Generating electricity by moving a droplet of ionic liquid along graphene

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NATURE NANOTECHNOLOGY | DOI: 10.1038/NNANO.2014.56 | www.nature.com/naturenanotechnology

Published 6 April 2014

Soujit SenGupta

Date: 19.04.2014

Introduction

Graphene is extremely sensitive to external stimulations and adsorptions but immersed graphene cannot generate a voltage from a flowing liquid.

Classical electrokinetic theory for streaming potential states a potential cannot be induced by a flowing liquid without a pressure gradient.

Coulomb drag, a process in which repulsive interactions between electrons in spatially separated conductors allow a current flowing in one of the conductors to induce a voltage drop in the other.

However, in graphene/liquid systems, electrokinetic phenomena (rather than Coulomb drag) should occur, because an electrical double layer will form at the interface of ionic liquids and graphene.

In this paper, they show that a voltage on the order of a few millivolts can be induced by
moving a droplet of ionic solution along a strip of graphene.

They refer to this effect as a drawing potential. The drawing potential is generated by moving a unique pseudocapacitor formed at the interface of the droplet and graphene along the strip.

The drawing potential is proportional to the velocity of the droplet in all the tested

Sample preparation

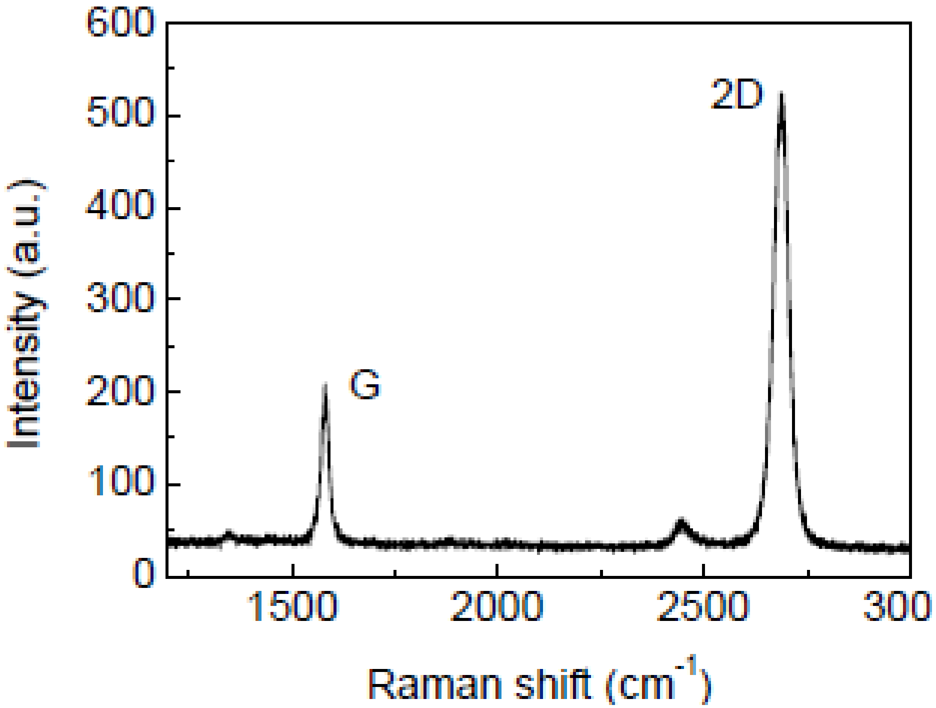
Monolayer graphene samples were grown on electrochemical polished copper foil by low-pressure chemical vapour deposition.

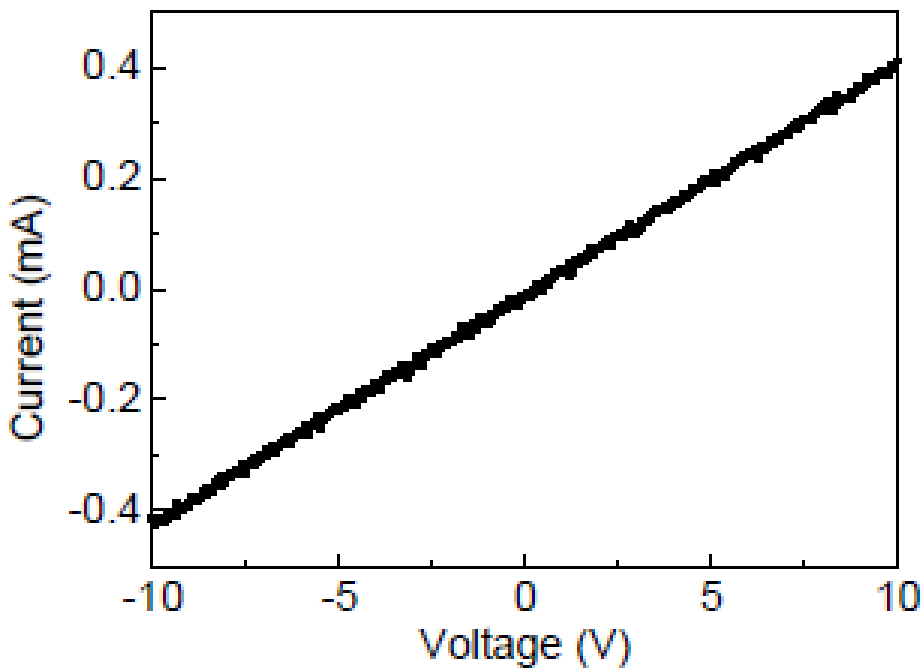
Graphene strips with dimensions of 5 × 110 mm2 were then transferred onto a polyester terephthalate (PET) substrate with unavoidable folded regions by a poly(methyl methacrylate) (PMMA) mediated method.

