NANOSIMS ANALYSIS OF SIDEROPHILE ELEMENTS IN METALLIC PHASES OF CHONDRITES.

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Introduction: The siderophile (iron-loving) elements, comprising the highly siderophile elements (HSE; including platinum group elements, Re and Au) and the moderately siderophile elements (MSE; including Co, Ni, Ge, Mo, Ag and W), tend to be enriched in metallic phases in the melt due to their high low-pressure metal-silicate partition coefficients (ca. 10^4 for HSE and 10-10^4 for MSE)[1]. In addition, the siderophile elements cover a wide range of elemental condensation temperatures, from the most refractory substances (such as Re, Os, Ru and Ir) to the more volatile elements (such as Au and Ge) in the solar nebula[2], which make them as ideal tracers for the process of nebula condensation. The chondrite is a relatively primitive rock and the metal particles are the important constituents of the chondrite, thus metallic phases in chondrites may record information about the origin and evolution of chondritic metals. For example, the composition pattern of the platinum group elements (PGE; including Ru, Rh, Pd, Os, Ir and Pt) in the metallic phases can reflect the process of metal grains' growth in solar nebula condensation under high temperature conditions[3]. The distribution of siderophile elements between kamacite and taenite in different rock types of chondrites can reveal the thermal history of an asteroid[4].

Traditionally, the analysis of siderophile elements in extraterrestrial materials mainly relies on instrumental neutron activation analysis (INAA) or radiochemical neutron activation analysis (RNAA). Owing to radioactive radiation and the fact that INAA only has a high sensitivity for the measurement of Ir, it is not appropriate for the analysis of other elements. Inductively coupled plasma spectroscopy (ICP-AES) and inductively coupled plasma mass spectrometry (ICP-MS) are also used to determine those elements in the metallic phase. However, they are only used for bulk analysis, and the loss of samples is huge. The application of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) and secondary ion mass spectroscopy (SIMS) have made it possible to in suit analysis with high sensitivity in micron-scale(normally >30 micron), whereas a portion of metallic phases in the chondrites we study are smaller than this detection range(Fig.3b). Besides, LA-ICP-MS still consumes samples to some extent and SIMS measurement does not cover all siderophile elements[5].

Extraterrestrial samples are rare and valuable, and some of the metal grains in the samples are extremely tiny (within a size of 10 × 10 μm, Fig3.b). So it is necessary to develop a new method to limit the damage and with high lateral resolution and capability to get the most comprehensive information about the samples. Nanoscale secondary ion mass spectrometry (NanoSIMS), characterized by high spatial resolution (down to 50 nm)[6], is used to analyze HSEs, Ni and Ge of metal standard targets(Fig1), two iron meteorites - Hoba and North Chile(Filomena)- and metallic phases of a L3 chondrite named Xinglongquan in this paper, in order to study the formation mechanism of metal grains in the solar nebula.

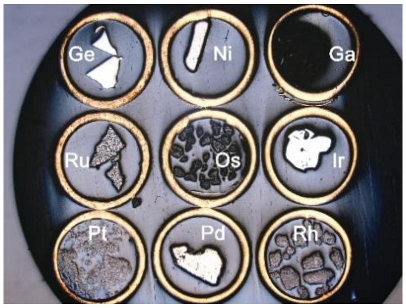

Fig 1. Metal samples' standard target

Methods: We used a scanning electron microscope (SEM) to take back scattering electron images and an energy dispersive spectrum(EDS) to do semi-quantitative measurements and perform element mapping. Measurements are carried out with Thermo Fisher Scientific Apreo S field emission SEM equipped with the QUANTAX EDS system at the Institute of Geology and Geophysics, Chinese Academy of Sciences(IGGCAS).

After a thorough study of petrology and mineralogy, we will use the NanoSIMS (Cameca NanoSIMS 50L, IGGCAS) in the following three experiments. First, all the samples in the metal target are measured using Duo and Cs source separately, to determine the ion yield of siderophile elements. Secondly, the two iron meteorites-Hoba and Filomena- will be measured as standards, and the results of NanoSIMS will be compared with those of INAA to verify the feasibility and calculate the accuracy of the method. Finally, the method was applied to analyze the metallic phases in ordinary chondrites to obtain the abundances and distribution patterns of siderophile elements.

