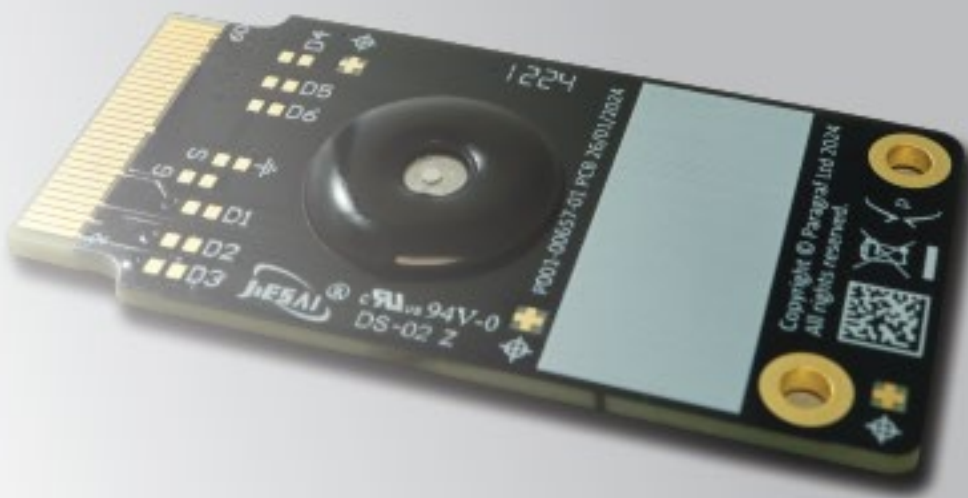




Acetone Gas Sensing with a GFET

Application Note



Contents

1	Summary.....	3
2	Relevance of Acetone Measurement.....	3
3	Graphene as a Tool for Gas Sensing	3
4	Device Overview: GFET-PV01	4
5	Experimental Methods	5
	5.1 Device Preparation	5
	5.2 ZnO Deposition	6
	5.3 Gas Sensing Measurements	6
6	Results.....	6
	6.1 Acetone Concentration-Response.....	6
	6.2 Selectivity Testing	7
	6.3 Long-Term Stability.....	8
7	Conclusion	8
8	Data Disclaimer.....	9
9	Next Steps.....	9
10	References	9
	10.1 Further reading.....	9



1 Summary

This application note demonstrates Paragraf's Graphene Field Effect Transistor's (GFET) significant potential for detecting the presence of acetone in gas at low concentrations with high sensitivity and selectivity. Additionally, experiments show consistent performance over a period of days, demonstrating robustness and reliability.

2 Relevance of Acetone Measurement

Acetone measurement offers valuable applications across multiple sectors. Breath acetone serves as a biomarker for metabolic state, indicating the amount of fat burnt for energy relative to carbohydrates.

In sports and wellness applications, acetone measurement provides immediate feedback on training effectiveness and diet quality. Endurance athletes may assess race pacing strategies and training session outcomes, while consumers benefit from real-time validation of dietary changes. Although measurement techniques remain in the research stage, conversion into consumer products presents substantial commercial potential, as products such as Lumen are already addressing in the growing wellness market.

Diabetes management represents a critical medical application. Global diabetes cases have surged fourfold since 1990, now affecting over 800 million adults (9.8% of the global population), with the highest burden in Southeast Asia and Eastern Mediterranean regions¹. Elevated breath acetone is associated with diabetic ketoacidosis (DKA), a serious complication of insulin insufficiency. According to BMJ Journals, average breath acetone concentrations in type-1 diabetes, type-2 diabetes, and healthy subjects are 7.86 ppm, 1.66 ppm, and 0.68 ppm respectively². Additionally, acetone levels correlate with residual beta-cell activity in the pancreas.