Multilayer graphene samples were obtained by superposing the monolayer graphene, without an organic contamination trapped interlayer, using an improved stacking method.

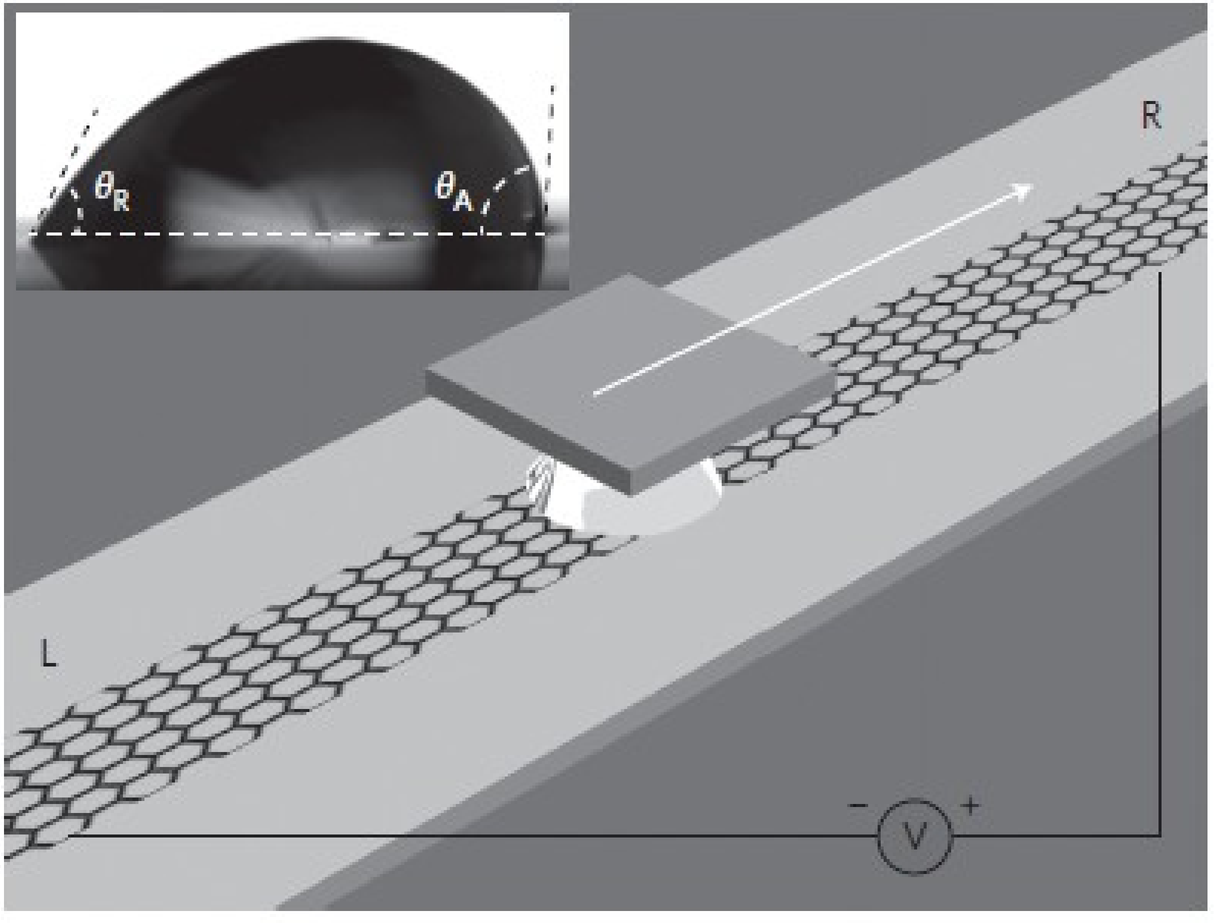
Two terminals of the graphene strip were connected with metal wires using silver epoxy to form an ohmic contact.

