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Gate-tunable graphene-based Hall sensors on flexible substrates with increased sensitivity

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AMO

INTRODUCTION

Applications of Hall sensors

- Speed Detection
- Precise Rotation Detection

Application Fields of Hall sensors

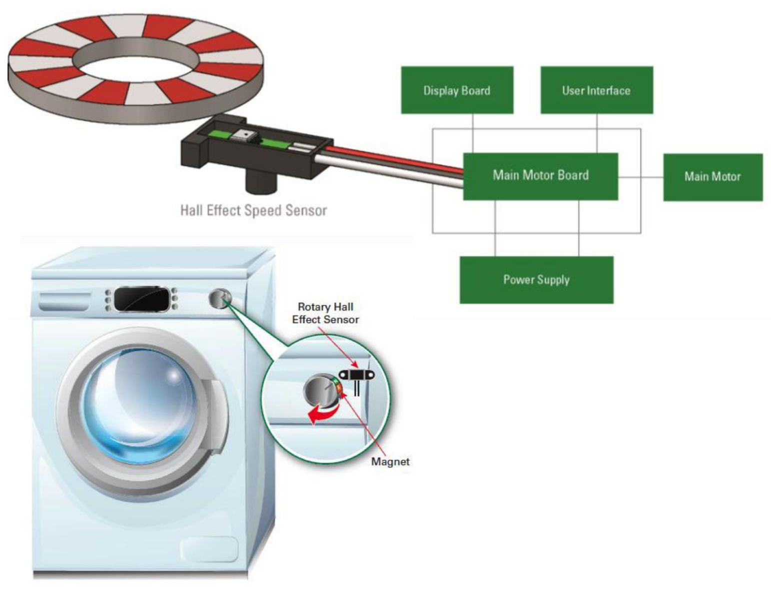
- Automotive
- Consumer Electronics
- Telecommunication
- Medical

Key Parameters

- Sv ~ µ , Si ~ 1/n and B_{min}

Graphene is an ideal material
Due to;

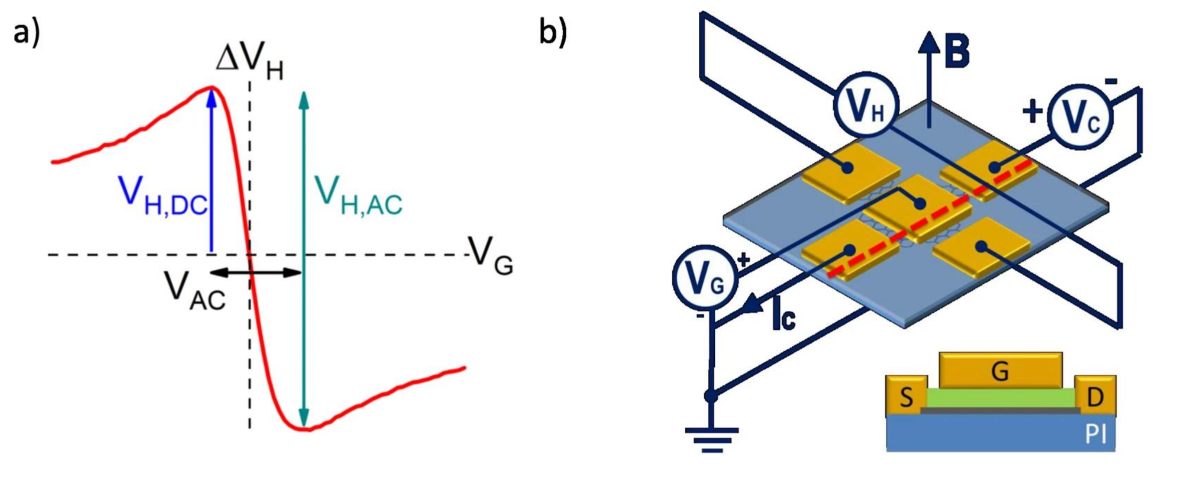
- High mobility
- Low carrier concentration



