

Waveguide Integrated Double Layer Graphene-SiN Modulators for On-chip Optical Interconnects

H. F.-Y. Watson¹, J. Wang¹, J. E. Muench¹, D. Zhang¹, V. Soriano², M. Bruna³, M. Romagnoli², A. C. Ferrari¹, and I. Goykhman^{1,4}

¹Cambridge Graphene Centre, University of Cambridge, 9 JJ Thomson Avenue, CB3 0FA, Cambridge, UK

²Consorzio Nazionale per le Telecomunicazioni (CNIT), National Laboratory of Photonic Networks, Via G. Moruzzi 1, 56124 Pisa, Italy

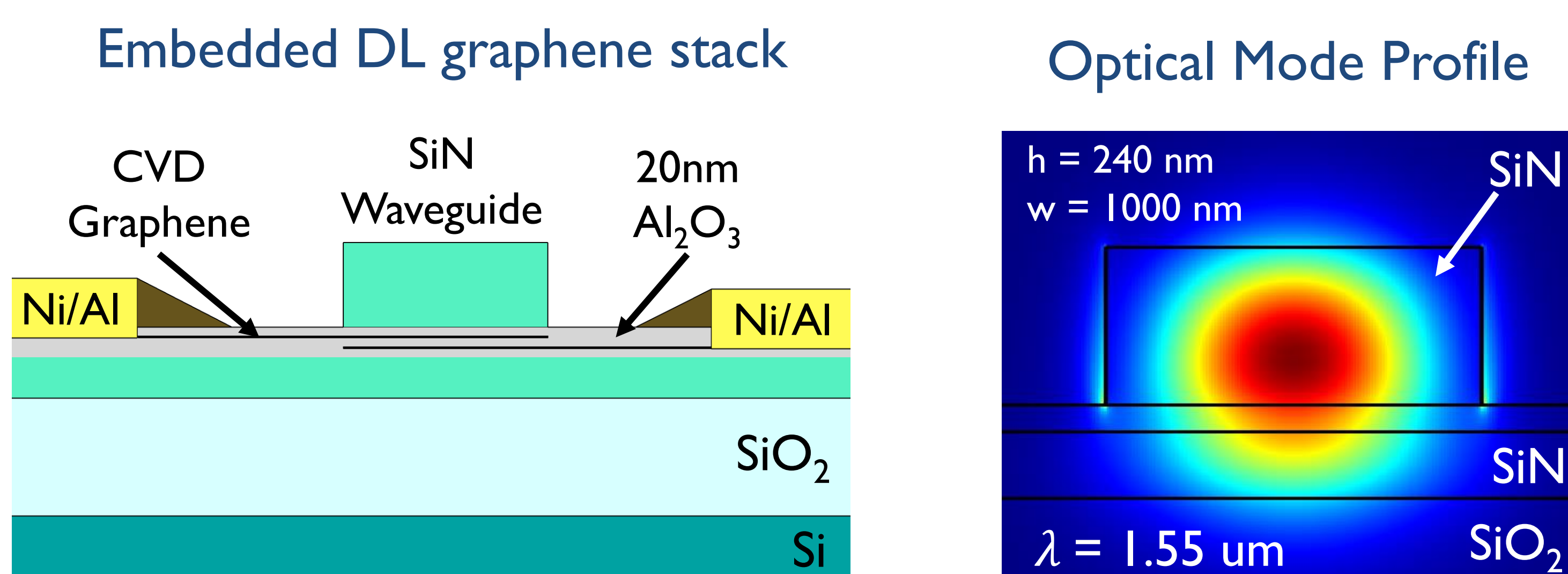
³Nokia-Bell Labs, 21 JJ Thomson Avenue, CB3 0FA, Cambridge, UK

