

Ultra-Low Crosstalk Thermally-Compensated Monolithic AlGaN/GaN MISHEMT Sensor Array for Robust Gas Detection

Karim Bouzid¹, Sri Saran Venkatachalam¹, Tarik Moudakir¹, Abhishek Juyal¹, Safa Othmani¹, Mickaël Petit¹, Simon Gautier¹

¹ Institut Lafayette, 2 rue Marconi 57070 Metz, France
karim.bouzid@institutlafayette.eu

Summary:

This work presents the impact of an optimized micro-fabrication process on monolithically integrated AlGaN/GaN MIS-HEMT (High Electron Mobility Transistor) sensors. We demonstrate exceptional electrical isolation with inter-device crosstalk, gate and off-state leakage currents in the pA range. This enables a multi-pixel differential measurement scheme to enhance signal stability and reject thermal common mode noise. Compact integration was achieved in an industry grade LCC16 package. Platform performance is validated through temperature compensated hydrogen detection with a thermal Common Mode Rejection Ratio (CMRR) of -60 decibels and operational stability exceeding 180 hours of continuous measurement, repeated over the span of 8 months.

Keywords:

AlGaN/GaN HEMT, Hydrogen Sensor, Sensor Array, LCC16 Packaging, Differential Sensing.

Background, Motivation and Objective

Gas safety necessitates reliable, high-sensitivity sensors, where AlGaN/GaN HEMTs excel due to their robustness in industrial environments. [1,2] However, scaling from discrete devices to consistent monolithically integrated arrays is typically hindered by inter-device crosstalk and parasitic leakage. [3] This work presents an optimized monolithic MIS-HEMT-based gas sensing platform, achieving leakage currents in the pico-ampere range through optimized mesa isolation and gate dielectrics. This technical foundation enables a distributed differential sensing scheme, validated via high-stability hydrogen detection, establishing a robust manufacturing framework for industrial-grade multi-pixel chemical sensing modules.

Description of the New Method or System

Our gas sensor platform consists of a monolithically integrated HEMT array on a 3.15 x 3.15 mm² die (see Fig. 1). The die is packaged in a standardized LCC16 package, allowing for plug-and-play integration into LCC16 sockets. Exceptional crosstalk current leakage performance and extremely low gate-source leakage enabled the simultaneous use of multiple devices of the array. A differential sense-reference topology is thus employed to rule out the contribution of environment fluctuation and low-frequency noise

and provide a stable output signal. In this implementation, one type of pixel is functionalized for H₂ detection, while adjacent reference pixels remain passivated, and which signals serve as a real-time environmental baseline.

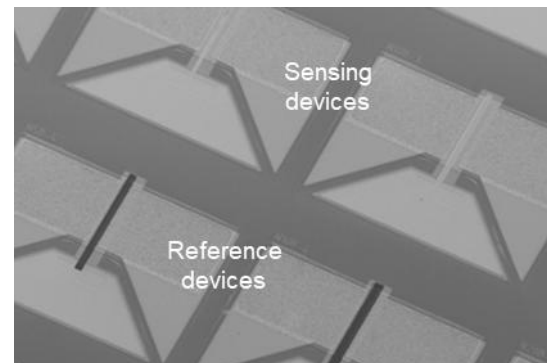


Fig. 1. SEM micrograph of the HEMT array showing the sensing (top) and reference (bottom) devices.

Results

In order to achieve the performance described, the following process flow is applied to 2" wafers with an AlGaN/GaN HEMT epitaxial structure grown by MOCVD. [4] Ohmic contacts were formed by a Ti/Al/Ni/Au metal scheme annealed at 850°C. Mesa etching was performed via optimized Cl₂/BCl₃ ICP etching until the buffer layer. A TMAH post treatment was then applied as Sun et al [5], followed by a PECVD SiN passivation layer, with openings for contact access. HfO₂

was then deposited by ALD to form the gate oxide. A thin film of Pt was deposited by sputtering to form the functionalized gate ($200 \times 10 \mu\text{m}$). A final SiN layer was deposited to passivate the gates of the reference devices. This process allowed for crosstalk leakage current density of $7\text{E-}11 \text{ A/mm}$ at $V_{\text{ds}}=5\text{V}$, off state current density of $5\text{E-}11 \text{ A/mm}$ at $(V_{\text{gs}};V_{\text{ds}})=(-10\text{V};5\text{V})$ and gate leakage current of $3\text{E-}11 \text{ A/mm}$ at $(V_{\text{gs}};V_{\text{ds}})=(-10\text{V};10\text{V})$. Wafer level mapping of electrical characteristics confirms very high uniformity of typical HEMT KPIs (saturation current, transconductance, $R_{\text{ds(on)}}$, threshold voltage, gate leakage current, off-state current, crosstalk current) as well as high device yield ($>95\%$).

