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SPATIAL MODULATION OF GRAPHENE'S CHEMICAL POTENTIAL

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erc GRAPHICS

ABSTRACT

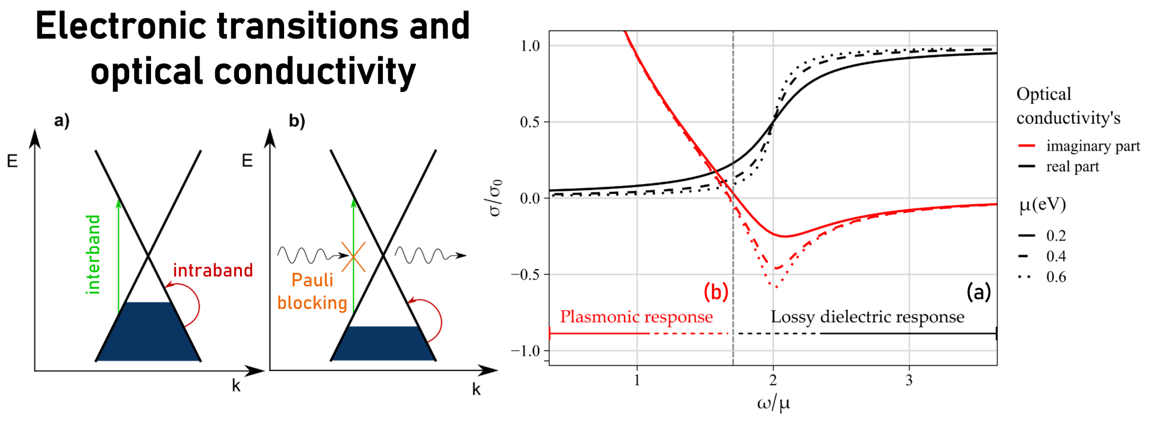
Controlling graphene's chemical potential is significant for photonic and plasmonic applications since this provides a way to modulate its optical properties at the core of tunable/reconfigurable devices [1]. In addition, chemical potential spatial control would allow us to engineer doping profile areas in graphene thus enabling the development of novel components without patterning the graphene sheet nor implementing complex matrices of electrodes [2, 3].

We here propose and characterize a structure to achieve spatial modulation of graphene's chemical potential by using charge transfer between graphene and transition metal oxide [4, 5]. Graphene is transferred onto a structure, which consists of a patterned 10nm-thick layer of tungsten oxide (WO3) deposited onto 90nm-thick silica layer on a silicon substrate. Depending on the supporting material, namely silica or tungsten oxide, graphene is expected to have a different chemical potential. Nano-XPS scans indeed suggest a chemical potential shift of 0.1eV between graphene areas in contact with either silica or tungsten oxide, which is further confirmed by Raman spectroscopy cartography.

This approach paves the way towards an easy implementation of spatial doping modulation in graphene without patterning or chemical modification of graphene.

CONTEXT

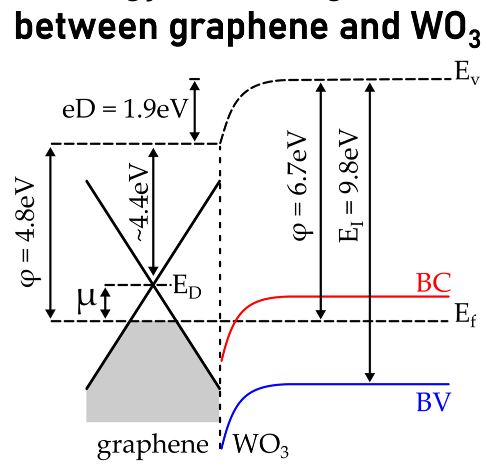
Electronic transitions and optical conductivity



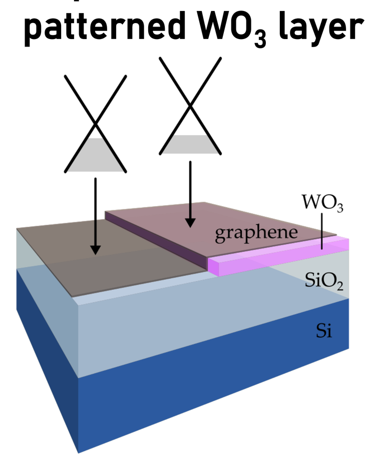
- Optical conductivity depending on graphene's chemical potential [7]
- Modulation of plasmon dispersion and photon absorption with the chemical potential [1]
- Chemical potential spatial control for the development of non-Hermitian photonic devices [2] and plasmonic metasurfaces [3, 8] without graphene patterning or complex electrode implementation

