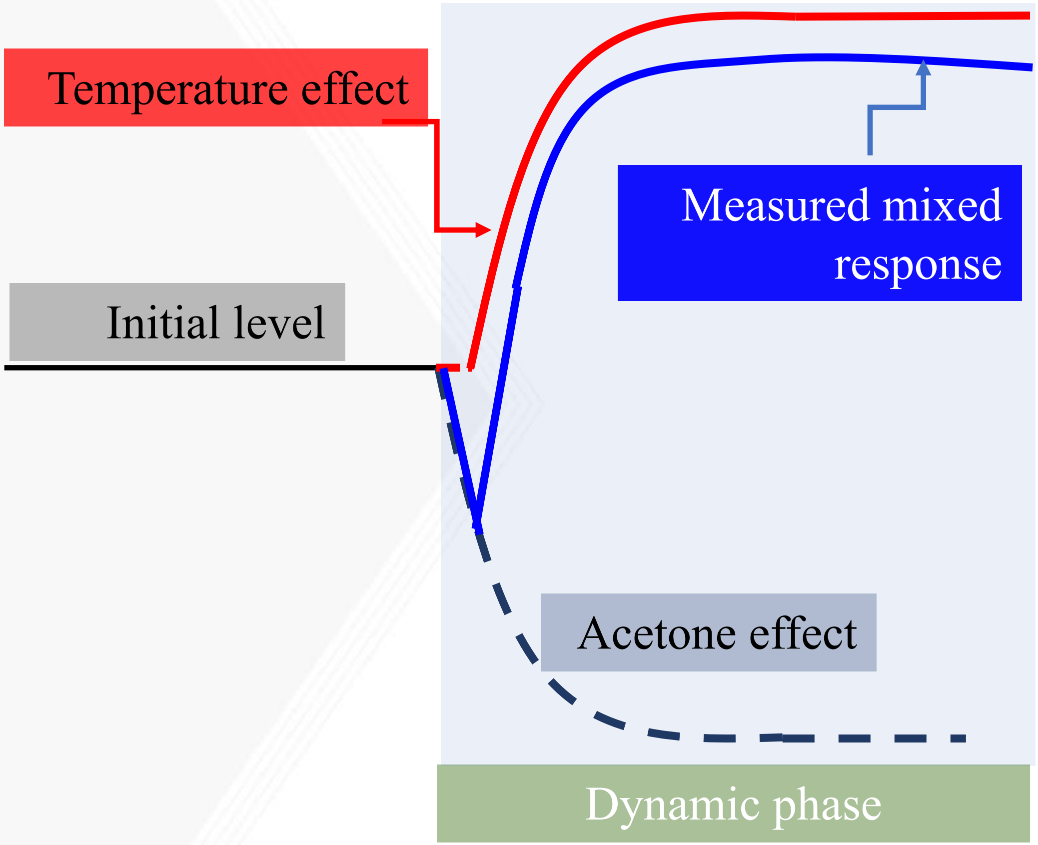
II. Experimental results: acetone @ 300°C

- **Acetone concentration:** 60ppm
- **Exposure time:** 30, 60, 90, 120s

Acetone duration	30s	60s	90s	120s
τ_r (s)	6	11	12	5
Sensitivity (µA/ppm)	4.2	4	2.7	2.2
Time before starting increase (s)	20	20	18	15