The experiment described below indicates that real-time, digital measurement for personal monitoring using Paragraf's mass-producible GFET technology is achievable. The GFET provides a platform on which partners may develop a low-cost, at-home breath sensor to enable patients to manage a range of health concerns through regular breath monitoring. Such devices stand to reduce costs and enable deployment in developing regions – particularly Africa – where economic growth drives increased diet-related health issues³.

3 Graphene as a Tool for Gas Sensing

From 2015 to 2021, 2,874 publications on graphene-based gas sensors were issued. Of these, 91 related specifically to acetone sensing⁴. In these publications, graphene has been shown to work well as a transducer in gas sensing applications where a change in resistance occurs due to absorption and/or decomposition of gases.

Typically, advantages from including graphene in gas sensors are related to its high specific surface area, high charge-carrier mobility and robustness towards high temperature cycling. Zhang et al. indicated that a graphene-ZnO composite showed excellent sensitivity towards acetone⁵.



The proposed mechanism by which this operates is an oxidation of acetone by ZnO to CO_2 and H_2O . This leads to an injection of electrons into the ZnO conduction band and therefore an increase in resistance of the material.

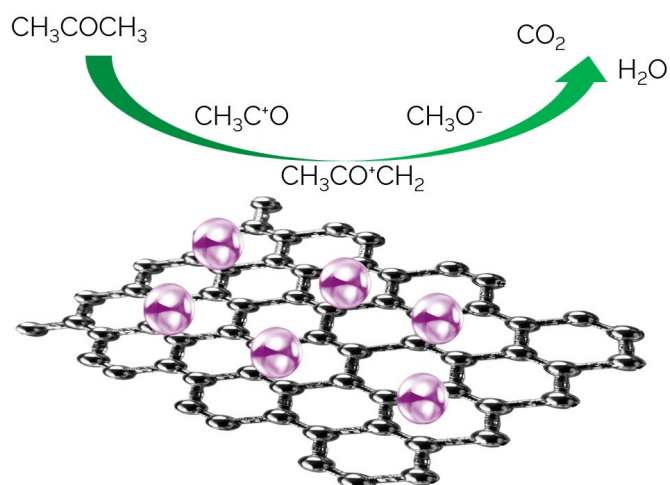


Figure 1. Proposed reaction pathway for acetone oxidation on the graphene–ZnO composite, showing the formation of CO_2 and H_2O .

4 Device Overview: GFET-PV01

The GFET-PV01 is a research-focused transistor with three electrode channels equally spaced around a large central gate, each distanced from one another to permit independent modification of each channel with manual pipetting. Pristine graphene devices (genuinely monolayer, free from polymer or metal contamination) were used from stock and represent performance that can be achieved by any scientist without additional equipment.

