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Lab & Production Materials

User protocol for graphene FET GRFETS10

Product Info graphene FET S10

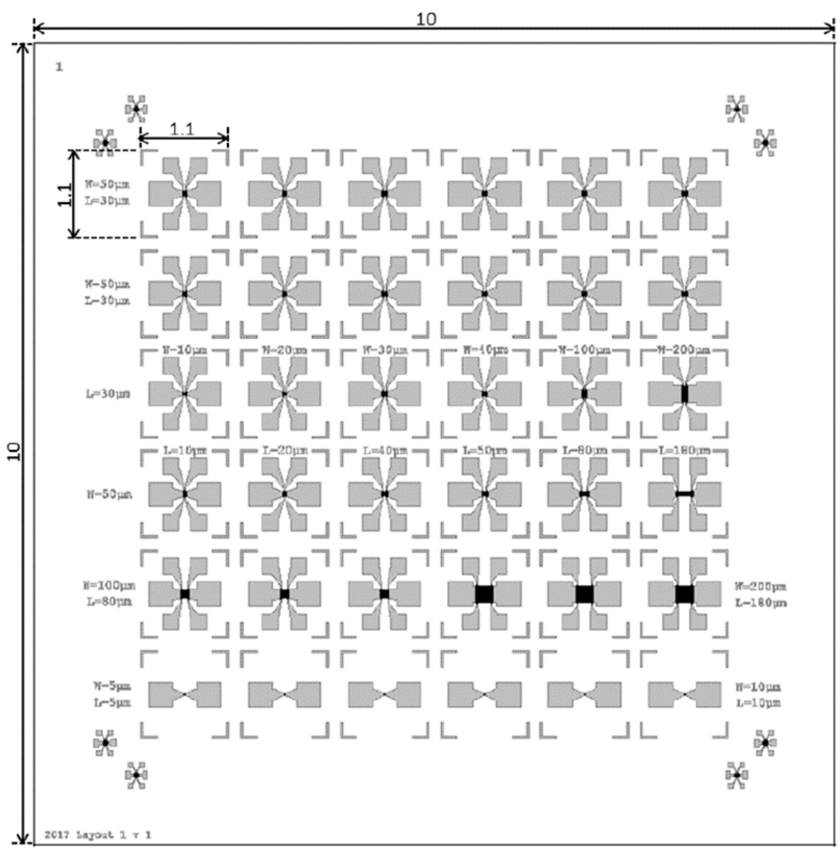
Monolayer CVD grown Graphene based field effect transistors (FET) S10.
Gate Oxide thickness: 90 nm
Gate Oxide material: SiO_2
Resistivity of substrate: 1-10 Ω·cm
Metallization: Nickel/Aluminium 140 nm
Graphene field-effect mobility: >1000 $cm^2/V \cdot s$
Residual charge carrier density: <2 x 10^{12} cm^{-2}
Dirac point: 10-40 V
Yield >75 %

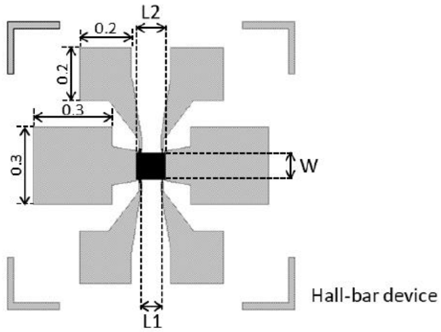
Absolute Maximum Ratings

Maximum gate-source voltage: ± 50 V
Maximum temperature rating: 150 °C
Maximum drain-source current density: 10^7 A/cm^2

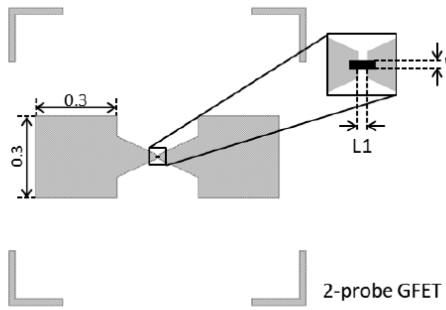
Device configuration

This Graphene FET chip provides 36 graphene devices distributed in a grid pattern on the chip. 30 devices have Hall-bar geometry and 6 have 2-probe geometry.
The Hall-bar devices can be used for Hall measurements as well as 4-probe and 2-probe measurements. There are graphene channels with varied dimensions to allow systematic investigation of device properties.