Alternating current (AC) modulated gate voltage provides two important advantages compared to Hall sensors under static operation;

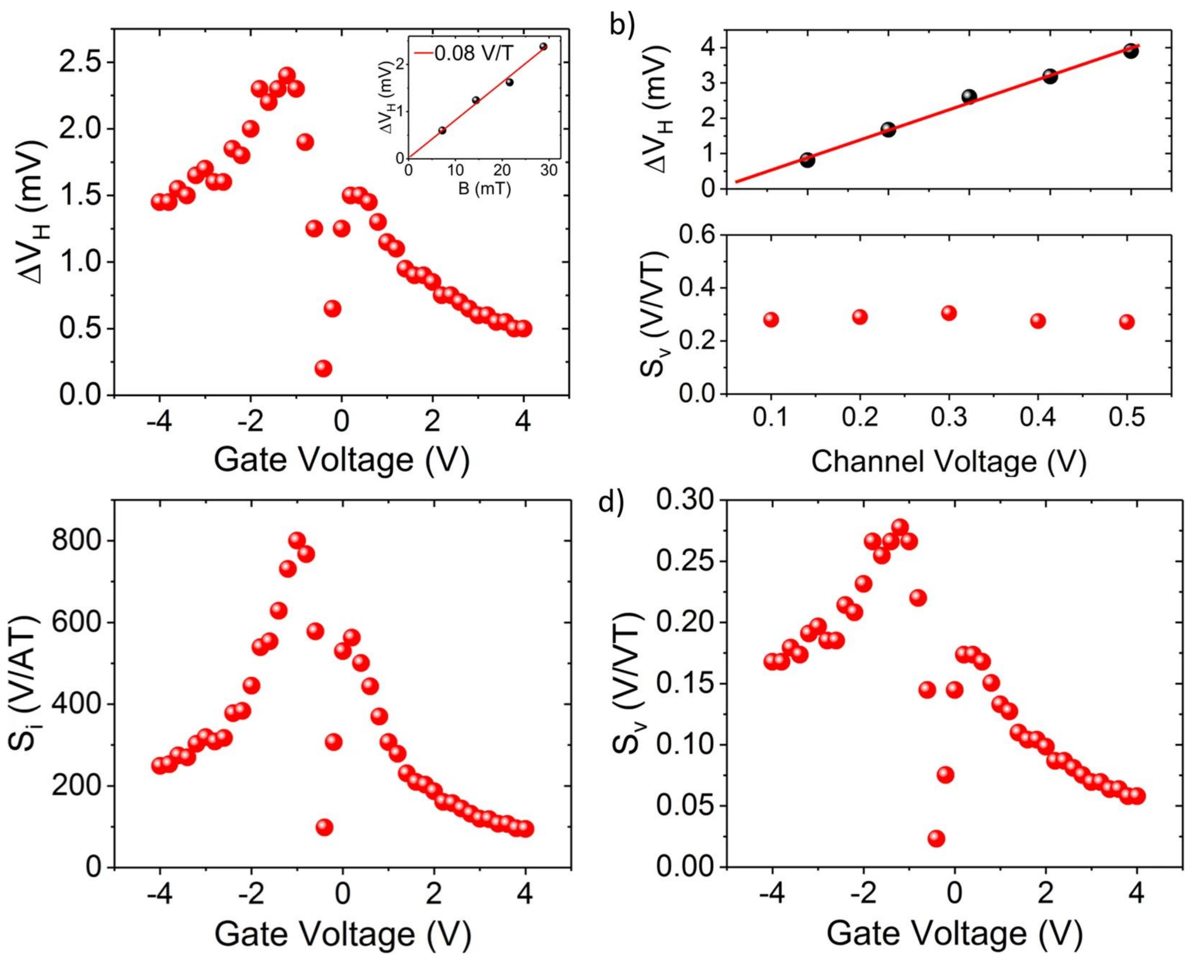
1. The sensor sensitivity can be doubled by utilizing both n- and p-type conductance.
2. A static magnetic field can be read out at frequencies in the kHz range, where the 1/f noise is lower compared to the static case. (better B_{min})

- Flexibility opens up new application fields like wearable sensors for personal fitness and healthcare systems .



