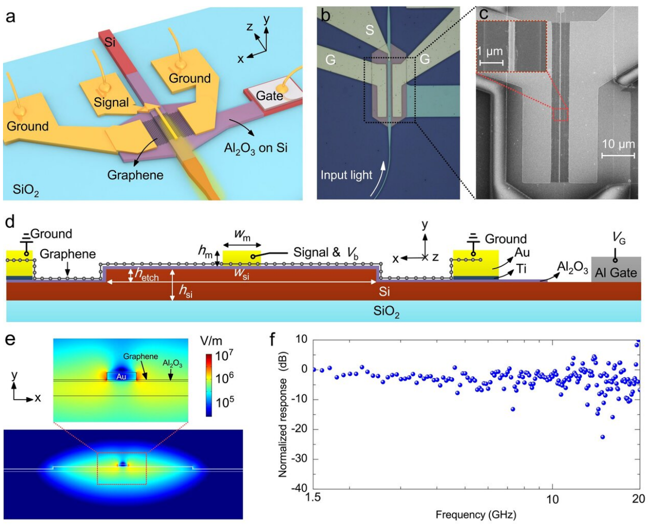
Silicon-graphene hybrid plasmonic waveguide photodetectors beyond 1.55 ?m

13 March 2020



a. Schematic configuration; b. Optical microscope; c. SEM pictures; d. Cross-section of the present silicon-graphene hybrid plasmonic waveguide with the signal electrode at the middle and the ground electrodes at both sides (here the metal-graphene-metal sandwich structure is utilized); e. The electric field component distribution of the quasi-TE0 mode for the optimized silicon-graphene hybrid plasmonic waveguide; f. Measured frequency response of Device B operating at ¦Ë=2?m (bias voltage: -0.5 V, gate voltage: 2.9 V). Credit: Jingshu Guo, Jiang Li, Chaoyue Liu, Yanlong Yin, Wenhui Wang, Zhenhua Ni, Zhilei Fu, Hui Yu, Yang Xu, Yaocheng Shi, Yungui Ma, Shiming Gao, Liming Tong and Daoxin Dai

Silicon photonics are known as a key technology for modern optical communications at the near infrared wavelength-band, i.e., 1.31/1.55 ?m. Currently silicon photonics researchers have attempted to extend the technology to the wavelength-band beyond 1.55 ?m, e.g., 2 ?m, for important applications in optical communications, nonlinear photonics, and on-chip sensing. However, the realization of high-performance silicon-based waveguide photodetectors beyond 1.55 ?m still faces challenges since there are some fabrication issues as well as wavelength-band limitations. As an alternative, two-dimensional materials (e.g., graphene) provide a promising solution because of the ability for broad operation wavelength-bands and the advantage of avoiding structure mismatch in the design and fabrication.

In a paper published in *Light: Science & Applications*, scientists from Zhejiang University and Southeast University in China proposed and demonstrated high-performance waveguide photodetectors beyond 1.55 ?m by introducing a novel silicon-graphene hybrid plasmonic waveguide. In particular, an ultra-thin wide silicon ridge core region with a metal cap atop is introduced to obtain a unique mode field profile, so that light absorption of graphene is enhanced. Furthermore, fabrication is easy and graphene-metal contact resistance is reduced, compared to the previous silicon-graphene hybrid waveguides. For example, graphene absorption efficiencies are as high as 54.3% and 68.6% for 20 ?m-long and 50 ?m-long absorption regions, when operating at 1.55 ?m and 2 ?m, respectively.

For fabricated photodetectors operating at 2 ?m, the measured 3 dB-bandwidths are >20 GHz (limited by the experimental setup), while the responsivities are 30-70 mA/W for 0.28 mW input optical power under -0.3V bias voltage. For the photodetectors operating at 1.55 ?m, the 3 dB-bandwidth is >40 GHz (limited by the setup), while the measured responsivity is about 0.4 A/W for 0.16 mW input optical power under -0.3V bias voltage.

In this work, mechanisms in graphene photodetectors are analyzed carefully, which suggested that the photo-thermoelectric effect is the dominant mechanism for photo-response when operating at zero bias voltage. When the photodetector operates at non-zero bias voltages, the dominant mechanism becomes the bolometric or photoconductive effect. This comprehensive analysis helps better understand the photocurrent generation in graphene-metal interfaces.

The scientists summarize the highlights of their work: "We have proposed and demonstrated high-performance silicon-graphene hybrid plasmonic waveguide photodetectors beyond 1.55 ?m. In particular, a novel silicon-graphene hybrid plasmonic waveguide was used by introducing an ultra-thin wide silicon ridge core region with a metal cap atop. The optical modal field is manipulated in both vertical and horizontal directions. Thus, the light absorption in graphene is enhanced, meanwhile the metal absorption loss is minimized. This greatly helps achieve sufficient light absorption of graphene within a short absorption region."

"The silicon-graphene waveguide photodetectors operating at 2 ?m were demonstrated with a 3 dB-bandwidth over 20 GHz. The measured responsivity is 30-70 mA/W at the bias voltage of -0.3V for input optical power of 0.28 mW. The photodetector at 1.55 ?m was also demonstrated with excellent performance. The present work paves the way for achieving high-responsivity and high-speed waveguide photodetectors on silicon for near/mid-infrared wavelength-bands," they added.

"In future works, more efforts should be given to introduce some special junction structures to minimize dark current and further extend the operation wavelength-band. Graphene waveguide photodetectors may play an important role in mid-infrared silicon photonics, which will play an important role in time resolved spectroscopy, lab-on-chip sensing, nonlinear photonics, as well as optical communication," they said.

More information: Jingshu Guo et al, High-performance silicon?graphene hybrid plasmonic waveguide photodetectors beyond 1.55 ?m, *Light: Science & Applications* (2020). DOI: 10.1038/s41377-020-0263-6

Provided by Chinese Academy of Sciences