9–2 Using Computer Simulations to Design a Superconducting Neutron Microscope

—Simulating All Radiation Types inside the Neutron Microscope and Predicting Its Behavior—

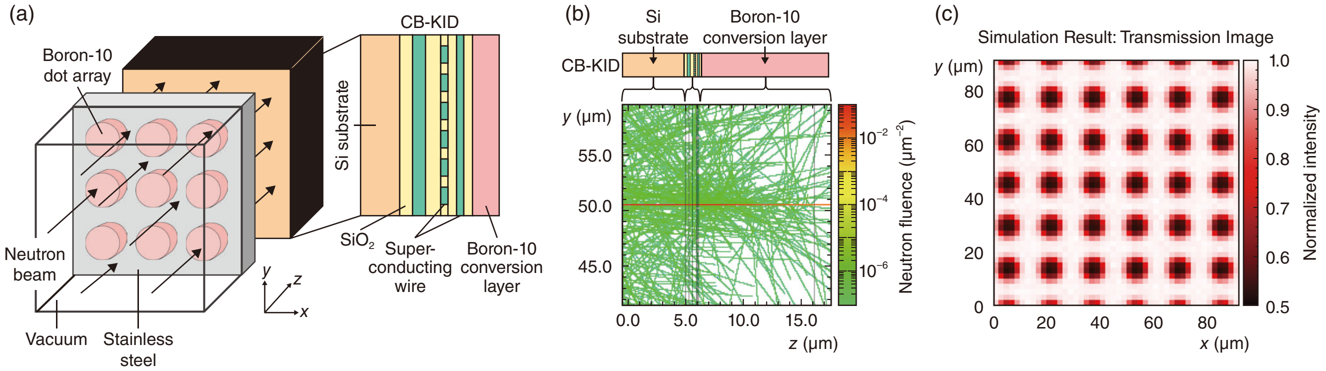

Fig.9-4 (a) Model of the CB-KID superconducting neutron microscope, (b) PHITS simulation of radiation tracks inside the CB-KID, and (c) simulated neutron transmission image from the CB-KID
(a) Schematic showing the boron-10 dot array test sample and a model of the CB-KID superconducting neutron microscope. The CB-KID is a stack of different layers of materials. The incident neutron beam undergoes nuclear reactions in the boron-10 conversion layer, which releases ^{4}He and ^{7}Li particles that are then detected by the superconducting wires. (b) Simulated neutron tracks, where the colors indicate the neutron fluence, or the number of neutrons per unit area. The horizontal red line in the figure shows the focused neutron beam which was simulated incident to the center of the detector. (c) Simulation results of a neutron transmission image from the CB-KID of the boron-10 dot array test sample (left side of panel (a)), where a uniform neutron beam was simulated incident on the CB-KID. Only a small number of neutrons could pass through the boron-10 dots; these show up as dark regions in the image.

As neutrons can penetrate deeply into matter, neutron beams can be used for imaging inside substances. Few facilities currently produce high-intensity neutron beams capable of neutron imaging, though various particle accelerators are being planned and constructed. However, further developments in high-resolution neutron microscopy technologies are necessary to take full advantage of high-intensity neutron beams.

The current-biased kinetic inductance detector (CB-KID) is one type of neutron microscopy technology that is under development in Japan. This innovative technology for micron-scale microscopy has improved upon existing neutron imaging technologies. In the CB-KID, incident neutrons undergo nuclear reactions in a thin film of boron-10 (the conversion layer), which converts the neutrons into helium-4 (^{4}He) and lithium-7 (^{7}Li) particles. The CB-KID then detects the positions of these individual particles using superconducting wires.

However, it is not possible to perform enough experiments to design the CB-KID, as there are a limited number of neutron beam facilities worldwide. Therefore, the Center for Computational Science and e-Systems developed a simulation model, shown in Fig.9-4(a), to support the detector's design in collaboration with Osaka Prefecture University and Japan Proton Accelerator Research Complex (J-PARC). In this model, the PHITS simulation code was used for simulating tracks and nuclear reactions of neutrons within the CB-KID. A representative example of the resulting simulated neutron tracks inside the CB-KID under irradiation by a focused neutron beam is shown in Fig.9-4(b). Here, the neutrons were tracked, the ^{4}He and ^{7}Li particles were produced from the nuclear reactions, and the maximum penetration lengths of these particles were calculated. The results demonstrated that only the ^{4}He and ^{7}Li particles produced in the boron-10 conversion layer caused a detectable signal, and therefore neither the ^{4}He and ^{7}Li particles produced in the test sample nor the gamma rays from nuclear reactions significantly affected the transmission images. This represents the first demonstration that gamma rays do not affect the transmission images, thus indicating that the CB-KID design is only sensitive to neutrons incident on the microscope, therefore making it suitable for neutron imaging.

A representative result of the simulated neutron transmission image of a test sample is shown in Fig.9-4(c). The result corresponded well with microscopy imaging of the test sample (an array of microscopic boron-10 dots 6 μm in diameter), thus validating the potential of the CB-KID neutron microscope for imaging sub-10 μm microscopic test samples. Future work will include the simulation of various modified designs for the neutron microscope to increase the resolution of its transmission images. Such numerical experiments are expected to accelerate the development of CB-KID by significantly reducing project costs and labor.

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Reference

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