Characterization

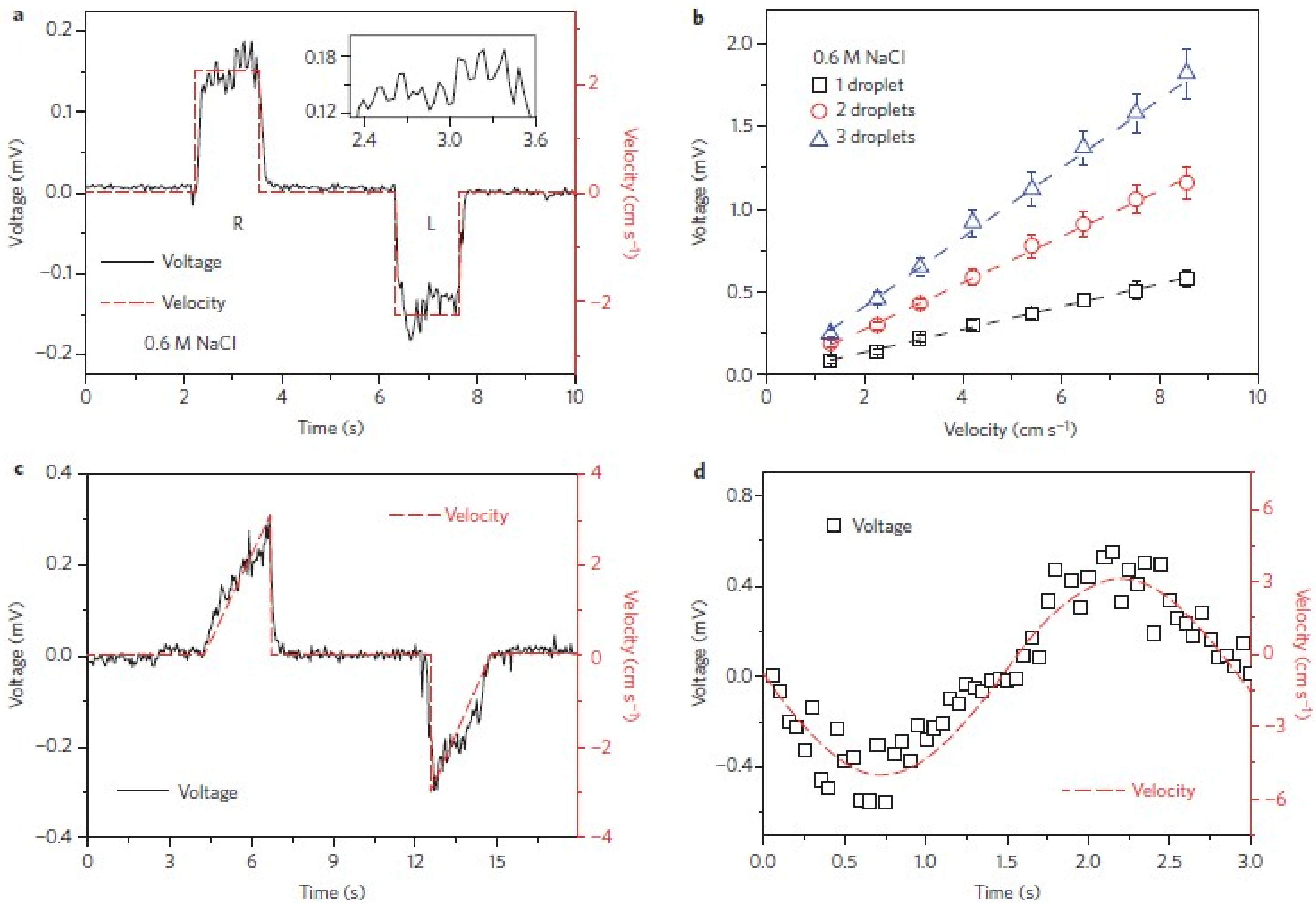




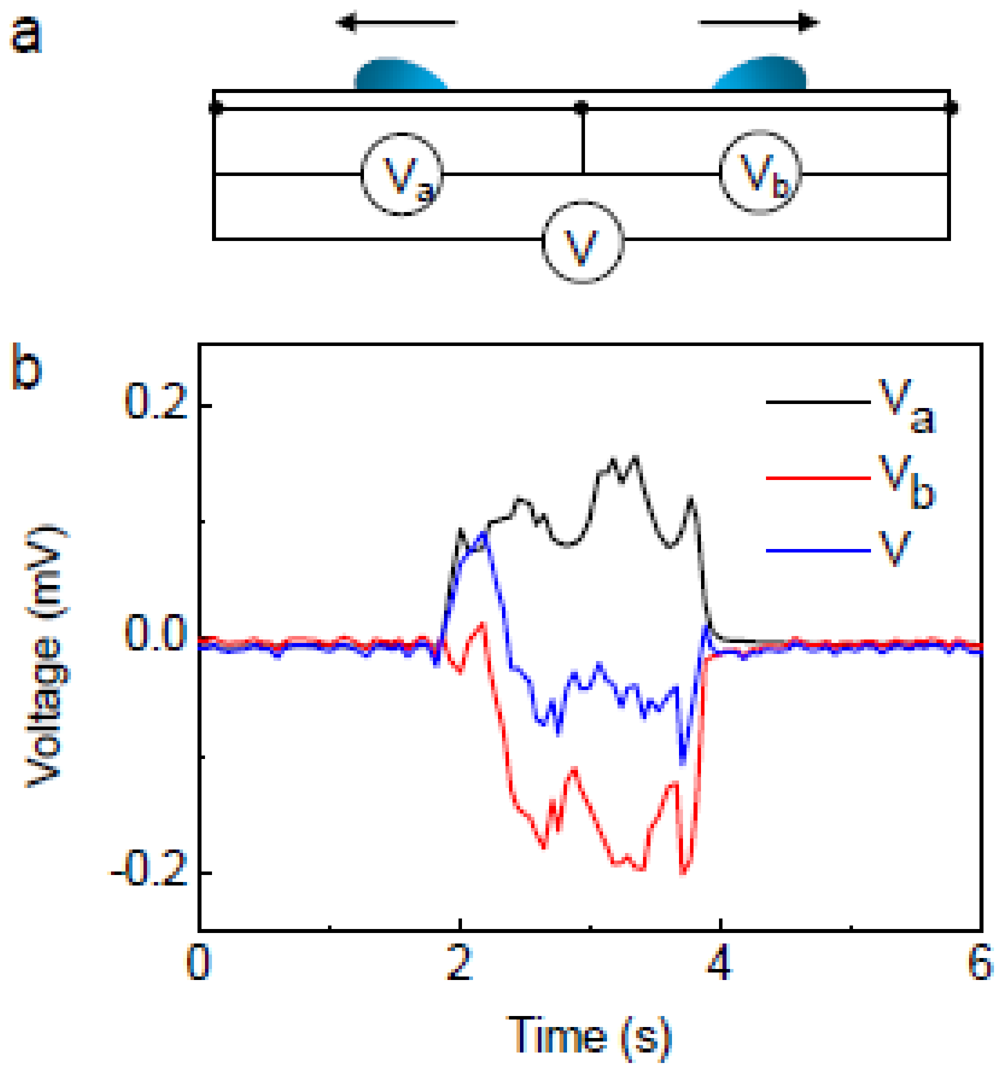
Experimental set-up

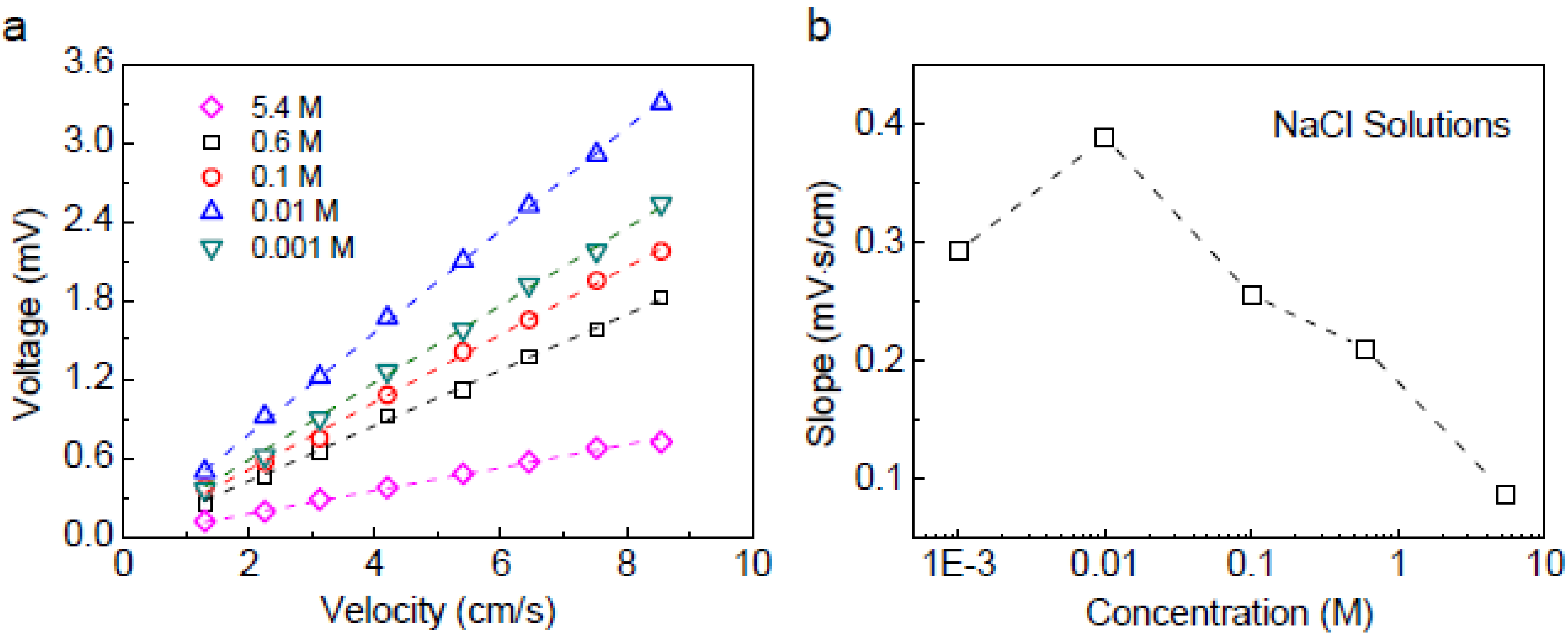


A liquid droplet is sandwiched between graphene and a SiO2/Si wafer, and drawn by the wafer at specific velocities. Inset: a droplet of 0.6 M NaCl solution on a graphene surface with advancing and receding contact angles of 91.98 and 60.28, respectively.

