GRAPHENE: FROM MATERIAL TO APPLICATIONS

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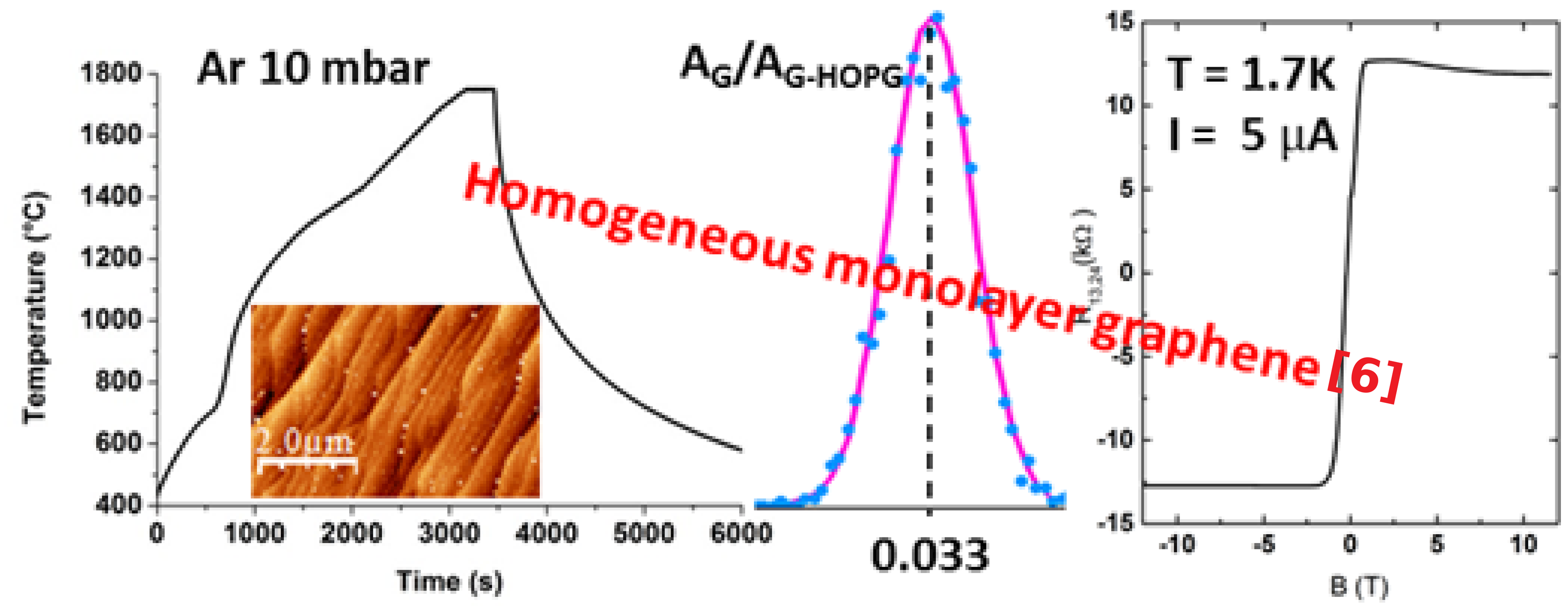
Context : agriculture is one of the major cause of the climate change [1]. In France, agriculture is responsible for 19 % of the national GHG emissions caused by 3 gases : N_2O (50%), CH_4 (40%) et CO_2(10%). Agriculture is doubly concerned since it already faces dramatic consequences, due to climate change, like decrease of crop yields. That motivates the transition toward a new agriculture paradigm, known as **agroecology**. Agroforestry is one of the agroecologic practice, which combines trees and cereal crops. Growing trees and roots will sequester carbon in soils allowing to mitigate the carbon impact of the cultivated parcell [2]. These practices require careful studies of the GHG of the cultivated parcel which would be sustained by new **gaz sensor** technologies : cheap, robust and sensitive.