II. Experimental results: Acetone @ 300°C

- **What happens?**
  - 2 competitive effects



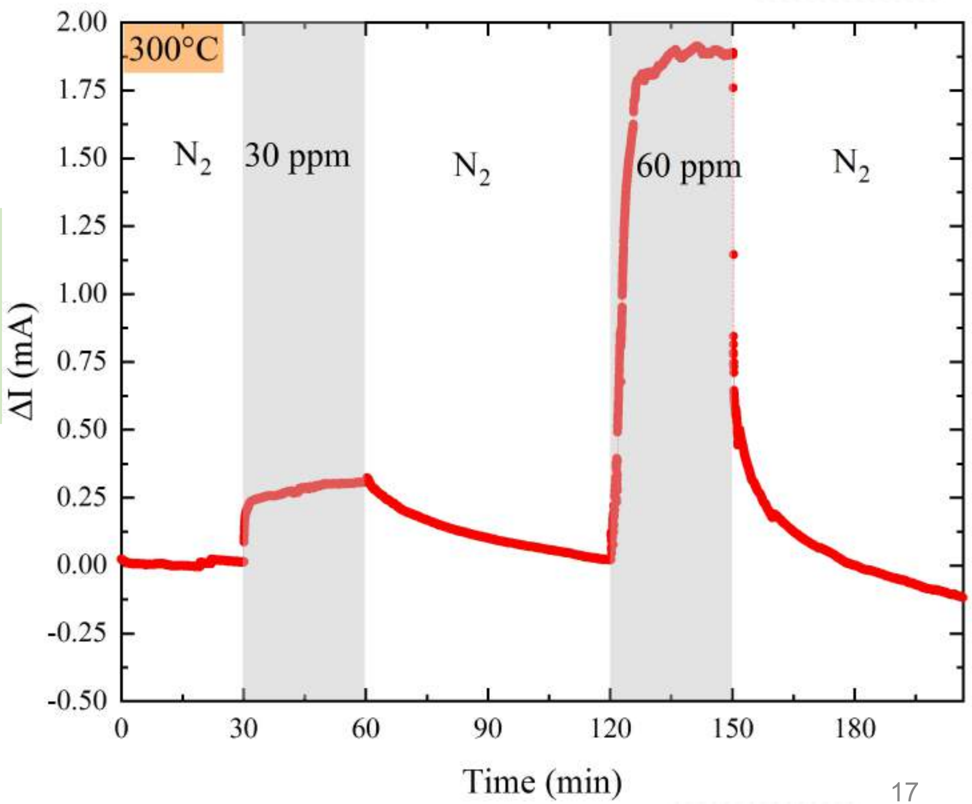
When a short duration flux is introduced:

- Cooling effect, proportional to the injection duration
- The acetone implies a decrease of the current
- Cooling involves an increase of the current
- Compensation occurs and hence the acetone response is limited

II. Experimental results: Acetone @ 300°C

- **Long time exposure**

In this case the acetone effect is entirely dominated by the cooling effect



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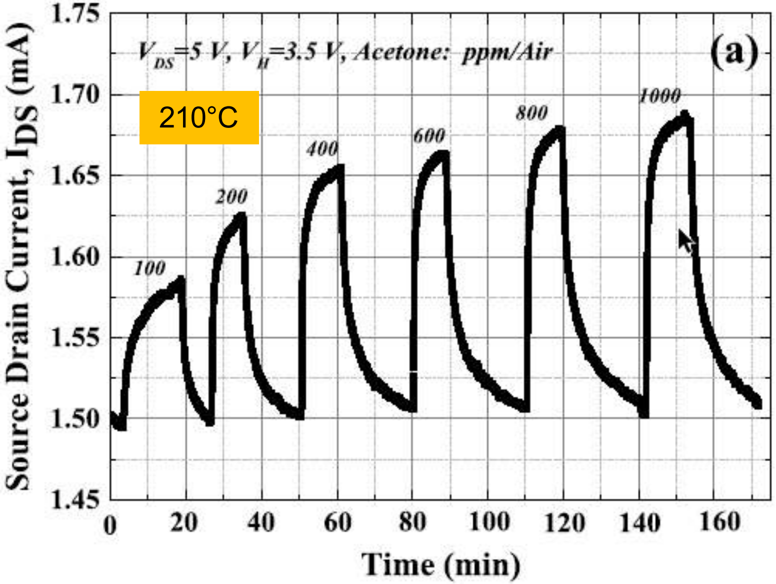
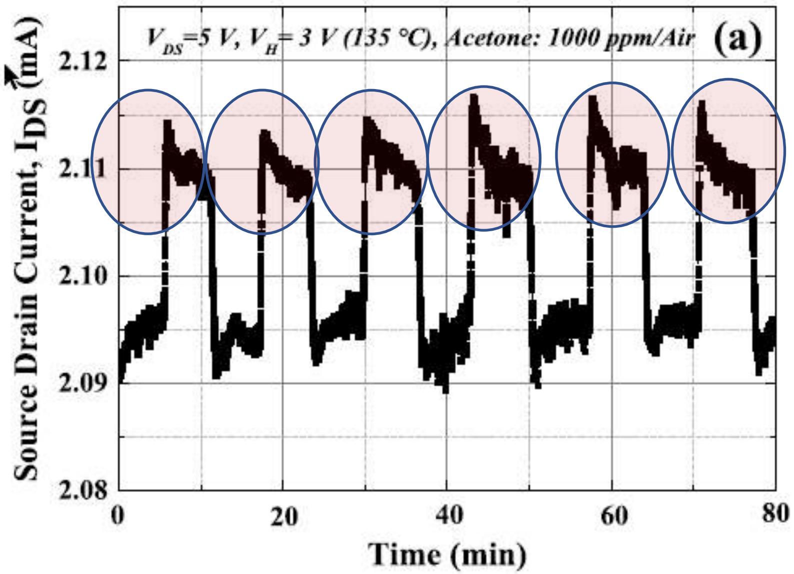
III. Discussion

