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

Science and Engineering (Interdisciplinary Science and Engineering)

Title of Project : Transmission Muon Microscope by muon microbeam, realizing 3-D Imaging

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Research Project Number : 17H06126 Researcher Number : 80209882
Research Area : Quantum Beam
Keyword : Muon, Ultra slow muon, Laser, Microscopy, Quantum interference, wave

【Purpose and Background of the Research】

When a surface muon (4 MeV) is incident on a tungsten foil (silica aerogel), muonium (bound state of a muon and an electron, which is like a light isotope of H) evaporates into vacuum with a yield of around 4% (7%). By cooling muonium by 7-8 orders from 4 MeV to 0.2 eV (0.03 eV) combined with the application of the laser resonant ionization method (1p-2p-unbound), ultra slow muon (USM) can be generated. Then reacceleration and focusing of USM helps to achieve muon as coherent wave. The essence of this research is to create a high intensity muon microbeam with excellent time and spatial resolution by using supercooling and reacceleration to demonstrate the wave-particle duality of muon. It will also provide a novel insight (3D image) to materials research [Fig. 1].

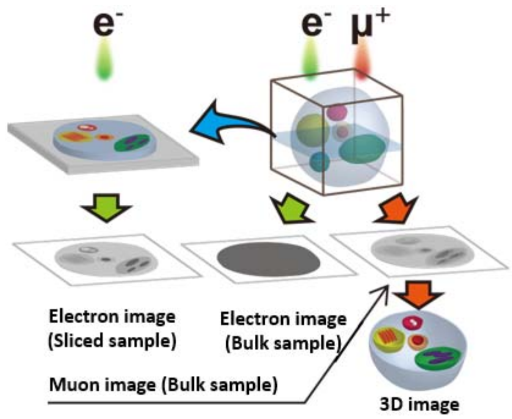

Fig. 1. 3D imaging of a 10 μm thick sample. Advantages of transmission muon microscope versus electron microscope.

【Research Methods】

To establish transmission muon microscope, the following 3 major research topics will be proceeded;

(A) Reacceleration of muon: USM will be accelerated up to 300 keV by induction acceleration to demonstrates the wave nature of the muon, and finally reaccelerated up to 10 MeV to get muon microbeam.

(B) Superconducting objective lens: It will be developed and used to focus muon which has 200 times heavier mass than electron.

(C) Transmission imaging: Development of normal focusing/projection lens and muon image detector for imaging of thick sample, such as alive cell or solar cell.

【Expected Research Achievements and Scientific Significance】

(1) Direct proof of quantum coherency of 2nd generation lepton: To demonstrate the muon as wave, a single crystal thin film of gold sample will be used to observe a muon diffraction image. A gold grating (408 pm) with diffraction angles 0.66 and 0.38 mrad for the acceleration voltages of 100 and 300 keV, respectively, will show diffraction patterns at a distance of 1m on a two dimensional image sensor SOI detector (14 μm resolution) compatible with vacuum. It will be a historical achievement to prove the quantum coherency exhibited by muon as a 2nd generation lepton in the standard model.

(2) Microscopic imaging of materials: Thick samples (> μm) will be visualized by using the transmission capability of the transmission muon microscope. The quantum interference of muon can be achieved by phase contrast method, and the electromagnetic field distribution inside the sample will be visualized using a phase plate made of carbon thin film (Aharonov-Bohm effect). The number of muons required to observe an image with a resolution of 256 x 256 pixels with a dynamic range of 8 bits is 256^3, and the time required to acquire one image in U-Line is several ten minutes to several hours.

【Publications Relevant to the Project】

・"**Ultra Slow Muon Project at J-PARC MUSE**", Y. Miyake et al., JPS Conf. Proc. 2, (2014)010101
・"**Ultra Slow Muon Microscopy by Laser Resonant Ionization at J-PARC, MUSE**", Y. Miyake, et al., Hyperfine Interactions 216 (2013) 79-83

【Term of Project】 FY2017-2021

【Budget Allocation】 159,300 Thousand Yen

【Homepage Address and Other Contact Information】

http://slowmuon.kek.jp/MuonMicroscopy.html