An atomic force microscopy study on the local surface potential difference of amorphous solid water formed by water vapor deposition at 15 and 100 K

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Amorphous solid water (ASW) is well known to abundantly exist as icy dust particles in molecular clouds. The icy dust particles, which are mineral nanoparticles covered with an ASW mantle primarily composed of H_2O, play an important role in chemical evolution in space. This is because the surface of icy dust facilitates a variety of molecular syntheses through physical and chemical processes such as adsorption, diffusion, reaction and desorption of atoms and molecules[1,2]. However, it is difficult to say that our understanding of ASW itself, which serves as the site for various physical and chemical processes, is sufficiently advanced.

ASW films formed by vapor deposition onto a cold surface are known to have negative surface potentials due to spontaneous polarization, which varies depending on the temperature and film thickness[3,4]. However, the mechanisms underlying this polarization, responsible for the surface potentials, remain unclear. Although previous studies that used Kelvin probe measurements have proposed the polarization model of ASW named tilted dipole model, the direct evidence confirming validity of this model has not been obtained yet. One of the major reasons is the low spatial resolution in the measurement of contact potential difference by the Kelvin probe method. To overcome this limitation in spatial resolution, we used FM-AFM to measure variations in the negative surface voltage of ASW with nanoscale resolution depending on the surface structures.

We conducted measurements on two types of ASW formed by water vapor deposition at 15 and 100K on a Si (111) 7×7 substrate in ultra-high vacuum conditions. The topographic images of the surface structure showed temperature dependence, attributed to the differences in diffusion length of water molecules on the surface until reaching stabilization at the measurement temperature. We also measured the local contact potential difference between probe tip and 400 measurement points set on ASW surface within a 200 nm x 200 nm are, respectively. On both ASW surfaces, the local contact potential difference varied at each measurement point without correlation with local thickness (topographic height). This suggests that this polarization phenomenon cannot simply attributed to the thickness of ASW but depends on the local structure. Our observations with nanoscale resolution imply that the tilted dipole model is a plausible representation of the spontaneous polarization of ASW.

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