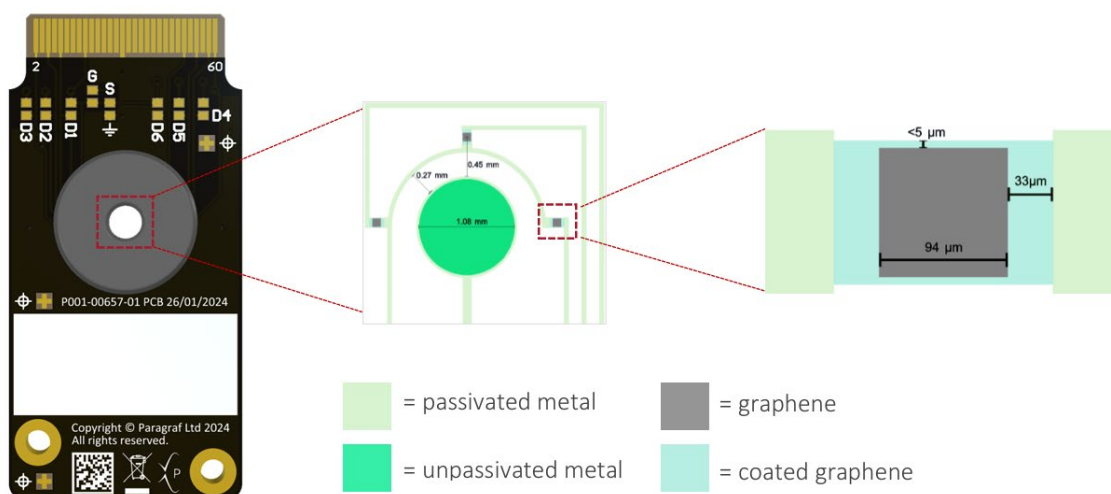


Figure 2. GFET-PV01 sensor layout



Paragraf's GFET is the only commercially scalable graphene device that is manufactured using standard semiconductor processes and equipment, offering unparalleled quality and consistency. These research prototypes were produced by Paragraf's foundry using proprietary technology and industry-leading knowhow in 2D materials.

5 Experimental Methods

Herein, a proof-of-concept acetone sensor is demonstrated through the deposition of a commercially available ZnO nanoparticle ink⁶ onto the standard GFET-PV01 and monitoring the response as a chemiresistive sensor to acetone, butanone and ethanol.

Though the GFET-PV01 is not specifically optimised for gas sensing applications, the chemiresistor configuration represents an initial approach.

Crucially, this device is able to operate at room temperature and with facile modification to the GFET, the device was able to monitor 5 ppm of acetone in dry air with a relative humidity of 10%.

5.1 Device Preparation

The GFETs used in this experiment are subjected to an annealing process in forming gas (5% hydrogen in argon) at 200°C for one hour in order to enhance sensitivity and stability of the resulting capped sensors.

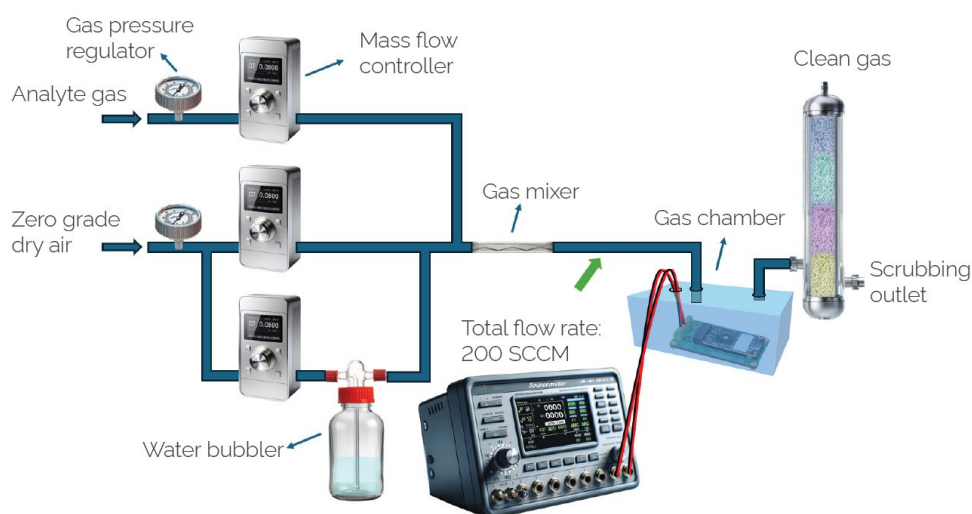


Figure 3. Setup designed to detect specific gas molecules by monitoring changes in the electrical properties of the GFETs.

The set-up, as illustrated in Figure 3, maintains a relatively low flow rate of 200 Standard Cubic Centimetres per Minute (SCCM), providing accurate and reliable measurements, highlighting the sensor's capability to detect target gases effectively



5.2 ZnO Deposition

The GFETs are incubated with 30 μL of ZnO ink, under controlled conditions, with IPA fumes for four hours to ensure proper adhesion and interaction with the graphene surface.

