# Ultra-high efficiency, fast graphene micro-heater on silicon

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# Ultra-high efficiency, fast graphene micro-heater on silicon

**Siqi Yan [1, 2], Xiaolong Zhu[1,3], Lars Hagedorn Frandsen[1], Sanshui Xiao [1,3], N. Asger Mortensen[1,3], Jianji Dong[2] and Yunhong Ding[1,*]**

[1]Department of Photonics Engineering, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark

[2]Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, 430074, Wuhan, China.

[3]Center for Nanostructured Graphene, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark

[*]corresponding author: yudin@fotonik.dtu.dk

**Abstract**-We demonstrate an ultra-high efficiency and fast graphene microheater on silicon photonic crystal waveguide. By taking advantage of slow-light effect, a tuning efficiency of 1.07 nm/mW and power consumption per free spectral range of 3.99 mW. A fast rise and decay times (10% to 90%) of only 750 ns and 525 ns are achieved. The corresponding figure of merit of the device is 2.543 nW • s, one order of magnitude better than results reported in previous studies.

Micro-heater on silicon waveguide is one of the most important building blocks in silicon photonics. Silicon photonic integrated circuits based reconfigurable switches are relying on micro-heaters [1], which requires low power consumption and fast tuning. Traditional metallic microheater design requires a thick silicon dioxide layer introduced between the silicon waveguide and the metallic heater to avoid the light-absorption loss, inevitably impeding heat transport and dissipation owing to the low thermal conductivity of $SiO_2$. The unique properties of graphene, e.g. low optical absorption loss, high thermal conductivity (~5300 W • $m^{-1}$ • $K^{-1}$) make graphene rather attractive as a heating material. Graphene heater can be in close contact to the silicon waveguide which significantly improves the tuning efficiency. However, the current performances of devices using graphene heaters are limited either by their relatively high power consumptions [2] or by their microsecond response times [3].

Here we report a new concept of enhancing the heater efficiency by the use of slow light in a silicon photonic crystal waveguide with a monolayer of graphene working as a heater. We demonstrate an energy-efficient graphene microheater with a tuning efficiency of 1.07 nm/mW and power consumption per free spectral range (FSR) of 3.99 mW, with the rise and decay times (10% to 90%) of only 750 ns and 525 ns.

A schematic of the slow-light-enhanced graphene microheater is shown in Fig. 1(a). A graphene monolayer is deposited onto the core-region of the silicon PhCW. The graphene is contacted by two gold/titanium (Au/Ti) pads. Ohmic heating is generated in the graphene via an applied voltage bias between two Au/Ti pads. The width of the graphene overlapping the photonic crystal line defect is designed to be narrower than the other part of the graphene to locally increase the Ohmic dissipation, which results in a more effective heating.

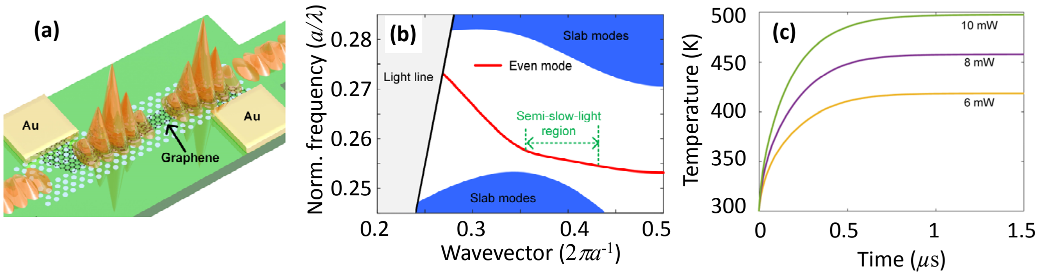


Fig. 1. (a) Schematic of the slow-light-enhanced graphene heater. (b) Band structure of the photonic crystal waveguide. The even guiding mode (red curve) consists of a semi-slow-light region (green dashed line). (c) The temperature response for different heating power.

