Usage Report for Fiscal Year 2024

Project Title:

Photonic structures for light-matter coupling

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1. Background and purpose of the project, relationship of the project with other projects

Our group investigates the interaction between nanoscale light emitters—such as carbon nanotubes and 2D layered transition metal dichalcogenides—and photonic structures. In this project, we aim to enhance light-matter coupling between 2D materials and planar air-hole photonic crystal waveguides and cavities. These structures are valuable for developing miniaturized semiconductor optoelectronic devices, which have potential applications in both classical and quantum on-chip technologies.

2. Specific usage status of the system and calculation method

Finite-difference time-domain (FDTD) simulations are performed using a supercomputer. The FDTD method is a widely used computational technique in electromagnetics, where space is divided into a discrete grid, and fields are evolved over time using discrete time steps while solving Maxwell's equations. We utilize an open-source FDTD package called MEEP [1]. The simulations can be divided into multiple parts, allowing parallel computation, making the supercomputer an ideal resource for performing fast and efficient simulations.

3. Result

Based on the simulation results, we have fabricated the photonic crystal waveguides with silicon-on-insulator (SOI) chips. We then transfer 2D material flakes of suitable thicknesses and shapes onto the photonic crystal waveguides. We have successfully observed light-matter coupling effects between the silicon waveguide and various 2D materials including hexagonal boron nitride (hBN), tungsten diselenide (WSe_2) and molybdenum ditelluride ($MoTe_2$). In addition, I designed and fabricated grating photonic crystal cavities that support air mode cavities with the potential for stronger coupling to emitters placed on its surface. Preliminary optical spectroscopy measurements show successful observation of such cavity modes.

4. Conclusion

The simulations conducted using the HOKUSAI Bigwaterfall 2 computing cluster have been crucial for the ideation, development, and overall progress of our research. Specifically, they have helped determine the optimal parameters for crystal waveguide nanofabrication and guided the selection of 2D materials for coupling experiments. Our experimental results are largely consistent with the simulations.

5. Schedule and prospect for the future

We are currently investigating how stacking different 2D materials influences their light-matter coupling properties with the waveguides.

6. Reference

[1] A.F. Oskooi, D. Roundy, M. Ibanescu, P. Bermel, J.D. Joannopoulos, and S.G. Johnson, MEEP: A flexible free-software package for electromagnetic simulations by the FDTD method, Comput. Phys. Commun. 181, 687 (2010).

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Fiscal Year 2024 List of Publications Resulting from the Use of the supercomputer

[Paper accepted by a journal]

C. F. Fong, D. Yamashita, N. Fang, S. Fujii, Y.-R. Chang, T. Taniguchi, K. Watanabe, Y. K. Kato, “Self-Aligned Hybrid Nanocavities Using Atomically Thin Materials,” ACS Photonics **11,** 2247 (2024).

[Poster presentation]

C. F. Fong, D. Yamashita, N. Fang, S. Fujii, Y.-R. Chang, T. Taniguchi, K. Watanabe, Y. K. Kato, ”Dielectric environment engineering with 2D materials for hybrid nanocavities”, *Fundamental Optical Processes in Semiconductors (FOPS) 2024,* Newfoundland, Canada (July 25, 2024).

C. F. Fong, D. Yamashita, N. Fang, S. Fujii, Y.-R. Chang, T. Taniguchi, K. Watanabe, Y. K. Kato, “Demonstration of hybrid photonic crystal nanocavity using atomically thin van der Waals flakes,” *META 2024, the 14th International Conference on Metamaterials, Photonic Crystals and Plasmonics*, Toyama, Japan (July 16 2024).