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Graphene Field Effect Transistor on Silicon Nitride Devices for Near-Infrared Wavelength Tuning

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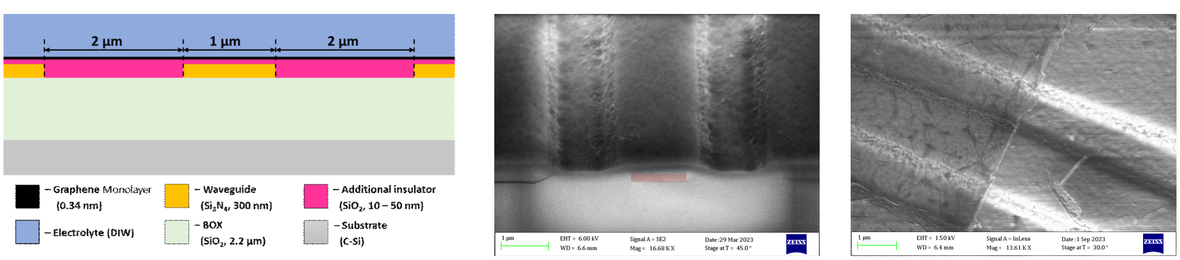
Abstract: In this work, we present the Graphene Field Effect Transistor (GFET) on Silicon Nitride waveguides for achieving the wavelength tuning in the Near-Infrared (NIR) range. The obtained Electrolyte-Graphene-Waveguide fabrication and characterization results are demonstrated.

1. Introduction

Graphene, a semi-metallic 2D material known for its zero-band gap and tunable wideband optical properties, presents an innovative approach to near-infrared (NIR) wavelength tuning. Its tightly confined free electrons within a single graphene atomic layer create a notably low density of states, particularly when the electron energy is close to the Dirac point. This characteristic gives rise to significant shifts in Fermi energy due to changes in carrier density, exerting a direct influence on the rate of interband transitions and the optical constant. Hence, the Fermi level of graphene can be adjusted under an external electric field, encompassing a range from NIR to terahertz (THz) wavelengths [1–3].

The potential of integrating graphene electrodes with silicon nitride (Si_3N_4)-based devices as a means to enhance tunability in the NIR spectrum is particularly promising [4]. Si_3N_4 exhibits low optical losses (< 1 dB/cm), transparency across a broad wavelength range (400-2350 nm), and a low thermo-optic coefficient (~2.45e-5 K^{-1} at 1.55 μm) but has weak or absent electro-optic coefficients.

In this study, we analyze, fabricate, and experimentally characterize the Electrolyte Graphene Waveguide, where the electrolyte is positioned above the graphene electrode as depicted in **Figure 1a**. The Si_3N_4-based Tunable Waveguides (TW) configurations (**Figure 1b**) were covered with a bi-layer of Graphene (**Figure 1c**). Leveraging electrical/electrolyte-gating in Graphene Field-Effect Transistor (GFET) allows for the possibility of epy wavelength shifts [3] in optoelectronic devices operating within the mid-infrared (MIR) to terahertz (THz) wavelength range. Another benefit of the electrolytic GFET is the decrease in power consumption when transitioning from the ±40 V (for the electronical (bottom) gating) of applied voltage to ±2 V (for the electrolyte (top) gating) [2]. This integration with on-chip tunable optical sensors supports advancements in high-precision measurements, enabled by the tunability of NIR resonance and device miniaturization.

