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SAW-driven plasmons in graphene heterostructures for sensing ultrathin layers

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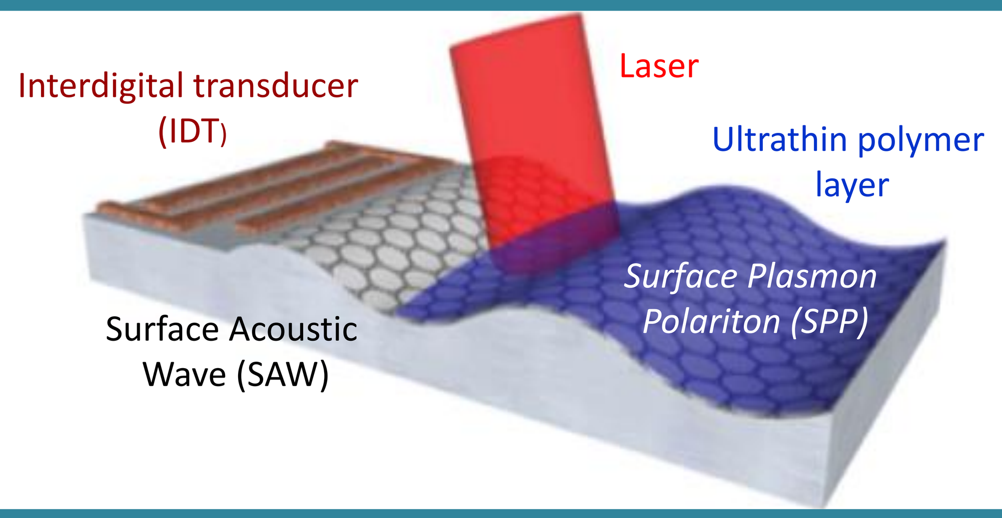
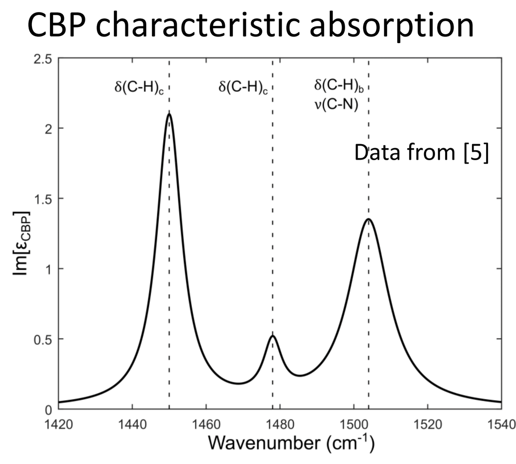
GRAPHENE PLASMON POLARITONS FOR SURFACE ENHANCED INFRARED ABSORPTION (SEIRA) SPECTROSCOPY FINGERPRINTING

