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

Transmission muon microscopy for visualizing electromagnetic fields inside of power-devices and life

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Purpose and Background of the Research

●Outline of the Research

Our modern civilization relies on electromagnetism through electronics, thus visualization of electromagnetic field inside power-devices contributes to our society's SDGs by improving the devices. For biology, the membrane potential of mitochondria is the basis of cellular energy production, and the propagation of action-potentials in brains governs information processing. Muons can visualize the electromagnetic fields inside macroscopic objects, because accelerated muons have a ultra-high capability to penetrate materials. The transmission muon microscope uses a muon beam mass-produced by accelerators. The quality of the muon beam is improved into ultra-high brightness by a multi-step beam cooling device. The beam is accelerated by cyclotron and obtains penetration capability. By the Lorentz method or phase contrast method, electromagnetic fields inside thick objects, e.g., power-devices and cells, are visualized.

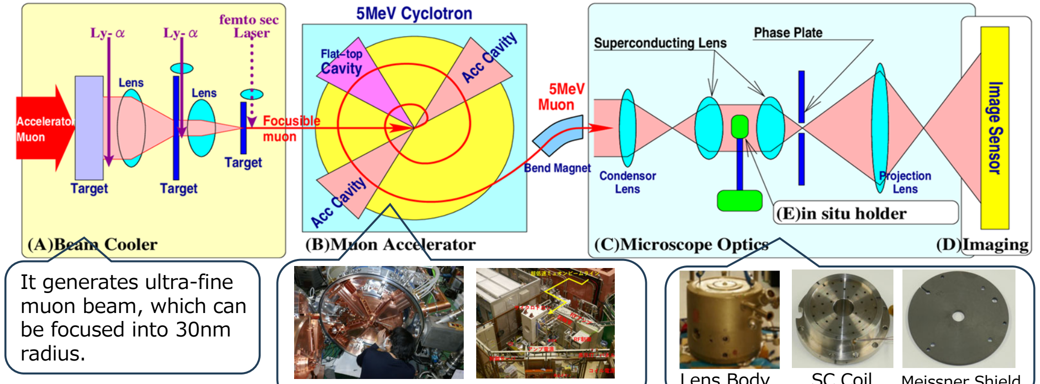
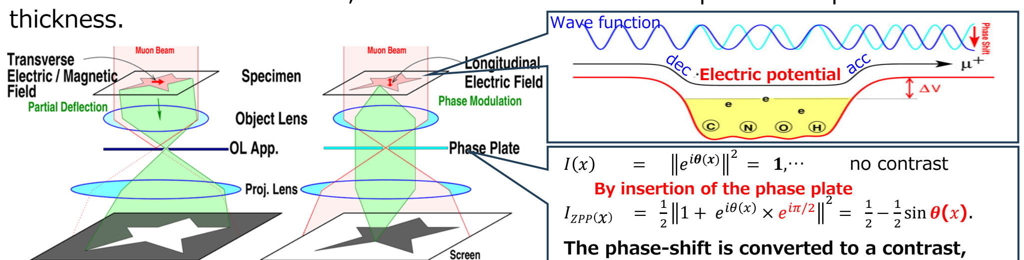


Figure 1. Outline of R&D

●Background Technology of the Transmission Electron Microscopy (TEM)

TEM can observe electromagnetic fields inside thin object with the highest resolution using the Lorentz method or phase-contrast method. However, the transmission ability of the electron-beam is weak, conventional TEM observes specimens up to 100s nm thickness.



$I(x) \;=\; \|e^{i\theta(x)}\|^2 \;=\; 1,\cdots$ no contrast

By insertion of the phase plate

$I_{ZPP}(x) \;=\; \frac{1}{2}\|1 + e^{i\theta(x)} \times e^{i\pi/2}\|^2 \;=\; \frac{1}{2} - \frac{1}{2}\sin\theta(x).$

The phase-shift is converted to a contrast,
Sensitivity 25mV/μm can visualize action-potential

Figure 2. Lorentz and phase-contrast methods.

●Concept of Transmission Muon Microscopy

In order to overcome the sample thickness limitations of the TEM, we replace the electrons in the TEM with accelerated muons. Accelerated muons have an extremely high capability to penetrate objects. This is the basic principle of a transmission muon microscope. We will employ the world's first muon cyclotron, and realize transmission observation of a 10 μm thick sample.

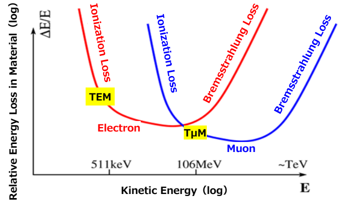


Figure 3 Penetration Capability

Expected Research Achievements

●Higher brightness and ultra-short pulse of ultra-slow muon beam generator

By further cooling the ultra-slow muon in multiple stages, an ultra-high quality muon beam that can be focused into 30 nm radius is generated. This brings out high spatial resolution and electromagnetic field resolution. In addition, by using a femtosecond laser in the final stage, an extremely short muon pule beam is realized. I will visualize the EM-field inside devices operating at high speed in a stroboscopic manner.

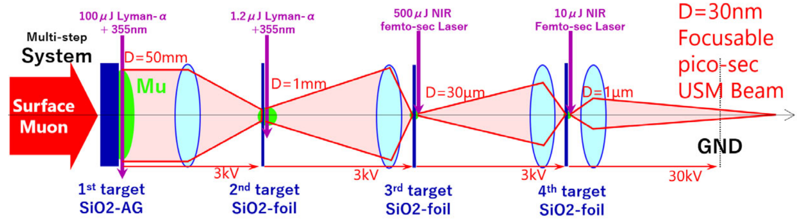


Figure 4. Concept design of the multi-step muon beam cooler

●Demonstration of a muon microscope that visualizes electromagnetic fields

We will develop a muon microscope using a superconducting objective lens. By installing the Lorentz method and phase contrast method, visualization of the electromagnetic fields in thick objects.

● EM-Imaging of Power-device

The electric field inside the ultra-high voltage SiC-MOSFET device developed by AIST will be visualized. The actual electric field concentration and weak points of the devices will be found out. It contributes to design higher performance devices.

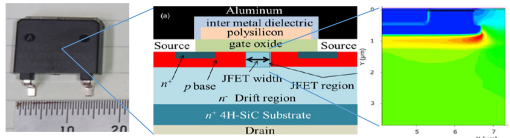


Figure 5. Exterior (left), Internal structure (center) and electric field simulation (right) of the SiC MOSFET developed by AIST.

●3D-measurement of electric potential inside mitochondria and nerve cells

We will establish an unprecedented method that measures the mitochondria in the entire cell and maps the relationship between mitochondrial shape and function. We also will establish a tomography method that rapidly freezes stimulated neurons or nerve networks, and then rotates the frozen sample while taking transmission images to visualize 3D-snapshots of action potentials propagating inside nerve cells and networks.

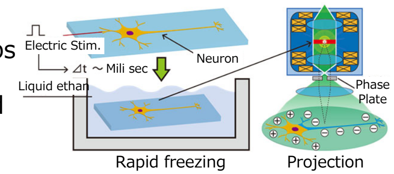


Figure 6. Visualization of the electric potentials in neurons.

Homepage Address, etc.	https://slowmuon.kek.jp/MuonMicroscopy.html