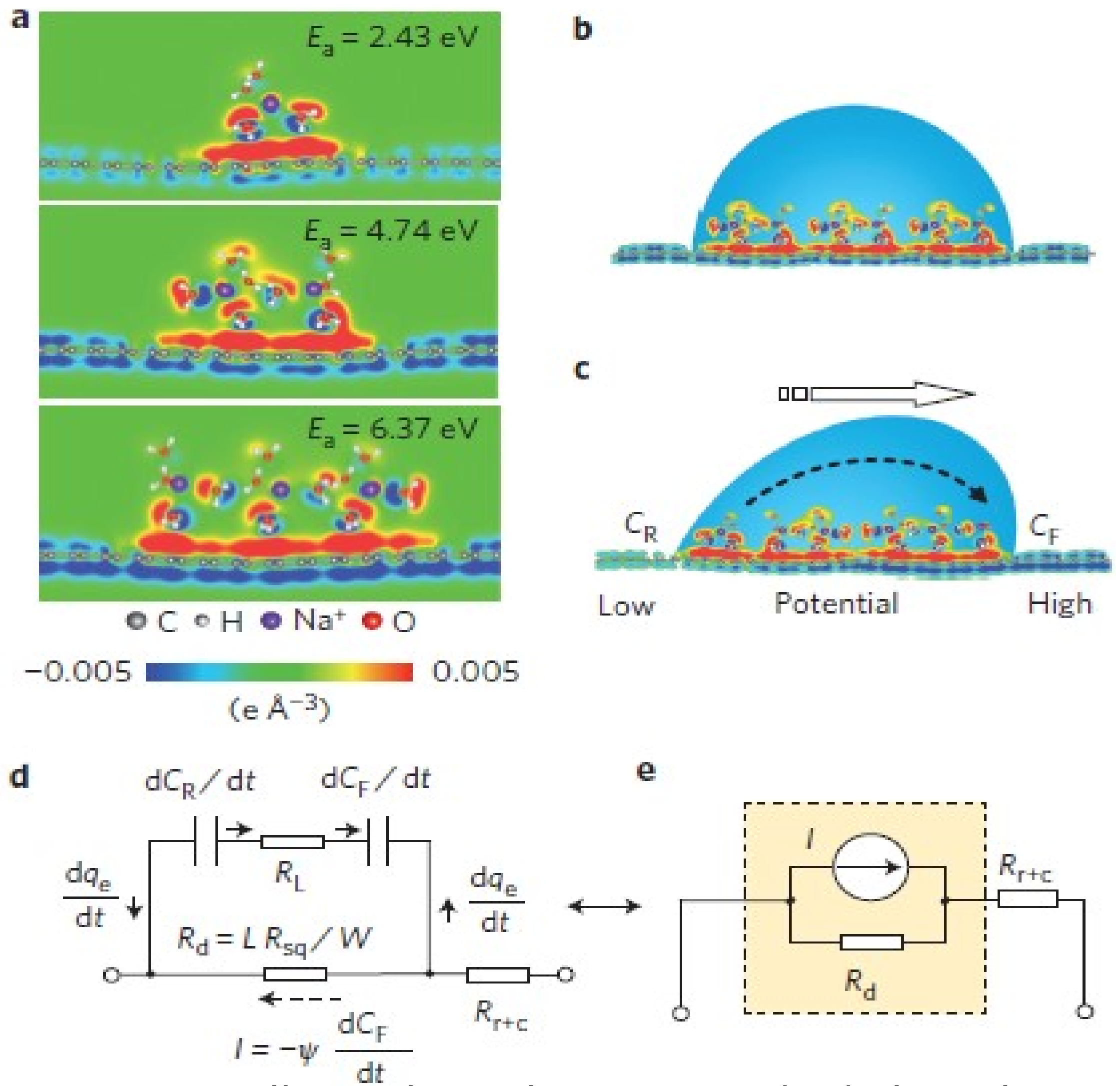


(a) Typical voltage signal produced by drawing a droplet on a graphene strip from left (L) to right (R) ends and then back. The inset highlights the voltage signal during the movement of the droplet. b, Voltage induced by moving one, two and three droplets. c,d, Voltage response to triangular-wave-like (c) and sine-wave-like (d) velocity of movement (red dashed lines) of a droplet.


a
Va
Vb
V
b
Va
Vb
V
0.2
0.0
-0.2
Voltage (mV)
0
2
4
6
Time (s)



a
b
5.4 M
0.6 M
0.1 M
0.01 M
0.001 M
Voltage (mV)
Velocity (cm/s)
NaCl Solutions
Slope (mV.s/cm)
Concentration (M)



a, DFT and the corresponding adsorption energy (Ea). b, Schematic illustration of the pseudocapacitance formed by a static droplet on graphene. c, Schematic illustration of the potential difference induced by a moving droplet. d, Equivalent circuit for c. Solid arrows indicate the flow direction of electrons in graphene and Na+ ions in the droplet. e, Simplified circuit of the system.

