Potassium Sensing with a GFET

Application Note

Contents

1 Summary

This application note describes the use of Paragraf's Graphene Field Effect Transistor (GFET) for potassium ion sensing using a PVC-based selective membrane. The study demonstrates clear selectivity for K^+ over common cations, rapid measurement response and practical manual channel functionalisation, distinguishing the GFET as a suitable tool for tracking potassium levels at concentrations and sensitivity applicable to a range of potassium-sensing applications.

2 Relevance of Potassium Measurement

Potassium is a key electrolyte underpinning normal nerve signalling, muscle contraction and especially heart rhythm. As such, measuring potassium is a routine component of basic metabolic panels, used to diagnose and monitor kidney disease, cardiovascular conditions and disturbances in acid–base balance.

Beyond its medical applications, though, potassium measurement has a range of industrial and regulatory uses, including:

- **Food and beverage:** Potassium levels are monitored for product formulation (for example, salt substitutes using potassium salts), legal labelling and consistent taste and texture.
- **Water and environmental monitoring:** Potassium concentration in surface, ground or industrial wastewater can indicate contamination sources, support compliance with discharge regulations and help characterise natural water chemistry.
- **Fertiliser and potash mining:** Potassium content is measured in ores, brines and finished products to control process efficiency and guarantee fertiliser grade.
- **Chemical and manufacturing processes:** Industries using potassium hydroxide or other potassium salts track concentration for corrosion control, reaction efficiency and quality assurance.
- **Agriculture and horticulture:** Measuring potassium in soil and fertiliser guides precise nutrient management, optimising crop yield and preventing both deficiency and wasteful over-application.

Across these sectors, potassium measurement supports process control, regulatory compliance and resource efficiency.

3 ISFET and GFET Approaches to Potassium Sensing

3.1 Ion-Selective Field-Effect Transistors

Currently, potassium sensing in most settings is conducted using liquid junction ion sensitive electrodes; however, these electrodes are bulky and prone to degradation due to the internal salt solution which is necessary for the device to operate. A potential solution to miniaturisation, including reduced power constraints and cost reductions for potassium sensing, is to use ion-selective field effect transistors.

In this device architecture, the resistance of a transducer is measured whilst applying a potential with a gate electrode to the surface through an electrolyte[1].

3.2 Membrane Functionalisation

The selective component comes from a thin film deposited on top of the transducer which has a high binding affinity for the chosen analyte. As the analyte is absorbed into the thin film, a potential difference is established across this film which leads to a change in potential. This leads to a change in the applied voltage across the transducer and the gate electrode, which leads to a change in transducer current.

3.3 Advantages of Graphene Field-Effect Transistors

The GFET offers a potential solution to the unmet needs in a majority of such applications, with excellent dynamic range, resolution and sensitivity complemented by small geometry. A change in the surface potential across the transducer and the gate electrode can be monitored in a GFET as a change in the minimum conduction point, also known as the Dirac point (DP), of the GFET transfer curve with respect to the applied gate voltage.

This application note provides feasibility evidence of this with sensors capped with a PVC-based membrane, with a potassium-selective molecule incorporated.

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.

