Ultrashort Electron Beam Science RIKEN-Hakubi Research Team（2023）

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

(0) Research fields

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 (FY2023) and plan

The focus of FY2023's work was the operation of the electron-beam apparatus. In the apparatus that we have designed and assembled, we have successfully generated a pulsed electron beam, which is a major step forward to conduct the planned experiments. We have also completed two self-built optical parametric amplifiers, which allow us to generate strong mid-infrared light for the temporal modulation of electron beams. In the following, we describe the results of our recent work done in collaboration with University of Konstanz in Germany.

<u>Ultrafast rocking-curve effects induced by optical-field cycles</u>

Electron diffraction is a powerful technique that can precisely determine the position of atoms and spatial distribution of electrons inside a material. The development of time-resolved electron diffraction with attosecond temporal and atomic spatial resolution is long awaited for investigating the motion of electrons in a material which are closely related to the mechanism of chemical reactions and photophysical properties.

In this study, we performed a proof-of-principle experiment of attosecond electron diffraction. We generated attosecond-short electron beams by employing our original method using a membrane, in which electron beams are periodically accelerated and decelerated by an optical electric-field cycles. Using the attosecond electron beam, we measured electron diffraction images from a single-crystal silicon thin film which was excited by light. When the delay time between the attosecond electron beam and the excitation light was scanned at the attosecond level, a periodic change in the electron diffraction intensity was observed.

We investigated the cause of the ultrafast change in diffraction intensity at attosecond level, and found that it is due to the dynamics of the electron beam. The electromagnetic field of the laser light inside and around the crystalline sample modulated the trajectory of the electron beam periodically, causing a shift in the incident angle of the beam from the Bragg diffraction condition that has to be satisfied for diffraction to occur (rocking-curve effect). Therefore, the periodic modulation in the beam's trajectory resulted in a change in diffraction intensity. Since the laser light used here has a wavelength of 1 µm and a corresponding cycle time of 3.4 fs, the electron diffraction intensity changed on a shorter time scale.

Using a longer-wavelength laser light, we expected to see a larger modulation of the incident angle and accordingly a larger field-induced rocking-curve effect. We have performed experiments using mid-infrared laser light with a wavelength of 7 µm and observed a stronger rocking-curve effect which is nonlinear with respect to the incident laser electric-field amplitude. The rocking-curve effect can be used as an ultrashort gate for producing and detecting electron pulses. In addition, the field-induced rocking-curve effect must be considered in pump-and-probe experiments using light as a pump and attosecond electron beams as a probe.

<u>Future plan</u>, we will improve the equipment under development in order to produce intense attosecond electron beams, which will be used for the study of reaction dynamics. Development of a laser system will also be continued to generate strong ultrashort laser pulses with various wavelengths and temporal durations for use in pump-probe experiments.

(3) Members

(RIKEN Hakubi team leader)
Yuya Morimoto

(Postdoctoral Researcher)
Yuichi Tachibana
Marie Ouillé

(Technical staff)
Yui Yamashita

(4) Representative research achievements

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Laboratory Homepage
https://epulse.riken.jp