Hall-bar device

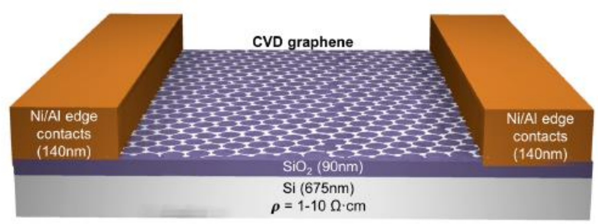


2-probe GFET

Channel geometries

Description	W (µm)	L1 (µm)	L2 (µm)	Quantity
Standard	50	30	50	12
Varying width	10	30	50	1
	20			1
	30			1
	40			1
	100			1
	200			1
Large square	100	80	100	3
	200	180	200	3
Varying length	50	10	30	1
		20	40	1
		40	60	1
		50	70	1
		80	100	1
		180	200	1
Small 2-probe	5	5	-	3
	10	10	-	3

Device cross-section



Device Features

- State-of-art graphene FETs utilizing consistent high-quality CVD grown monolayer graphene
- Devices are not encapsulated and can be functionalized by additives
- Perfect platform for sensor research and development
- 36 individual graphene FETs per chip
- Mobilities typically > 1000 cm^2/V·s

Applications

- Graphene device research[1]
- FET based sensor research for active materials deposited on graphene[2]
- Chemical sensors[2]
- Biosensors[3,4]
- Bioelectronics[3,4]
- Magnetic sensors
- Photodetectors

Basic handling instructions

The monolayer CVD graphene used in this FET device is highly prone to damage by external factors. To maintain the quality of the devices, we recommend taking the following precautions:

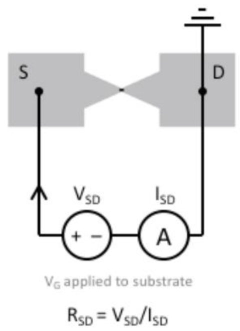
- Be careful when handling the graphene FET chip. Tweezers should not contact the device area directly. Metallic tweezers should be avoided, since they can damage/scratch the chip's surface
- Take precautions against electrostatic discharge
- Ideally store in inert atmosphere or under vacuum in order to minimize adsorption of unknown species from the ambient air
- Do not sonicate the graphene FET dies
- Do not apply any plasma treatment to the graphene FET dies
- Do not subject the graphene FET dies to strongly oxidizing reagents

Usage protocol:

2-probe devices

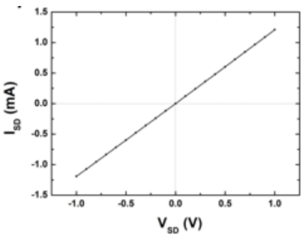
These devices allow field-effect measurements by simultaneously applying two voltages:

• Source-drain voltage (V_{SD}): applied between the two probes (source and drain), while one of them is grounded (see Figure below).



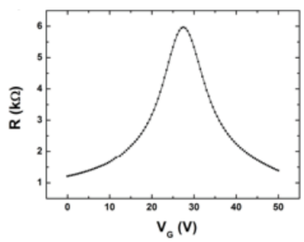
Scheme of the 2-probe device, with the corresponding electrical measurement configuration.

V_{SD} enables the transport of charge carriers through the graphene channel, generating an associated source-drain current (I_{SD}). V_{SD} can be varied in order to get the desired I_{SD} outcome (see Figure below).



Typical output curve measured at room temperature in vacuum.

• Gate voltage (V_G): applied to the Si on the substrate. V_G creates an electric field on the graphene channel, modulating the conductivity of graphene (see Figure below).



Typical transfer curve measured at V_{SD}= 20mV (right), measured at room temperature in vacuum.

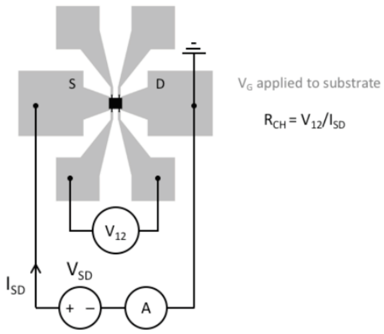
The Si can be contacted either from the top surface by scratching the 90 nm-thick SiO_2 with a diamond pen in one of the chip corners; or alternatively from underneath the chip, for instance via a probe station chuck.

