Research Group for Nanoscale Structure and Function of Advanced Materials

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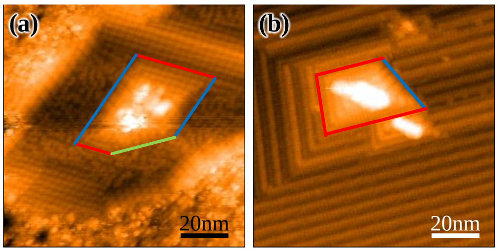
Macroscopic properties of matter based on local states could be understood by investigating a nanoscale region of a sample. An experimental technique that can be used to selectively investigate a surface, bulk, impurity/defect, or ultrathin film can extend the field of materials research. Existing technical developments enable us to efficiently produce high-intensity beams, especially beams of synchrotron light, electrons, neutrons, muons, and positrons, which are useful for studying various atomic structures and dynamics of functional materials at the length scale of advanced beams. In addition, experimental techniques that can obey local states such as surface, interface, and impurity have been developed as well, and they can be used to obtain new scientific insights. Our objective is to develop these new advanced measurement technologies and study the nanoscale structures of functional devices and materials in order to clarify the essential properties of matter.



Uniform Si nano-dot fabrication using reconstructed structure of Si(110) [1]

We investigated the Si nano-dot (ND) formation on Si(110) by using scanning tunnelling microscope (STM). The Si-NDs are Si crystals continuously grown from the substrate during the thermal decomposition of thin oxide layer on Si(110). The NDs fabricated on the flat surface of the Si(110)-1 × 1 structure are surrounded by four types of facets with almost identical appearance probabilities, as shown in Fig. 1(a). Moreover, an increase in the size of the NDs leads to the variety of its morphology due to the increase of the number of facets. In contrast, most Si-NDs fabricated at the domain boundary of straight-stepped Si(110)-16 × 2 reconstructed structure have uniformed shape, which has three (17, 15, 1) facets and one (17, 15, 3) facet, as shown in Fig. 1(b). The base line of the (17, 15, 1) facet corresponds to the step of the 16 × 2 reconstructed structure, suggesting that the reconstructed structure determines the direction of the facet's base line. This also suggests that the reconstructed structure dominates the facet structure, because each direction of the base line has only one type of stable facet structure. Therefore, the Si(110)-16 × 2 reconstructed structure can be the template of uniform-structured NDs, leading new fabrication technique of the NDs to realize the novel functional devices.

Fig. 1 STM images of the typical Si NDs on (a) the 1 × 1 structure and (b) 16×2 reconstructed structure. The red, blue and green lines around the NDs indicate base lines of the facets along the crystal directions of <112>, <332>, <552>, respectively.

Development of µSR spectrometer for ultra slow muon [2]

At J-PARC muon science facility (MUSE), we are advancing material researches by using muons. A muon belongs to Lepton particle and used as a sensitive probe of magnetic fields inside materials. This method is known as "muon spin relaxation (µSR)". At MUSE, "ultra slow muon" (USM) beam is developing at U1 beam line. USM is low energy muons (0.2-30 keV), generated by using intense 4 MeV positive muon beam and lasers. The corresponding muon range for implantation is 0~200 nm deep for the case of copper, where we can continuously investigate properties of specimen from near surface to bulk region.

At the U1A area in the downstream of the USM beamline, we have installed µSR spectrometer with MUSE group. The entire spectrometer assembly including a cryostat, positron detectors, magnets, other electronic devices and their power supplies is contained in a large metallic cage that is on an electrically isolated stage. The beam implantation energy is varied by tuning electrostatic potential of the stage over a range of 0-30 kV that serves to decelerate USMs at the entry section of the spectrometer. The required features for the USM µSR spectrometer are common to those for conventional ones, except sample environment which must be compatible with ultra-high vacuum condition. Moreover, cares must be taken to minimize thermal radiation for controlling sample temperature without beam windows and radiation shields that interrupt the USM implantation. The spectrometer is furnished with a set of Helmholtz coils for applying an external magnetic field up to 0.14 Tesla along beam direction. As positron counters, "Kalliope" developed by KEK were installed.

This spectrometer is already working and commissioning of the total USM system is going on. USM µSR spectrometer will be used for researches of surface, interface and bulk states and unique scientific results will be obtained.

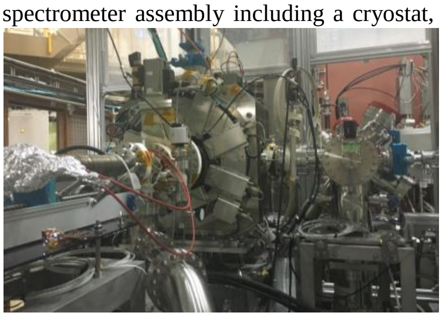


Fig. 2 µSR spectrometer for ultra slow muon at J-PARC MUSE.

References

[1] M. Yano, Y. Uozumi, S. Yasuda, and H. Asaoka, Jpn. J. Appl. Phys. **57**, 06HD04 (2018).

[2] W. Higemoto, R. Kadono, N. Kawamura, A. Koda, K. M. Kojima, S. Makimura, S. Matoba, Y. Miyake, K. Shimomura and P. Strasser, Quantum Beam Sci. **1**(1), 11 (2017).