Terahertz silicon photonics for 6G and beyond information communication systems

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Abstract

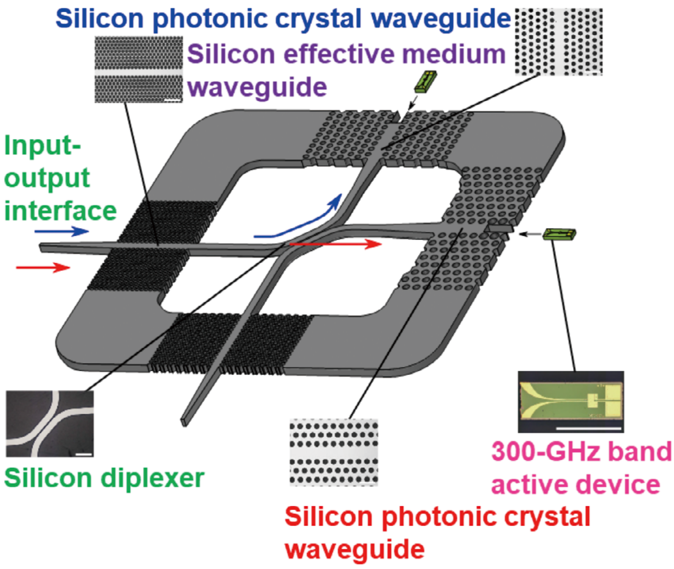
A wide untapped bandwidth exists between radio and light waves in the electromagnetic spectrum known as terahertz waves. Terahertz frequencies (0.1–10 THz) combine the penetration of radio waves and large bandwidth of light, making them excellent candidates for next-generation 6G information communication technology and beyond, such as ultra-broadband wireless communication, spectroscopic sensing, nondestructive imaging, and high-resolution ranging. However, terahertz frequencies are at the upper limit of the capabilities of conventional electronics, and the development of terahertz devices and systems is a challenging field that requires interdisciplinary research. In this study, we have explored terahertz silicon photonics, which employs silicon semiconductors as a low-loss dielectric medium for terahertz-wave manipulation, to overcome the information loss in the terahertz band. We have developed ultralow-loss waveguides in the 1-THz band and an efficient interface integrated with active terahertz devices in the 0.3-THz band.

Background & Results

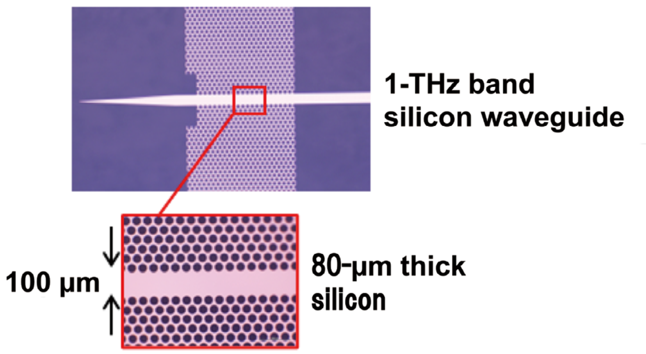
Globally, the use of mobile devices for accessing the internet and the number of connected devices is increasing exponentially. Soon, machines will communicate with each other over the Internet of Things, which will require even more powerful wireless networks capable of transferring large volumes of data rapidly. Terahertz waves are a section of the electromagnetic spectrum that have a raw spectral bandwidth far broader than that of conventional microwave-based wireless communications. A study on terahertz silicon photonics to effectively manage terahertz waves is critical for the development of subsequent 6G and beyond generations of information communication systems. Additionally, a low-loss platform for integrating terahertz devices is essential for various practical applications. However, the propagation loss of transmission lines in conventional electronics is high in the terahertz region, owing to high ohmic loss in metals. Hence, an alternative metal-free integrated platform is necessary for manipulating terahertz waves. Photonic crystals are metal-free dielectric microstructures with periodic refractive index distributions on scales comparable to wavelengths of interest. Various advanced terahertz devices based on silicon photonic crystals and related microstructures have been developed, including ultralow-loss waveguides, compact frequency selectors, compact and broadband antennas, and high-Q cavities. Active functions, including terahertz-signal generation, detection, frequency conversion, and modulation, can be subsequently integrated with the terahertz silicon photonics platform. Accordingly, an efficient mode converter suitable for the deep-subwavelength region was developed in this study for integrating terahertz active devices.

Significance of the research and Future perspective

Terahertz silicon photonics can facilitate the development of advanced communication and sensing systems. Terahertz communications could realize extremely low-latency wireless communications for advanced remote-control applications such as automated driving, autonomous operation, drones, and robots, which can be remotely controlled by artificial intelligence systems. Terahertz waves could enhance the precision and resolution of sensing owing to their shorter wavelength compared with microwaves for 6G and beyond communication generations.



Developed terahertz circuit based on terahertz silicon photonics



Fabricated one-terahertz band silicon waveguide

Patent: Japanese Patent Application No. 2020-128220

Treatise: Yu, Xiongbin; Headland, Daniel; Nishida, Yosuke et al. Hybrid integration between resonant tunneling diodes and unclad microphotonic diplexer for dual-channel coherent terahertz receiver. IEEE Journal of Selected Topics in Quantum Electronics. 2022, 28 (3), 8500210, doi: 10.1109/JSTQE.2021.3130813
Koala, Ratmalgre; Maru, Ryoma; Iyoda, Kei et al. Ultra-low-loss and broadband all-silicon dielectric waveguides for WR-1 Band (0.75–1.1 THz) modules. Photonics. 2022, 9 (8), 515, doi: 10.3390/photonics9080515

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