Sun et al.2019





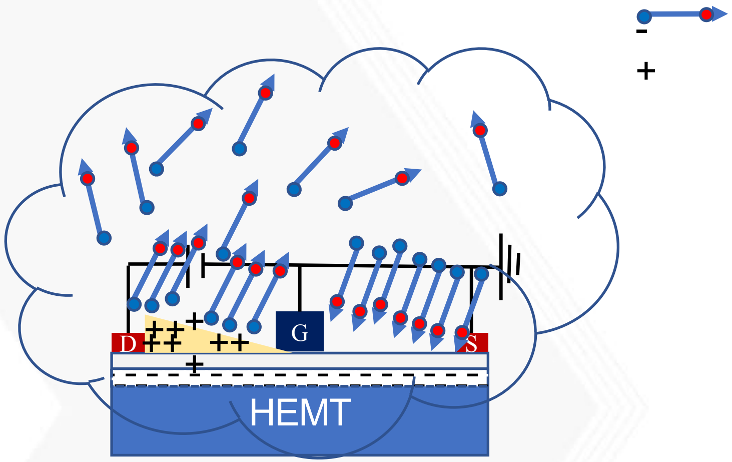
Increase of the current under acetone in air and @ 210°C

Some decrease is observed, @ the saturation region for lower temeprature (135°C)

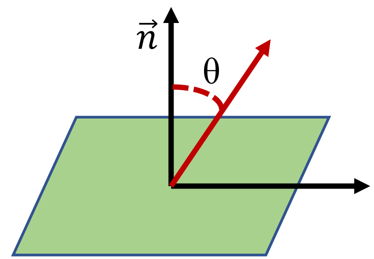
III. Discussion: How it sworks?

Dipolar moment theory

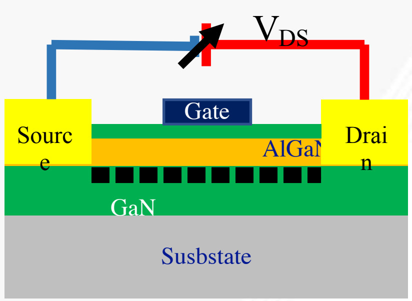
(Rabaa and Stiens, 2012)



- Polar molecules interaction with the surface charge lies a surface potential change:



$$\Delta V = \frac{N_{sp}p(cos\theta)}{\varepsilon\varepsilon_o}$$



N_{sp}: dipole density per unit area
θ: angle between the surface normal and the dipole moment
ε: dielectric constant of the gas and ε_o is the vacuum permittivity

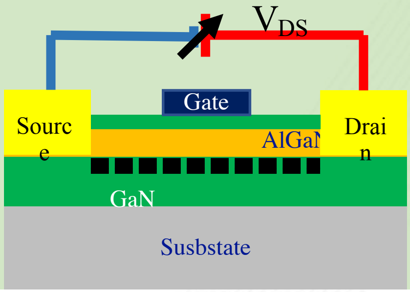
III. Discussion: How it sworks?