CHARGE TRANSFER WITH WO_3

Energy levels alignment between graphene and WO_3

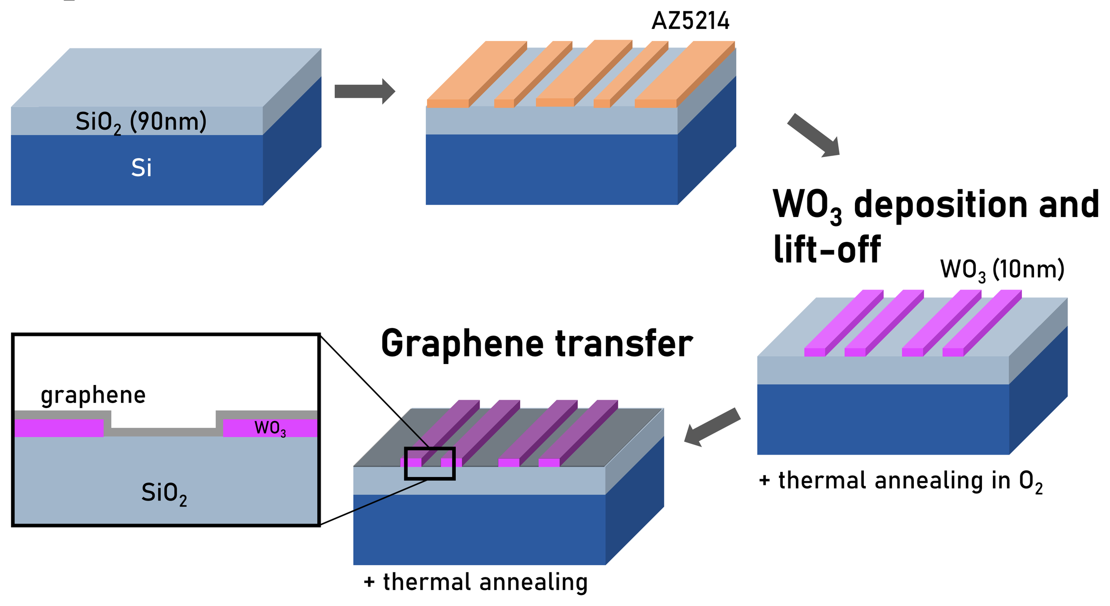


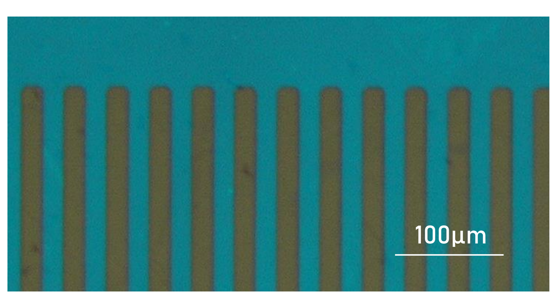
Graphene transfer on patterned WO_3 layer



- Charge transfer between graphene and transition metal oxides demonstrated with MoO_3 [4]
- Electrostatic p-doping of graphene expected on WO_3 [5] with an estimated µ~0.4eV
- Spatial modulation of graphene's chemical potential investigated using graphene transfer on a patterned WO_3 layer

