EVEN MORE CHONDRULES BORN IN PLASMA: SIMULATION OF GAS-GRAIN COLLISIONS

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Introduction: The exact process of chondrule formation is still not known - common scenarios are formation in a protoplanetary nebular environment: e.g. X-wind model [1] or nebular shock fronts, where precursor grains are heated by collisions with gas [2].

Most chondrules appear to have been heated to 1500–1600 ºC, followed by a rapid cooling of usually between 10 to 1000 ºC/h [3].

In this part of our study about the formation of chondrules by shock processes, we try to simulate the formation of chondrules by gas-grain collisions in a nebular environment.

Techniques: For the first experiments a basic atmospheric pressure RF arc discharge was used for this work. The arc was generated between copper electrodes separated by 15 mm using a low voltage solid state switching circuit to drive a Tesla coil (natural frequency ~ 325 kHz).

The gas temperature in the arc column has been determined in an earlier experiment through fitting of modeled rotational structure of emission spectra: at 25W power input, the gas temperature is in the region of 2500 +/- 100 K.

A mixture of fine grained feldspar (Ab_{73}) forsterite (Fo_{88}), sulphide and metal was ground to a grain size <100 µm. The powder was dropped vertically through the arc plume. The resulting processed materials were recovered, embedded in resin, polished and analyzed for their chemical composition using SEM/EDX.

Results: Abundant spherical melt droplets in sizes up to 0.1 mm were formed in the experiments (Fig.1). The polished samples show typically grains embedded in a groundmass (Fig.2). Bubbles in some phases indicate that the material was molten, while the lack of bubbles shows that these materials probably are relict grains. Some grains partially melted as shown by elevated Fe contents in their rims, results of some mixing with the Fe-rich groundmass (Fig.3). Chemical analysis using SEM/EDX shows that most of the embedded grains show no change compared to the starting materials. Exception is the groundmass, which is a mixture of the starting materials (Fig.4).

Discussion: The occurrence of bubbles allows estimation the temperature experienced by the material. Melt rims of forsterite show that the temperature was higher than the melting point of this phase (1890ºC). The spherical appearance of the droplets means that they solidified/crystallized at least on the outside extremely fast. The cooling rates experienced by the grains were orders of magnitudes higher than the 1000 C/h calculated for natural chondrules [3]. This probably is result of dense atmosphere which allowed rapid cooling.

The oxidizing environment of the atmosphere also resulted in the complete loss of S from the system. Also, the metallic Fe went completely into the groundmass.

Summary & Outlook:

The first round of experiments using plasma arcs at atmospheric conditions resulted in spherical droplets, which have a resemblance of actual chondrules. This is a step forward compared to earlier experiments using a similar technique [4].

However, the oxidizing, high pressure environment causes differences to 'real' chondrules, like unmelted feldspar grains and domination of relict grains.

For this reason, we started with a second series of experiments using nitrogen gas at pressure ranges close to those of the solar nebula. We placed the arc discharge in an environmental chamber. This allowed conducting the experiments in a non-oxidizing environment using nitrogen gas. Also, the pressure can be lowered to ~10^{-4} bar. This is identical to the (probable) upper pressure limit in the early solar nebula [5]. First experiments have shown that a plasma arc can be easily produced in such an environment (Figs.5 and 6).

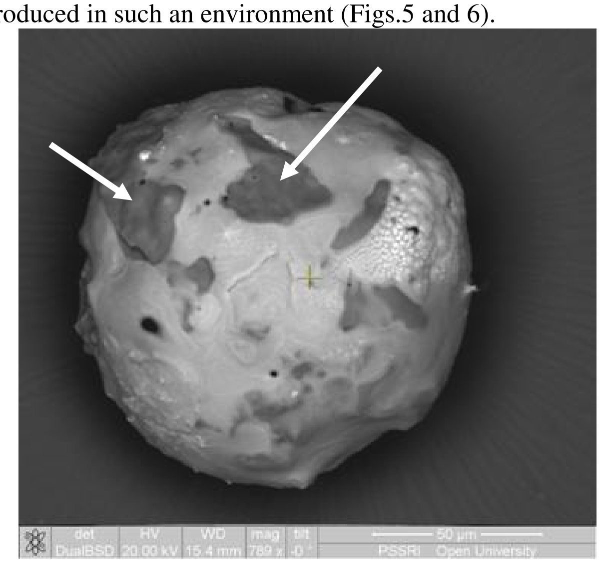

Fig.1: Typical droplet produced in the atmospheric experiments. Angular, probably unmelted grains (arrows) are embedded in the groundmass (bright). SEM/BSE images.

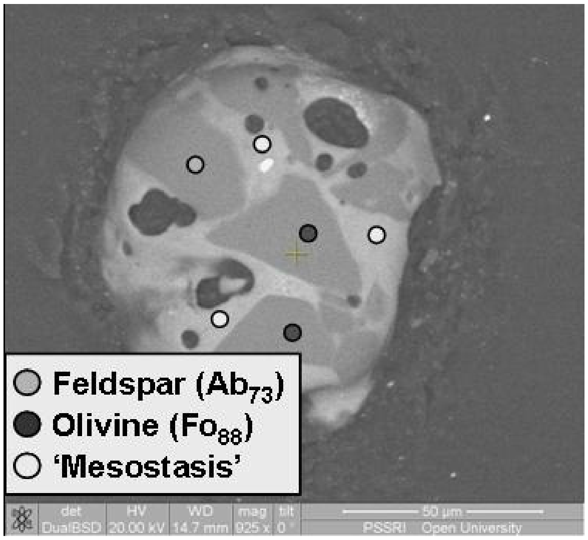

Fig.2: Polished melt spherule (SEM/BSE). The points show phases identified by EDX. Bubbles indicate melted phases.