Results:

Hoba(IVB) and North Chile(Filomena)(IIA). Hoba is a nickel-rich ataxite with a nickel content of up to 16.4 wt.%[7]. Polished thin sections exhibit mineral orientation at high magnification(Fig 2.a) and the direction actually represents the Widmanstädtten orientation[8]. Schreibersite appears occasionally, usually within a size of 1 × 1 μm. North Chile(Filomena) is a hexahedrite with a nickel content of 5.8 wt.%[7]. There is no visible kamacite or taenite, and schreibersite exists in long columns and is distributed in a certain direction under microscopic observation (Fig2.b). The phosphorus content of the meteorite is about 0.02%.

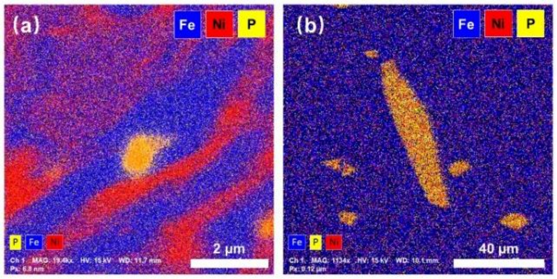

Fig 2. Element mapping images of Hoba(a) and Filomena(b)

Xinglongquan(L3). The Xinglongquan chondrite consists of chondrules, silicate matrix and metallic phases. Chondrules with clear boundaries and chondrules' fragments constitute up to 51.2 vol%[9] and the silicate matrix consists mainly of coarse olivine and pyroxene. The metallic phase is mainly composed of Fe-Ni metal (ca. 4.4 vol%) and troilite(ca. 1.9 vol%)[9]. The metallic phases exist in the form of large grains in the matrix (Fig3.a) and mainly fine particles in the chondrules(Fig3.b). A few larger grains of Fe-Ni metal appear in the chondrules.

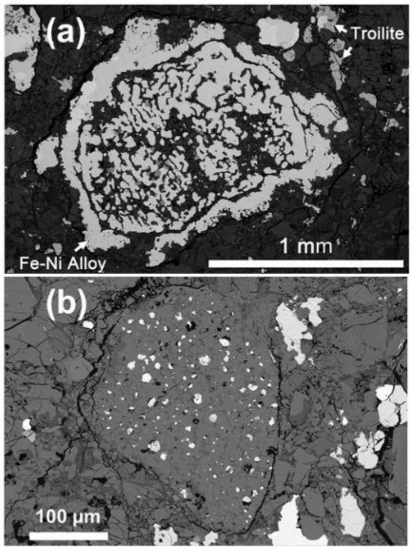

Fig 3. Back scattering electron image of metallic phases in the matrix of Xinglongquan

Experimental data of metal targets. The yield of secondary ions (Table 1) is obtained according to the abundances of elements in the samples and the current of the primary ion beam of NanoSIMS. As shown in Table 1, the ion yield of Os, Ir, Pt, Au, Ni and Ge with Cs$^+$ primary ion beam is higher than that with O$^+$ primary ion beam, while the ion yield of Ru, Rh and Pd with Cs sources is far below that of the O source.

Table 1. Ion yield of siderophile in NanoSIMS

Element	Ion Yield (cps/ppm/nA)	
	Yield with Cs	Yield with O
^{60}Ni	8.0885	1.7625
^{74}Ge	6.0883	3.4521
^{195}Pt	26.2985	0.0266
^{191}Ir	22.3414	0.1609
^{192}Os	4.0650	1.5610
^{108}Pd	0.7559	3.4769
^{103}Rh	0.04	9.6
^{101}Ru	0.6536	40
Au	25.4	0.025

Discussions: We noticed that at high magnification, the two iron meteorites' polished thin sections exhibit micro mineral particles, resulting in the inhomogeneous distribution of elements. However, the INAA data we need to make comparison is the bulk data. Therefore, we should choose a larger region with relatively uniform elements when performing NanoSIMS measurements on iron meteorites.

According to the results of NanoSIMS measurements for the metal targets, Os, Ir, Pt, Au, Ni and Ge are suitable for measurement with Cs sources and Ru, Rh and Pd are suitable for measurement with O sources.

Ongoing work: Since something had happened in our NanoSIMS, we did not finish all the experiments. The instrument is under maintenance and is expected to be repaired in mid-January. We will supplement the data measured by NanoSIMS for the two iron meteorites and the metallic phases of the ordinary chondrite before the start of the meeting, and compare those with the EPMA and INAA data to explore the reliability and accuracy of the method. When we get sufficient data, we will attempt to explain the origin of the metallic phases in ordinary chondrites.

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