(a) Comparison of measured ΔV_{Hall} and basic operating principles using a DC gate voltage and an AC modulated gate voltage across the charge neutrality point. In the latter, both sensitivity maxima for n- and p-type conductance can be utilized and the effective sensitivity is doubled by AC gate modulation.
(b) Isometric device schematic of the top gated graphene Hall sensor

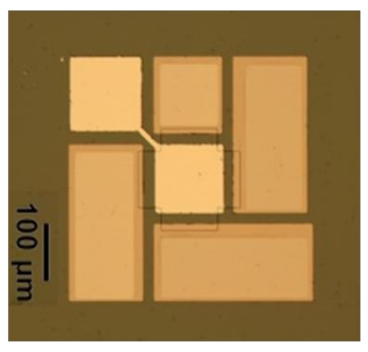
Hall Sensor Under Static Operation



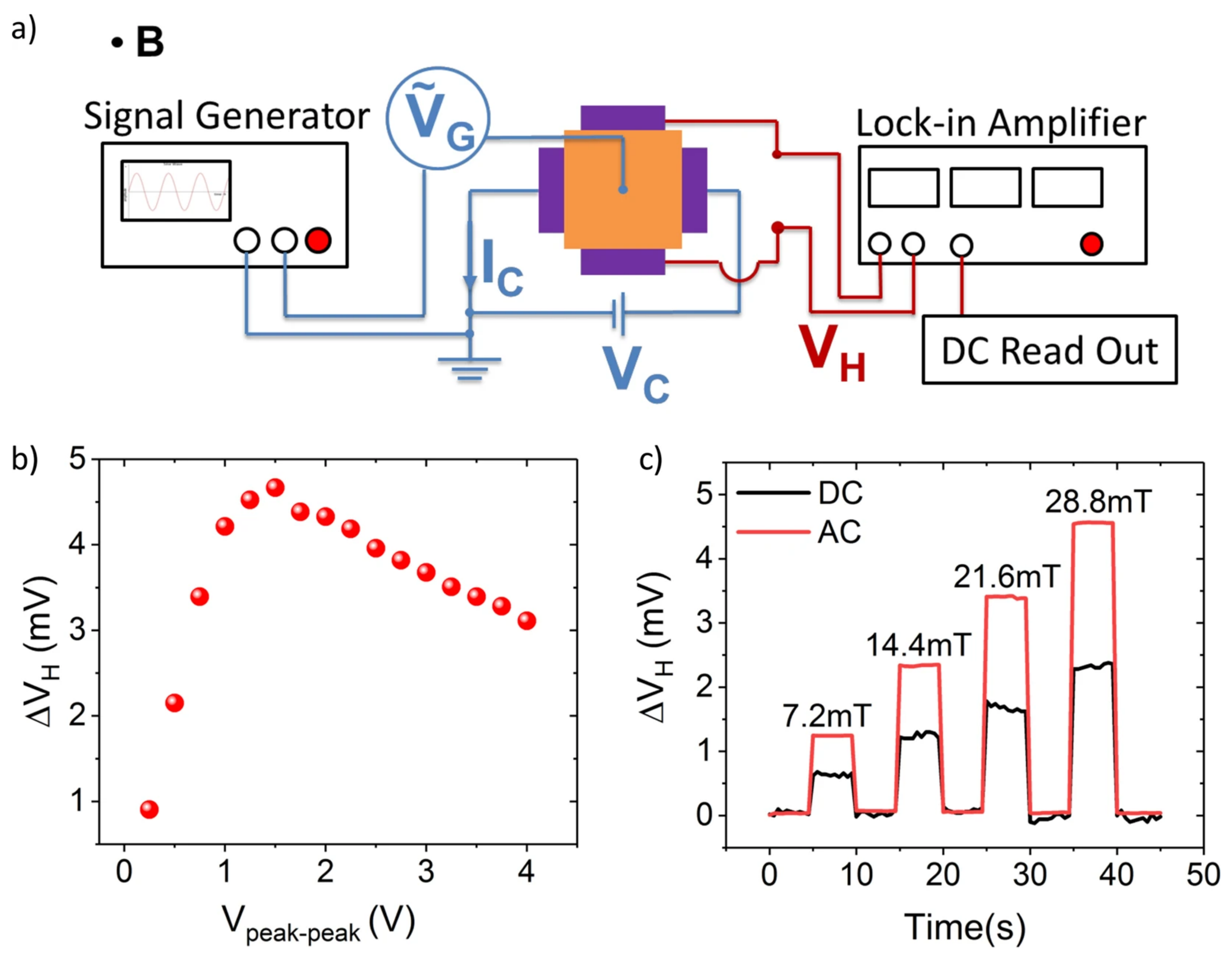
Hall measurements of the sensor. **(a)** Magnitude of the ΔV_{Hall} as a function of the gate voltage at $V_{Channel}$ =300mV. The inset shows ΔV_{Hall} as a function of the magnetic field at V_{Gate} =−1.2V. **(b)** ΔV_{Hall} and voltage sensitivity Sv as a function of channel voltage. **(c,d)** Absolute values of current sensitivity Si and Sv plotted against V_{Gate} at $V_{Channel}$ =300mV.

