Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SMP044-01 Room:301B Time:May 25 10:00-10:15

muSR study on the behavior of trace hydrogen in silicates

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Hydrogen is the most abundant element in the solar system and the presence of water, which is formed by binding hydrogen and oxygen, makes the Earth a habitable blue planet. It is also believed that the presence of water, even if its amount is very small, alters physical and chemical properties of silicates significantly (for example, depression of melting temperature, decrease in viscosity, increase in electrical conductivity, etc.) and therefore plays an important role in geodynamics such as igneous activity and mantle convection and, what is more, in the terrestrial evolution from past to present to future.

That is why "water (hydroxyl)" in silicates has attracted a lot of interest and so far been studied by many researchers. On the other hand, "isolated hydrogen" in silicates may have been overlooked in previous studies because it is hard to probe the behavior of isolated hydrogen with ordinary techniques used in mineral physics and crystal chemistry. In the field of semiconductor science, however, it is well known that eliminating isolated-hydrogen atoms from a semiconductor is quite difficult and that their presence has remarkable effects on its physical properties. In the broad sense, silicates are classified as a semiconductor (i.e., wide-gap semiconductor) and therefore it may be possible that the same scenario takes place in them. The purpose of this study is to clarify the behavior of "isolated hydrogen" and "water" in silicates with muon spin rotation/relaxation/resonance (muSR) techniques, which have worked well in studies on "isolated hydrogen" in semiconductors.

Muon is a particle having a mass about 9 times less than that of proton and a spin of 1/2. In certain materials, a positive muon can pick up an electron to form a hydrogen-like atom called muonium. Therefore, positive muon can be considered to be a lighter version of proton. In muSR measurements, information about the site, the electronic state, and the diffusion dynamics of muon (an isotope of proton) can be obtained, by measuring the time evolution of the spin polarization of the muon implanted into a sample. Neutron diffraction is also a powerful tool to probe the behavior of hydrogen in materials. However, in neutron diffraction measurements, hydrogen should be in a framework structure of materials. muSR has the advantage of being able to probe the behavior of trace hydrogen irregularly located in interstitial sites of materials.

Japan Proton Accelerator Research Complex (J-PARC, Tokai-mura, Japan) is now successful in producing the most intense pulsed-muon beam in the world. The intense beam makes it possible to conduct muSR measurements on a relatively small sample (approximately 15 mm in diameter and 1 mm in thickness) at Materials and Life Science Experimental Facility (MLF). We applied to non-proprietary use experiments at MLF to clarify the effect of microscopic structures of silicates on the behavior of trace hydrogen and have the first beamtime in March 2011. In the first beamtime, we will conduct muSR measurements on high-pressure crystalline and glassy phases of SiO2 at ambient pressure. The samples have been prepared by using a belt-type high-pressure apparatus at National Institute for Materials Science (NIMS). In the future, we plan to develop high-pressure in-situ muSR techniques to conduct experiments at the conditions of the Earth's Interior. At the meeting, we will report about the first beamtime and discuss our plan to use muSR techniques in Earth science.