Mil parcell under Faidherbia Albida at Senegal (http://agraf.msem.univ-montp2.fr/Senegal.html)

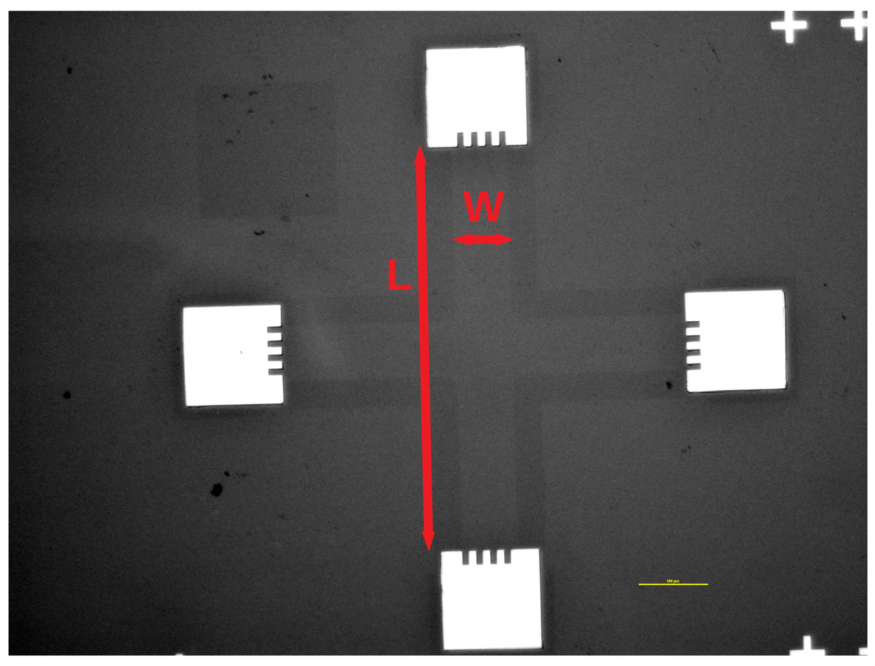
Graphene which has been early identified as very promising gaz sensor [3] still focuses interest in this direction [4,5].
Is graphene sensitive enough to detect greenhouse gaz at a level allowing to sustain agroecologic studies ?

Hall cross design on homogeneous and continued graphene growth on silicon carbide.

