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Micro-texture of isotopically anomalous material in Acfer 094 matrix.

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Oxygen is the most abundant element in solids formed in the Solar System and has three isotopes (16, 17, 18), which exhibit mass-dependent and mass-independent fractionations (MIF), providing important constraints on the conditions during formation of solids in the early solar nebula. The variations in MIF of oxygen isotopes are generally attributed to mixing of two isotopically distinct nebular reservoirs: ^{16}O-rich and ^{17,18}O-rich. The existence of ^{16}O-rich reservoir in the early Solar System has been inferred from isotopic compositions of high-temperature nebular condensates and unique chondrules. However, little had been known about the ^{17,18}O-rich nebular reservoir, until a recent discovery of an isotopically anomalous material in the ungrouped carbonaceous chondrite Acfer 094, called new-PCP (Sakamoto et al., 2007). Here, we report mineral chemistry and micro-textures of the isotopically anomalous (delta$^{17,18}O_{SMOW}$ up to +180 permil) Fe-S-Ni-O material using synchrotron radiation X-ray diffraction analysis (SR-XRD) and transmission electron microscopy (TEM).

A sample of new-PCP for SR-XRD and TEM was cut out from a polished thin section of Acfer 094 by a focused ion beam (FIB) technique using SMI3050TB system of SII NanoTechnology. SR-XRD measurements were carried out in the BL13A beam line at Photon Factory, High-energy Accelerator Research Organization (PF-KEK) in Tsukuba, Japan. Microstructural observations and electron diffraction analyses were undertaken using a conventional TEM (JEOL JEM-2010) and an EDS system (Thermo Electron Noran system SIX) of the Mineralogy Laboratory of Hokkaido University. Elemental maps were performed with a scanning TEM (STEM, HITACHI HD2000) and an EDS system (EDAX Genesis series) of the Open Facility of Hokkaido University.

The SR-XRD and TEM study indicate that this material consists of the symplectically intergrown magnetite ($Fe_3O\{4\}$) and pentlandite ($Fe_{5.7}Ni_{3.3}S_8$); the volume ratio of the magnetite to the pentlandite is ˜2.3. Magnetite forms column-shaped grains (10˜30nm in diameter and 100˜200nm in length); pentlandite occurs as worm-shaped grains or aggregates of grains 100˜300nm in size between magnetite crystals. The wormy grains are assemblage of magnetite-pentlandite showing a symplectitic texture in tens nm scale. Although the X-ray diffraction supports identification of iron oxide as magnetite, the electron diffraction patterns show that magnetite has a weak 3-fold superstructure, possibly due to ordering of vacancies.

We infer that this material was formed by sulfurization and oxidization of metal grains either in the solar nebula or on an icy planetesimal. The intersite cation distribution of pentlandite suggests timescale of the oxidation was no longer than 1000 years.