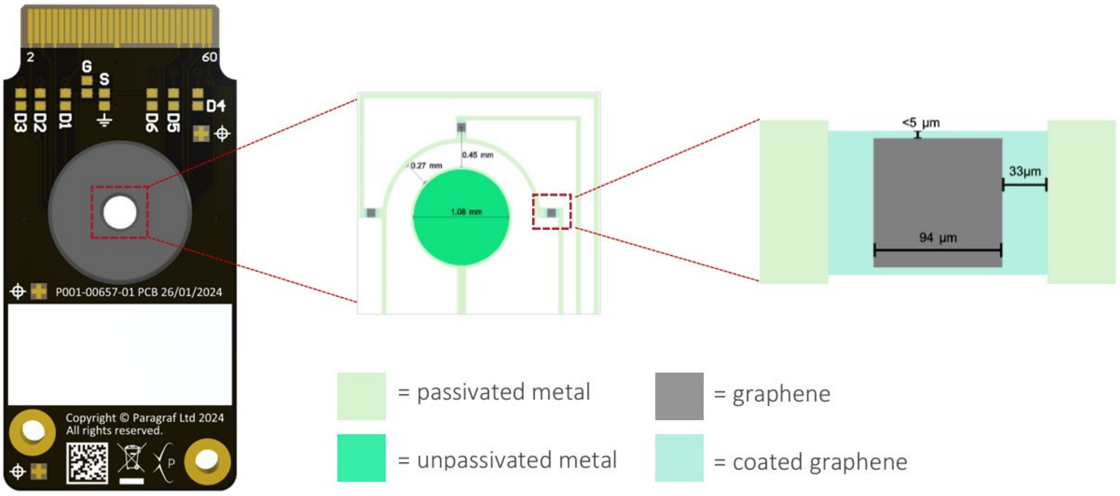

Figure 1. GFET-PV01 sensor layout

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

5.1 Materials and Reagents

5.1.1 Membrane components

- Potassium ionophore III
- Potassium tetrakis(4-chlorophenyl) borate (a lipophilic salt)
- Poly(vinyl chloride) (PVC)
- Dioctyl sebacate
- Tetrahydrofuran (THF).

5.1.2 Test ions

Na^+, K^+, NH_4^+, Mg^{2+} and Ca^{2+} prepared using standard Na_2PO_4/NaH_2PO_4 buffer solutions per **5.4 Test Solution Preparation**.

5.1.3 Equipment

- GFET-PV01 devices
- Silver/silver-chloride (Ag/AgCl) gate paste
- Integra Vacusip handheld aspirator
- Dual Source Measure Units (SMUs)
- Paragraf Dirac Point Tracking software.

5.2 Membrane Preparation

The membrane solutions are prepared per Fakih ***et al.***[2] (20 mg ionophore, 10 mg lipophilic salt, 330 mg PVC, 660 mg dioctyl sebacate in 4 mL THF). An ionophore-free control membrane is produced equivalently. Solutions are left to dissolve for one hour in an ultrasonic bath.

5.3 Device Functionalisation

1. 1.5 µL of each membrane are deposited onto the appropriate GFET channels, leaving one channel uncoated.
2. An Ag/AgCl paste is applied to the central gate under a microscope, avoiding contact with the graphene channels.
3. The device is annealled at 100°C for 10 minutes.

5.4 Test Solution Preparation

The following solutions are prepared for selectivity and concentration-response measurements:

Ion	Composition
Na^+	5 mM Na_2PO_4H / 5 mM $NaPO_4H_2$ / 10 mM NaCl / DI water
K^+	5 mM Na_2PO_4H / 5 mM $NaPO_4H_2$ / 8 mM NaCl / 2 mM KCl / DI water
NH_4^+	5mM Na_2PO_4H / 5 mM $NaPO_4H_2$ / 8 mM NaCl / 2mM NH_4Cl / DI water
Mg^{2+}	5mM Na_2PO_4H / 5 mM $NaPO_4H_2$ / 8 mM NaCl / 1mM $MgCl_2$ / DI water
Ca^{2+}	5mM Na_2PO_4H / 5 mM $NaPO_4H_2$ / 8 mM NaCl / 1mM $CaCl_2$ / DI water

Serial dilutions are combined of K^+ in Na^+ to produce a concentration-dependent curve.

5.5 Measurement Setup

The GFET devices are connected to an SMU via a custom-built multiplexer device to switch between graphene channels. For each measurement, 30 µL of test solution is applied to the sensor well before the aspirator is removed. There is no washing step between sequential samples. Paragraf's bespoke Dirac Point Tracking software determines the Dirac point. All measurements against a Na^+ test-solution baseline should be taken to maintain stable pH and ionic strength throughout the experiment.