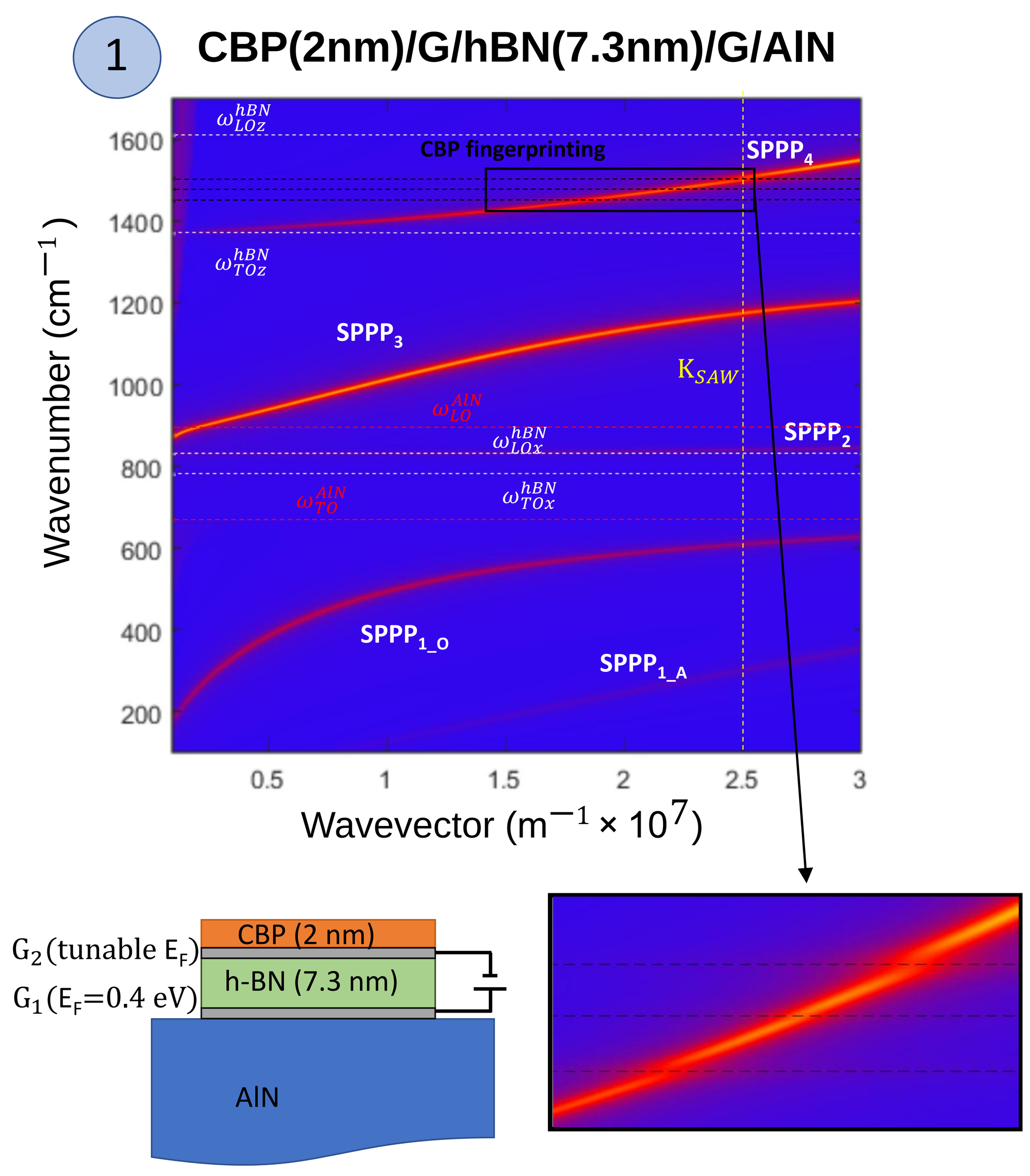
- Large size mismatch between IR light ($\lambda\sim\mu$m) and molecules (size$\sim$nm) results in low absorption cross-section, thus weak signals in spectroscopy.
- Graphene offers great confinement of EM radiation in the form of tunable surface plasmon polaritons [1,2]. Surface Acoustic Waves (SAWs) can be used to couple far field radiation into polaritons through a dynamic diffraction grating without any patterning [3,4].
- The interaction between two coupled oscillators (dipole moment of molecule and electric field of polariton) driven by an external force (light) leads to a Fano resonance (transparency window within the absorption peak).
- In this work, a transfer matrix method is used to study SAW-assisted Surface Plasmon-Phonon Polaritons (SPPPs) in graphene on AlN heterostructures for the detection and fingerprinting of thin layers of 4,4′-bis(*N*-carbazolyl)-1,1′-biphenyl (CBP), which is a good initial benchmark for biosensing.



