Micro-structural evolution of amorphous silicates with annealing: clues for understanding the origin of GEMS in IDPs. Z. Djouadi$^1$, C. Davoisine$^2$, H. Leroux$^2$, L. d’Hendecourt$^1$, A.P. Jones$^1$ and D. Deboffle$^1$, $^1$Institut d’Astrophysique Spatiale (IAS), Bâtiment 121, F-91405 Orsay, Université Paris-Sud 11-CNRS (UMR 8617) France. $^2$Laboratoire de Structure et Propriétés de l’Etat Solide – UMR 8008, Université des Sciences et Technologies de Lille, 59655 Villeneuve d’ascq Cedex, France.

**Introduction:** GEMS (Glass Embedded with Metal and Sulfides) are a major component of the anhydrous IDPs (Interplanetary Dust Particles) [1]. Despite numerous studies devoted to them there is currently no consensus regarding their origin and their formation process. A pre-solar, as well as an interstellar origin have been invoked [2, 3]. The interesting feature of the GEMS is that they are frequently found enclosed by carbonaceous materials [4]. We thus propose here a possible scheme for the formation of the GEMS from a redox reaction involving amorphous silicate heated in the presence of carbon atmosphere [5].

**Experimental:** Thin silicate films (typically 50 to 100 nm in thickness) are synthesized by electron-beam evaporation of the precursor (San-Carlos olivine: $\text{Mg}_{1.8}\text{Fe}_{0.2}\text{SiO}_4$) onto 3 mm diameter diamond substrates thus ensuring a high surface to volume ratio in accordance with interstellar dust models [6]. Thermal processing was performed in a tubular furnace under vacuum ($10^{-7}$ mbar) at temperatures of 870, 970 and 1020 K. The evolution of the silicate structure was monitored by infrared (IR) spectroscopy (VERTEX 70 FTIR from Bruker). The smooth surface of the diamond allows an easy extraction of the deposited film for TEM characterization. Microstructural analyses are obtained with a Philips CM30 TEM operating at 300 kV and the crystallographic characterization is achieved using selected area electron diffraction (SAED). The microscope is also equipped with an X-ray energy dispersive spectrometer (EDS) for micro-analysis.

**Results:** Spheroidal metallic nano-particles (2-50 nm) are found within the silicate films, which are still amorphous after annealing at 870 K even for a long duration (up to 780 hours) or partially crystallized into forsterite for annealing up to 1020 K (figure 1). These nano-particles are composed of iron and nickel and are randomly distributed. The iron initially present in form of FeO, has segregated from the amorphous phase in the form of metallic globules (Figure 2). This clearly suggests that a reduction has occurred according to the reaction $\text{FeO} + \frac{1}{2} \text{O}_2 \rightarrow \text{Fe} + \frac{1}{2} \text{O}_2$. The total pressure during annealing was $10^{-7}$ mbar, the very low partial pressure necessary for the reduction reaction is probably due to carbon-rich contaminants coming from the pumping system, which consumes oxygen via the reaction $\text{C} + \frac{1}{2} \text{O}_2 \leftrightarrow \text{CO}$ inducing thus metal formation according to the reaction $\text{FeO} + \text{C} \rightarrow \text{Fe} + \text{CO}$. Our hypothesis has been confirmed by other experiments performed at higher $\text{O}_2$ vapor pressure by injecting an oxygen flux at controlled pressure of $10^{-4}$ mbar. The resulting heated samples did not exhibit any metallic nano-particles.

**Conclusion:** The observed microstructures closely resemble those of the GEMS found in chondritic IDPs. Since IDPs contain abundant carbonaceous matter, a solid-state reduction reaction may have occurred during heating in the hot inner regions of the proto-solar disc. One can invoke radial transport and mixing to explain the presence of this material in the outer cooler and comet-forming regions of the nebula. Finally, locking iron as metallic particles within the silicates explains why astronomical silicates always appear observationally Fe-poor.

![Figure 1: TEM micrograph of annealed sample at 870 K (a) and 1020 K (b). Note the presence of the metallic nano-particles enclosed in the silicate.](image1)

![Figure 2: Mapping the different elements present in the precursor (San-Carlos Olivine).](image2)