

MICROSTRUCTURE AND THERMAL HISTORY OF METAL PARTICLES IN CH CHONDRITES.

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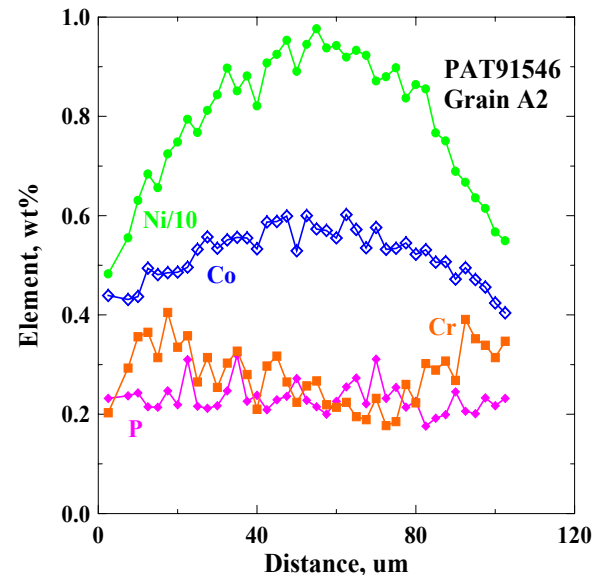
Introduction: Fe-Ni metal particles with smooth Ni, Co, and Cr zoning patterns, 8-13 wt.% Ni in the center of the particle to 3-5 wt.% Ni at the rim, have been identified in several CR-clan (CH, Bencubbin-like, and CR) chondrites, [1]. These zoning patterns are broadly consistent with an origin by gas-solid condensation in the solar nebula at temperatures between ~1500 to 1300 K and fast cooling rates, 2 to 25 K/day, [2,3]. Apparently, this condensate metal was not melted during chondrule formation or affected significantly in the solid-state by alteration during parent body processing. Consideration of diffusional redistribution of Ni, Co, Cr and siderophile elements have further constrained the calculated condensation temperatures and cooling rates of the zoned condensates [4,5]. These condensate metals have irregular shapes and vary in size from 50 to 350 μm as revealed in some detail by optical and SEM techniques [6, 7]. In addition to zoned condensate particles, other types of metal particles have been observed. These include zoned condensates with exsolution-precipitates [1,5], unzoned homogeneous metal with no exsolution-precipitates [5,8], unzoned metal exhibiting exsolution-precipitates [1,5] and high Ni metal grains [8].

Only a few preliminary studies [4,5] have examined the microstructure of the metal particles in CH chondrites. The purpose of this study is to obtain detailed microstructural and microchemical information at the nm to μm scale for a select suite of metal particles in CH chondrites. With this information, we will be able to determine the degree of exsolution, temperature – time relationships for individual particles, effect of shock-mechanical deformation, and the relation between various types of metal particles.

Experimental Procedure: Over 20 metal particles from 4 CH chondrites, PAT 91546, ALH 85085, Acfer 214 and NWA 739 (discussed in [9]), were selected for detailed microstructural analysis. Sections of the 4 chondrites were prepared for metallographic analysis. The samples were etched in 2% nital to reveal the microstructure of the metal particles. Optical and scanning electron microscopy (SEM) were employed to determine the microstructure and the presence or absence of precipitates, recrystallized grains, mechanical deformation, etc. Detailed x-ray scanning, using a JEOL 8200 electron probe microanalyzer (EPMA), was employed to observe chemical variations of Fe,

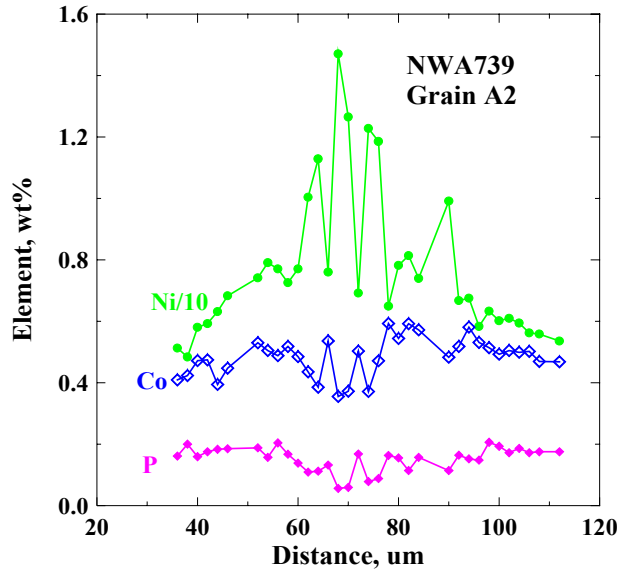
Ni, P, Cr, Si, and S within and between metal particles. Quantitative chemical analyses of μm -sized regions of the metal particles were obtained using line scans across the metal particles. Selected regions of several metal particles were analyzed using a FEI Tecnai F30ST field emission transmission - analytical electron microscope (TEM-AEM) operated at 300keV. A FEI focused ion beam (FIB) instrument was used to obtain TEM thin samples approximately 10 μm long and 5 μm in depth in selected portions within the line scans obtained using EPMA. Electron backscatter diffraction (EBSD) using a ZEISS Supra 55VP SEM outfitted with an EBSD unit from HKL, using Channel 6 software, was used to determine orientation relationships in recrystallized metal grains.