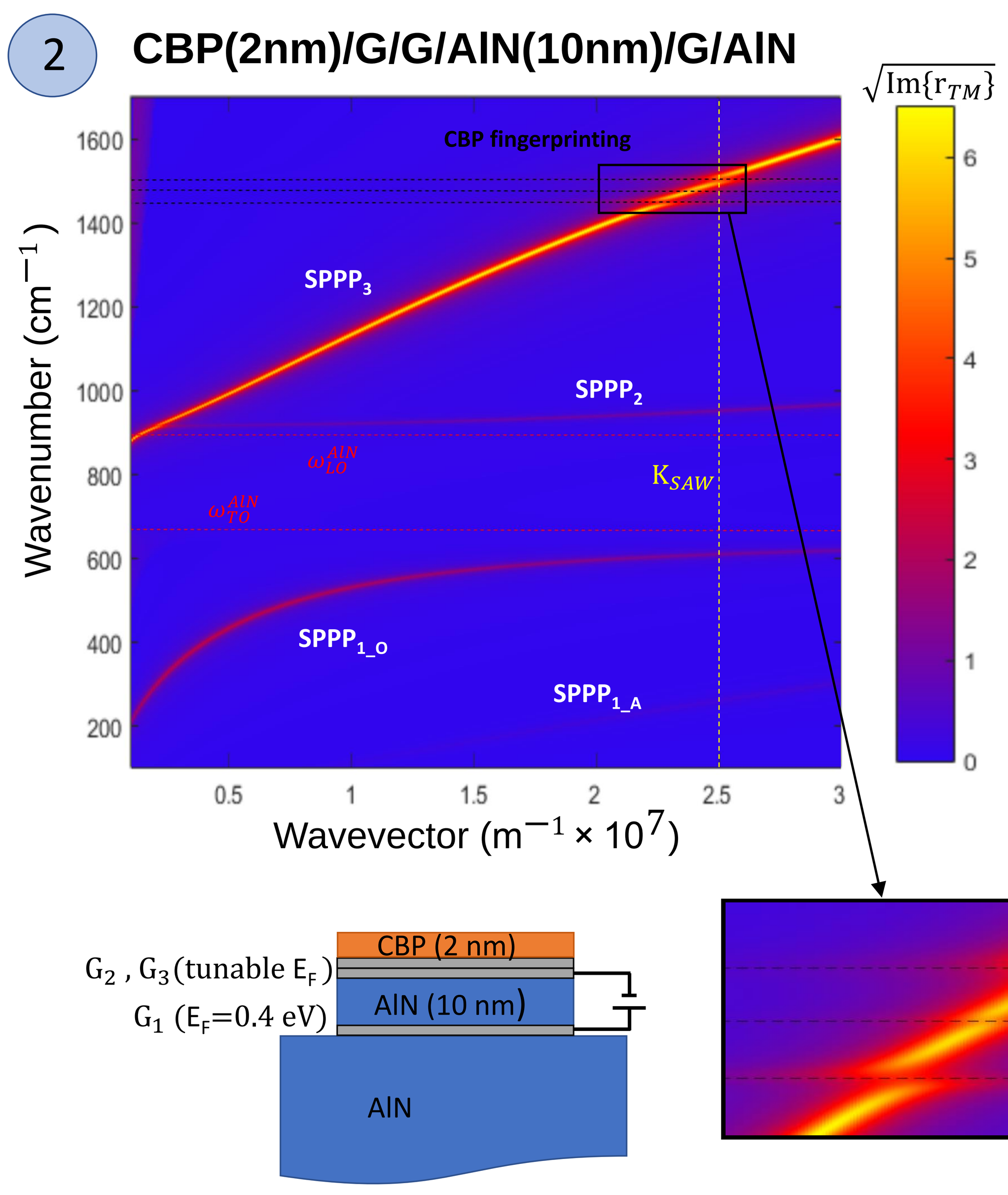
CBP characteristic absorption



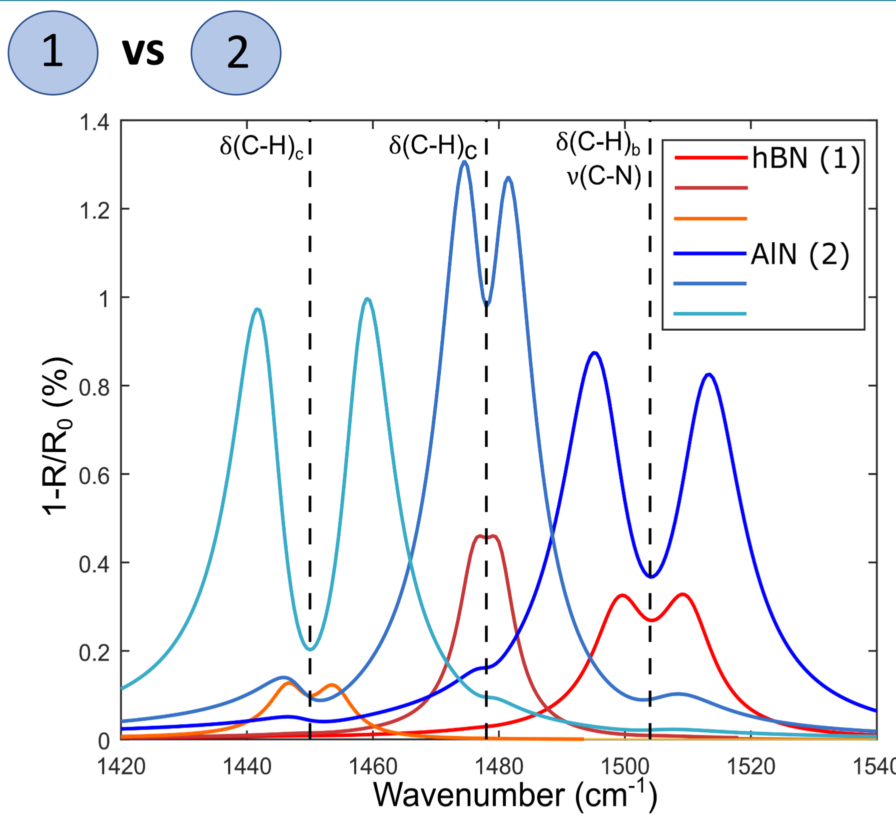
SURFACE PLASMON-PHONON POLARITONS (SPPP) IN GRAPHENE/AlN-BASED HETEROSTRUCTURES COVERED BY ULTRATHIN POLYMER LAYERS