Dipolar moment theory

(Rabaa and Stiens, 2012)

Model

- $I_{DS} = Wqv_d(x)n_s(m,x)$, n_s being the charge density in the channel
- $n_s(m,s) = \frac{\varepsilon_o \varepsilon(m)}{qd} \times \left(V_{gs} + \Delta V - v_{th}(m) - V_{DS} - \frac{E_F(m)}{q}\right)$
- $v_{th} = \phi_b - \frac{\Delta E_C(m)}{q} - \frac{qN_d d^2}{2\varepsilon_o \varepsilon(m)} - \frac{|\sigma(m)|}{\varepsilon_o \varepsilon(m)} d$

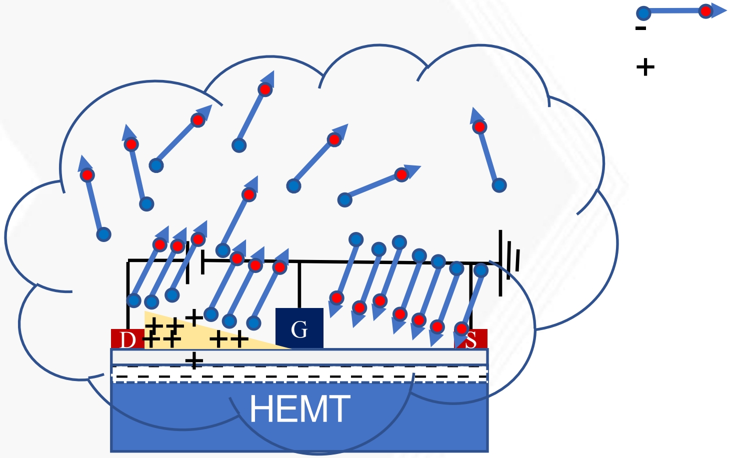


III. Discussion: How it sworks?

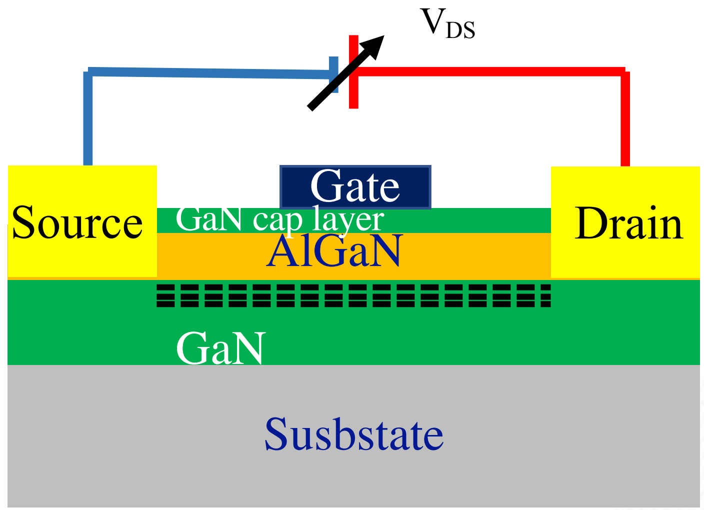
Dipolar moment theory

(Rabaa and Stiens, 2012)

In our case



$\Delta V < 0 \Longrightarrow I_{DS} \searrow$ That is what observed in the acetone case



IV. Conclusion

- ✓Acetone effect decreases the current @ RT with a sensitivity of 33µA/ppm, **the highest ever reported at Room temperature**
- ✓At high temperature, the temperature effect conterbalance the acetone effect, especially for longer exposition time.
- ✓Dipolar moment electrostatic interaction is mainly responsible for the sensor response
- ✓Temperature can be usefull only to accelerate the sensor regeneration
- ✓**Care must be taken to annihilate temperature response**

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Aknowledgments

Team members

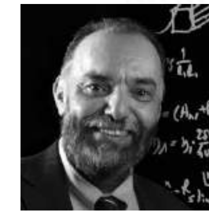
Ali AHAITOUF

Yacine HALFAYA

Simon GAUTIER

Paul VOSS

Jean Paul SALVESTRINI



Abdallah OUGAZZADEN

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Grand Est
ALSACE CHAMPAGNE-ARDENNE LORRAINE

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