Ligand-free nanoparticles made by scalable laser synthesis for catalysis applications

Mark-Robert Kalus[1,2]
Niko Bärsch[1]
Stephan Barcikowski[2]

kalus@particular.eu

[1] Particular GmbH, Lise-Meitner-Straße 9, Burgdorf, Germany
[2] Technical Chemistry I, University of Duisburg-Essen and Center for NanoIntegration Duisburg-Essen CENIDE, Germany

After decades of intensive research nanomaterials are widely implemented as functional elements on surfaces, into volumes and as nanohybrids, with a wide spectrum of applications such as catalysis and biomedicine. However, integration of the "nanofunction" into products is still limited due to drawbacks of gas phase and chemical synthesis methods. Ligands and stabilizers have to be removed by calcination and additives may cause catalysts poisoning. The quantitative removal of the ligands is very challenging and accompanied by unwanted side effects like particle aggregation and contamination causing deactivation of the building blocks' surface.

Pulsed Laser Ablation in Liquids (PLAL) makes it possible to fabricate ligand-free nanoparticles with high purities [1] and controlled size distribution [2] for a variety of materials (e.g. Au, Pt, Ni, alloys...). The naked nanoparticles have shown to better fit to kinetics expected by theoreticians, in particular at high conversion rates [1]. Hence, maybe purity is convenient for catalysis and nanoparticle application research, providing textbook-like reference materials.

Related to chemical energy conversion application, deposition of naked nanoparticles on inorganic and carbon supports creates heterogeneous catalysts with 100% cumulative yield and with mass loading up to 60% adjustable [3]. No calcination or pre-reaction activation is required since no chemical precursors or excess of reactants are employed which often have to be removed after conventional nanoparticle synthesis. Furthermore, recent findings indicate that the process stability of the catalyst during oxidative conversion at elevated temperature is increased during heterogeneous (supported colloids) catalysis [4].

The productivity of the laser-based nanoparticle production method is limited by different entities such as laser-induced cavitation bubbles [5], which contain the generated nanoparticles, and so-called persistent bubbles [6]. We could achieve good reproducibility and a linear up-scaling of nanoparticle generation by applying a continuous flow and using a high-power picosecond laser system consisting of a 500W ps-laser source and a laser scanner with scanning speeds of up to 500m/s. Nanoparticle outputs up to the gram/hour regime were obtained in this way making this method a versatile alternative for rapid prototyping of heterogeneous catalysts [5].

Overall, this talk is intended to give the audience an insight into the principles of the laser-based nanoparticle production process, the immobilization of the naked nanoparticles on particulate supports as well as the utilization of the nanoparticles in homogenous and heterogeneous catalysis.

References

[1] S. Gu, K. Kaiser, G. Marzun, A. Ott, Y. Lu, M. Ballauf, A. Zaccone, S. Barcikowski and P. Wagener, Catalysis Letter, 145 (2015), 1105.

[2] V. Merk, C. Rehbock, F. Becker, U. Hagemann, H. Nienhaus and S. Barcikowski, Langmuir, 5 (2013), 4213.

[3] P. Wagener, A. Schwenke and S. Barcikowski, Langmuir, 28 (2012), 6132.

[4] W. Dong, S. Reichenberger, S. Chu, P. Weide, H. Ruland, S. Barcikowski, P. Wagener and M. Muhler, Journal of Catalysis, 330 (2015), 497.

[5] R. Streubel, S. Barcikowski, B. Gökce, Optics Letters, 41 (2016), 1486.

[6] M-R. Kalus, N. Bärsch, R. Streubel, E. Gökce, S. Barcikowski, B. Gökce, Physical Chemistry Chemical Physics, 19 (2017), 7112.