dCF/dt = C0Wv

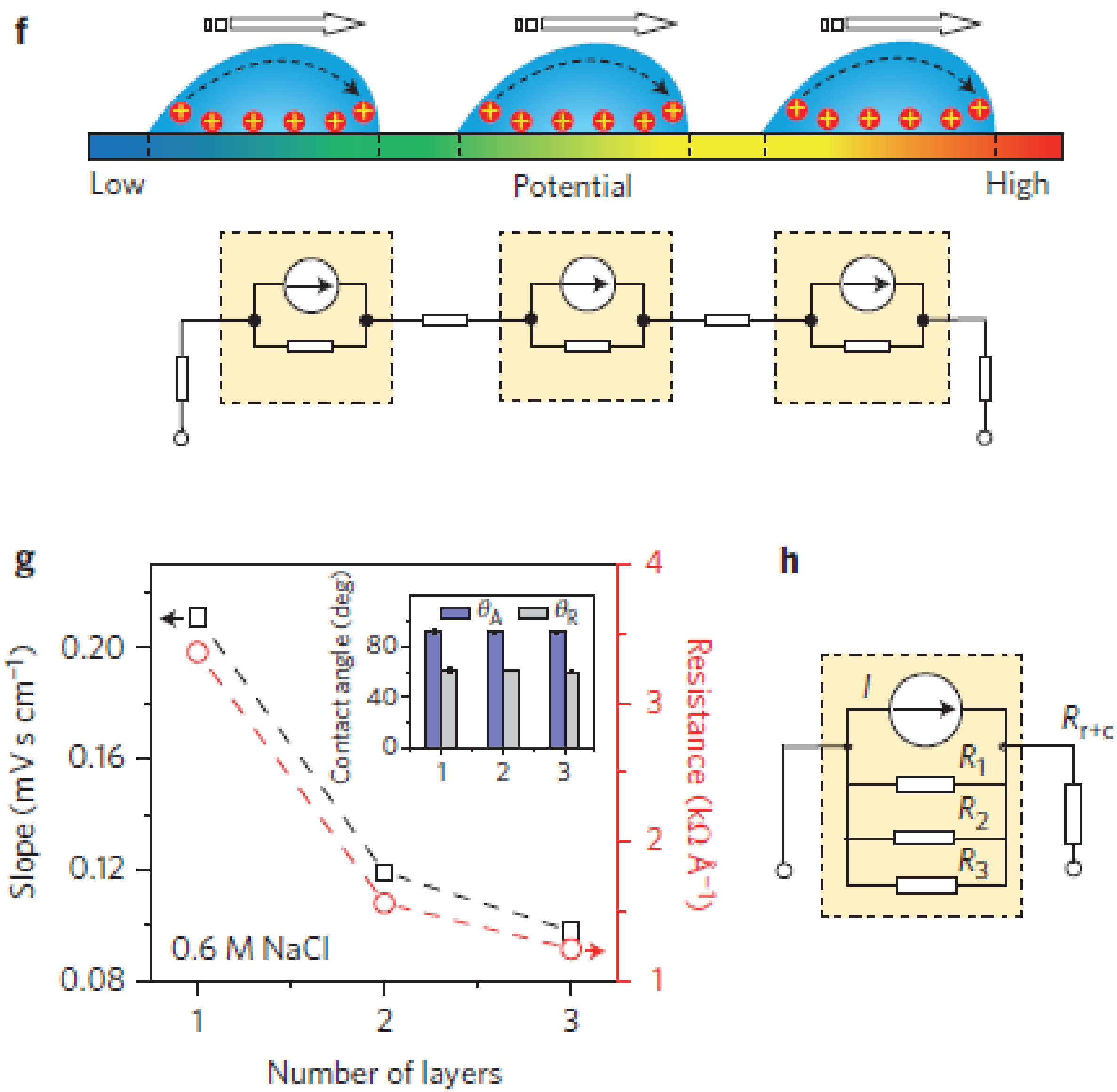
dCR/dt = -C0Wv

$$I = -\frac{\mathrm{d}q_e}{\mathrm{d}t} = \psi\frac{\mathrm{d}C_F}{\mathrm{d}t} = -\psi\frac{\mathrm{d}C_R}{\mathrm{d}t} = -\psi W C_0 v$$

