Direct observation on the atomic structure of 2D oxide nanosheet and its structural degradation under electron beam

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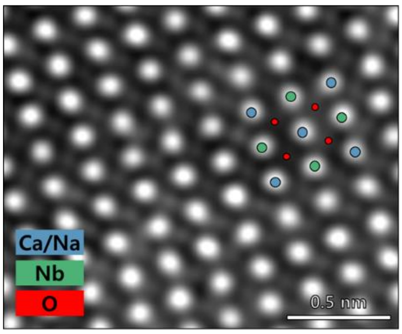
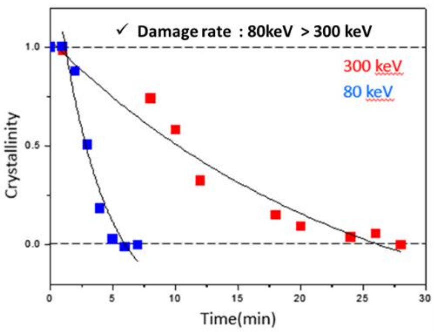
Electronic devices have become miniaturized and the demand for new materials showing enhanced physical properties has dramatically increased. Two-dimensional (2D) inorganic nanosheets are one of the promising new materials for high-k dielectric materials in microelectronics. $Ca_2Na_2Nb_5O_{16}$ (CNNO) perovskite oxide nanosheet shows superior high-k property and chemical stability under thickness of 10 nm [1]. Also, unexpected ferroelectric property was reported on CNNO nanosheet recently [2]. By the way, observation on the atomic structure of the 2D oxide nanosheet such as CNNO is challenging since they are easily damage under accelerated electron beam. So there are limited reports on the microstructure investigation of the 2D oxide nanosheet [3-4]. However, more detailed observation on the atomic structure of 2D oxide nanosheets is necessary to understand its unique physical properties. Thus, investigating the e-beam induced damage mechanism and finding optimum TEM observation conditions are crucial for further advances of electronic devices using 2D oxide nanosheets.

Here, we directly observed the atomic structure of CNNO nanosheet and investigated the damage mechanism of the CNNO nanosheet under various e-beam irradiation conditions in TEM and STEM.

CNNO nanosheets are fabricated by exfoliation method with a starting template material of $KCa_2Na_2Nb_3O_{16}$. The observation as well as e-beam irradiation on CNNO nanosheet was performed in aberration-corrected STEM (Titan S80-300; FEI) at different acceleration voltage of 80 keV and 300 keV. E-beam current was controlled under 0.935 nA. Mass loss in specific element upon e-beam was traced using a Talos TEM (FEI; Talos F200X) microscope equipped with an X-FEG and super-X EDS system with four silicon drift detectors (Bruker).

Unexpected damage rates under the e-beam irradiation were observed in the CNNO nanosheet at different acceleration voltage; a damage rate was faster at low-accelerating voltage than high-accelerating voltage (see figure below). At low-accelerating voltage, a radiolysis damage mechanism was dominant than knock-on damage. Based on the results, we found optimum (S)TEM observation conditions for 2D nanosheets, and we directly confirmed the atomic structure of the CNNO perovskite oxide nanosheet from the TEM and STEM results which are shown in the figure below.





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