Embedding nanocrystals (NC) in non-volatile flash memories are promising devices for computers, mobile phones or USB keys. The insertion of a semiconductor (SC) in an insulating matrix requires the elaboration of complex "oxide/SC/oxide/Si(001)" heterostructures, and the control of the associated successive growth steps. It's in this context that we have studied the Ge initial growth mechanisms on LaAlO$_3$(001), a crystalline oxide with a high dielectric constant (high-k material). In a previous work [1, 2], it has been shown the chemical and structural properties obtained in-situ, by X-ray photoelectron spectroscopy, X-ray photoelectron diffraction, electron diffraction (LEED and RHEED) and transmission electron microscopy (TEM). 10 monolayers (ML) Ge have been deposited at 600°C by molecular beam epitaxy on a c(2 x 2) reconstructed LaAlO$_3$(001) surface. In these conditions, islands can be observed due to a lower LaAlO$_3$(001) surface free energy. Some of them exhibit a preferential relationship in their heteroepitaxy (Fig 1), where the Ge(001) planes are parallel to the LaAlO$_3$(001) ones, but rotated by 45° in the [001] direction, i.e. Ge<110>// LAO<100>. In this presentation we turned our attention to other types of NC on the LAO(001)-c(2x2) surface. We show that several growth modes are actually present: i) NC formation supported by a Ge wetting layer of 1 atomic plane (Fig 2). ii) NC, usually twinned with a coherent (11-1) $\Sigma 3$ twin plane, as shown in figure 3 where Ge<110>// LAO<100>. In this case a chemical process of relaxation occurs at the interface characterized by the formation of a mixed ML of Ge-La. iii) Between the NC (fig.4), the presence of a germanium layer consisting of a few atomic ML is observed. This diversity of growth modes is the result of an almost instantaneous crystallization of the germanium surface at 600°C, in which lattice parameter distortions and interfacial energy are involved. In order to promote this diversity, we have probably to consider a sequenced process, but quasi instantaneous, in which there is a change in the surface energies.

Fig. 1: Round shaped Ge NC (Restored wave function phase image)

Fig. 2: Stranski-Krastanov growth mode (STEM dark field image)

Fig. 3: Twin and chemical relaxed mixed Ge-La monolayer (STEM dark field)

Fig. 4: Ge layer (Restored wave function phase image)