Two-dimensionnal electrodes for micro/nano-resonators with high quality factor

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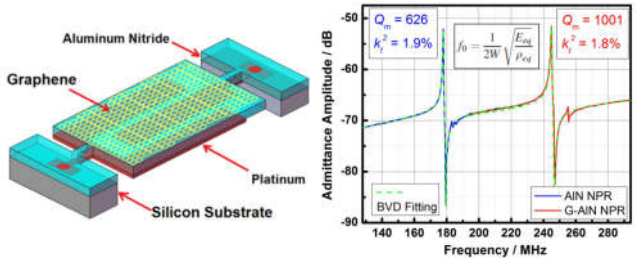
Context:

The electrodes play an important role in the performances of a piezoelectric resonator. They are used for excitation and detection of the resonator vibrations. Usually, electrodes are in gold, with a thickness of ~ 200 nm. However, for resonators with small dimensions and a very high intrinsic quality factor, these gold electrodes spoil the quality factor because of the viscous dissipation of the energy contained in the gold layer [1]. The 2D materials, like graphene, which is a one atom thick conductive layer with a very low mass, is expected to overcome this issue.

State of the art:

Graphene top electrode for ultrahigh frequency piezoelectric nano-electromechanical systems [2]:



	gold	graphene
Thickness (nm)	150	0.6
Mass density (kg/m³)	19300	2200
Sheet resistance (Ω/□)	0.163	30 – 1000 [3]

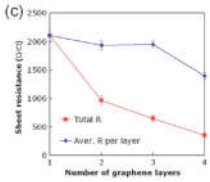
resonator	f_0 (MHz)	Q
AlN	178	626
G-AlN	245	1001

- ✓ Higher operating frequency
- ✓ Higher quality factor
- × Only the top electrode is made in graphene
- × Non patterned graphene electrode

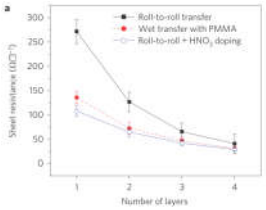
Graphene sheet resistance:

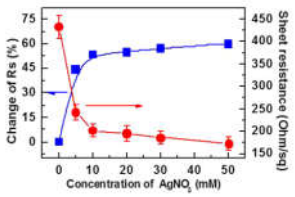
Several techniques to reduce the graphene sheet resistance as:

- ➢ Improving the transfer technique [4]

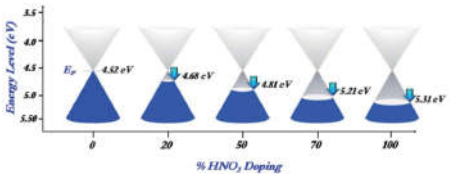


- ➢ Graphene doping [3] [5]:





The Fermi level and the charge carrier concentration can be tuned by doping



Energy dissipation:

Quality factor:

$$Q = 2\pi \frac{E_{stored}}{E_{dissipated\ /period}} \text{ and } Q = \left(\frac{1}{Q_{viscous}} + \frac{1}{Q_{resonator}}\right)^{-1}$$

Gold electrodes

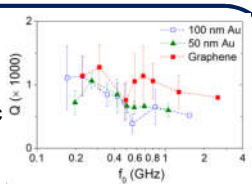
The viscoelasticity of the gold layer induce damping of the resonance:

$$Q_{viscous} = A \times Qe_{lectrode} \frac{E_{resonator}}{E_{electrode}} \frac{t_{resonator}}{t_{electrode}}$$

with A a coefficient, $Q_{electrode}$ the quality factor of the electrodes (strongly dependent on the deposition technique for gold electrodes), E_X the Young's modulus of and t_X the thickness of the material X

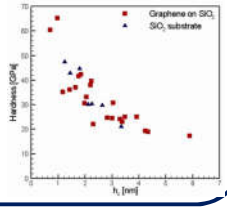
Graphene electrodes

Weak van der Walls interaction of graphene with the underlying piezoelectric substrate ➔ less energy dissipation at high frequency [2]



Transferred graphene on SiO_2: impurity scattering that increases the resistivity and limits the mobility at room temperature due to charged impurities in the substrate [6] and local defects in graphene (as vacancies) ➔ graphene on h-BN can reduce the resistivity [7]

No difference in hardness between graphene on SiO_2 and SiO_2 substrate. Hardness is related to plasticity so graphene seems to behave elastically on SiO_2 [8]
➔ no damping
Same behavior on quartz ?



Perspectives:

The aim of this thesis is to develop a fabrication process of 2D electrodes for micro/nano-resonators with high quality factor. Unlike gold electrodes, 2D crystals may be less intrusive but still conductive. Their resulting performances will be characterized (quality factor, thermal behavior, long term frequency stability).

Bibliography:
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