【Grant-in-Aid for Scientific Research (S)】

Broad Section D

Title of Project： Petaherz-scale solid state physics exploring by attosecond high-harmonic-based ultrafast spectroscopy

OGURI Katsuya
(NTT Basic Research Laboratories, Quantum Science and Technology Laboratory, Executive manager)

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Keyword：Petahertz electronics, Attosecond physics, Lightwave-driven phenomena, 2D materials

【Purpose and Background of the Research】

The three innovative optical technologies, which were invented in the early 21st century, attosecond pulse generation technology, optical clock technology, and carrier-envelope phase stabilization technology have allowed light to be measured in the time domain on a 10^{-18} second scale and to be stabilized in the frequency domain with a 10^{-18} fractional uncertainty. The technological progress has currently enabled us to utilize a light wave as a precisely controllable electromagnetic wave with an extremely high frequency approaching 1 petahertz (PHz: 10^{15} Hz) or "PHz wave".

In this project, we will explore ultrafast dynamics of the electronic coherent responses and nonequilibrium relaxation induced by an interaction between a lightwave electric field and internal quantum degrees of freedom of electrons such as polarization, spin, and valley on a time scale from 100 as to 10 fs. We call this time scale, which corresponds to one cycle of light wave from visible to infrared, as “PHz scale”. By investigating with both experimental and theoretical approaches, we will pioneer a new framework of “PHz-scale solid state physics”.

【Research Methods】

In this project, we investigate an ultrafast lightwave-electron interaction in various 2D materials including semiconductors, ferromagnets, and topological insulators, which show characteristic band structures, spin and magnetic properties, and topological orders. In order to proceed this research comprehensively, we will combine the following three approaches of (i) development of new extreme attosecond spectroscopic systems, (ii) high quality 2D-materials growth and characterization, and (iii) the first-principles computation and real-time quantum simulation for solid state materials.

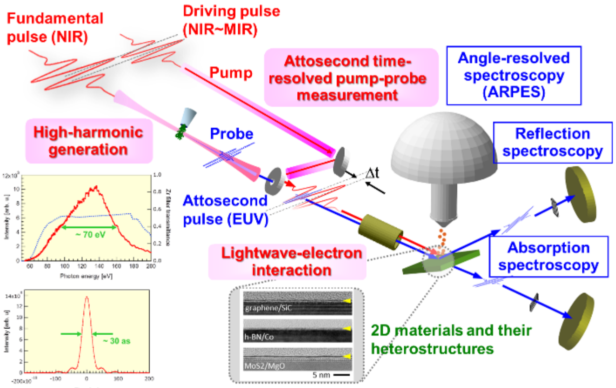

Figure 1. Schematic illustration of an extreme attosecond spectroscopic system for measuring solid state materials.

For the new attosecond spectroscopic techniques, we will develop a high-repetition-rate system with a frequency of from 0.1 to 1 MHz to improve the quality of data by increasing the data acquisition. The high-repetition attosecond time-resolved system will be combined with not only reflection and absorption spectroscopy but also angle-resolved photoelectron spectroscopy (ATTO-ARPES), and a magneto-optical Kerr effect (ATTO-MOKE). By applying these techniques to various 2D materials and their layered structures and heterostructures, we explore various ultrafast interaction between lightwave and electronic polarization, spin, and valley. In addition, we seek a better understanding of these experimental observations by theoretical approach such as the time-dependent density-matrix (TD-DM) method.

【Expected Research Achievements and Scientific Significance】

This research opens a new scientific field of “PHz-scale solid state physics”, which provide a framework beyond the usual approximations such as the envelope approximation and the rotating wave approximation assumed in the conventional optical solid state physics. The PHz-scale solid state physics will pave the way for the breakthrough in the novel ultrafast electronic functionalities with unprecedented operational speed controlled by light-wave field.

【Publications Relevant to the Project】

・ K. Oguri, H. Mashiko, T. Ogawa, Y. Hanada, H. Nakano, and H. Gotoh, “Sub-50-as isolated extreme ultraviolet continua generated by 1.6-cycle near-infrared pulse combined with double optical gating scheme,” Appl. Phys. Lett. 112, 181105 (2018).
・ H. Mashiko, K. Oguri, T. Yamaguchi, A. Suda, and H. Gotoh “Petaheltz optical drive with wide-bandgap semiconductor,” Nature Physics 12, 741 (2016).

【Term of Project】 FY2020-2024

【Budget Allocation】 154,900 Thousand Yen

【Homepage Address and Other Contact Information】
http://www.brl.ntt.co.jp/J/group_010/group_010.html