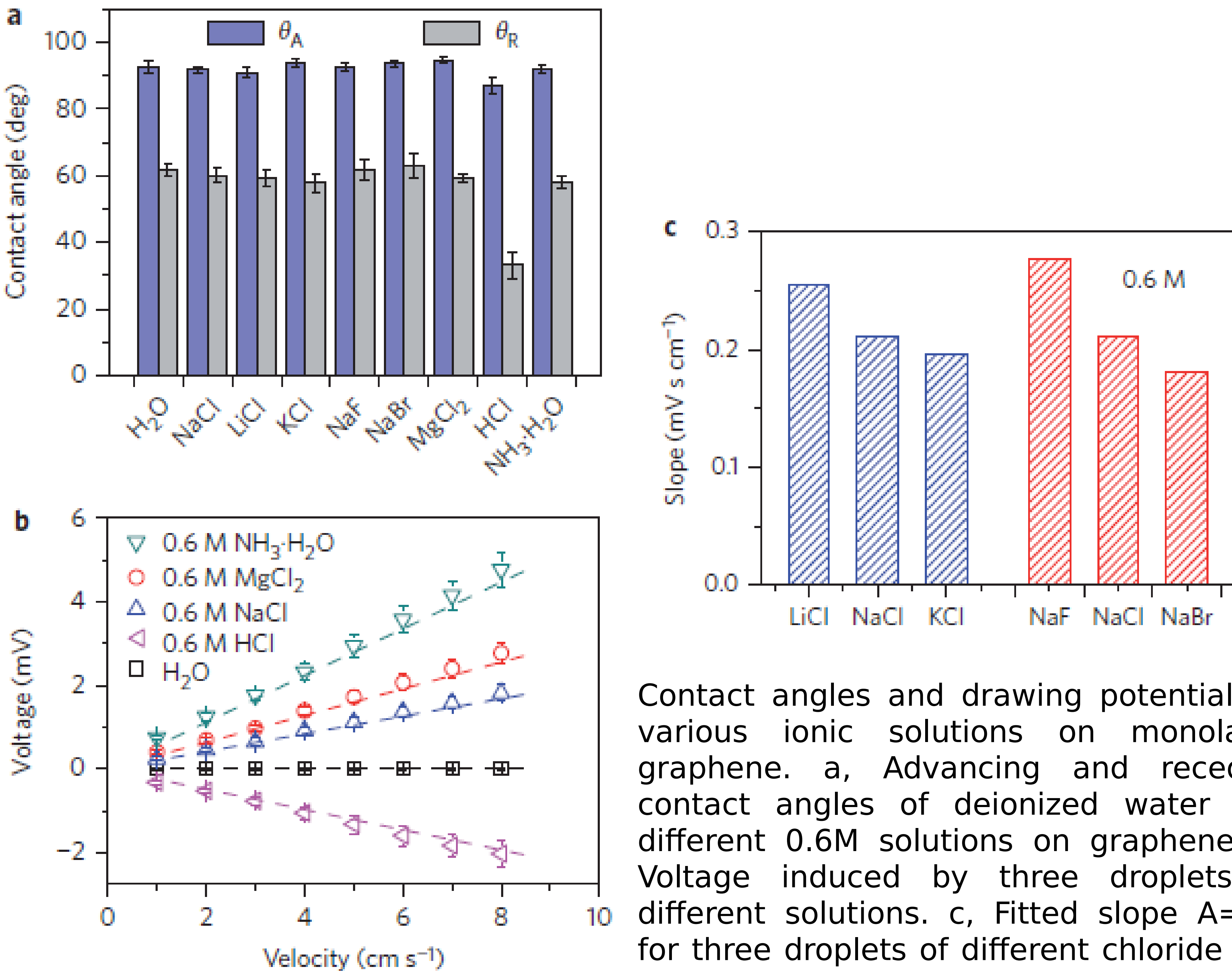
Open circuit voltag

$$V = R_d I = -LR_{sq}\psi C_0 V$$

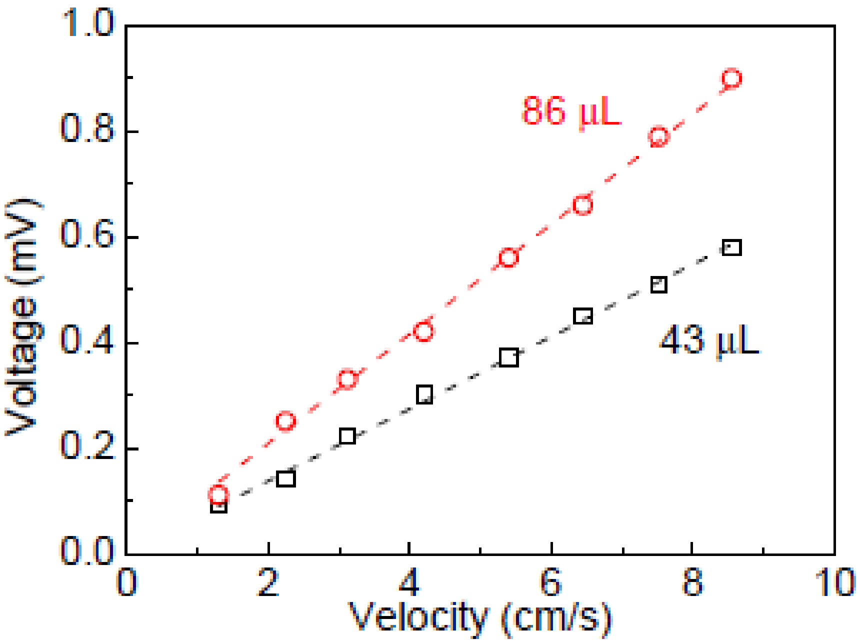
For the narrow gap between the positive and negative charged layers, C0 should be exceptionally high. This can explain why drawing a tiny droplet on graphene can produce voltage up to millivolt order.



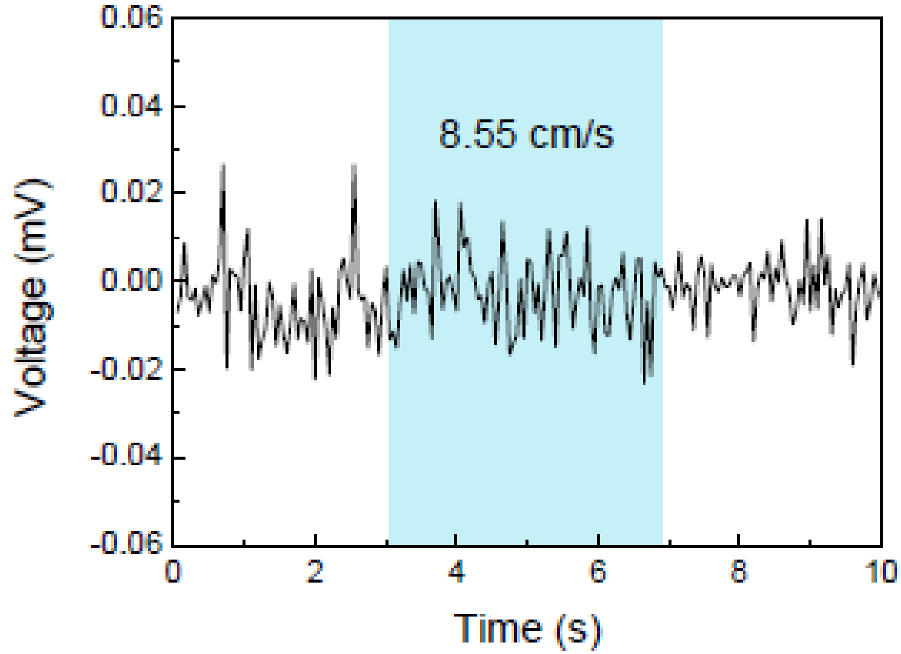
f, Schematic illustration and equivalent circuit for three moving droplets on graphene. g, Drawing potential and resistance change with number of graphene layers. Inset: Advancing and receding contact
angles of the solution on single-, bi- and trilayer graphene. h, Equivalent circuit for a moving droplet on trilayer graphene.



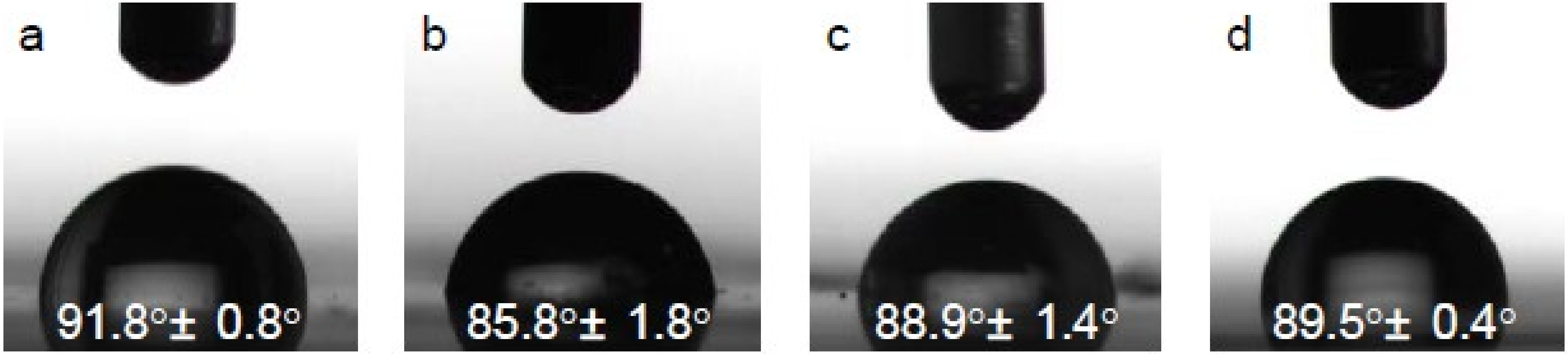
Contact angles and drawing potential for various ionic solutions on monolayer graphene. a, Advancing and receding contact angles of deionized water and different 0.6M solutions on graphene. b, Voltage induced by three droplets of different solutions. c, Fitted slope A=V/v for three droplets of different chloride and sodium salts.