⁴Technion Israel Institute of Technology, Haifa 3200003, Israel

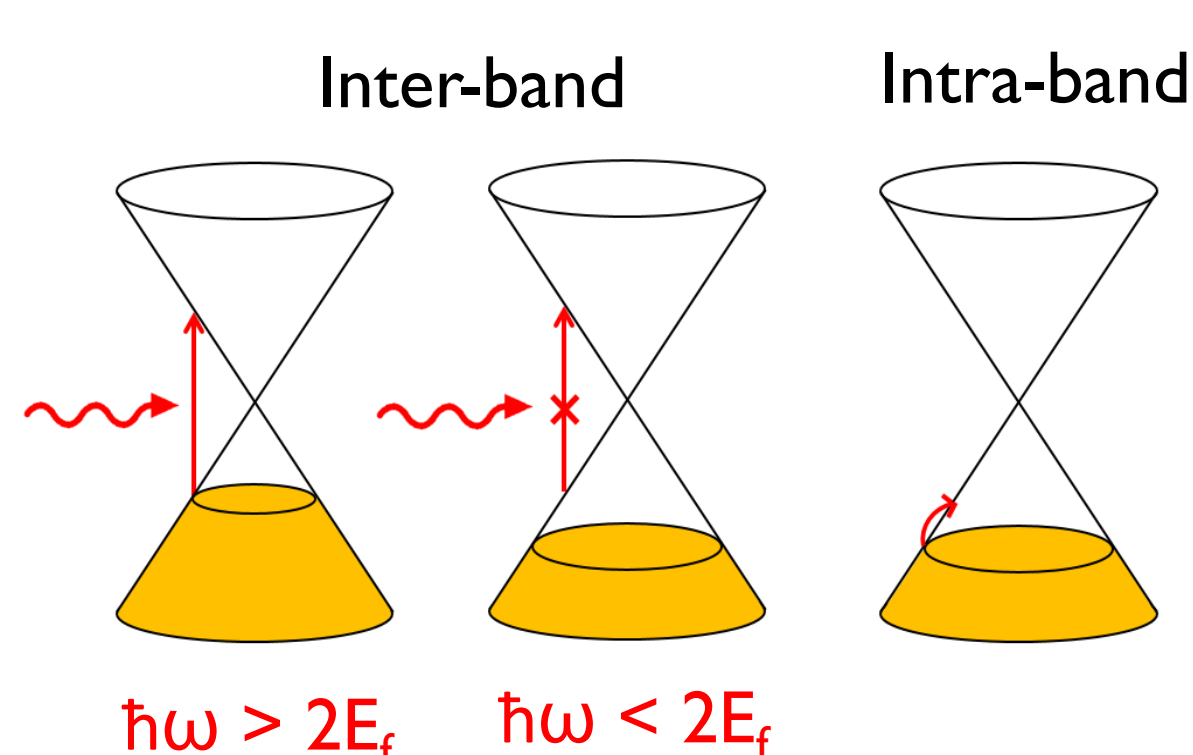
Motivation

Optical modulators are essential components of optoelectronic links [1]. Si-photonics is an emerging technology for short-reach optical interconnects [1]. On-chip integrated Si electro-refractive (phase) and Si-Ge electro-absorption (amplitude) modulators are currently employed to encode information into guided light [1]. However, Si-based optical modulators are unlikely to meet future requirements of power consumption, insertion loss, and device scaling [1].

Device Structure



Graphene Optical Conductivity



$$\sigma(\omega) = \frac{\sigma_0}{2} \left(\tanh\left(\frac{\hbar\omega + 2E_F}{4k_B T}\right) + \tanh\left(\frac{\hbar\omega - 2E_F}{4k_B T}\right) \right) - i \frac{\sigma_0}{2\pi} \log \left[\frac{(\hbar\omega + 2E_F)^2}{(\hbar\omega - 2E_F)^2 + (2k_B T)^2} \right] + i \frac{4\sigma_0}{\pi} \frac{E_F}{\hbar\omega + i\hbar\gamma} \quad [2]$$