Results: Five types of metal particles 20 to 200 μm in size were observed in PAT 91546, NWA 739, ALH 85085, and Acfer 214: these are described below.

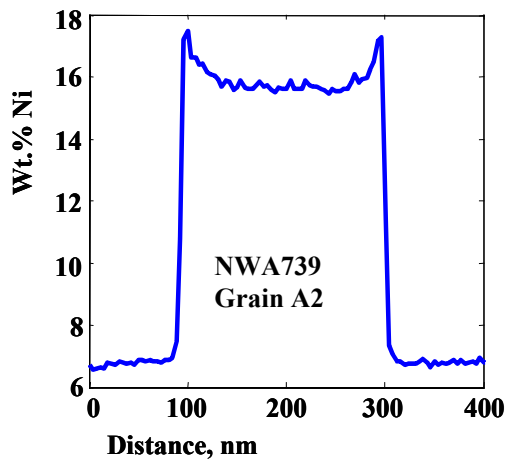


Zoned condensates. The central regions of these particles are enriched in Ni and Co and depleted in P, Cr and Fe, as described by previous studies [1] (See Fig 1 above). TEM-AEM analysis of grain A2 in PAT 91546 shows a lath structure (martensite) in the center of the particle with a Ni content of ~ 10 wt%. No precipitates are observed in the TEM section at a scale of $\geq 20\text{nm}$.

Zoned condensates with precipitates. The central regions of these particles are enriched in Ni. However, there is evidence by optical, SEM, and EPMA analysis of the presence of Ni-rich, Co- and P-poor exsolution precipitates (See Fig 2 below). Small Cr sulfides are observed throughout the particles.



TEM-AEM analysis of grain A2 in NWA 739 shows precipitate sizes from 1-2 μm to <200 nm. X-ray scans from the AEM show taenite precipitates with classic “M” shaped Ni profiles as shown in Fig 3 below for a 200nm wide precipitate. Precipitation at grain boundaries and grain boundary diffusion is observed. Using the Ni concentration gradient, we estimate reheating to about 630°C for a month followed by cooling to below 500°C during a similar period of time.



Unzoned homogeneous particles. These particles are kamacite and have Ni contents between 4 and 6

wt% and Co contents of 0.45 ± 0.05 wt%. They contain no precipitates. One of the unzoned particles contains 1.3 to 1.6 wt% Cr, and ~ 3.5 wt% Si. Similar Si rich grains have been observed previously in CH chondrites [10]. Several particles are recrystallized and polycrystalline with different crystal orientations, as shown by EBSD. It has been proposed that these grains may form by homogenizing zoned metal grains [6], diffusive equilibration of solids that were not isolated as rapidly from the condensing gas as zoned metal [5], or equilibrium condensation from a gas of solar composition at temperatures below 1250K as discussed by [8].

Unzoned particles containing precipitates. No Ni zoning is observed in the x-ray scanning pictures but the particles have a much greater range of Ni contents than the homogeneous metal particles. These particles contain Ni rich precipitates of micron size. P and Co generally decrease with increasing Ni as a result of the exsolution-precipitation process during reheating. One of these particles is present in a chondrule in PAT 91546.

Tetrataenite. A high-Ni metal grain of 50-50 Fe-Ni was observed in ALH 85085. The particle is small, 10x20 μm in size, and contains Co of ~ 0.15 wt%, and Cr of ~ 0.015 wt%.

Discussion: All of the CH chondrites we studied contain a wide variety of metal particles: none of these chondrites has a unique metal grain population. The metal component is a mixture of particles with varying thermal histories that were not produced in the same physical location. In order to understand the details of the thermal histories, further fine-scale TEM studies are necessary.

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