6 Results

6.1 Concentration-Dependent Response

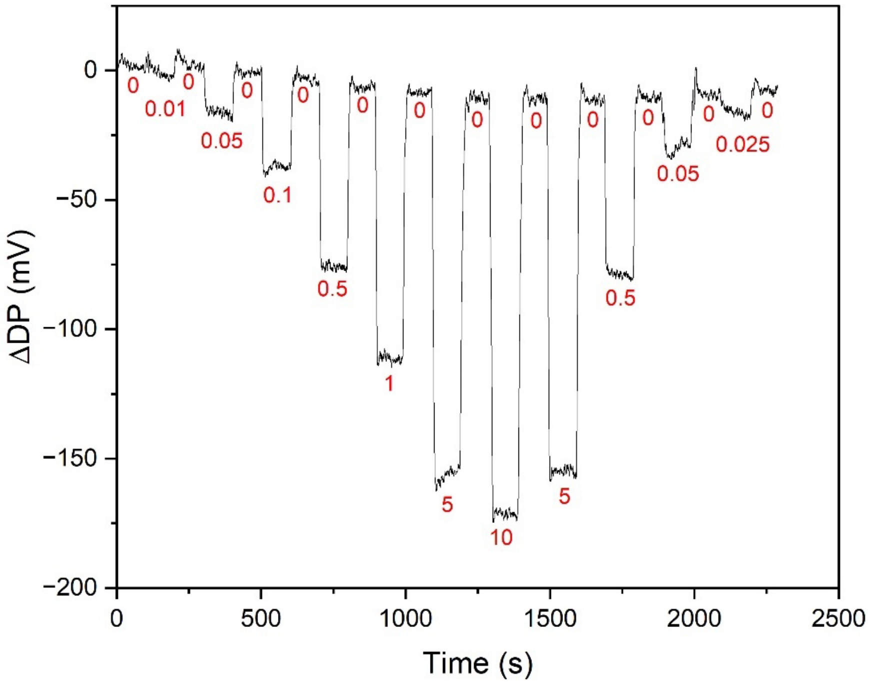

Figure 2. A trace showing the change in Dirac point over time with a baseline Na^+ test solution and varied concentrations of K^+ test solutions [KCl] shown in mM in red.

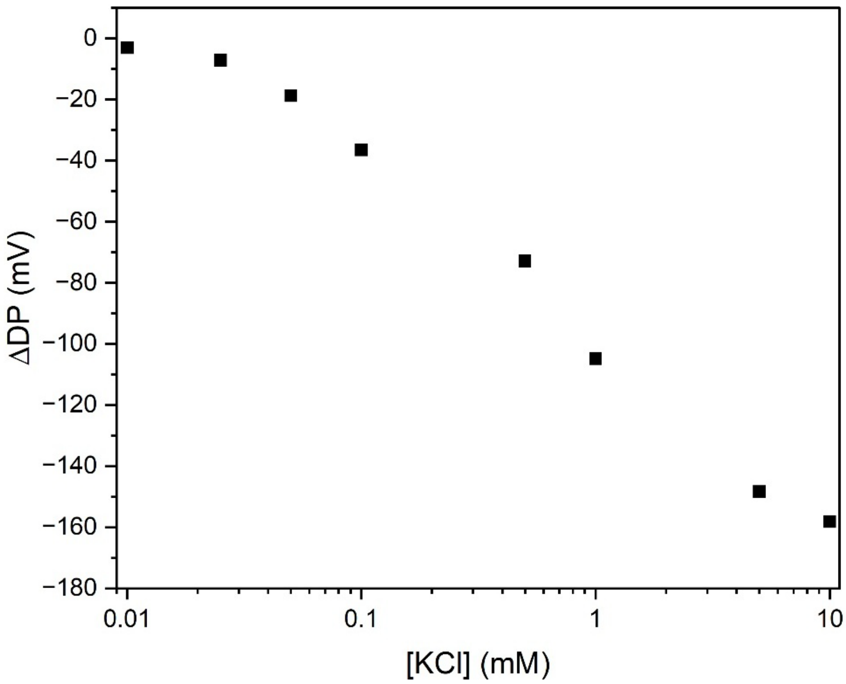

Figure 3. Change in Dirac point with respect to concentration of KCl in solution. Data is taken from figure 1, using the average value at each concentration.