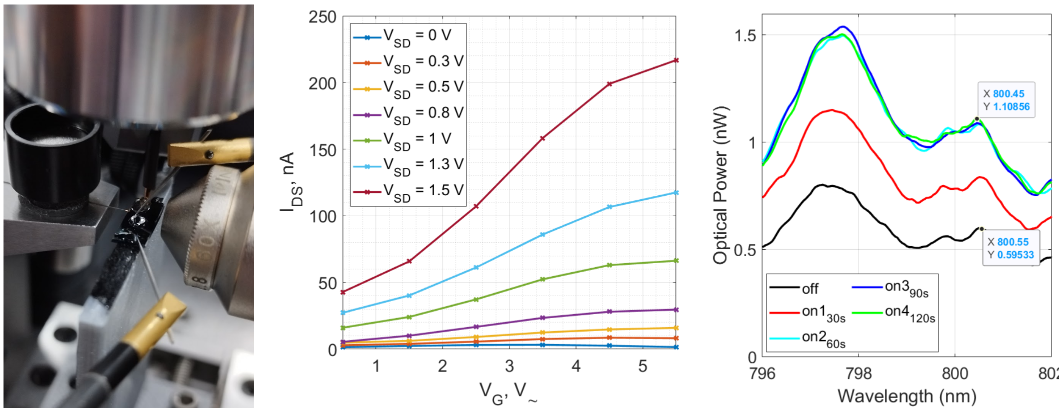


(a) **(b)** **(c)**

Fig. 1. (a) EGW TD configuration integrating GE with the indication of the different layers and their thicknesses, SEM pictures: (b) after dry etching planarization with highlighted waveguide in light red and (c) bi-layer of graphene on the fabricated chip.

2. Experimental results

A 20x2 mm long chip covered with a single layer of graphene was selected for the measurements. The distance between microneedles electrodes was set at 10 mm, and 5 μL of deionized H_2O as electrolyte was applied (see **Figure 2a**). The results of the GFET electrical test are presented in **Figure 2b**. The results indicate that the optimal performance, in terms of flow of carriers through the graphene layer, can be achieved by applying a V_{SD} of 1.5 V and V_G of 5.5 V. By applying this voltage to the GFET and aligning a light source operating within the 790-810 nm wavelength range and with a power of 2 mW to the 2x0.3 μm Si_3N_4-based waveguide, the optical spectra were measured, as depicted in **Figure 2c**.



(a) **(b)** **(c)**

Fig. 2. (a) experimental characterization of the GFET on the end-fire setup with applied electric microneedle contacts, (b) the drain-source current to the gate voltage dependence of GFET and (c) optical spectra of 2x0.3 μm Si_3N_4-based waveguide (V_{SD} = 1.5 V and V_G = 5.5 V) measured at 30 second intervals.

The obtained results demonstrate the GFET extinction coefficient change between 2 states: "On" (1.05 $nW_{800\ nm}$) and "Off" (0.54 $nW_{800\ nm}$), applying the voltage. An analysis of the smooth peak of the spectrum at a wavelength of 800.55 nm (in the "Off" state) reveals a wavelength shift of 0.1 nm to 800.45 nm in the "On" state of the GFET. For a more accurate analysis of the wavelength shift, a high-Q resonance is required.

3. Conclusions

This study specifically focused on the device fabrication process. Emphasizing planarization of nanophotonic devices before graphene transfer was a deliberate strategy to mitigate cracking. Promising results were achieved in the patterning of the graphene layer, offering the prospect of reduced absorption and device miniaturization. Numerical results [2,3] suggest that wavelength shifts of several nanometers can be achieved. The electrolytic Graphene Field-Effect Transistor (GFET) allowed to increase the current flowing through graphene layer, which increases the carrier density and causes the shift of the Femi level of graphene (i.e. its n and k values). This ability to tune the wavelength is further supported by the experimental results, showcasing the modulation of signal amplitude by applying voltage to the GFET.

This study plays a key role in providing guidance for the design and fabrication of wavelength tuning for graphene-based optical devices in the near-infrared spectrum. The demonstrated tunable device exhibits potential for the implementation of high-precision tunable hybrid lasers with an external cavity. Additionally, the obtained results from tuning the length of waveguides create an opportunity for integrating these devices with components such as MicroRing Resonators, potentially leading to the development of tunable sensors.

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References

1. D. de Ceglia, M. A. Vincenti, M. Grande, G. V. Bianco, G. Bruno, A. D'Orazio, and M. Scalora, "Tuning infrared guided-mode resonances with graphene," J. Opt. Soc. Am. B **33**(3), 426 (2016).
2. A. S. Vorobev, G. V. Bianco, G. Bruno, A. D'Orazio, L. O'Faolain, and M. Grande, "Tuning of Graphene-Based Optical Devices Operating in the Near-Infrared," Applied Sciences **11**(18), 8367 (2021).
3. A. S. Vorobev, G. V. Bianco, G. Bruno, A. D'Orazio, L. O'Faolain, and M. Grande, "Near-infrared wavelength tuning of monolayer graphene on Silicon Nitride waveguides," Photonics and Nanostructures - Fundamentals and Applications **54**, 101130 (2023).
4. C. Qiu, Y. Yang, C. Li, Y. Wang, K. Wu, and J. Chen, "All-optical control of light on a graphene-on-silicon nitride chip using thermo-optic effect," Sci Rep **7**(1), 17046 (2017).