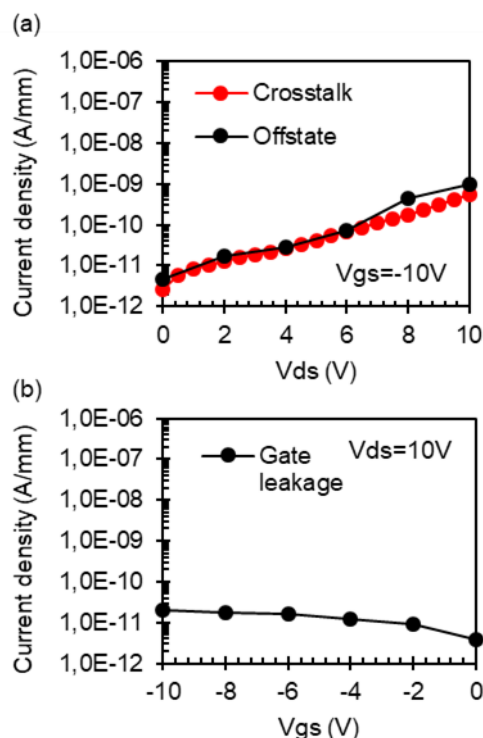


Fig. 2. a) Crosstalk and off-state leakage current densities vs applied voltage (for off-state leakage, $V_{\text{gs}} = -10 \text{ V}$). b) Gate leakage current density vs gate-source voltage ($V_{\text{ds}} = 10\text{V}$).

After dicing and packaging, chips were exposed to different gas compositions. During testing, gate and source were connected together, and 5V was applied to the drain. Drain-source currents were monitored for both sensing and reference devices. As a primary validation case, the platform was characterized in N_2 with H_2 concentrations from 1 to 100 ppm at 20°C . Sensitivity, defined as the difference in currents between sensing and reference devices normalized by the baseline current of the sensing device, was observed between 6% and 10%. Crucially, the differential measurement architecture achieves a thermal CMRR of down to -60 dB at low concentrations, effectively suppressing thermal noise and baseline fluctuations (see Fig. 3).

Long-term testing (several test cycles of 180 hours of continuous operation repeated over the span of 8 months) demonstrates a remarkably stable baseline recovery for the differential measurement signal (see Fig. 4).

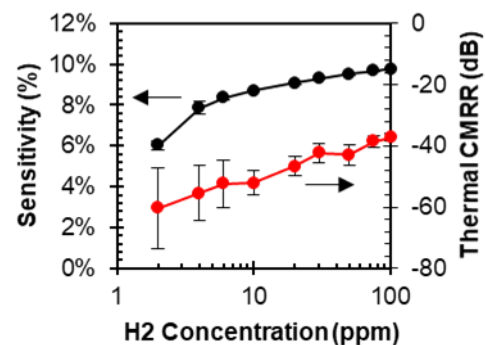


Fig. 3. Differential pair sensitivity (Black line) and thermal Common Mode Rejection Ratio (Red line) vs. H_2 concentration (1-100 ppm) at 20°C .

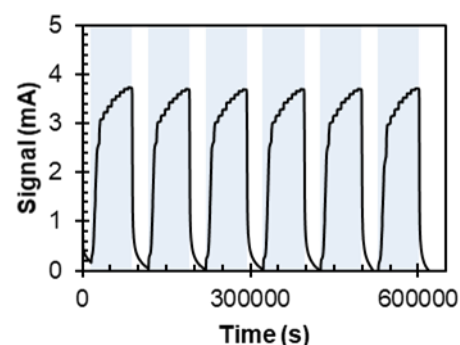


Fig. 4. Differential measurement output showing 6 detection cycles (Light blue zones) over 650,000 seconds (1 week). Full recovery is demonstrated after each H_2 exposure cycle in N_2 (1 to 100 ppm).

Additionally, a preliminary testing in ambient air showed no cross-sensitivity to common industrial interferents including IPA, acetone, water vapor, and butane/propane mixture, while sensitivity to H_2 remains unaffected. This test provides early insight into the selectivity of the sensor, paving the way for a higher Technology Readiness Level.

References

- [1] Bhat, A. M. et al, *Micro and Nanostructures*, 176, 207528 (2023); doi: 10.1016/j.micna.2023.207528
- [2] Jiang, Y. et al, *Journal of Materials Chemistry C*, 11(30), 10121-10148 (2023); doi: 10.1039/D3TC01126G
- [3] Garg, T. et al, *IEEE Electron Devices Reviews*, 1, 16-30 (2024); doi: 10.1109/EDR.2024.3491716
- [4] Taher, M. I. B. et al, *International Journal of Hydrogen Energy*, 55, 1514-1522 (2024); doi: 10.1016/j.ijhydene.2023.12.070
- [5] Sun Y. et al, *Nanomaterials*, 10(4), 657 (2020); doi: 10.3390/nano10040657