Tunable Graphene-Dielectric Epsilon-Near-Zero Metamaterial (ENZ MM)

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Abstract

ENZ MMs are media with vanishing real part of the relative permittivity. Useful for spatial light control, enhanced light-matter interaction and nonlinear optics. By mixing subwavelength metal and dielectric, fine-tuning of the ENZ operation wavelength of the resulting effective medium over wider ranges is possible. We show a Graphene/Ge multilayer ENZ MM in the IR region, and discuss its dynamic tunability via external control of the graphene's potential.

T/R measurements of optical responses in a bilayer graphene/Ge(670±10nm) ENZ MM (GFET):

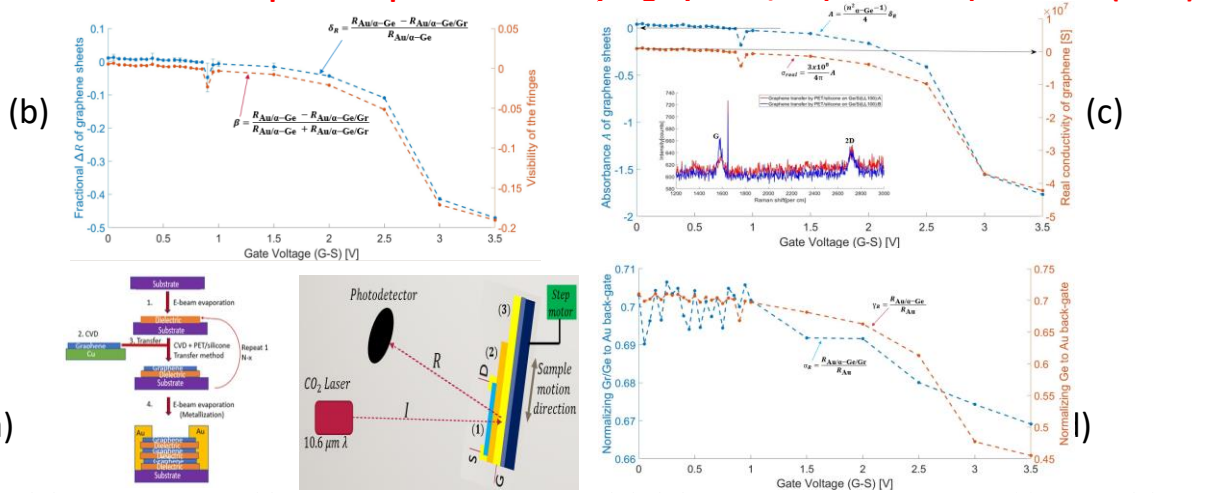

Fig 2 (a) Flow diagram (i) and electro-optic set-up (ii), (b) Gr contrast & visibility of fringes, (c) $\boldsymbol{A}$, and $\boldsymbol{\sigma_g'}$, (d) Normalized Gr/Ge and Ge to back-gate Au at $10.6\mu m$ vs V_g

Project Description: Goal: 5-p Gr/Ge ENZ MM stacks (fig. 1a) and tune $\boldsymbol{\varepsilon'_{r||eff}}$ with $\boldsymbol{V_g}$. ENZ region is $|\varepsilon_r'| \leq 1$, results in fig 1b.

Gr's μ_c tuned by $\boldsymbol{V_g}$ as

$$|\mu_c| = \hbar v_F \sqrt{\{\pi |a_o(\boldsymbol{V_g} - V_{dirac})|\}}$$ [1],

So fig 1b(i) is tunable

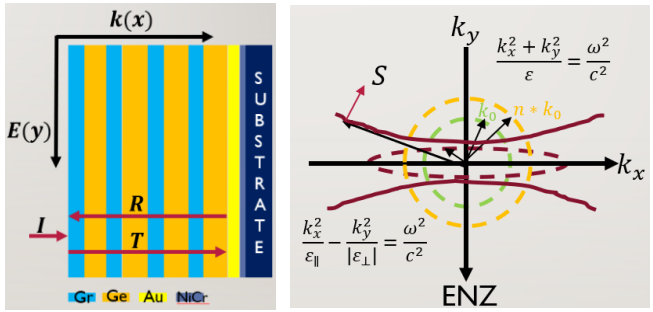

Fig.1 Design (a) & IFC (b)

Due to nonlocality, T-M E-field continues at interface with $k \perp$ to 1D film (fig 1a), so interaction is only by EMA, $t = (t_g + t_d) \approx t_d \ll \lambda$,

So, $\boldsymbol{\varepsilon'_{r||eff}} = \frac{\boldsymbol{t_g\varepsilon_g + t_d\varepsilon_d}}{\boldsymbol{t_g + t_d}}$; $\varepsilon_g = \varepsilon_d - j\frac{\sigma(\omega,\mu_c)}{\omega\varepsilon_0 d_g}$ [1]

Key Results, Conclusions, Comments, Impact

- In fig 2, Contrast, A, σ_g', & visibility of fringes at $10.6\mu m$ changed by $\boldsymbol{V_g}$.
- σ_g' transitions from the elliptic through the zero at $\approx 0.65\, V_g$ to the hyperbolic regions, with $-\sigma_g'$, for subwavelength imaging, as $\boldsymbol{V_g}$ increases.
- Normalized Ge to Au has same trend as contrast, showing negligible loss
- Trend in A similar to that of 4p Au-SiO_2 ENZ MM of ref [2]
- Check σ_g' enhancement in proposed structure; extract the $\boldsymbol{\varepsilon'_{r||eff}}$; and at what $\boldsymbol{V_g}$ the near-zero permittivity occurs.

Refs: 1. Sayem *et al. 978-1-4799-4166-7/14/$31.00,* 2014 IEEE
2. Gao, *et al.* App. Phys. Lett. 103, 051111 (2013)