# Status of spin- and angle-resolved photoelectron spectroscopy with laser light at Laser and Synchrotron Research Laboratory

Spin- and angle-resolved photoelectron spectroscopy (SARPES) is a powerful technique to investigate the spin-dependent electronic states in solids. For example, one looks at the exchange splitting of ferromagnetic materials. Also, recently, strongly spin-orbit coupled materials, such as Rashba spin-split systems and topological insulators have been intensively studied. We developed a SARPES apparatus with a vacuum-ultraviolet (VUV) laser at Laser and Synchrotron Research Laboratory in the Institute for Solid State Physics, named LOBSTER (Laser-Optics-Based Spin-vecTor Experimental Research) machine. The LOBSTER machine is utilized to obtain precise information on spin-dependent electronic structures near the Fermi level in solids. We started a project to construct the LOBSTER machine from FY 2014 and joint researches at this station have started from FY 2015.

Figure 1 represents an overview of the LOBSTER machine [1]. The apparatus consists of an analysis chamber, a sample-bank chamber connected to a load-lock chamber, and a molecular beam epitaxy (MBE) chamber, which are kept in an ultra-high vacuum (UHV) environment and are connected with each other via UHV gate valves. The hemispherical electron analyzer is a

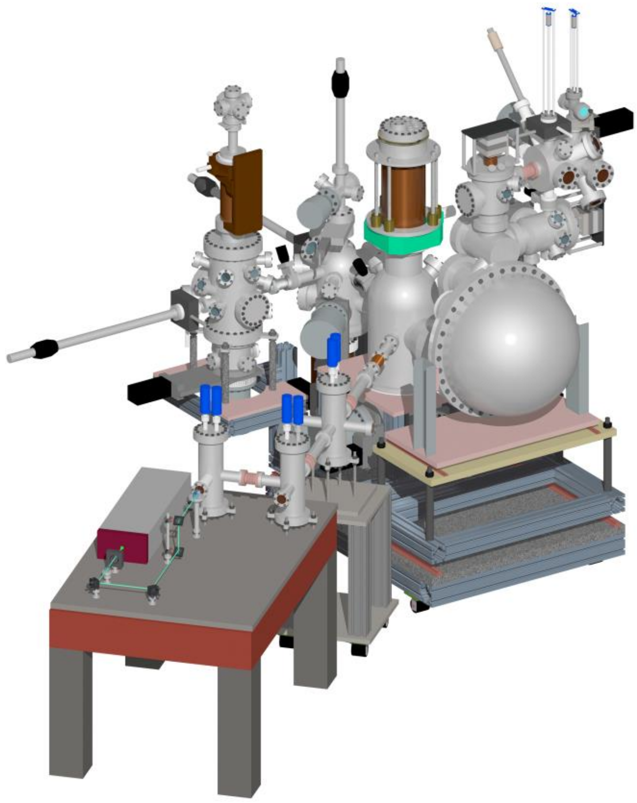

Fig. 1. Overview of the LOBSTER machine developed at the Laser and Synchrotron Research Laboratory at the Institute for Solid State Physics [1].

custom-made ScientaOmicron DA30-L, modified to attach the very-low-energy-electron-diffraction type spin detectors. The electrons are excited by 6.994-eV photons, yielded by 6th harmonic of a Nd:$YVO_4$ quasi-continuous wave laser with repetition rate of 120 MHz. A helium discharge lamp (VG Scienta, VUV5000) is also available as a photon source. At the MBE chamber, samples can be heated by a direct current heating or electron bombardment. The surface evaluating and preparing instruments, such as evaporators, low energy electron diffraction, sputter-gun and quartz microbalance, can be installed. At the carousel chamber, 16 samples can be stocked in the UHV environment.

In FY 2018, eight research papers were published. Among these, one of the most significant papers is the discovery of a weak topological insulator (WTI) state in a bismuth iodide, reported by Prof. Kondo group [2]. In this study, the authors were performed ARPES and SARPES with high-energy and spatial resolutions using the VUV laser for the bismuth iodide. They demonstrated a quasi-one-dimensional Dirac surface state. They also found that a crystal transition from the β-phase to the α-phase drives a topological phase transition from a nontrivial WTI to a normal insulator at roughly room temperature. The authors concluded that the weak topological phase can open a new pathway for developing novel spintronic devices that benefits from highly directional, dense spin currents that are protected against backscattering.

**Reference**

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