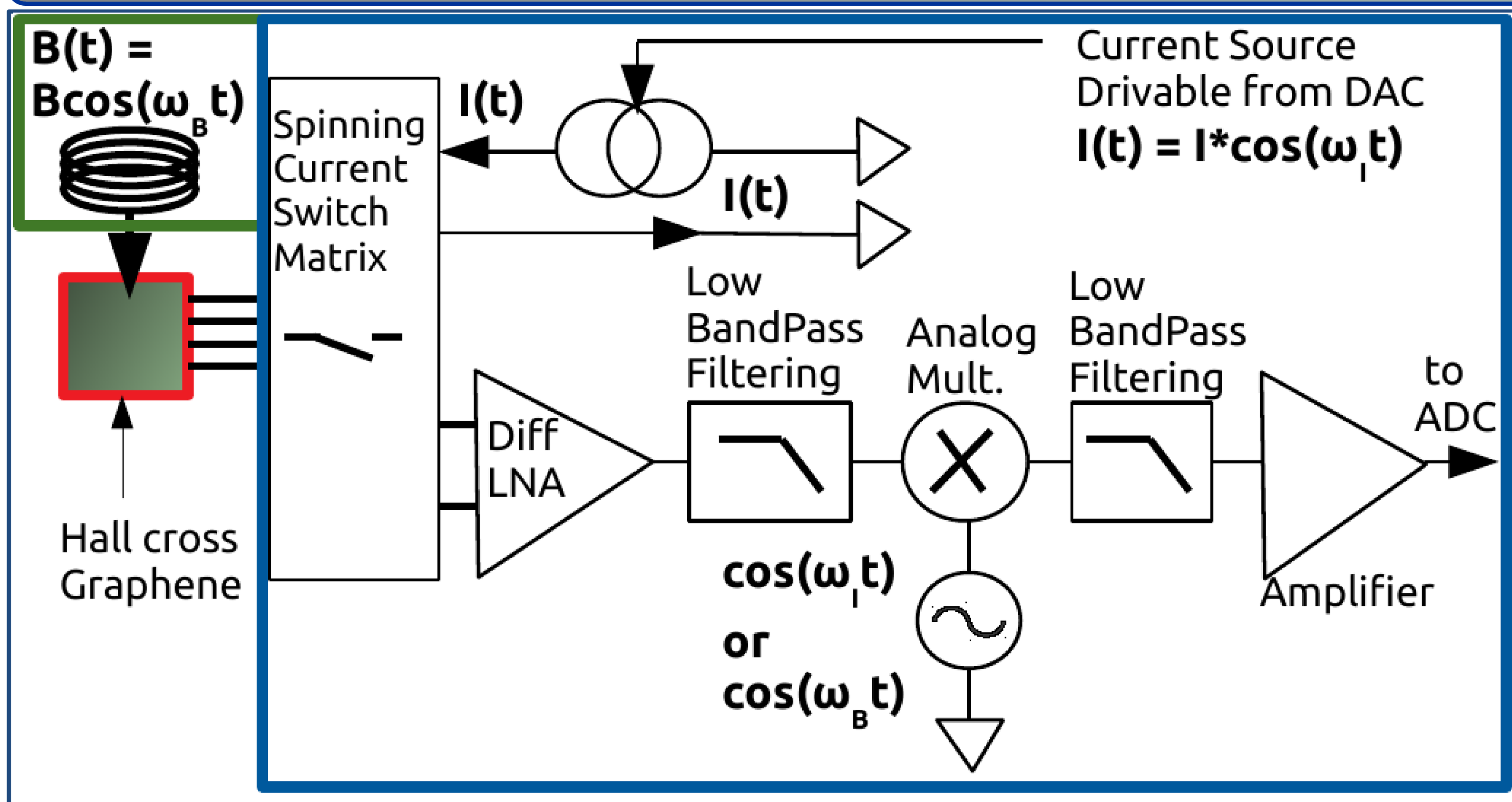


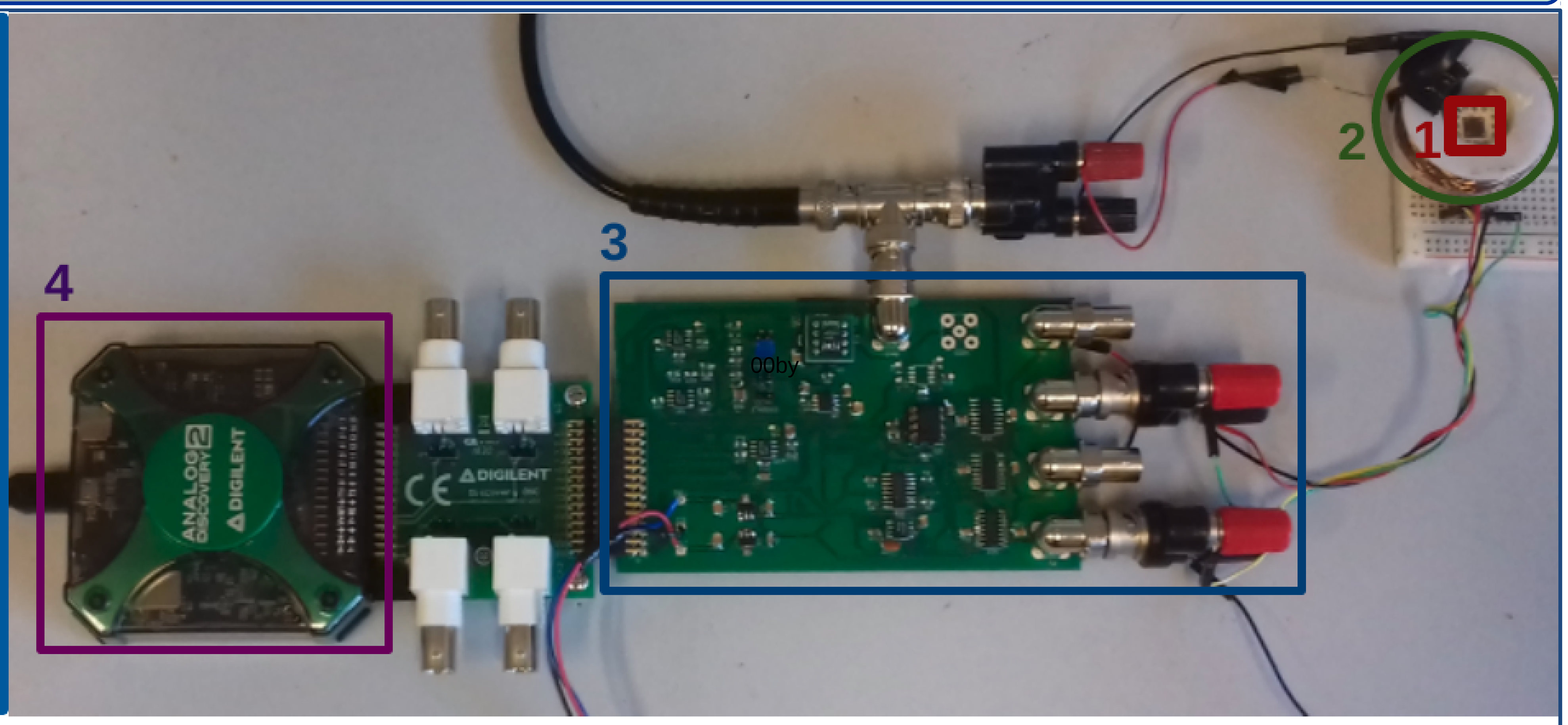
Graphene Hall cross design by electron beam lithography