6.2 Functionalisation Verification

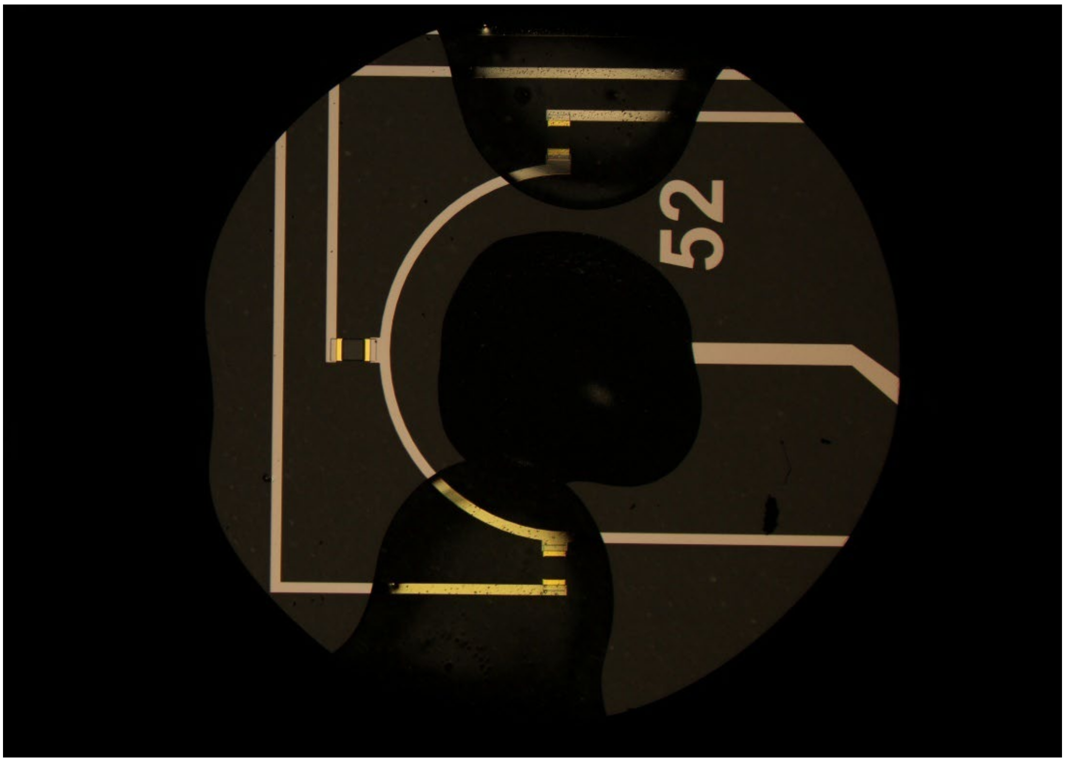

Figure 4. Microscope image at 2.5x mag showing independent functionalisation of GFET channels.

6.3 Cation Selectivity

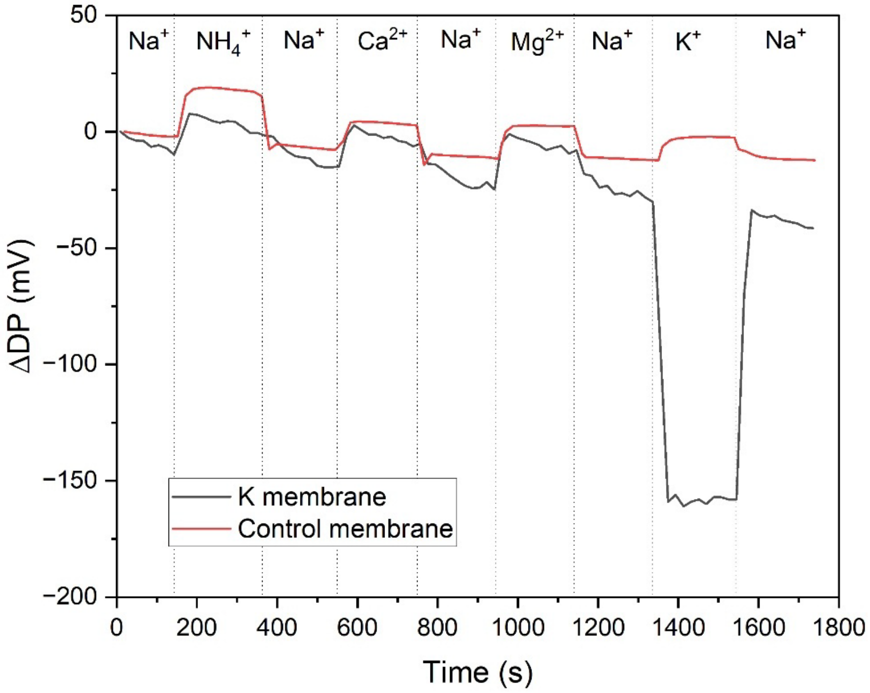

Figure 5. *A trace showing the change in Dirac point over time with a baseline Na^+ test solution ($[Na^+]$ = 2 mM) and varied cationic test solutions ($[NH_4^+]$ = 2 mM, $[Ca^{2+}]$ = 1 mM, $[Mg^{2+}]$ = 1 mM, $[K^+]$ = 2 mM).*

