LABORATORY STUDY OF THE IRRADIATION AND THERMAL PROCESSING OF SILICATE DUST ANALOGS. Z. Djouadi¹, L. d’Hendecourt¹, H. Leroux², J. Borg¹, A. P. Jones¹, D. Deboffle¹ and N. Chauvin³.
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Introduction: Before the results from the Short Wavelength Spectrometer instrument (SWS) on board the Infrared Space Observatory (ISO) in the 90′s, it was largely thought that all silicate dust in space was totally amorphous. The extensive results provided by ISO have shown the existence of different forms (e.g. crystalline, amorphous and/or both of them), depending essentially on the astrophysical environment where they are detected. Various studies on silicate dust analogs have shown that chemical as well as structural modifications can take place. Most of these studies have been devoted to an understanding of the primary modifications (structure and chemical composition) due to ion irradiation [1-3] or thermal processes [4-5], but very little has been done regarding further evolution of irradiated silicates. In order to evaluate the dust ability to recrystallize in cold environments, we have studied thermal processing of silicates after a further irradiation stage [6].

Experimental: We have developed an experimental protocol simulating different possible interstellar and circumstellar physical processes such as ion irradiations and temperature annealing. Thin silicate films (typically 100 nm in thickness) are synthesized by electron-beam evaporation of the precursor (San Carlos olivine: Mg₁₈Fe₆Si₄O₁₄) onto diamond substrates of 3 mm in diameter thus ensuring a high surface to volume ratio in accordance with interstellar dust models. He⁺ irradiation, under vacuum (10⁻⁵ mbar), at room temperature, at low energies (5 keV and 10 keV) and at fluences similar to those of interstellar shock waves (10⁶ and 10⁷ cm⁻²) were used in order to completely amorphize the samples. Thermal processing was then performed in a tubular furnace under vacuum (10⁻⁷ mbar) at a temperature of 750°C for heating times between 30 minutes and 20 hours. The evolution of the silicate structure was monitored by infrared (IR) spectroscopy (IFS 66V FTIR from Bruker), in the range 4000-250 cm⁻¹ (2.5-40 μm) with a spectral resolution of 4 cm⁻¹. IR spectroscopy is very sensitive to study structural modifications and it also allows comparisons with the astrophysical observations such as those provided by ISO.

Results: Using the silicate 10 μm band evolution (fig.1) and according to the definition of activation energy used in [5] and [7] we extracted a value of recrystallization activation energy of pre-irradiated olivine-type silicates. The value obtained in this work (41700 ± 2400 K) is very close to the values of crystallization activation energies published by others [4-5]. Our result suggests that the crystallization is independent of the history of dust: in particular the defect concentration due to irradiation does not play a major role in stimulating the crystallization at low temperatures. Since high temperatures are needed to recrystallize (typically 1000 K), thermal diffusion is not the predominant physical process responsible for the crystallization in cold environments. Other processes are thus needed to explain crystallization of silicates in cold environments.

Astrophysical implications: The crystalline silicates observed in cold environments (around young stars and some comets) have probably been crystallized before their injection into these environments. If not, low temperature thermal annealing alone cannot explain the observed crystallization even when fully irradiated silicates, simulating aging ones in the diffuse ISM, are considered. Other processes for recrystallization must be considered, and owing to the presented results, may probably involve dynamical processes that take place in protostellar nebulae.

Figure 1. The 10 μm band evolution with annealing time at 750°C.