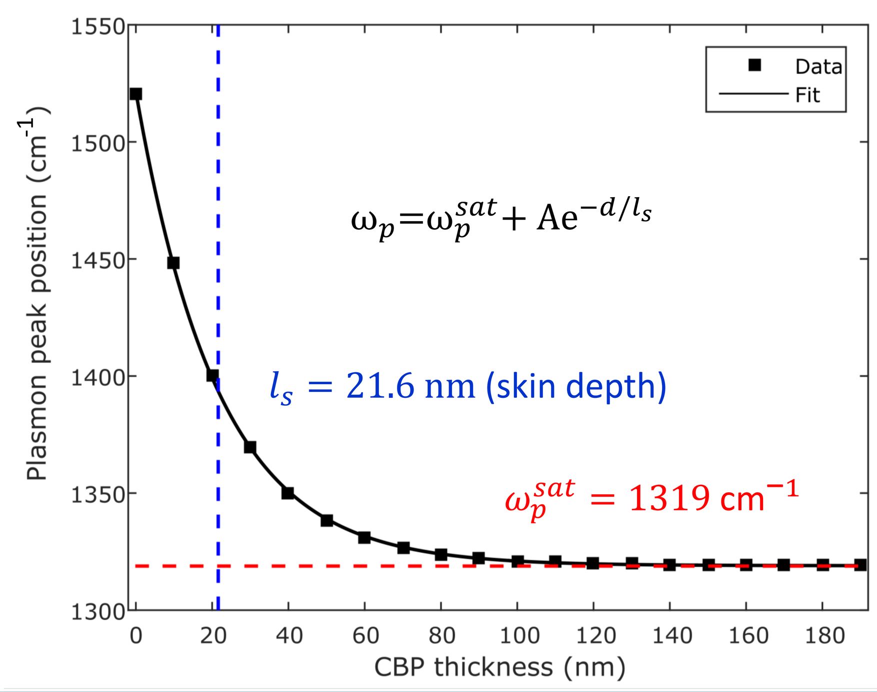
- Bottom doped graphene layer (G_1) allows gate-doping of undoped top layer (G_2) with h-BN as insulator.
- Hybridization with h-BN phonon creates branch ($SPPP_4$) in CBP fingerprint region.