The tuning efficiency is significantly enhanced owing to the semi-slow light effect that is obtained in the PhCW, which increases the effective interaction length between the heater and the waveguides [5]. By optimizing the positions of the first and second rows of holes adjacent to the line-defect, the band structure with semi-slow light effect is obtained (see Fig. 1(b)). Fig. 1(c) indicates the theoretical response time of the proposed microheater, 420 ns response time is achieved, which is faster than most previous reported microheaters.

The slow-light-enhanced graphene heater was fabricated by CMOS fabrication process and the graphene wet transfer process. The false-color SEM image is shown in Fig. 2(a). In order to test the efficiency, the device is incorporated in a Mach–Zehnder interferometer. By applying external voltage on the device, both the static (see Fig. 2(b)) and the dynamic response (see Fig. 2(c) and 2(d)) of the device are measured. The interference dips shift at 1533.71 nm and 1525.12 nm as functions of the tuning power is represented, and tuning efficiencies of 1.07 nm/mW and 0.65 nm/mW are achieved, respectively. A fast rising and decaying times (between 10% and 90%) are measured to be 750 ns and 525 ns, respectively, as indicated in Fig. 2(d). The corresponding figure of merit of the device [6], i.e. the product of the power consumption per FSR and the average response time, is 2.543 nW·s, which is one order of magnitude better than previous reported results [6].

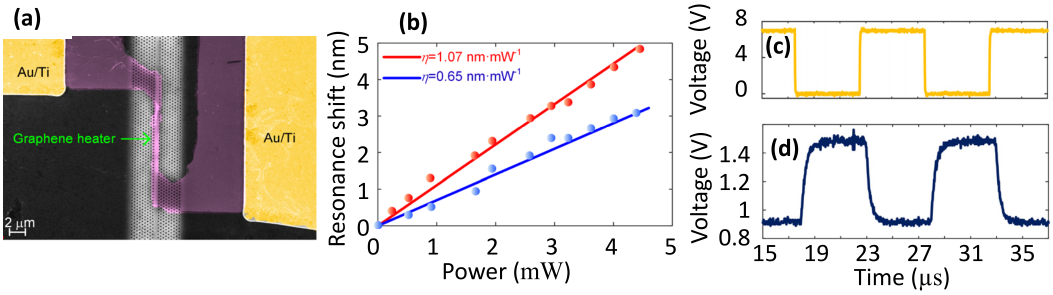


Fig. 2. (a) False-color SEM image of the slow-light-enhanced graphene heater. (b) Measured resonance shifts for the interference dips at 1525.12 nm (blue) and 1533.71 nm (red) as functions of the applied heating power. (c) Driving electrical signal and (d) corresponding temporal response signal.

In summary, we demonstrate an ultra-high efficiency and fast graphene microheater on semi-slow light silicon photonic crystal waveguide. We achieved ultra-high tuning efficiency of 1.07 nm/mW and power consumption per FSR of 3.99 mW. A fast response times (10% to 90%) of only 750 ns and 525 ns is demonstrated.

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**REFERENCES**

1. Y. Ding et al., “Reconfigurable SDM switching using novel silicon photonic integrated circuit,” *Sci. Rep.*, Vol. 6, 39058, 2016.
2. S. Gan *et al.* “A highly efficient thermo-optic microring modulator assisted by graphene,” *Nanoscale*, Vol. **7**, 20249-20255 (2015).
3. L. Yu et al. “Thermally tunable silicon photonic microdisk resonator with transparent graphene nanoheaters,” *Optica*, Vol. 3, 159-166 (2016).
4. S. Yan et al., “Slow-light-enhanced energy efficiency for graphene microheaters on silicon photonic crystal waveguides,” *Nature Commun.*, Vol. 8, 14411, 2017.
5. D. Schall *et al.* “Infrared transparent graphene heater for silicon photonic integrated circuits,” *Opt. Express*, Vol. 24, 7871-7878 (2016).