FABRICATION



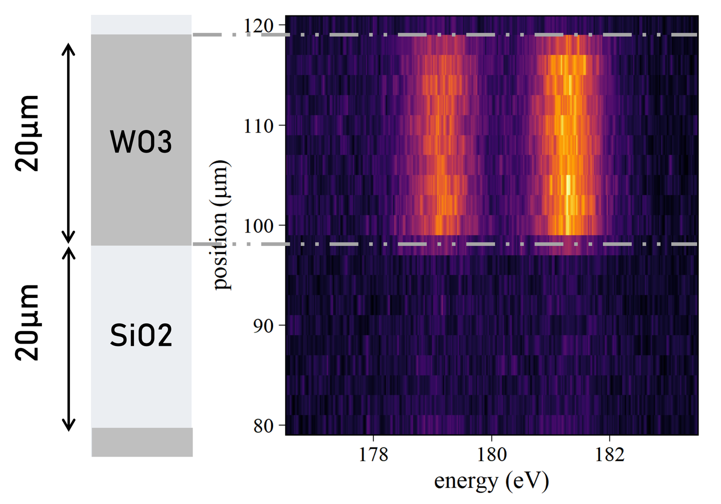


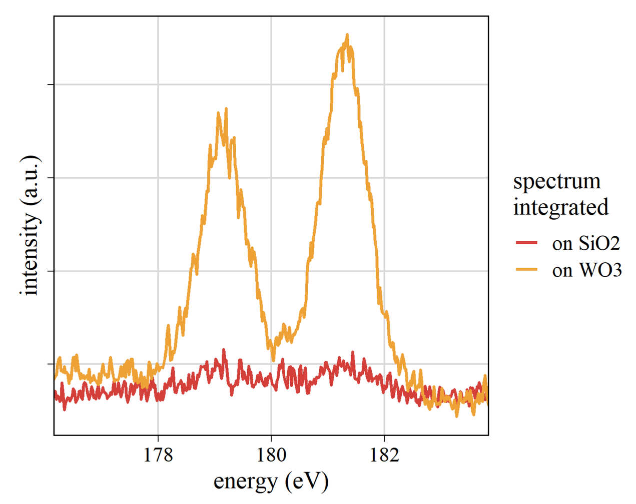
Optical image of fabricated sample

- WO_3 deposition using magnetron sputtering with Ar/O_2 plasma at room temperature
- Layer patterning using UV-lithography and lift-off
- Graphene transfer via PMMA stamp (ACS material Trivial Transfer)