- Size = 600µmx80µm
- Graphene etching
- Contact pads Ti/Au (10nm/100nm) deposition
- Wire bonding
- Check Raman



From graphene to sensor : development of a dedicated electronic board (@300K)





1: graphene on SiC - 2: magnetic coil - 3: analog board - 4: digital board

Magnetotransport mode

a) Conductivity measurement

- Constant current biasing
→ 2 wires V(I) (Hall cross) or 4 wires Van der Pauw (Square sample)

$$R_{HallCross} = \rho \frac{L}{W} \qquad R_{sq} = \rho \frac{\pi}{\ln(2)}$$

$$\Rightarrow \sigma = q n \mu$$

b) Doping measurement@300K

- Magnetic field modulation
- Constant current biasing
→ Hall voltage measurement

$$\Rightarrow V_{Hall} = \frac{IB\cos(\omega_B t)}{nq}$$

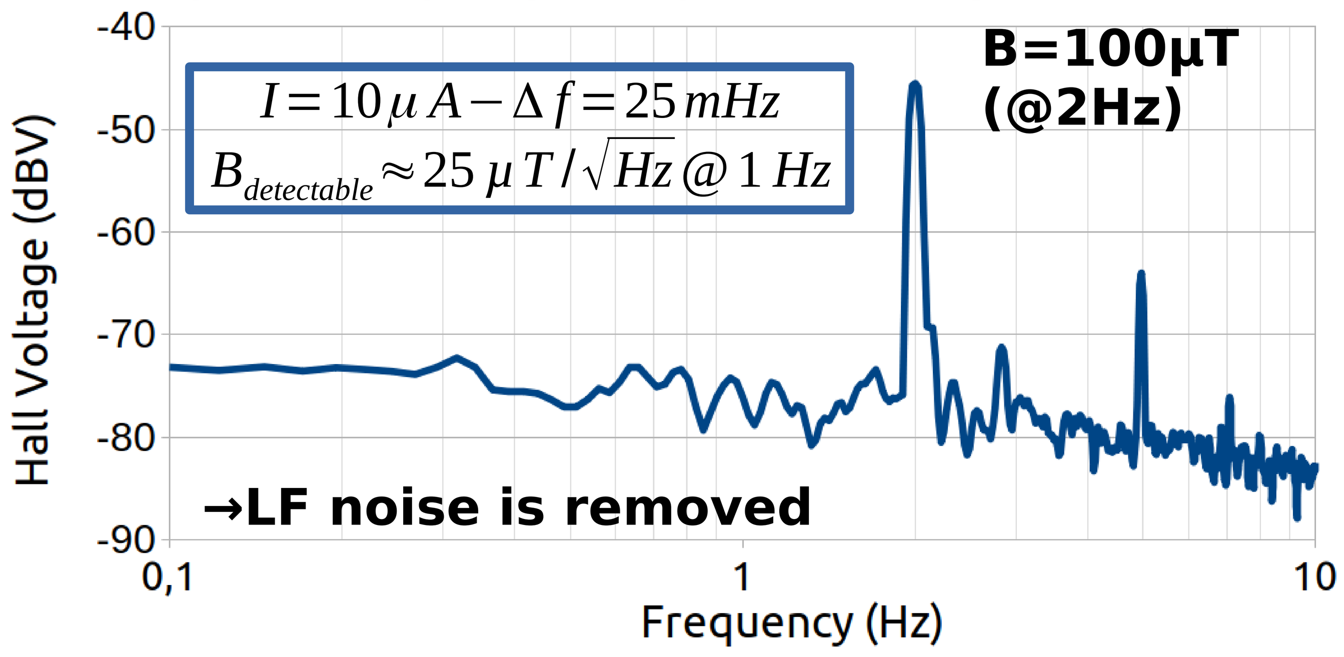
$$n = 4\times10^{12}\,cm^{-2}$$
$$\mu = 1110\,cm^2/(V.s)$$

