BL23SU
JAEA Actinide Science II

1. Abstract

The JAEA actinide science beamline BL23SU is mainly dedicated to the actinide material science. The beamline is also utilized for the surface chemistry and biophysical spectroscopy. There are three end stations in the beamline: real-time photoelectron spectroscopy station in the experimental hall and actinide science stations in the RI laboratory building.

2. Surface chemistry experimental end-station

The surface chemistry experimental end-station at BL23SU is dedicated to investigating chemical reactions and functionalities of solid surfaces and interfaces, primarily using soft X-ray photoelectron spectroscopy (XPS). Since April 2021, the station has also supported the ARIM Japan program of MEXT. During the 2022B shutdown, a new electron energy analyzer (Scienta Omicron Hipp-3) was installed, enabling microscopic photoelectron spectroscopy under near-ambient pressures. Initial tests demonstrated sufficient energy resolution to resolve Si 2p spin–orbit splitting and spectroscopy capability in a nitrogen atmosphere at ~1 Pa. Further improvements to the beamline exhaust and gas introduction are expected to allow measurements up to 3000 Pa. Microscopic spectroscopy feasibility was confirmed with line-space test samples. User experiments were conducted in 2024A, while 2024B was dedicated to maintenance, including analyzer repair. This report summarizes key findings obtained at the end-station.

Precise control of interfaces between dielectric materials and semiconductor surfaces is essential for advanced electronic devices. Hafnium oxide (HfO_2) is a leading candidate for high-k dielectrics. In this study, the initial oxidation of Hf-adsorbed Si(111) surfaces was investigated as a function of Hf coverage using synchrotron radiation X-ray photoelectron spectroscopy combined with supersonic O_2 beams. Clear differences in the chemical states of oxidized Hf silicates were observed, demonstrating that both interfacial and surface chemical states vary significantly with Hf coverage. These findings provide insights valuable for the fabrication of nanoscale HfO_2-based devices in silicon semiconductor technology. [1].

Oxidation presents a major challenge for mono-elemental 2D materials such as silicene, germanene, and stanene, as it degrades their structural and electronic properties. In this study, we demonstrated that oxidized germanene on Ag(111)/Ge(111) can be effectively reformed via simple vacuum annealing at ≈500–600 °C. The reformation is driven by the desorption of GeO and GeO_2, followed by Ge segregation to the surface, restoring the $(7\sqrt{7}\times7\sqrt{7})$ R19.1° supercell structure characteristic of high-quality as-grown germanene. Remarkably, this process is robust: germanene can be reformed even after air exposure, and the desorption reaction is not suppressed in an O_2 backfill atmosphere. The intrinsic instability of oxidized germanene at high temperatures thus facilitates clean reformation without residual oxygen. These results demonstrate that vacuum annealing provides a reliable approach to synthesize and maintain high-quality germanene, highlighting a robust method for fundamental studies on group-

IV 2D materials [2].

The activation and deterioration mechanisms of Ti-Zr-V non-evaporable getter (NEG) coatings were investigated using synchrotron radiation photoelectron spectroscopy. Upon heating to 250 °C for activation, surface Zr initially acquires oxygen from Ti and V oxides, leaving metallic Ti and V exposed, followed by diffusion of oxygen from Zr-oxide into the coating, producing metallic Zr at the surface. Deterioration was studied by introducing O_2 gas at 250 °C, with the oxidized depth profile measured by X-ray photoelectron spectroscopy. In deteriorated coatings, Zr and Ti oxidize deeply, restricting oxygen migration and suppressing surface metallization. These results provide key insights into the chemical evolution of Ti-Zr-V NEG coatings, aiding strategies to improve their performance and durability. [3].

Charge transfer at metal–organic interfaces was studied via atomic hydrogen addition to an imidazole-terminated alkanethiolate self-assembled monolayer (Im-SAM) on Au(111) at room temperature. Using NEXAFS, IRRAS, work function measurements, and DFT calculations, we investigated whether hydrogenation of the imidazole groups forms imidazolium cations with electron transfer to the Au substrate, even in the absence of solvation or counterions. Experiments confirmed the formation of imidazolium moieties upon atomic H irradiation, and theoretical analysis supported electron transfer associated with cation formation. Work function measurements further indicated that a fraction of imidazolium radicals converted to cations, providing insight into interfacial charge transfer processes and the role of hydrogenation in modulating electronic properties at metal–organic interfaces [4].

As described above, the surface chemistry experimental end-station has been extensively utilized for investigating the physicochemical properties, surface/interface functionalities, and reaction mechanisms of various materials.

3. Actinide science stations

In the RI laboratory building, there are photoelectron spectroscopy station and soft X-ray magnetic circular dichroism (XMCD) station, and the scanning transmission X-ray microscopy (STXM) stations.

At the photoelectron spectroscopy station, photoelectron spectroscopy studies for strongly correlated materials such as actinide and rare-earth compounds have been conducted. As a scientific result, the detailed electronic state of heavy fermion superconductor UTe_2 was studied.

At the XMCD experimental station, we have promoted a wide range of research on strongly correlated electron systems such as topological insulators and functional magnetic materials. But the operation of the XMCD station has still been suspended due to a serious malfunction of the insertion device, which was found in February 2022.

The commissioning of the STXM installed at the downstream end of BL23SU in RI laboratory has completed. We have confirmed that a spatial resolution of about 30 nm with a 25 nm FZP has been achieved in 2022A. The STXM measurements for a radioactive sample was conducted in 2024A and 2024B terms. Some user experiments have also been conducted.

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References

[1] Kakiuchi, T. *et al.* (2024) *J. Phys. Chem. C* **128,** 13052.

[2] Suzuki, S. *et al.* (2024) *Small methods* **9***,* 2400863.

[3] Kamiya, J. *et al.* (2024) *e-Journal of Surface Science Nanotechnology,* **22,** 316.

[4] Kato, H. S. *et al.* (2024) *J. Phys. Chem. Lett.* **15**, 10769.