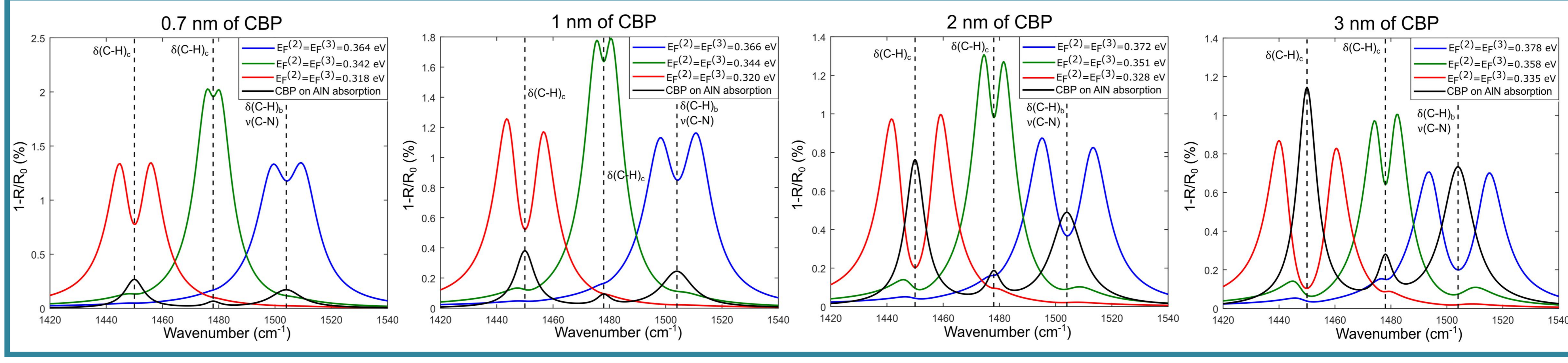
- Bottom doped graphene layer (G_1) allows gate-doping of undoped top layers (G_2 and G_3) with AlN as insulator. Recently, transfer of III-nitride 2D layers has been reported [6].
- $E_F^{(2)+(3)} = E_F^{(2)} + E_F^{(3)}$ [7] blue-shifts $SPPP_3$ towards the fingerprinting region.



- Polariton swept in wavenumber to match different resonances of CBP by tuning graphene E_F.
- Stronger Fano resonances (deeper transparency windows) result from larger differences in damping of oscillators.
- Transparency with h-BN spacer (1) is weaker than with AlN (2), since hybridization with h-BN phonon increases polariton lifetime leading to a closer damping value to that of CBP.