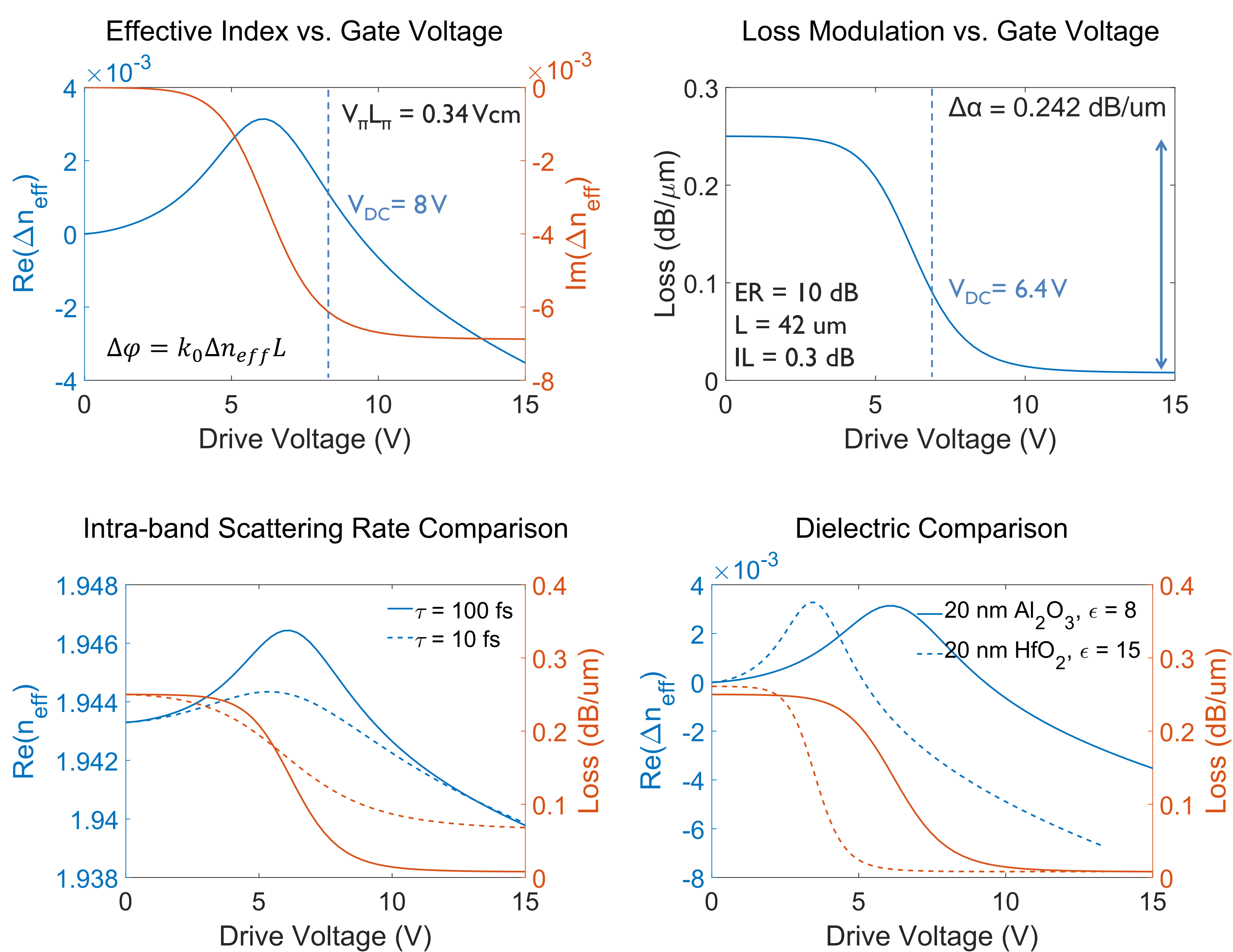
Inter-band

Intra-band

- High-quality graphene with a low scattering rate γ suppresses intra-band scattering for sharp transition to transparency due to Pauli blocking