5.3 Gas Sensing Measurements

The GFET is exposed to a specific concentration of the target gas in a sealed chamber, with the temperature maintained at 30°C and the relative humidity at 10%. The gas flow rate is regulated at 200 SCCM to ensure a consistent exposure.

Baseline measurements are taken before introducing the target gas and the sensor's response is monitored continuously during the exposure period.

After the test, the chamber is purged with dry air in order to reset the sensor for subsequent tests. The setup is designed to detect specific gas molecules by monitoring changes in the electrical properties of the GFETs, providing accurate and reliable measurements.

6 Results

6.1 Acetone Concentration-Response

When acetone-spiked dry air, with a relative humidity of 10%, is passed over the ZnO-GFET sensors at room temperature, a reversible response can be seen at acetone concentrations of 5 ppm with the sensor signal saturating at a concentration of 25 ppm. The sensor exhibits rapid recovery, indicating that it is reusable even without a heater. Dynamic response and recovery curves show the sensor's ability to detect and recover from different levels of acetone, highlighting its sensitivity and response time across concentrations ranging from 5 ppm to 500 ppm.

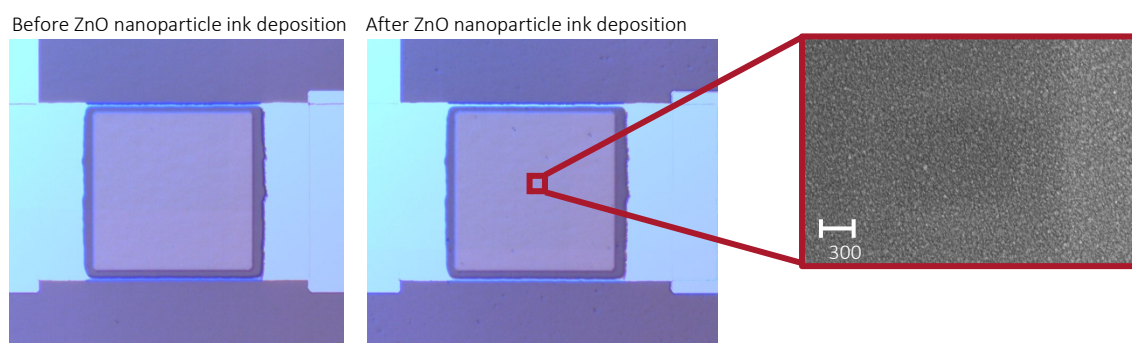


Figure 4. Optical images of the channel before and after ZnO nanoparticle ink deposition, and SEM image post deposition, demonstrating homogeneous coverage of the die. The before image shows the initial state of the channel, while the after image highlights the uniform distribution of ZnO nanoparticles across the surface

6.2 Selectivity Testing

When the selectivity of the sensor is tested by spiking with butanone and ethanol, the sensors exhibit a lower response to butanone and no significant response to ethanol up to 500 ppm (n = 3). This demonstrates the sensor's ability to selectively detect acetone over ethanol and butanone across the specified concentration range.