Measured Hall Mobility of the graphene is 4400 cm^2 /Vs

Microscope Image



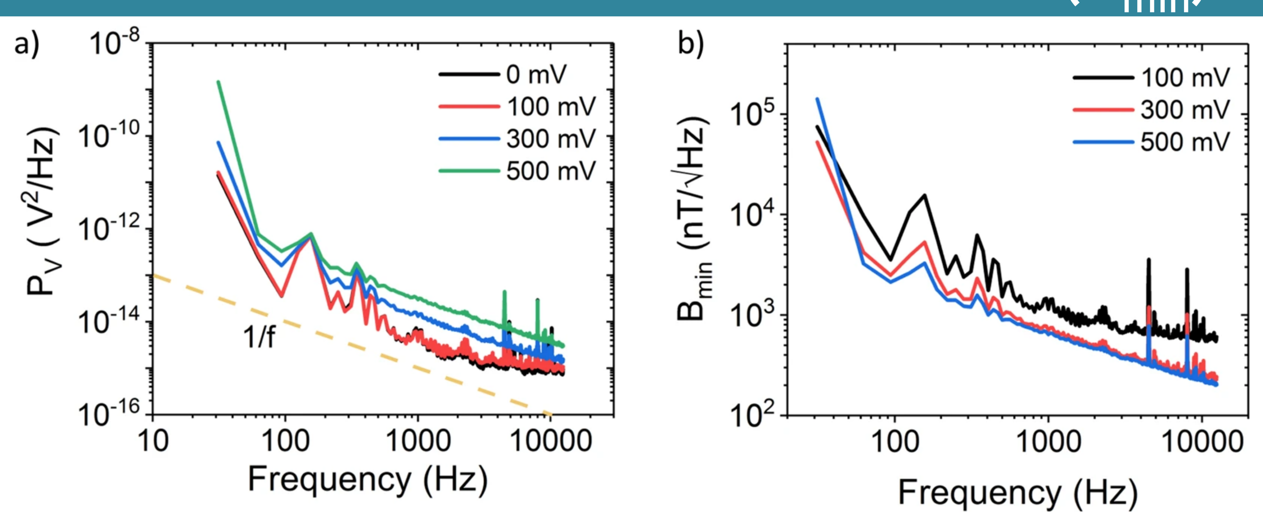
Hall Sensor Under AC modulated Gate Voltage



