Ultrashort Electron Beam Science RIKEN-Hakubi Research Team（2021）

RIKEN Hakubi team leader: Yuya Morimoto (Ph.D.)

(0) Research field

CPR Subcommittee: Chemistry

Keywords: Ultrashort electron beam, Electron beam imaging, Nonlinear optics, Attosecond science, Atomic collisions

(1) Long-term goal of laboratory and research background

Electron beams are used for example in electron microscopy and electron-beam lithography, where high spatial resolution is required. By using state-of-the-art laser and electron-beam technologies, we aim at controlling the temporal structure of an electron beam with ultimate attosecond resolution (attosecond = one quintillionth of a second) and applying the controlled electron beams for imaging and controlling ultrafast chemical reactions. We explore the atomic-scale dynamics of electrons in a material which is the initial step of most photochemical reactions.

(2) Current research activities (FY2021) and plan (until Mar. 2025)

The Ultrashort Electron Beam Science RIKEN-Hakubi Research Team was established in October 2021. In FY2021, we focused on setting up a laboratory, including the renovation of rooms and the design of equipment. We will continue to prepare for experiments so that experimental results can be obtained by the end of FY2023. Below are the results of the theoretical study conducted in FY2021.

Ultrafast electron dynamics in graphene

Petahertz electronics is an emerging technology that can significantly improve the speed of computation. The goal of this research field is to control the properties of matter (e.g., electrical conductivity and magnetism) at optical frequencies. Further development of petahertz electronics requires an understanding of its fundamental physics, i.e., the ultrafast interaction of light and matter at the atomic level. In collaboration with the University of Tokyo and the Friedrich-Alexander-Universität Erlangen-Nürnberg, we have theoretically investigated how electrons in graphene, a typical material in petahertz electronics, respond to intense few-cycle laser pulses.

We used a unique theoretical model based on the tight-binding approximation and the semiconductor Bloch equation. We calculated the atomic-scale residual currents induced by few-cycle pulses. We found that regardless of the laser polarization direction, the residual current flows mainly through the bonds parallel to the polarization direction. Furthermore, we found that the charge density between carbon atoms after the excitation oscillates with the excitation laser field amplitude. The observed oscillation was attributed to the strong-field-driven Rabi oscillation. This theoretical study showed that electron dynamics occurring at the atomic level contains rich information about the light and matter interaction, which is the basis of petahertz electronics. Therefore, this study facilitates future experimental works using ultrashort electron beams.

Future plan, In order to verify the theoretical predictions, an experiment will be conducted.

(3) Members

(Hakubi team leader)

Yuya Morimoto

(4) Representative research achievements

1. “Atomic real-space perspective of light-field-driven currents in graphene”, Yuya Morimoto, Yasushi Shinohara, Kenichi L. Ishikawa, Peter Hommelhoff, **New. J. Phys. 24**, 033051 (2022).

2. 「レーザー光による電子線制御技術の開発とアト秒イメージングへの応用：アト秒電子パルスの発生と検出」，森本 裕也，しょうとつ, **18**, 125-141 (2021).

3. “Attosecond Electron Beams generation, detection and potential applications”, Yuya Morimoto, The 4th Workshop of the Reaction Infography, November 5, 2021, Online.

4. 「アト秒電子パルスの発生と超高速イメージング応用への試み」，森本裕也，日本顕微鏡学会　超高分解能顕微鏡法分科会　研究会, 2022年2月18日，オンライン

Laboratory Homepage

https://epulse.riken.jp