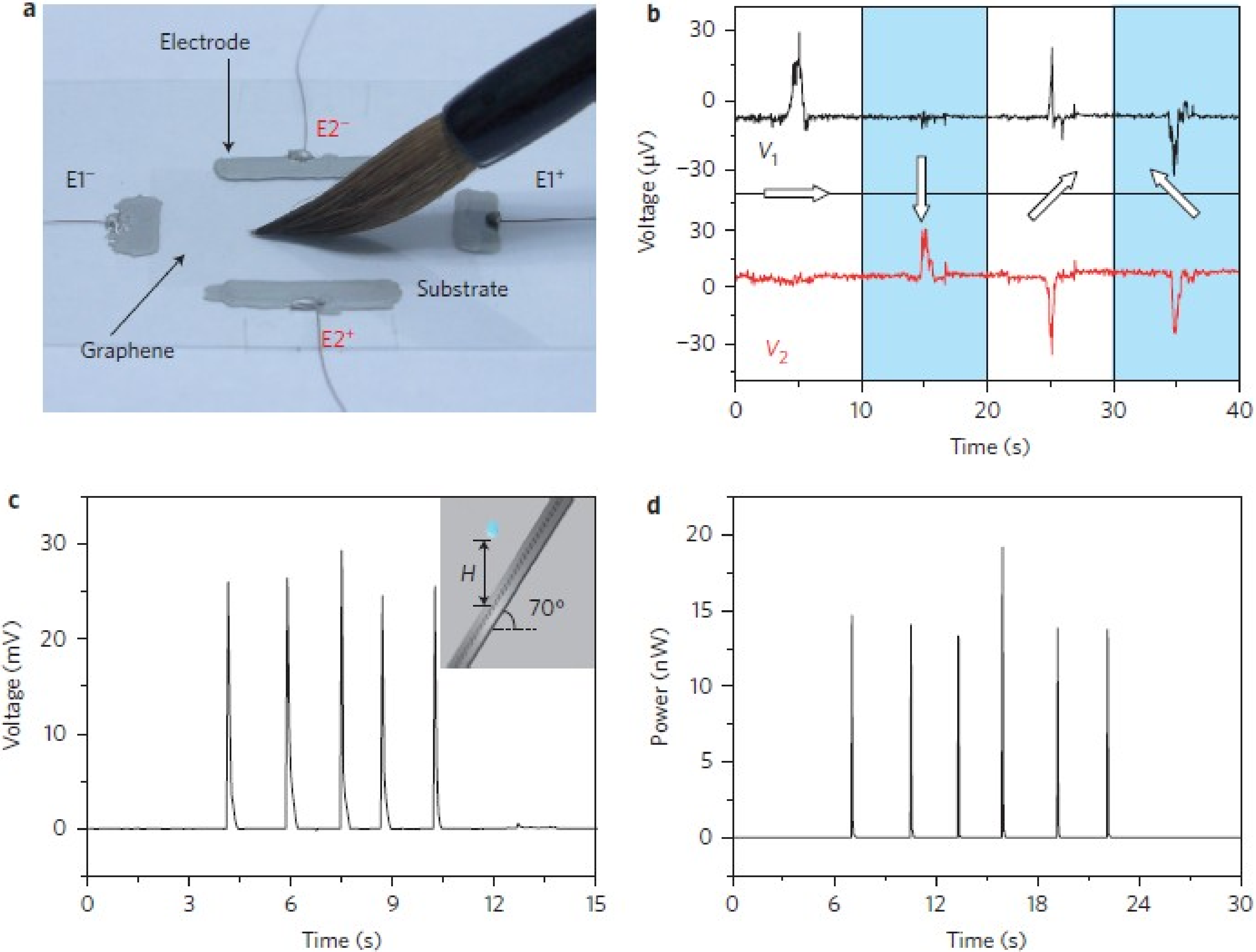
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
Voltage (mV)
Velocity (cm/s)
86 μL
43 μL



0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
0
2
4
6
8
10
Voltage (mV)
Time (s)
8.55 cm/s



Contact angle of the graphene under different conditions. a, Deionized water on pristine graphene. b, 0.6 M HCl on graphene. c, Deionized water on graphene, which has been wetted by 0.6 M HCl. d, Deionized water on graphene, which has been rinsed by deionized water for 30 min after wetted by 0.6 M HCl for 2 min.


a
Electrode
E2⁻
E1⁻
E1⁺
Substrate
Graphene
E2⁺
b
Voltage (μV)
V1
V2
Time (s)
c
Voltage (mV)
H
70°
Time (s)
d
Power (nW)
Time (s)

Summary and Conclusion

They have reported a drawing potential effect in graphene.

Droplets of ionic liquids moving on graphene can generate electricity due to a novel electrokinetic phenomenon in which a pseudocapacitor formed under the droplet is driven forward, charging and discharging at the boundary of the droplet.

This mechanism allows the creation of various prototypes, including a velocity sensor, a
handwriting sensor and an energy-harvesting device.


Thank You