Application of a STXM analysis for diamond in ureilite

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A member of primitive achondrite, ureilite is an ultramafic rock, and contains considerable amount of carbon. Although most carbon in ureilite occurs as graphite, a small amount of diamond accompanies the graphite in some ureilite. The formation mechanism of diamond included in ureilite has been enigmatic for decades. Most diamonds in ureilite are from several nano-meters to micro-meters in size. A specific crystallographic orientation between graphite and diamond was observed in some ureilite. Based on these mineralogical features, most previous studies concluded that diamonds in ureilite were formed by a high-pressure condition induced by planetesimal collision occurred on a parent-body of ureilite [e.g., 1]. On the other hand, many coarse-grained diamonds (~100 micro-meter > across) were found in Almahata Sitta ureilite. Considering mineralogical and isotopic characteristics, it is possible that the coarse-grained diamonds included in Almahata Sitta ureilite formed from a fluid or melt in the deep interior of an ureilite parent-body or through CVD process in the solar nebula [2]. Recently, scanning transmission X-ray microscopy (STXM) has been applied for earth and planetary science field such as environmentology and astrobiology [e.g., 3]. X-ray absorption fine structure (XANES) can be obtained by STXM measurement. A bonding-state of element and chemical species can be clarified from XANES. FIB-assisted STXM measurement with a well-shaped X-ray beam (~30 nm) by a zone plate allows us to conduct functional group analysis and speciation at a specific interesting point. Functional group and speciation mapping images also can be taken by using a precious drive sample stage. The bonding-states of carbon and their 2-D distributions in the graphite-diamond assemblage of ureilite would be a clue for diamond formation mechanism. In addition, the bonding-state and chemical species of impure elements such as iron and nitrogen included in the graphite-diamond assemblage could constrain pressure, temperature and oxygen partial pressure conditions at a place where diamond formed. Accordingly, we have tried to adopt FIB-assisted STXM measurement for diamond in ureilite. A part of the coarse-grained diamond in Almahatta Sitta ureilite was excavated by FIB for STXM measurement, and became a foil. STXM measurement was carried at BL4U, UVSOR. Synthetic graphite and natural terrestrial diamond were also measured as a reference material. XANES of graphite, diamond and amorphous carbon (C-K edges) could be obtained from the foil successfully, and their 2-D distributions were constructed using a dedicated image processing application. The amorphous carbon portion is a deposition (made by a FIB-CVD) to reduce a damage on the foil during FIB thinning. Although the diamond appears to be a single crystal under a TEM image, several isolated (island-like) graphite portions (~100 x 200 nm across) were formed in the diamond. Some isolated graphite portions appear to be arranged along with a diamond {111} plane. The diamond was rimed with thin graphite layers (~100 nm > thickness). It is likely that the graphite is evidence for a transformation from diamond to graphite.

[1] Nakamuta et al., JMPS, 111, 252-269, 2016.
[2] Miyahara et al., GCA, 163, 14-26, 2015.
[3] Suga et al. under review.

Keywords: Diamond, Ureilite, STXM