Simulation & Results

Optical Performance



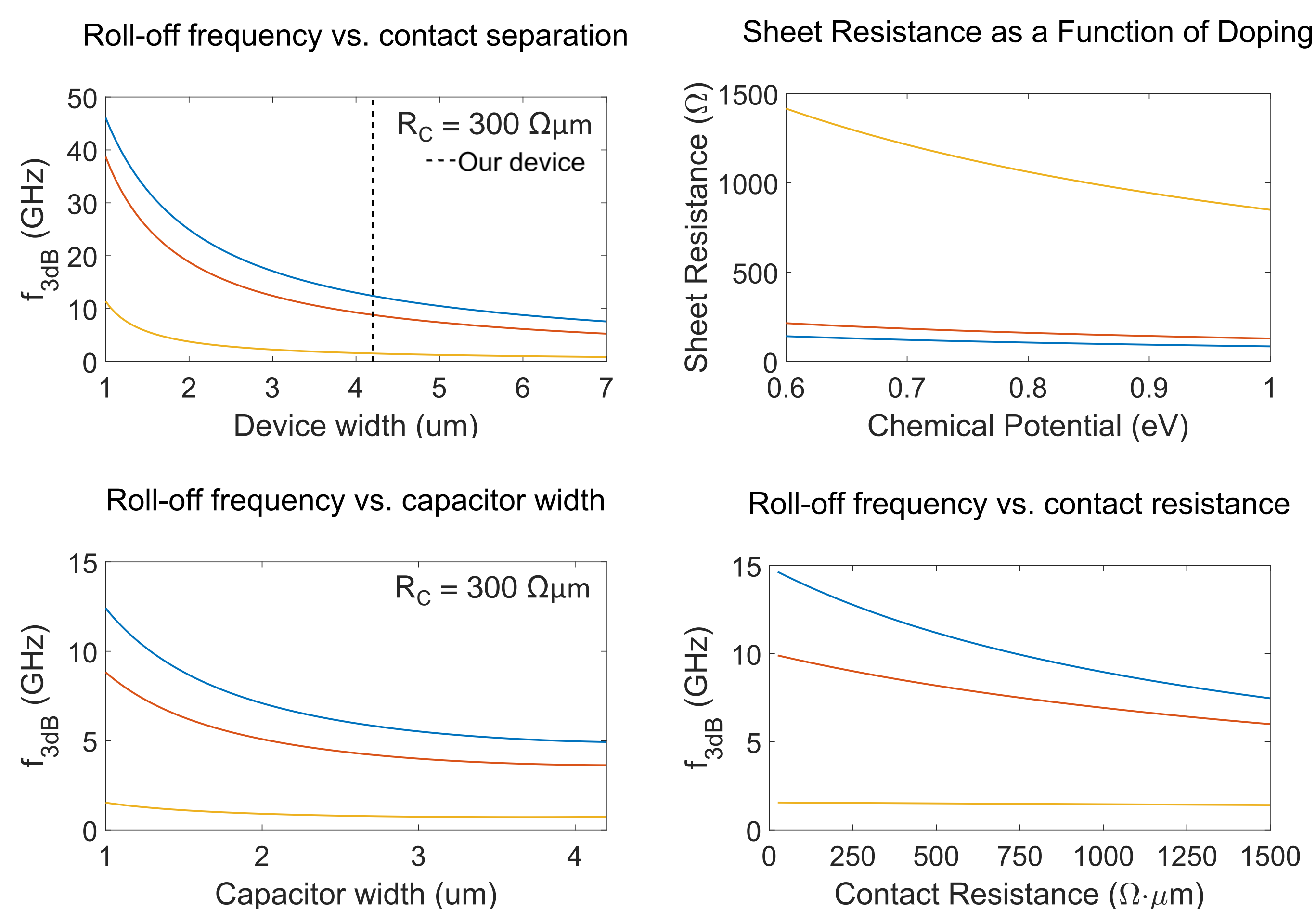
- Applied bias across graphene-graphene capacitor changes real and imaginary components of the waveguide mode
- Operating in Pauli blocking regime reduces losses
- Increased light-graphene interaction improves modulation efficiency which reduces device lengths and energy consumption
- Improved modulation efficiency from high-quality graphene with long scattering times
- Can reduce required DC bias by using a high-k dielectric like HfO_2

Electrical Performance

$$f_{3dB} = \frac{1}{2\pi RC} \quad [3]$$



- $\tau = 100 \text{ fs}$, $\mu_{0.1 \text{ eV}} = 8568 \text{ cm}^2/\text{Vs}$
- $\tau = 66 \text{ fs}$, $\mu_{0.1 \text{ eV}} = 5655 \text{ cm}^2/\text{Vs}$
- $\tau = 10 \text{ fs}$, $\mu_{0.1 \text{ eV}} = 870 \text{ cm}^2/\text{Vs}$



- Operational speed can be greatly improved with high-quality graphene and minimised contact-contact distance to reduce resistance contribution from ungated graphene sections
- Circuit capacitance can be reduced by minimising the overlap of graphene layers
- Reduced contact resistance important for high-quality graphene

References

- [1] G.T. Reed, et al., Nature Photonics, 4, 518-526, (2010)
 [2] Y.-C. Chang, et al., Applied Physics Letters, 104, 261909, (2014)
 [3] S. Ye, et al., Selected Topics in Quantum Electronics, IEEE Journal of, 23, 1-5, (2017)

Acknowledgments