Active and passive mode-locking of a laser using a graphene modulator on an SOI chip

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2023 IEEE Photonics Conference (IPC) | 979-8-3503-4722-7/23/$31.00 ©2023 IEEE | DOI: 10.1109/IPC57732.2023.10360780

***Abstract*— This study experimentally demonstrates the ability of an integrated graphene modulator on a silicon-on-insulator chip to both passively and actively mode-lock a fibre laser. Passive mode-locking is demonstrated at a repetition rate of 28 MHz, and active mode-locking is demonstrated at 10 GHz.**

Keywords—Mode-locked laser, Graphene, Saturable absorber, Modulator

I. Introduction

In this study, we present the utilization of a graphene electro-optic modulator integrated on a silicon chip, showcasing its capability to achieve both passive and active mode-locking in a laser. Mode-locked lasers generate optical pulse-trains consisting of multiple laser lines that are evenly spaced and synchronized in phase and frequency. These lasers have wide-ranging applications in telecommunications, gas spectroscopy, and biomedical research [1-3].

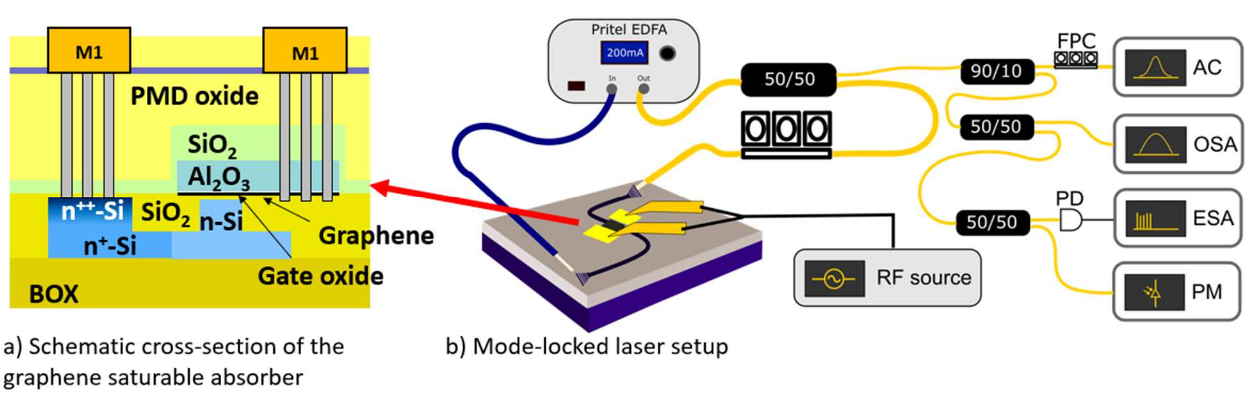
Graphene exhibits numerous attractive properties that make it highly suitable for mode-locking lasers. It operates across a broad spectrum of frequencies, encompassing the entire infrared (IR) and near-infrared (NIR) bands. Additionally, graphene offers advantages such as low-saturation power, fast recovery times, and adjustable absorption and modulation depths.

Previous demonstrations have successfully employed graphene as a saturable absorber in passive mode-locked fibre lasers, either by placing a graphene sheet in the evanescent tail of a propagating mode in a fibre or by placing it onto a polymer waveguide [4-6]. Furthermore, active mode-locking using graphene has been achieved previously by placing graphene on top of a gold reflector separated by a HfOx gate dielectric, enabling electro-optic modulation when a voltage is applied between the mirror and the graphene sheet. This modulation was shown to enable mode-locking at the fundamental frequency of a fibre laser cavity [7].

In this research, we showcase the ability of a graphene electro-optic modulator integrated on a silicon-on-insulator (SOI) chip to enable both passive and active mode-locking in a laser cavity.

II. Device overview

The graphene saturable absorber assembly was fabricated on imec's 220 nm thick silicon photonics platform, with graphene integration performed in imec's 300 mm fab using standard CMOS production tools. A schematic cross-section of the single-layer graphene saturable absorber is shown in figure 1a). The assembly consists of a planarized 500 nm wide socket waveguide, which serves as an electrical gate to control graphene's chemical potential. Ion doping implantation was employed in three steps to reduce electrical resistance while keeping optical losses at a minimum. A 5 nm thick SiOx layer electrically isolates the graphene from the gate. Graphene, grown via chemical vapor deposition on a 6-inch wafer, was



a) Schematic cross-section of the graphene saturable absorber
b) Mode-locked laser setup

Figure 1 Graphene modulator and mode-locked laser setup transferred onto a patterned 300 mm silicon wafer by Graphenea. This graphene was encapsulated and shaped by a 30 nm thick ALD-AlOx layer, and is electrically contacted using a Ti/TiN/W stack and a final Cu contact layer. Further details on the manufacturing, electro-amplitude modulator performance and wafer-reliability can be found in reference [8].

The mode-locked laser cavity, shown in Figure 1b, consists of ring laser cavity using a Pritel EDFA as an amplifier. A 50/50 splitter is used to couple light out of the laser cavity, and a cleaved single mode fibre is used to couple to the graphene modulator on chip. Finally a cleaved polarisation maintaining fibre is used to capture the light radiating from the chip guiding it back to the amplifier completing the laser cavity.