Hall Bars

1. Field-effect measurement

A common improvement of the 2-probe GFET measurement is to apply a source-drain voltage between two outer contacts, measure the current between those two contacts, while measuring the voltage directly across the

graphene channel using two additional inner contacts, V_{12} (see Figure below). This way, the resistance of the graphene channel can be measured without inducing any voltage drops at the graphene-metal interfaces.



Scheme of the 4-probe measurement in a Hall bar device, with the corresponding electrical measurement configuration

The graphene-metal interface resistance does depend on V_G but not in the same way as the graphene channel resistance. Therefore measuring the graphene channel resistance directly in the 4-probe measurement configuration can achieve greater sensitivity to applied gate fields or surface charge changes.

The resistivity of graphene is usually expressed per unit thickness, i.e. the so-called sheet resistance: $R_S = R_{CH}\frac{W}{L1}$,

wherein R_{CH} is the resistance of the graphene channel, W and L_1 is the width and inner length of the graphene channel, respectively. The field-effect mobility (μ_{FE}) can be calculated using the following equation:

$$\mu_{FE} = g \cdot \frac{1}{C_{SiO2}},$$

wherein:

- $g = d_\sigma/dV_G$ is the transconductance, with $\sigma=1/R_S$,
- C_{SiO2} is the capacitance per unit area of the 90 nm-thick SiO_2 dielectric.

μ_{12} is usually calculated using the maximum transconductance.

The field-effect charge carrier density (n_{FE}) is calculated as follows: $n_{FE} = \mu_{FE} \cdot R_S/e$

In order to extract the residual carrier concentration n_0, i.e. the charge carrier density at the Dirac point, we can use the following equation: $n_{FE} = \sqrt{n_0^2 + n_G^2},$

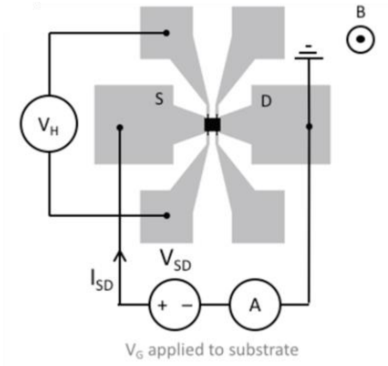
wherein n_G is the gate-induced charge carrier density, which is calculated from: $V_G - V_D = \frac{e}{C_{SiO2}} n_G + \frac{\hbar v_F \sqrt{\pi \cdot n_G}}{e},$

wherein V_D is the Dirac voltage and v_F is the Fermi velocity.

2. Hall Effect measurement

Hall Effect measurement is an alternative way to obtain the mobility and charge carrier density of graphene.

In this case, V_{SD} is applied between the horizontal contacts, whereas the transversal voltage or Hall voltage, V_H, is measured. V_H varies with the applied out-of-plane magnetic field B, due to the Lorentz force the charge carriers experienced. The Lorentz force deflects the charge carries toward the transverse contact, an electric field is thus created and measured by V_H (see below figure).



Scheme of the Hall Effect measurement configuration in a Hall bar.

The Hall mobility (μ_H) and charge carrier density (n_H) are calculated according to: $n_H = \dfrac{1}{R_H \cdot e}$

Where R_H is the Hall coefficient: $R_H = \dfrac{dV_H}{dB} \cdot \dfrac{1}{I_{SD}}$

The mobility can then be calculated as: $\mu_H = \dfrac{n_H \cdot e}{R_S}$

De-Doping treatment

Graphene on SiO_2 is often p-doped after exposing to air due to the adsorption of water molecules and other adsorbents that shifted the Dirac point to positive gate voltages, which can cause the Dirac voltage fall out of the recommended gate voltage range. Simultaneously, a large hysteresis can usually be observed between the forward and backward sweeps of the transfer curve.

Immersing the graphene FET chip in acetone for at least 12h can reduce doping. After that, the chip should be rinsed with IPA, dried with an Ar or N_2 gun, prior to the measurement of the chip. In order to keep this treatment effective, electrical characterization should be carried out in inert atmosphere or in vacuum.

In addition, storage of the chips in a low humidity environment (N_2 cabinet, desiccator, or vacuum) is highly recommended.

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