東京大学大学院工学系研究科 総合研究機構
第22回「次世代電子顕微鏡法」講演会
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Exploring nanoscale excitations with time-resolved electron spectroscopies

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The evolution of technology drives the construction of increasingly complex and compact devices. Consequently, comprehending the physics underlying excitations and effectively controlling them in devices necessitates tools with precision at the nanometer or atomic scale. In this sense, spectroscopies in electron microscopes (electron energy loss spectroscopy, EELS, and cathodoluminescence, CL) have strongly impacted advances in nano-optics [1]. These spectroscopies have some penalties in comparison to photon experiments: lack of excitation energy control and polarization degrees of freedom and limited spectral resolution. In this seminar, I will describe applications of electron spectroscopies to 2D materials nano-optics. Following this, I will demonstrate innovative strategies to overcome their inherent limitations by integrating them with a light injection/collection system, complemented by time-resolved experiments (using a ns-blanking system or a Timepix3 event-based electron detector).

Electron inelastic scattering in matter exhibits a broadband nature. As a result, the exchanged energy during each scattering event can only be determined through the detection of individual electrons with nanosecond time resolution [2]. With this, the energy losses leading to CL photon emission can be determined. This methodology, called cathodoluminescence excitation (CLE) spectroscopy, allows for the probing of excitation pathways leading to photon emission [3], similar to the approach in photoluminescence excitation (PLE) spectroscopy. CLE provides access to materials' relative quantum efficiency with nanometer precision. I will discuss the implications of these time coincidence experiments for phase shaped EELS [4].

Finally, high quality factor optical modes are interesting for sensing applications, but probing them requires ~μeV energy resolution in the IR-UV range, beyond the range accessible to EELS by orders of magnitude. I will discuss how electron energy gain spectroscopy (EEGS) [5] can achieve μeV resolution and access high quality factor optical modes in whispering gallery modes in dielectric spheres. EEGS requires laser injection and nanosecond to femtosecond temporal resolution in a TEM.

[1] A. Polman, *Nat. Mater.* **18**, 1158 (2019).
[2] Y. Auad, *Ultramicroscopy* **239**, 113539 (2021).
[3] N. Varkentina, et al., *Sci. Adv*. **8**, abq4947 (2022).
[4] H. Lourenço-Martins, et al., *Nat. Phys.*, **17**, 598 (2021).
[5] Y. Auad et al., *Nat. Comm*. **14**, 4442 (2023).

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