Magnetometer mode

Biasing current modulation/demodulation
+ Spinning current [6] => cancellation of the offset

$$\Rightarrow V_{Hall} = \frac{I\cos(\omega_I t)\,B}{nq} + R_{offset}\,I\cos(\omega_I t)$$

Spectrum acquiring of Graphene SiC - Magnetometer Mode

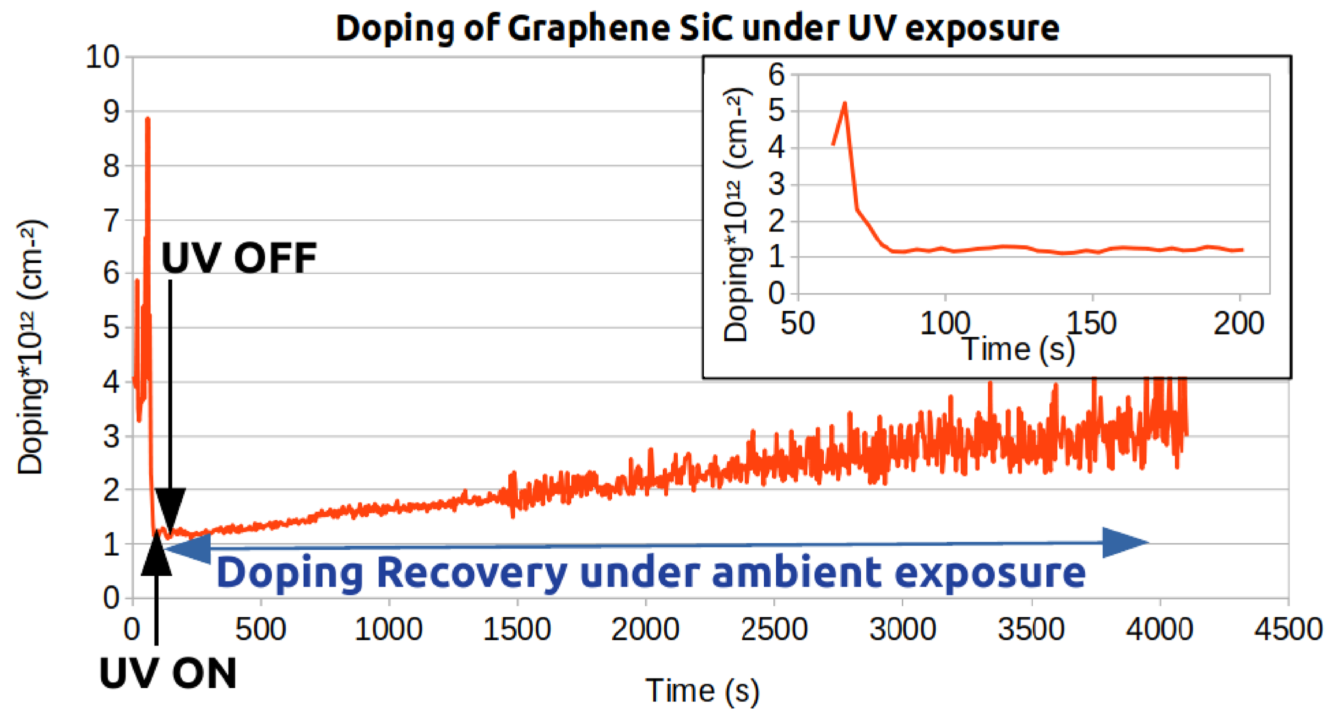


Doping-meter mode

Magnetic field modulation
+ spinning current
+ current modulation (option)

$$\Rightarrow n(t) = \frac{IB\cos(\omega_B t)}{V_{Hall}(t)\,q}$$

Doping of Graphene SiC under UV exposure



→ temporal tracking of doping

Conclusion & perspectives

The spinning current method combined to current modulation allows to remove LF noise giving rise to equivalent magnetic noise **at low frequency** (i.e. <1Hz) significantly impoved with respect to previous work [7]. Improving factors will permit to make graphene suitable candidate for magnetic field sensing.
The doping-meter mode is a first step towards the gas sensing ability [8] which will need to fonctionalize the graphene.

Acknowledgments
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