Amorphous Silicates as Precursors for Cosmic Carbonates.

Sarah J. Day[1,2], Stephen P. Thompson[2], A. Evans[1] and Julia E. Parker[2],
[1]Astrophysics Group, Keele University, Keele, Staffordshire, ST5 5BG (sjd@astro.keele.ac.uk), [2]Diamond Light Source, Harwell Science and Innovation Campus, Didcot, Oxon, OX11 0DE

Context

Silicates are one of the most primitive, refractory dust species known to have been present within the pre-solar nebula. Calcic pyroxenes ($(Ca,Mg)Si_2O_6$) and forsteritic olivines ($MgSiO_4$) are found within meteorites as characteristic mineral components of Calcium Aluminium Inclusions (CAIs) [1]. The chemical structure of such materials is directly related to their formation history and subsequent evolution, therefore studying the physical properties of these minerals can provide a diagnostic with which to gain valuable information about the environmental conditions within the early solar nebula, and the processes leading to their formation

Through the use of laboratory analogues the effect on chemical structure as a function of thermal processing can be quantified. Using a combination of synchrotron X-ray powder diffraction (SXPD) and Fourier transform infrared spectroscopy (FTIR) the presence of certain spectral features can be directly related to changes in the physical structure of the grain material. Understanding the relationship between spectral features and the structural evolution of grains is extremely important, making astronomical spectra a useful tool in our understanding of solar system and planetary formation.

Experimental

Amorphous cosmic silicate analogues have been produced through vacuum ageing of Sol Gels [2]. This produces disordered, fine grained, amorphous powders of composition $Mg_{(x)}Ca_{(1-x)}SiO_3$, where $0 < x < 1$, analogous to silicates present within the interstellar and proto-solar medium [3, 4]

Using SXPD, on beamline I11 at Diamond Light Source [5], the structure of these analogues is monitored as the samples are exposed to gaseous CO_2 under non-ambient thermal conditions. This is performed in-situ using a gas cell, with a CO_2 pressure of 1 bar. Scans are performed using a position sensitive detector (PSD) [6], specially designed for fast X-ray diffaction measurements. This enables details of the kinematics and structural mechanisms governing the transition from amorphous to crystalline during thermal annealing to be established.

SEM imaging and Raman spectroscopy were also used to complement these measurements and to provide futher characterisation of the samples.

Preliminary Results

Fig. 1 shows the fine grained, porous nature of the vacuum-dried analogues. No isolated grains can be observed, even at a resolution of $\sim 5\mu$m, instead the powder forms a network of branch-like structures.

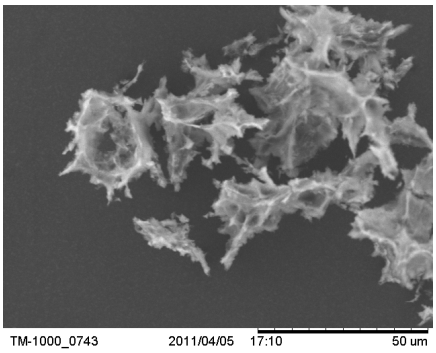

Figure 1: SEM image of vacuum-dried powder, no isolated grains can be distinguished even at a resolution of $\sim 5\mu$m.

FTIR spectra of five analogues of different composition are shown in Fig. 2

The spectra confirm the similarity of the analogues to astronomical silicates, exhibiting the broad feature at 10μm characteristic of amorphous silicates observed in a wide variety of astronomical environments, including the interstellar medium [7], circumstellar regions around both young stellar objects and asymptotic giant branch stars [8], and in planetary systems [9]. There are also a number of interesting features, including a shoulder at 11.3μm and two broad features at 7μm and 16.2μm that vary with composition, strengthening with increasing calcium content.

Fig. 3 shows real time PSD scans taken as a sample was heated in-situ from 296K (room temperature) to 1250K, using a Cyberstar hot air blower, whilst being exposed to CO_2. This lead to full crystallisation of the samples at temperatures above 1050K.

The importance of this is to gain a detailed understanding of the physical properties of amorphous silicates in vacuum, in order to determine the processes

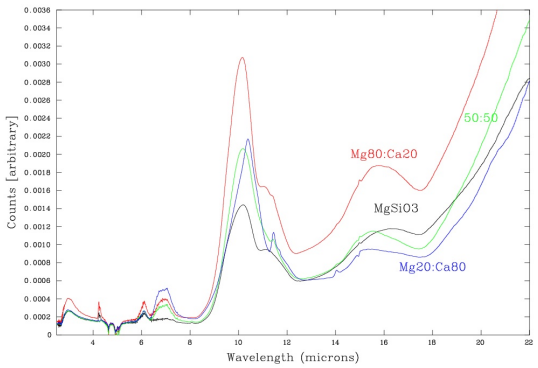

Figure 2: FTIR spectra of sample compositions x = 0. 0.2, 0.5, 0.8, 1

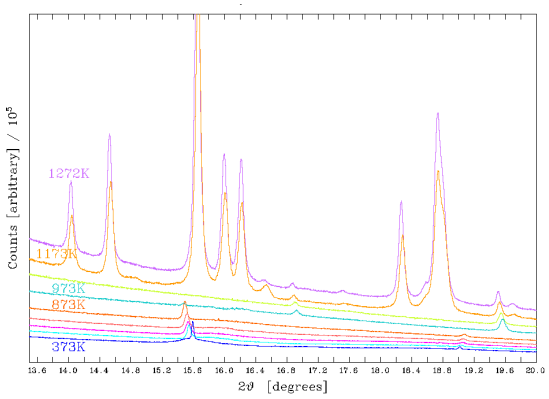

Figure 3: Crystallisation sequence of amorphous $Mg_{(0.5)}Ca_{(0.5)}SiO_3$

occurring in astrophysical environments and how to identify the features in the astronomical infrared spectra that indicate such processes. It also has relevance to understanding the formation of carbonates, recently discovered in non-aqueous astrophysical environments [10, 11, 12].

The results of this research will be presented, focussing on the the structural mechanisms involved with the thermal evolution of silicates in order to place physical constraints on the environments and the possible formation routes of astrophysical carbonates.

References

[1] G. J. MacPherson, et al. In A. N. Krot, E. R. D. Scott, & B. Reipurth, editor, *Chondrites and the Protoplanetary Disk*, volume 341 of *Astronomical Society of the Pacific Conference Series*, page 225. 2005.

[2] S.P Thompson, et al. *in prep.*, 2011.

[3] K. Demyk, et al. *A&A*, 364:170–178, 2000.

[4] B.T. Draine. *Annu. Rev. Astron. Astrophys.*, 41:1–46, 2003.

[5] S.P Thompson, et al. *Rev. Sci. Instrum.*, 80:75107–1, 2009.

[6] S. P. Thompson, et al. *J. Synchrotron Rad.*, 18(4):637–648, 2011.

[7] R. F. Knacke, et al. *ApJ*, 155:L189, 1969.

[8] A. K. Speck, et al. *A&A Suppl. Ser.*, 146:437–464, 2000.

[9] I. Mann, et al. *A&A Rev.*, 13:159–228, 2006.

[10] F. Kemper, et al. *Nature*, 415:295–297, 2002.

[11] C. Ceccarelli and E. Caux. *A&A*, 395:L29 – L30, 2002.

[12] A. Chiavassa, et al. *A&A*, 432:547–557, 2005.