CONDENSATION OF THE FIRST SOLAR SYSTEM SOLIDS - EXPERIMENTAL APPROACHES.
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Introduction: Ca- and Al-oxides are highly refractory mineralogical phases. Type-A Calcium-Aluminium-rich inclusions (CAIs) in some meteorites show a zonar structure with the highest Al_2O_3 contents in the center and phases like Hibonite ($CaAl_{12}O_{19}$) and Grossite ($CaAl_4O_7$) towards the rims. This mineralogy shows parallels to a theoretically calculated formation sequence for assumed solar conditions, based on fractionary crystallization: the "full condensation code" [1]. CAIs are interpreted to represent the first solid matter of the young solar system that was formed in a hot, reducing environment during the cooling of the initial solar molecular cloud [2].

However, it is still unclear if these early condensates were formed under fractionated or equilibrated conditions. Also, questions of the kinetics and the precise nature of these processes (homogeneous / heterogeneous condensation) have still to be answered. In order to explore the details of these processes we developped an experimental device to study high temperature/low pressure condensation from a gas with solar composition. The main goal of this project is to get data from in-situ and post-mortem measurements of newly formed condensates, an experimental condensation sequence and finally an experimental proxy of the young stellar environment.

Methods: The primary idea of the new experiments is based on previous work of [3], which used laser ablation techniques to get a gas of solar composition for high temperature condensation experiments.

The new experimental setup (Fig. 1, left) consists of two vacuum chambers which are vertically connected by a thin alumina tube (inner diameter 4 mm). These chambers can be evacuated by two independant vacuum pumping systems (turbo-molecular/primary pumps). An experiment starts by evacuating the entire system to $P > 10^{-6}$ mbar. After reducing the power of the turbo pump for chamber 1, this chamber is evacuated mainly through the alumina tube and chamber 2. The experimental condensation pressures are equal to the pressure in chamber 1. By controlling the pump power, vacuum condensation experiments can be done in the range within $10^{-1} > P_{exp} > 10^{-5}$ mbar.

The alumina tube is extended into chamber 1 and ends a few millimeters above a rotating glass target for a UV laser. This piece of glass has a CMAS composition with solar element ratios (54 wt.% SiO_2, 4 wt.% Al_2O_3, 39 wt.% MgO and 3 wt.% CaO). Interaction of the laser beam with the target produces a plasma/gas with the desired composition.

The lower part of the alumina tube in chamber 1 is also surrounded by a series of four graphite furnaces. These furnaces are used to produce a certain temperature profile in the tube. To control the temperatures, S-type thermocouples are used. External thermocouples are fixed very close to the furnaces, but outside of the alumina tube. Another thermocouple can be inserted and moved inside of the tube. It records a profile of the real temperatures in the tube under experimental conditions. These data are used to get calibration curves for the external thermocouples. The internal thermocouple has to be removed for all experiments. Currently, temperatures can reach 1600 K in each furnace.

After the furnaces are brought to experimental temperatures in vacuum, the UV-laser is activated. Gas particles are produced by shock cooling of the ablation plasma and forced to enter the alumina tube. They pass the first furnace (F1) with a temperature maximum, causing a rehomogenization of the gas. The second and third furnaces (F2 & F3) provide the desired condensation temperature over a distance of several millimeters between them. Furnace 4 (F4) causes a symmetry of the entire temperature profile (see Fig. 1, right).

For in-situ experiments, the entire device will be installed in a beamline at the European Synchrotron Radiation Facillity (ESRF) in Grenoble, France. The X-ray beam can enter the tube through a small window between the furnaces F2 and F3 to interact with the condensates. Diffraction data (using SAXS and WAXS techniques) are collected by a CCD camera and provide information about mineralogy, grain size distribution and kinetics.

For post-mortem experiments we collect the condensates by fixing a sample collector (Pt or Cu grid) that enters the alumina tube through the small window.

Preliminary Results: Until the deadline of this abstract, five post mortem experiments have been done. Experiments were done at $P_1 = 5*10^{-4}$ mbar (condensation temperatures 1000 K, 1220 K and 1325 K) and $P_2 = 2*10^{-1}$ mbar (condensation temperatures 1145 K and 1225 K). For all five experiments, the homogenization temperature (at F1) was between 1500-1600 K, the time of laser-target interaction was 120 minutes and the oxygen fugacity was close to the C/CO buffer.