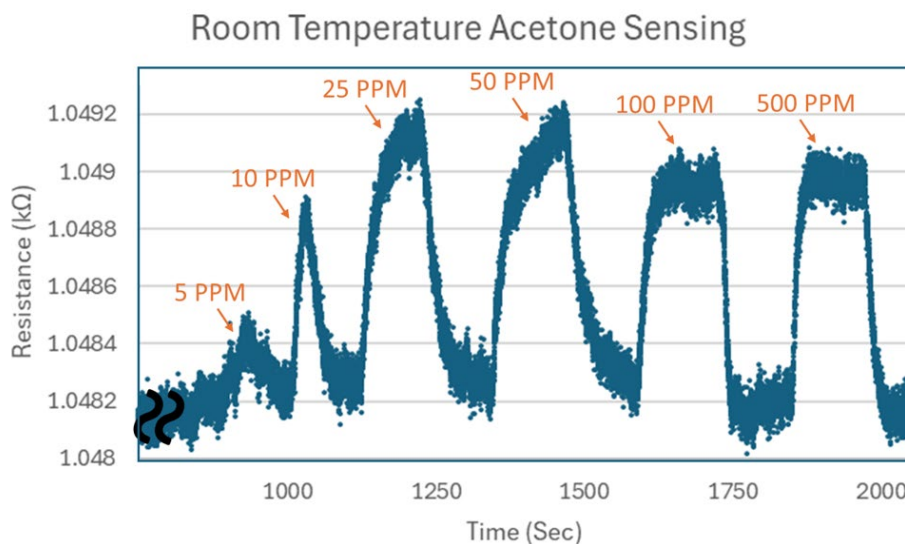


Figure 5. Dynamic response and recovery curves of ZnO-GFET exposed to varying acetone gas concentrations, ranging from 5 to 500 ppm. The curves illustrate the sensor's ability to detect and recover from different levels of acetone, highlighting its sensitivity and response time across the specified concentration range.

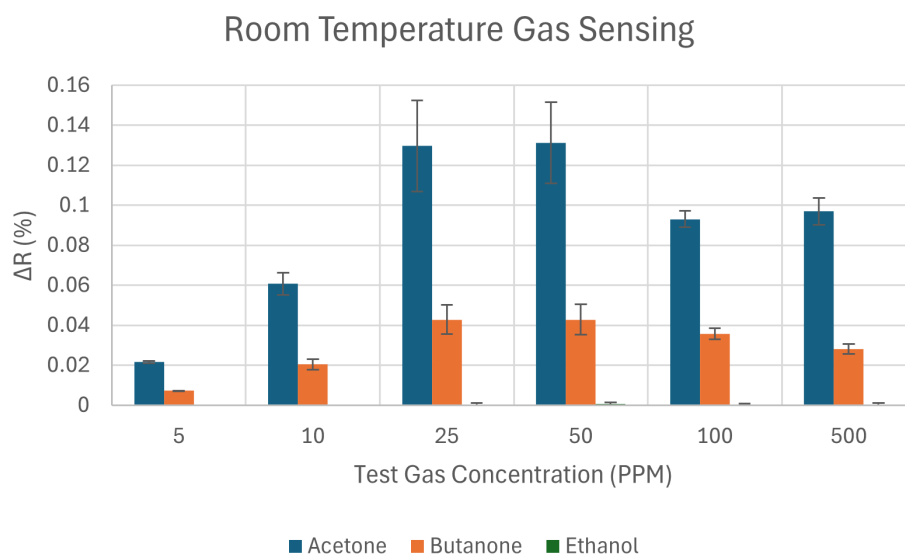


Figure 6. Selectivity characteristics of the acetone gas sensor compared to ethanol and butanone at varying gas concentrations, ranging from 5 to 500 ppm. The figure demonstrates the sensor's response to each gas, highlighting its ability to selectively detect acetone over ethanol and butanone across the specified concentration range.



6.3 Long-Term Stability

A comprehensive stability test conducted on a GFET to evaluate its long-term performance entails storing the device in a laboratory environment without any protective measures for 93 days.

Despite the absence of controlled storage conditions, the sensor exhibits remarkable stability. Subsequent testing reveals that the sensor's readings remained consistent with the initial measurements, demonstrating its robustness and reliability.

This outcome highlights the sensor's potential for dependable operation in a variety of practical applications, even when optimal storage conditions are not maintained.