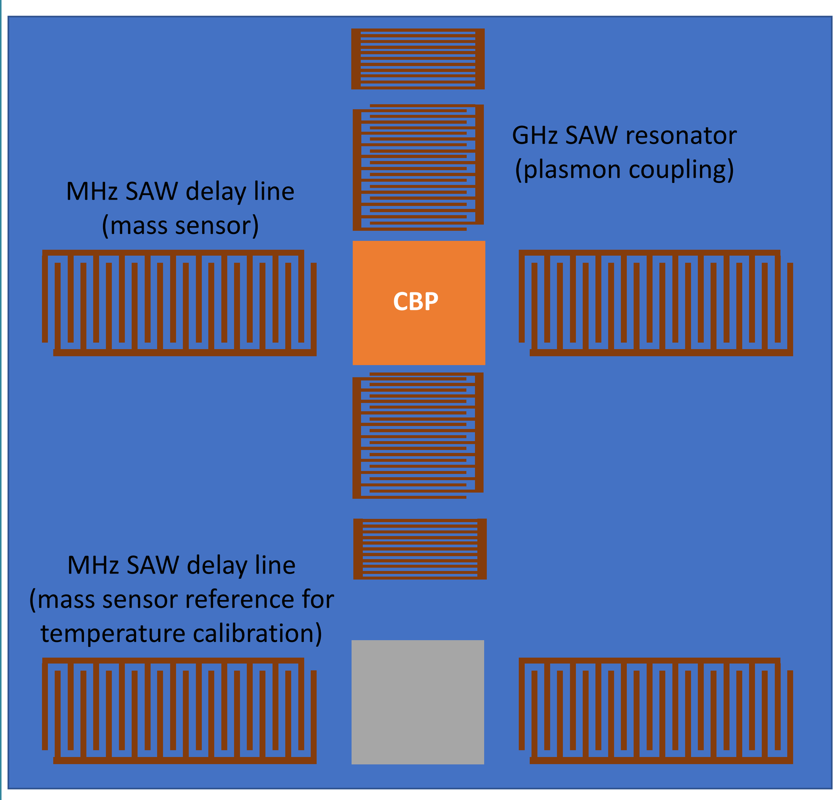


DETECTION OF CBP ON GRAPHENE/GRAPHENE/AlN/GRAPHENE/AlN HETEROSTRUCTURE



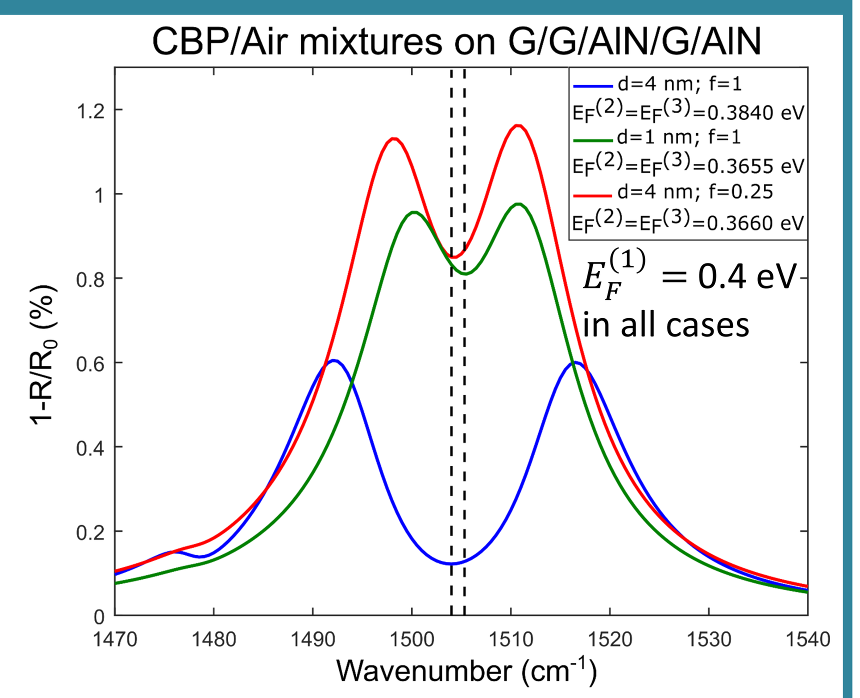
- SEIRA fingerprinting of ultrathin CBP layers (0.7-3 nm) with larger signal (dips in color curves) than regular absorption (peaks in black curves).
- When increasing the CBP layer thickness, both width and depth of transparency window increase as the dipole moment that interacts with the plasmon and thus the coupling strength are enhanced. This is more evident for the central resonance (1478 cm^{-1}).
- $E_F^{(1)} = 0.4$ eV for all four cases.

FURTHER FUNCTIONALITIES



- SAW-assisted plasmon-phonon polaritons can identify a chemical compound through its IR fingerprint, whereas the SAW can also quantify amount of chemical (mass) deposited by measuring changes in acoustic central frequency.
- In incomplete layers (i.e. mixtures of chemical/air modeled as a change in volume fraction, f, of chemical in air) a difference in plasmon amplitude appears, along with a frequency shift of the vibrational resonance.
- Optical frequency shift can be used to determine whether deposited chemical forms a complete layer, allowing to distinguish two configurations with same amount of mass (red and green curves in CBP/Air calculations).

CBP/Air mixtures on G/G/AlN/G/AlN



Bruggeman's theory [8] is used to model the permittivity of a CBP/Air mixture to simulate an incomplete CBP layer.

CONCLUSIONS

- The interplay of SAW-mediated plasmon polaritons in unpatterned graphene with the vibrational fingerprints of a chemical can be used to detect ultrathin layers of said substance by SEIRA.
- Different heterostructures comprising graphene on AlN can be used to identify analytes by means of their IR fingerprint. Better results are obtained when neither the spacer nor the substrate present phonons within the detection range.
- By electrostatic doping of the graphene sheets, several vibrational resonances can be accessed within a range of analyte thickness.
- A better performance than by regular IR spectroscopy can be achieved when examining layers thinner than 3 nm.
- SAW mass sensors can be combined with the SAW-assisted plasmon coupler to retrieve more information about the analyte.

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