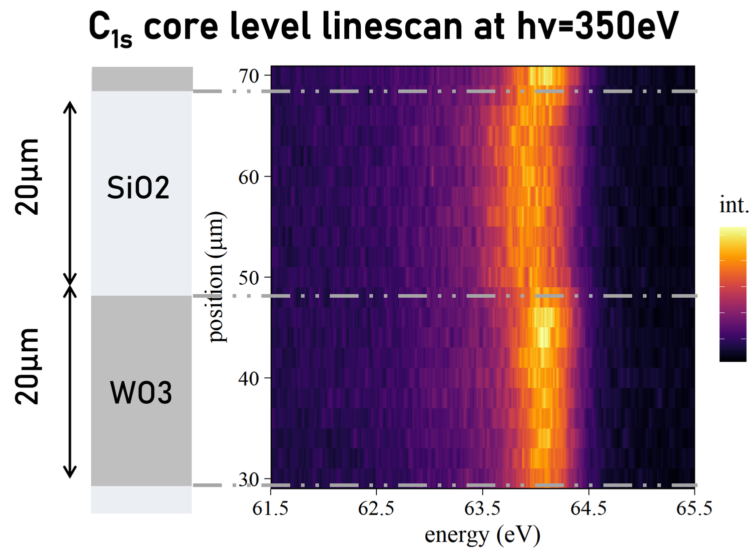
NANO-XPS MEASUREMENTS

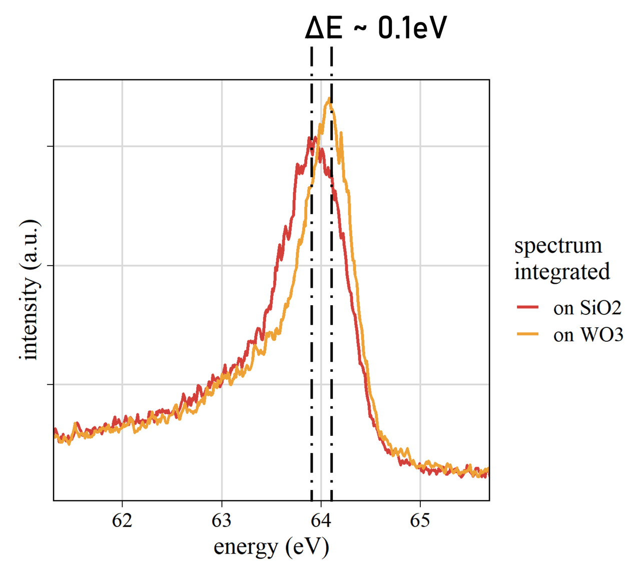
W_{4f} core levels linescan at hv=220eV





C_{1s} core level linescan at hv=350eV



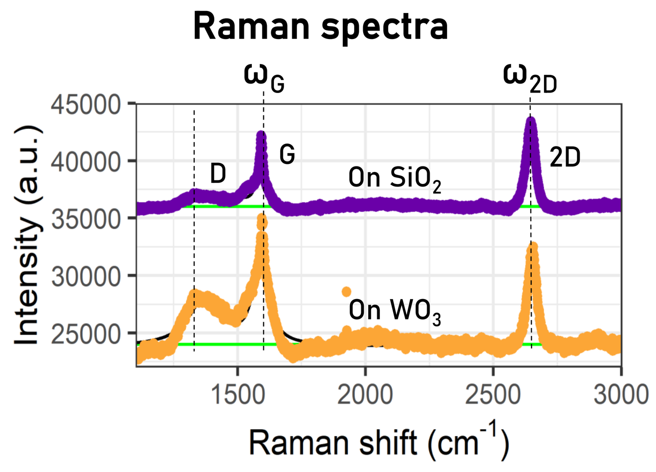


- Measurements carried at ANTARES beamline of SOLEIL synchrotron [9]
- Excitation with focalized photon probe <1µm and selected energy hv
- WO_3 structures observed using tungsten core levels (W_{4f}) observed at hv=220eV
- Evidence of patterning obtained by scanning the probe over the surface
- Observation of graphene related carbon core level (C_{1s}) observed at hv=350eV
- Effect of WO_3 structures on C_{1s} core level position
- Energy shift of about 0.1eV between graphene on SiO_2 and graphene on WO_3
- Similar C_{1s} line shape over the surface indicating the same chemical environment

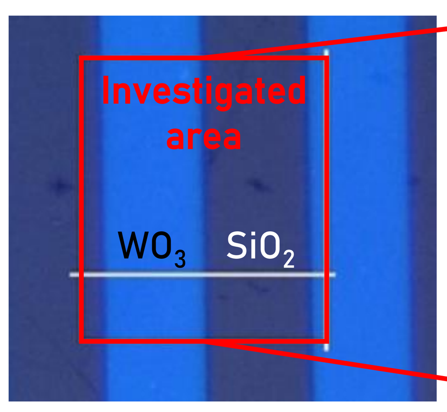
- Variations in carbon core level energy related to variations in electrostatic doping
- Energy shift attributed to p-doping induced by WO_3