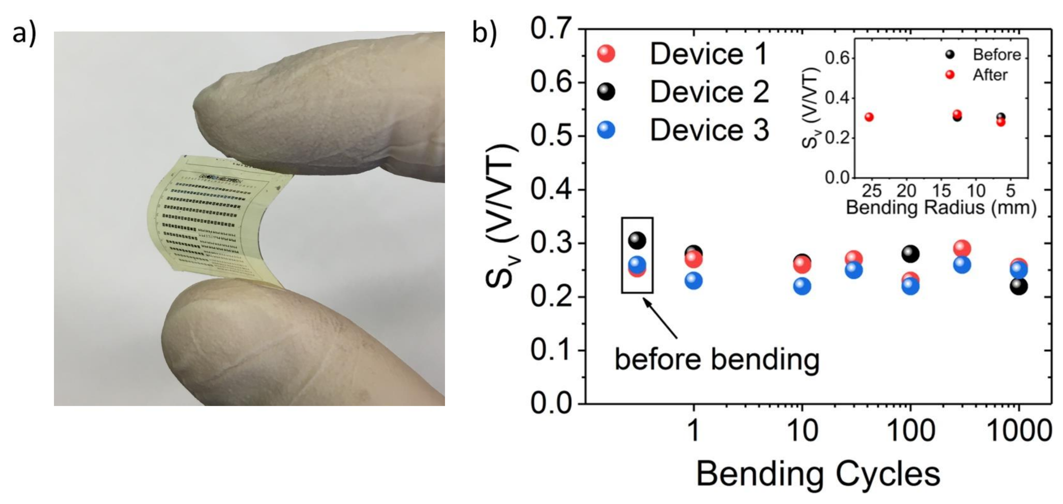
(a) Illustration of AC gate modulation setup . **(b)** Hall voltage response of the device to the varying magnetic field at a peak to peak gate modulation amplitude at 28.8 mT. **(c)** Offset removed Hall voltage under DC (black) and AC (red) operation over time, while the magnetic feld was stepped between 7.2 mT up to 28.8 mT

- Sensitivity is doubled compared to static operation and values up to 0.55 V/VT was achieved on flexible polyimide (PI) substrates.

Noise and Minimum detectable field(B_{min})



Bending Tests For Flexible Hall Sensor



Comparison with Other Hall Elements

	Substrate	S_i (V/AT)	S_v (V/VT)	B_{min} (nT/√Hz)	Frequency (kHz)	Conditions
Si[1,28]	Rigid	100	0.1	5000	3	n/a
AlInSb[4,6]	Rigid	2750	2.2	58	1	Vacuum
GaAs[28]	Rigid	1100	n/a	800	3	n/a
Exfoliated Gr-hBN[9]	Rigid	4100	2.16	50	3	Vacuum
CVD Gr[29]	Rigid	800	n/a	500	3	Vacuum
CVD Gr[30]	Rigid	2093	0.35	100	3	Air
CVD Gr[8]	Flexible	75	0.093	n/a	n/a	Air
CVD Gr-hBN[22]	Flexible	2270	0.68	n/a	n/a	Air
Bismuth[31]	Flexible	2.3	n/a	n/a	n/a	Air
This work	Flexible	1500	0.55	500	2	Air
This work (max)	Flexible	2580	0.68	290	2	Air

Exfoliated hBN

Metrics comparison of different high-performance Hall elements working at room temperature

- **Results show that our CVD graphene based Hall sensors on flexible substrates outperforms all the other Hall sensor elements on flexible substrates and are highly competitive with respect to all existing technologies on rigid substrate. The measured minimum magnetic resolution of our Hall sensors also is close to the very best values achieved by exfoliated graphene based Hall sensors**

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