SEM/FEG-SEM analysis of collected particles were done and are in progress. Additional and more precise analysis by EPMA and TEM will follow.

After post-mortem experiments, some of the detected particles are glassy, round spherules with diameters between 0.5 and 10 µm. With a composition close to the used glass target, they are identified as ejecta from the laser ablation process.

Numerous other particles are much smaller (> 100 nm), round to angular in contours and show a strongly varying chemistry between purely forsteritic to calcium-aluminous and 100 % Al_2O_3 composition. In some cases euhedral crystal shapes are identified. The strong variation in chemistry excludes an interpretation as ejecta. Instead, peculiar stoechiometry and crystalline habitus support a formation as condensates. Further systematic experiments at higher temperatures are in progress.

In-situ experiments at ESRF are scheduled for October in this year.

[1] Ebel, D. & Grossman, L. (2000) *GCA, 64(2)*, 339-366. [2] Amelin, Y. et al. (2002) *Sci, 297*, 1678-1683. [3] Toppani, A. et al. (2006) *GCA, 70*, 5035-5060.

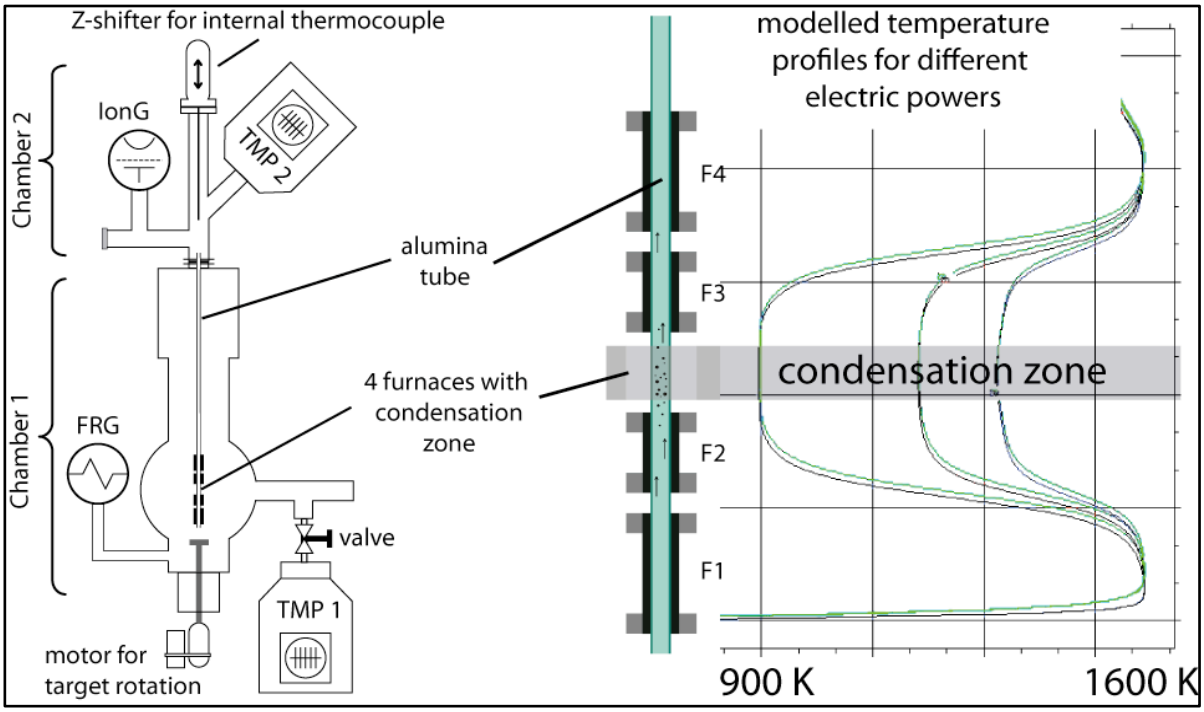

Fig. 1: Schematic view of the experimental setup (not scaled). IonG, FRG = vacuum gauges, TMP = turbo molecular pump, F1-F4 = furnaces. The temperature modeling was done by A. DEGIOVANNI, ENSEM, Nancy (France).