III. Passive mode-locking

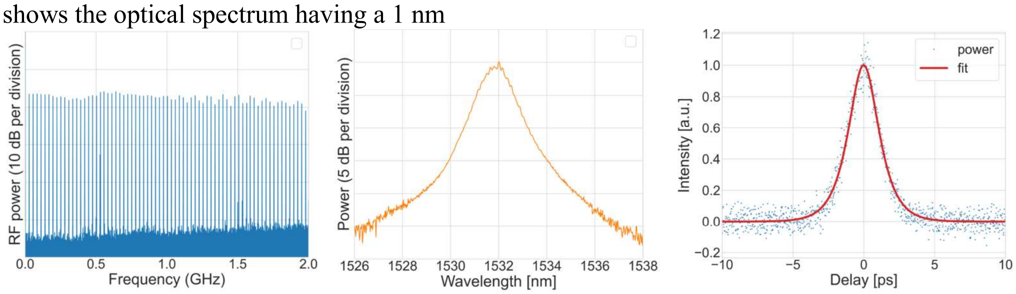
When no RF modulation is applied on the graphene saturable absorber, passive mode-locking occurred at a repetition rate of 28 MHz consistent with the mode-locked laser cavity length. Figure 2a shows the flat RF spectrum from the mode-locked laser, and Figure 2b shows the optical spectrum having a 1 nm 3 dB bandwidth centered around 1531 nm. Figure 2c shows the optical pulse measured using an autocorrelator with a sech pulse having a 1.7 ps pulsewidth with an average output power of 3 dBm.

IV. Active mode-locking

The laser was actively mode-locked by applying an 18 dBm 10GHz RF signal to the graphene modulator. Figure 3a shows the RF spectrum of the mode-locked laser indicating a strong noise suppresion. Figure 3b shows the optical spectrum of the actively mode-locked laser and Figure 3c shows the temporal trace out of the actively mode-locked laser cavity. The laser has an average optical output power of 0 dBm in this configuration.

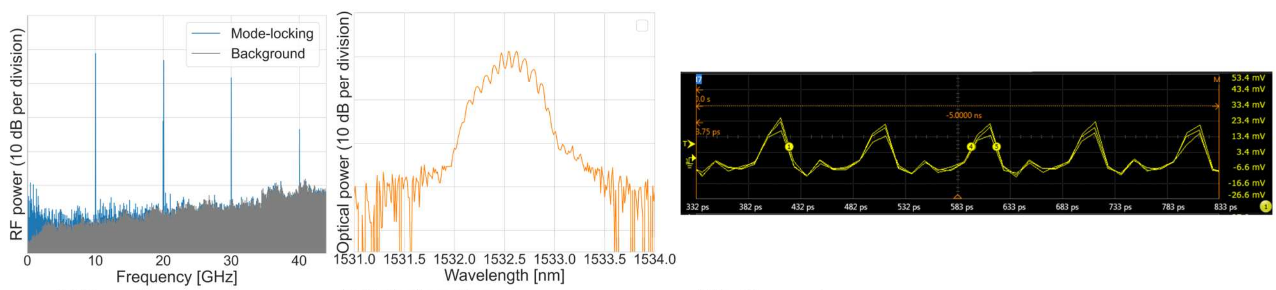
V. Conclusion

This study showcases the ability of a graphene electro-optic modulator integrated on a silicon chip to both passively mode-lock a laser cavity at the laser fundamental frequency and actively mode-lock a laser at 10 GHz .



a) RF spectrum b) Optical spectrum c) Autocorrelation trace

Figure 2 Passive mode-locking results



a) RF spectrum b) Optical spectrum c) Oscilloscope trace

Figure 3 Active mode-locking results

[1] N. Picqué and T. W. Hänsch, Frequency comb spectroscopy. Mar 2019

[2] M. A. Abbas, Q. Pan, J. Mandon et al. “Time-resolved mid-infrared dual-comb spectroscopy,” Scientific Reports, vol. 9, no. 1, Dec. 2019

[3] T. Bajraszewski, M. Wojtkowski, M. Szkulmowski, et al., “In vivo corneal high-speed, ultra high-resolution optical coherence tomography,” Tech. Rep. 120, 2007, pp. 889–894

[4] Y. W. Song, S. Y. Jang, W. S. Han, et al., “Graphene mode-lockers for fiber lasers functioned with evanescent field interaction,” Applied Physics Letters, vol. 96, no. 5, 2010.

[5] B. Ryu, Y. Song et. al. Efficient Optical Saturable Absorbers with Graphene on Polymer Waveguides for Femtosecond Laser Pulse Formation ANNALEN DER PHYSIK 2018, 530

[6] T. Reep B. Kuyken et al., “An experimental demonstration of a passively mode-locked laser using an integrated graphene saturable absorber,” in IEEE Benelux Photonics Chapter - Annual Symposium 2022, Eindhoven, The Netherlands, 2022, pp. 197–200.

[7] J. Boguslawski, Y. Wang, H. Xue, X. Yang, D. Mao, X. Gan, Z. Ren, J. Zhao, Q. Daiand, and G. Sobon, “Graphene Actively Mode-Locked Lasers,” Adv. Funct. Mater. 28(28), 18015391, 2018.

[8] Wu, C., Van Thourhout, D. et. al. Wafer-Scale Integration of Single Layer Graphene Electro-Absorption Modulators in a 300 mm CMOS Pilot Line. Laser Photonics Rev 2023, 2200789.