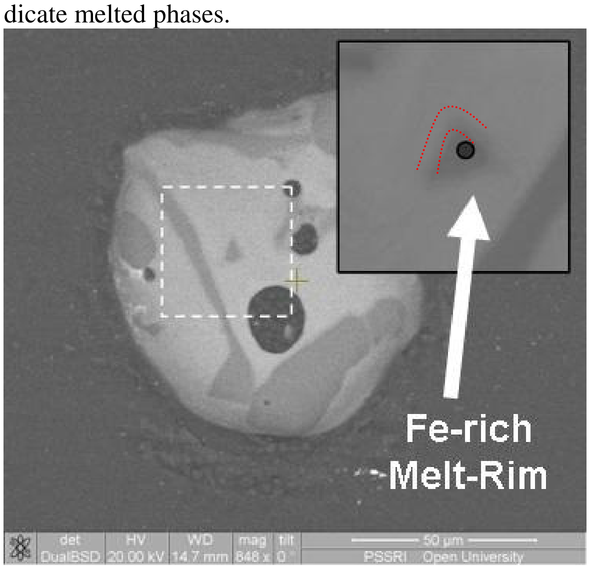

Fig.3: SEM/BSE image. The enlarged image shows a forsterite grain with a melt rim in contact with the groundmass/mesostasis.

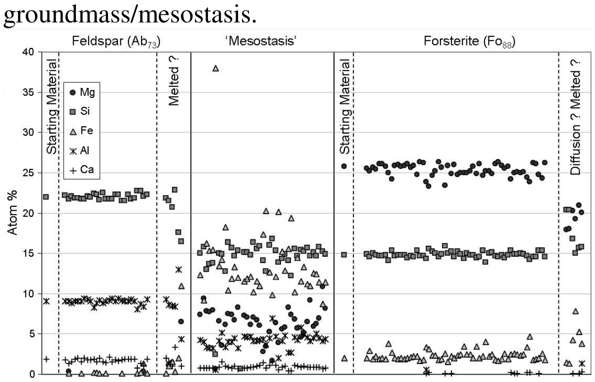

Fig.4: Chemistry of phases in 'chondrules' from atmosphere-pressure experiments. Starting materials are always on the left, followed by run products.

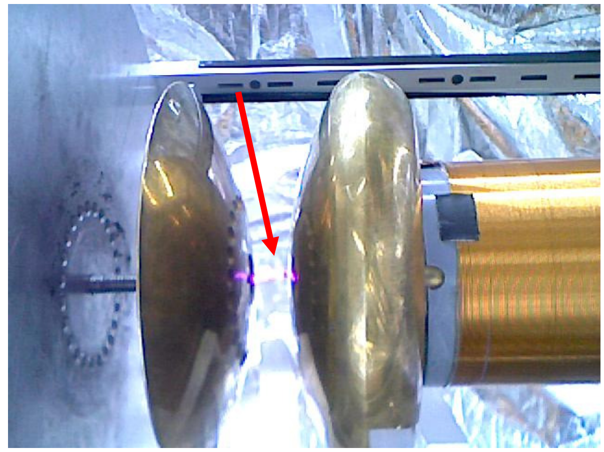

Fig. 5: Plasma arc (arrow) at normal atmosphere.

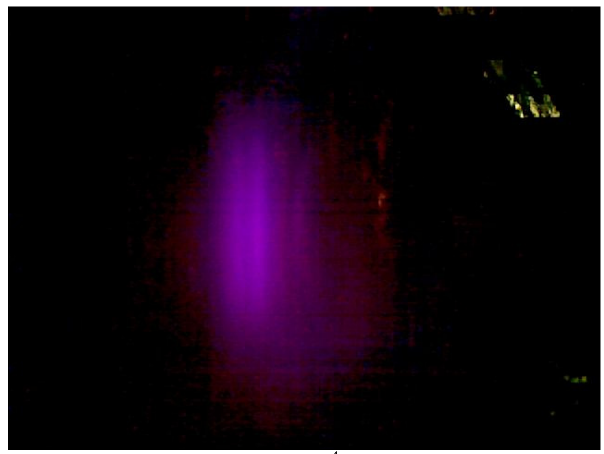

Fig.6: Plasma arc at 3.5×10^{-4} bar in a N_2 atmosphere, using the same set-up as in Fig.3 (with lights off).

References:

[1] Shu et al. (2001) *The Astrophysical Journal* 548: 1029-1050. [2] Desch and Connolly Jr. (2002) *Meteoritics & Planetary Science* 37:183-208. [3] Zanda B. (2004) *ESPL* 224:1-24. [4] Guettler et al. (2008) *Icarus* 195: 5094-510. [5] Petaev M.I. and Wood J.A. (2005) In: Chondrites and The Protoplantary disk, Astron.Soc.Pac. Conf. Series 431.