

Understanding of the Size Control of Biocompatible Gold Nanoparticles in Millifluidic Channels: *in situ* SAXS/XANES/UV.

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Abstract:

The high potentiality of applications of gold nanoparticles leads to the development of several synthetic routes for size and shape selection. If experimental strategies have been described to achieve such control, predictions in this field are still lacking when the nature of the reducing agent or the ligands are modified. In the particular case of the synthesis of gold nanoparticles in water with no added extra ligands¹ (very promising for biomedical applications), the control of the size and polydispersity is more difficult to obtain. A complete description of the underlying mechanism is mandatory to go towards more prediction in the control of size, shape and polydispersity. This project focuses on a mechanistic understanding of size controlled of biocompatible gold nanoparticles (GNP's).

The control of the mixing of the reducing solution with the gold salt solution is certainly a key point to control the nucleation and growth steps and as a consequence the dispersion. Recently, microfluidics tools have been used to improve the mixing during nanoparticles synthesis with apparently a good way to access to a higher monodispersity^{2,3}. In this context, we elucidated the size control of gold nanoparticles synthesized in surfactant free water⁴ with a continuous flow mode also used to produce higher concentration (3 mM) of stabilized gold nanoparticles. The reaction between a reducing agent (ascorbic acid) and a gold(III) salt in water is very rapid (>1s). The originality of our approach was to finely modulate the initial pH of the reducing agent instead of the gold precursor to modify the kinetic of the reaction. The pH modification of the initial gold precursors Au(III) are stopped by the acceleration of their reduction into Au(0), ensuring the control of the final size (from 3 to 25 nm) of the gold nanoparticles with a low polydispersity in size in aqueous surfactant free solution. *In situ* SAXS/XANES/UV measurement with high time resolution (20 to 100 ms) have allowed the accurate measure of the size distribution of nanoparticles with the precise concentration of the different redox species during the reaction⁶. These experimental results were combined with the use of a model⁵ based on the coupling of nucleation and growth equations together with a progressive injection of monomers. The main result is that the size of the particles is indeed controlled by the kinetic of reduction of gold atoms. As a consequence, the measure of the injection of monomers is the key to obtain prediction of the size of the final nanoparticles. At the end, we have shown that a millifluidic set-up equipped with a homemade mixer offers a robust way of rapid mixing to obtain a reproducible production of large amounts of nanoparticles.

References

- [1] Andreescu D., Sau T.K. and Goia D.V.J.; *J. Colloid Interface Sci.* **298** (2006), 742-751.
- [2] Song Y., Hormes J. and Kumar C. S. S. R, *Small*, **4** (2008) 698-711.
- [3] Luty-Blocho M., Fitzner K., Hessel V. , Löb P., Maskos M. , Metzke D., Paclawski K., Wojnicki M., *Chem. Eng. J.* **171** (2011), 279-290.
- [4] Jun H., Testard F., Malloggi F., Coulon P-E., Menguy N., Spalla O., *Langmuir*, **28** (2012) 15966-15974.
- [5] Abécassis B., Testard F., Kong Q., Baudalet F., Spalla O., *Langmuir* **26** (2010), 13847-13854.
- [6] Jun H., Testard F., Tache O., Spalla O., submitted.

Figures:

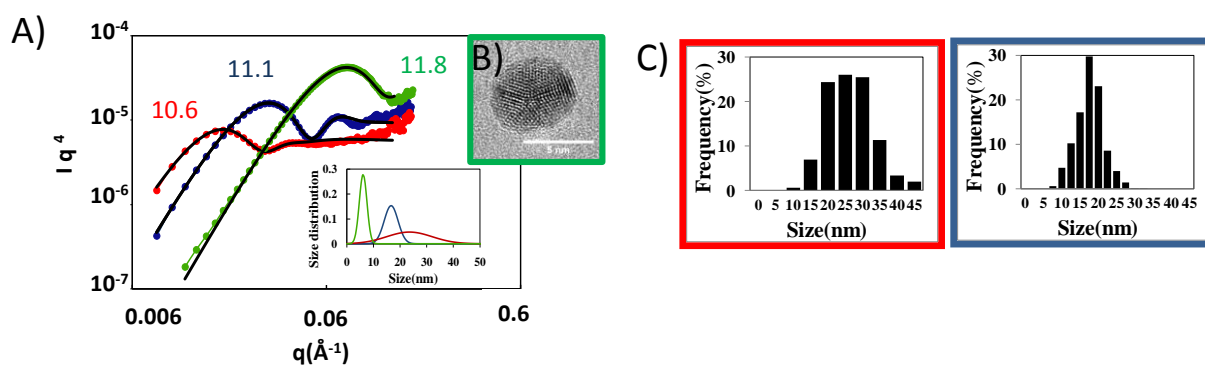


Figure 1: A) SAXS patterns of GNP's obtained with $[\text{Au(III)}]_i = 6\text{mM}$, $\text{AA/Au(III)} = 2$, (red): pH = 10.6, (blue): pH=11.1 and (green): pH=11.8. B) HRTEM of representative gold nanoparticles obtained at pH=11.8. C) Size distribution from TEM analysis for red (pH=10.6) and blue (pH=11.1).