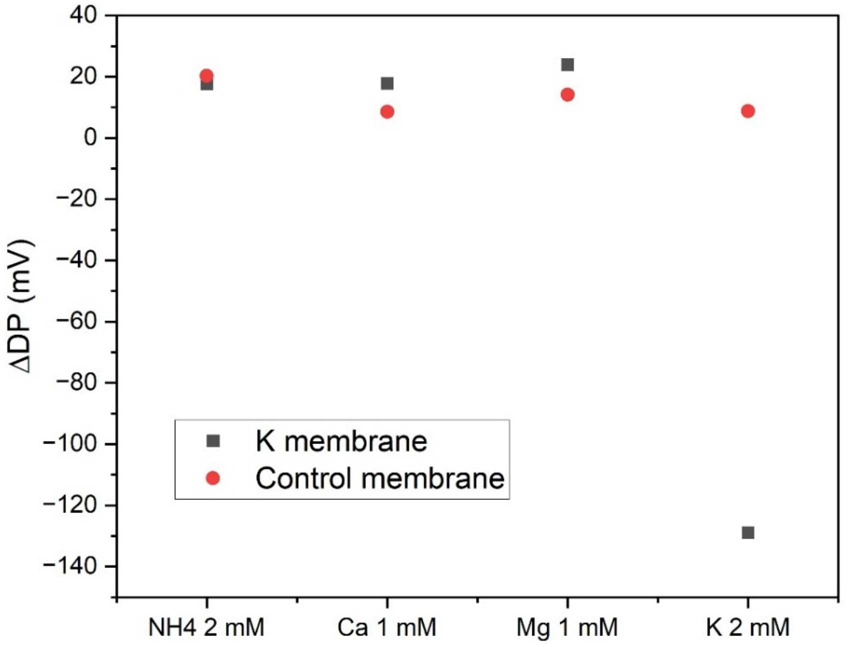

Figure 6. *Change in Dirac point with respect to cation against a Na^+ ion baseline. Data is taken from figure 4 using data 10 seconds before and after the solution exchange*

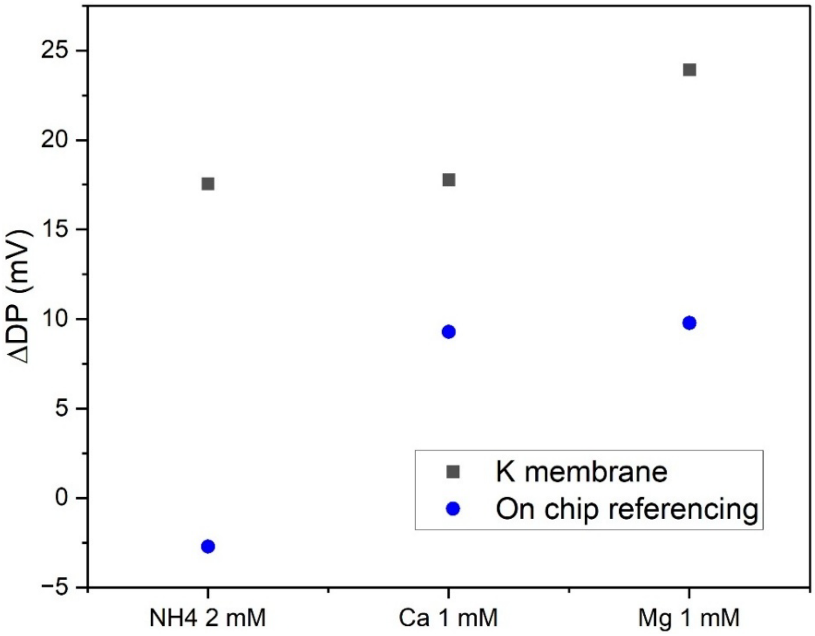

Figure 7. *Change in Dirac point with respect to cation showing reduction in non-selective cation response by referencing the K⁺ membrane response to the control membrane response on the chip*

7 Conclusion

GFETs combined with a potassium-selective membrane provide a robust and sensitive platform for K⁺ detection. The results demonstrate:

- clear K⁺ selectivity over common cations
- fast response (<10 s)
- sensitivity below 25 µM
- ability to suppress non-selective signals through internal referencing
- feasibility of manual multi-channel functionalisation

These findings support the applicability of GFET-based sensing to a wide range of ion-detection research needs.

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. Cao. ISFET-based sensors for (bio)chemical applications: A review. Electrochemical Science Advances - Wiley Online Library (2023) https://chemistry-europe.onlinelibrary.wiley.com/doi/10.1002/elsa.202100207
2. Fakih, I., Durnan, O., Mahvash, F. et al. Selective ion sensing with high resolution large area graphene field effect transistor arrays. Nat Commun 11, 3226 (2020). https://doi.org/10.1038/s41467-020-16979-y

10.1 Further reading

1. https://www.nhs.uk/Conditions/potassium-test/

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