2. 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 known as a powerful technique for studying spin-dependent electronic states in solids. Up to the 1990s, utilization of this technique was strongly limited into mainly ferromagnetic materials; the main target was their large exchange splitting (~several hundred meV) because the efficiency of spin detections was so low that one needs to sacrifice both energy and angular resolutions. However, the recent progress of the spin detector improves the efficiency and enables us to precisely investigate small spin-structures in non-magnetic spin-orbit coupled materials and even its unique texture in momentum space, such as Rashba spin-split systems and topological insulators. Recently, we have developed the SARPES apparatus using vacuum-ultraviolet ($h\nu$=6.994eV) lasers at Laser and Synchrotron Research Center (LASOR) in the Institute for Solid State Physics (ISSP) [1]. Our SARPES machine is currently utilized to obtain precise information on spin-dependent electronic structures near the Fermi level in solids (~several meV). We have started a project to construct the laser-SARPES machine from FY 2014 and joint researches at this station have started from FY2015.

Our laser-SARPES apparatus consists of an analysis chamber, a carousel sample-bank chamber connected to a load-lock chamber, and a molecular beam epitaxy (MBE) chamber. All of these chambers are connected via UHV gate valves. Figure 1 represents the hemispherical electron analyzer, which is custom-made ScientaOmicron DA30-L, modified to attach the very-low-energy-electron-diffraction (VLEED) type spin detectors. The electrons are currently excited by 6.994-eV photons, yielded by 6th harmonic of a high-power Nd:YVO_4 quasi-continuous wave laser. 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

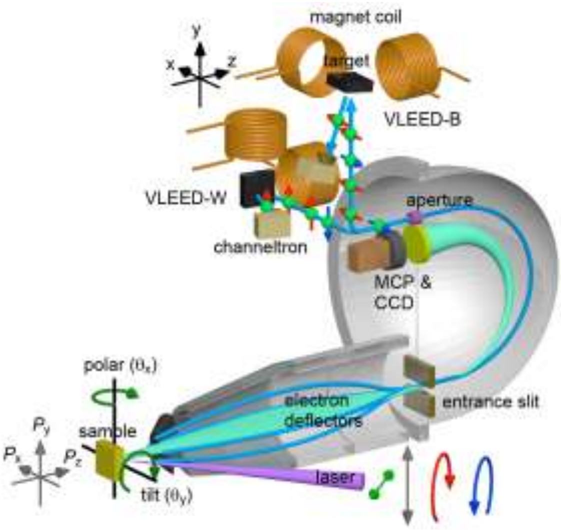

Figure 1: The laser-SARPES machine at LASOR at ISSP [1]. The double VLEED spin detectors are attached to a hemispherical analyzer (DA30-L, ScientaOmicron). Currently, 7-eV laser for high energy resolution measurement and 10.7eV pulsed laser for pump-probe measurement are available.

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 FY2019, eleven research proposals from outside of the institute were accepted and conducted. Spin-polarized states were investigated in both bulk and surface of various topological materials including magnetic and superconducting ones, atomic layers, and ferromagnetic compounds.

Since FY2018, we have started to upgrade our laser-SAPRES apparatus to combine with a pomp-probe laser technique. The laser system utilized for this project is a pulsed 10.7eV laser system, developed by Kobayashi group in LASOR at ISSP [2, 3]. This laser system is based on the Yb-doped fiver with the high repetition rate (1 MHz) with a pulse length of 270 fs. The light polarizations of 10.7eV can be selectively controlled by MgF_2 half-wave plate. In addition to a great capability of the time-resolution, our 10.7eV laser gives more wide momentum information in contrast to the low photon energy source such as 7eV, which is demonstrated in Figure 2. Thus, this state-of-the-art pump-probe SARPES apparatus can be widely used for studying unoccupied electronic states in spintronics materials and their ultrafast carrier/spin dynamics.

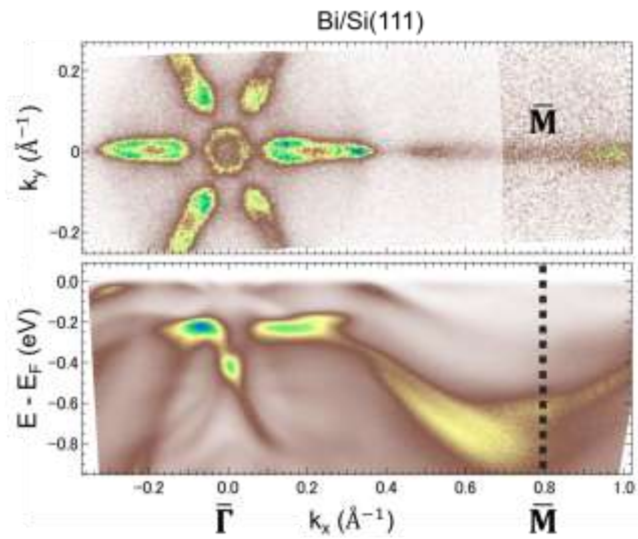

Figure 2: The Fermi surface mapping and band structure mapping for Bi thin films grown on Si(111) substrate, observed by 10.7eV laser [2, 3]. Such a photon energy can cover wide momentum information even around the Brillouin zone corner.

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