RAMAN SPECTROSCOPY

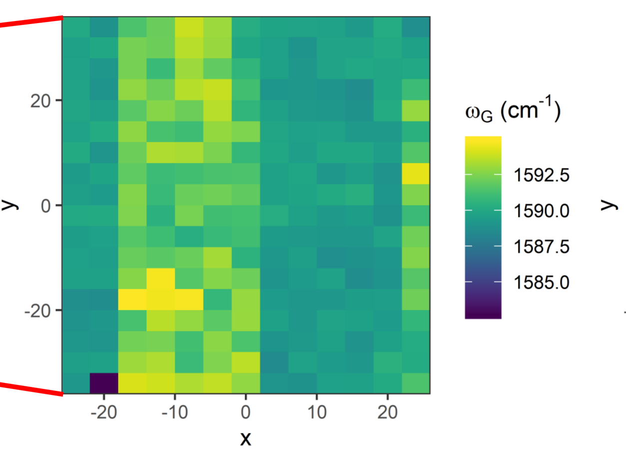
Raman spectra



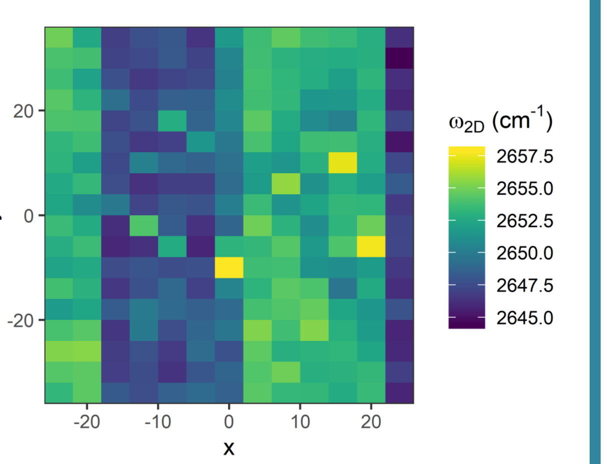
Optical image



G frequency map

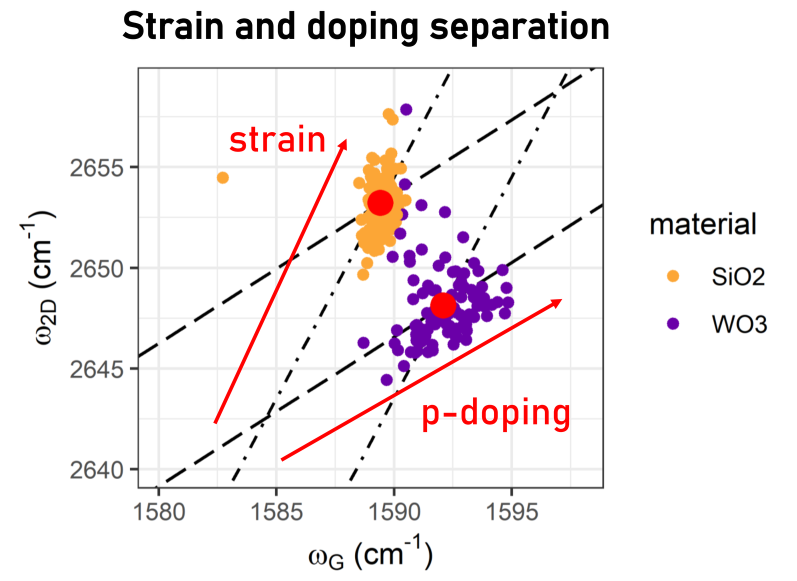


2D frequency map



- Measurements performed using a confocal microscope with 633nm laser
- Observation of graphene related bands on Raman spectra
- Band broadening of D and G bands associated with the presence of amorphous carbon [10]
- Observation of substrate induced effects on G and 2D bands cartography

Strain and doping separation



- Cartography over a WO_3 structure with 40µm period
- Separation of strain and doping using G and 2D frequency maps [6]
- Doping modulation of about 0.1eV
- Strain modulation of about 0.2%

- Spatial modulation of graphene's chemical potential confirmed using Raman spectroscopy with doping modulation of 0.1eV

CONCLUSION

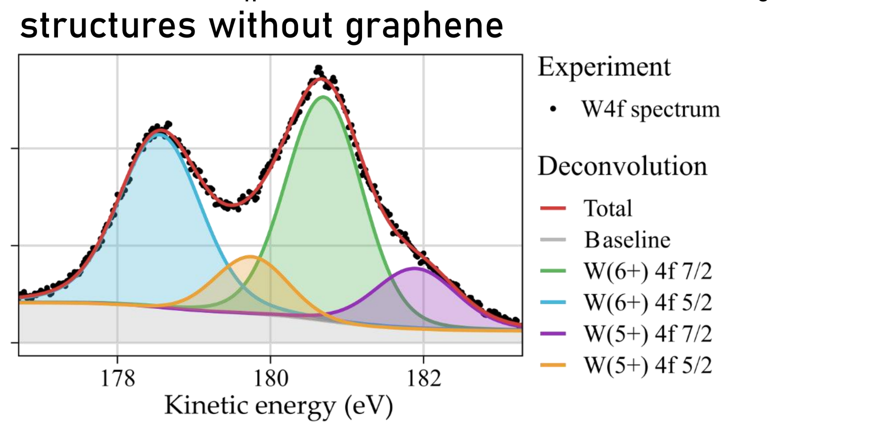
- Demonstration of charge transfer between graphene and WO_3
- Demonstration of graphene's chemical potential spatial modulation using WO_3 patterns on SiO_2

- Doping modulation of 0.1eV obtained using simple fabrication process
- Template readily available for developing novel plasmonic and mid-IR devices

PERSPECTIVES

- Evidence of oxygen vacancies in WO_3 [11] attributed to thermal annealing in vacuum
- Room for improvement of charge transfer figures
- Application of the method with other oxides

Nano-XPS W_{4f} core levels measured on WO_3 structures without graphene



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