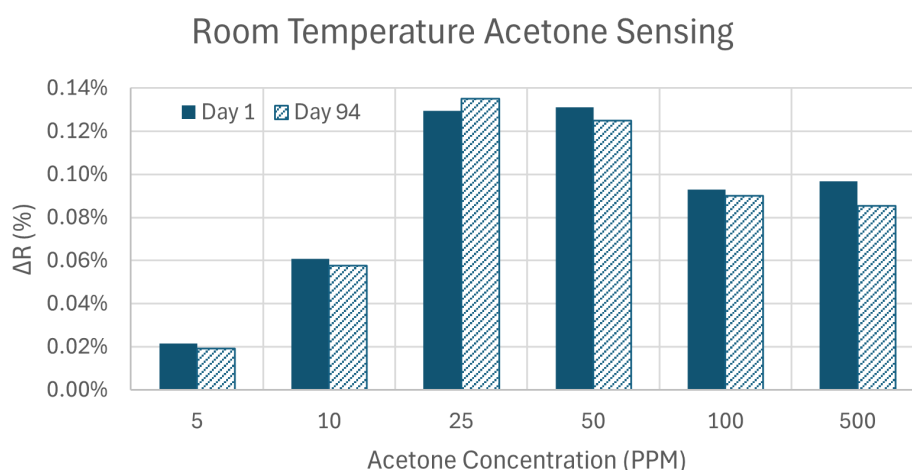


Figure 7. Stability test results showing consistent sensor readings after 93 days of unprotected storage. The graph illustrates the consistency of the sensor's readings, which remained comparable to the initial measurements, demonstrating the sensor's robustness and reliability.

7 Conclusion

The GFET demonstrates significant potential for non-invasive monitoring of acetone levels in multiple applications. This proof-of-concept study highlights the sensor's ability to detect acetone at low concentrations with high sensitivity and selectivity, even at room temperature and low humidity conditions. The ability to monitor acetone levels accurately is crucial for ensuring safety in industrial settings, diagnosing respiratory infections and managing diabetes.

The successful implementation of this sensor technology, despite being in a non-optimised format, could lead to more-widespread use of breath analysis for medical diagnostics, providing a rapid, non-invasive and cost-effective method for detecting biomarkers associated with various health conditions. This work lays the foundation for future advancements in gas sensor technology, particularly in developing more sensitive and selective sensors that can be used in real-time, near-patient settings. The potential applications of this technology are vast, ranging from industrial safety to healthcare, underscoring the importance and value of continued research and development in this field.



8 Data Disclaimer

The data shared herein is intended to serve as evidence of use case and exemplification that can be replicated independently. Further experimentation may build on these tests to establish specific product or application alternatives that meet specific needs or research interests.

9 Next Steps

If you would like to try GFET for your own molecular sensing experiments, and learn more about other promising applications of graphene sensing, please visit our [web site](#). GFET devices, as well as the plug-and-play GFET Discovery Kit data acquisition system, are in stock and on sale now at our [Online Store](#).

For custom pricing on larger orders, or to access our foundry services for bespoke solutions, please email sales@paragraf.com.

We would welcome the opportunity to discuss your specific requirements and are actively looking for partners and collaborations to support you in your graphene applications. Please get in touch via enquiries@paragraf.com.

10 References

1. <https://news.un.org/en/story/2024/11/1156971>
2. <https://doi.org/10.1136/bmjdr-2021-002174>
3. <https://www.sciencedirect.com/science/article/abs/pii/S0033062013001849>
4. <https://link.springer.com/article/10.1557/s43578-021-00456-3>
5. Sensors 2016, 16, 1876; <https://doi.org/10.3390/s16111876>
6. <https://www.sigmaaldrich.com/GB/en/product/aldrich/793361>

10.1 Further reading

1. <https://www.webmd.com/diabetes/acetone-breath-diabetes>

Copyright © Paragraf Limited 2024-2026. All rights reserved. No part of this document may be reproduced in any form without the prior written permission of Paragraf. The Paragraf name, the Paragraf logo and the Paragraf icon are trademarks of Paragraf Limited and are registered trademarks in the United Kingdom, United States of America, European Union, Singapore, Taiwan, China, Japan and Republic of Korea. All other trademarks are the property of their respective owners.

Company number: 09889431. Address: 7-8 West Newlands, Somersham, Cambridgeshire, UK, PE28 3EB.

