**Corrosion protected 3D core-shell nanocolloids**

Hyeon-Ho Jeong1,2,\*, Mariana Alarcón-Correa1,3, Andrew G. Mark1, Tung-Chun Lee1,4, Peer Fischer1,3

1Max Planck Institute for Intelligent Systems, Heisenbergstrasse 3, 70569 Stuttgart, Germany

2Institute of Materials, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

3Institute for Physical Chemistry, University of Stuttgart, Pfaffenwaldring 55, 70569 Stuttgart, Germany  
4Institute for Materials Discovery and Department of Chemistry, University College London, Christopher Ingold Building, 20 Gordon Street, London WC1H 0AJ, United Kingdom

\*E-mail: [hjeong@is.mpg.de](mailto:hjeong@is.mpg.de)

**Abstract**

The electronic, optical, magnetic, and catalytic properties of nanoparticles depend on their geometry and material composition.1 Applications in liquids and in particular water are, however, limited for a number of promising nanomaterials, as they are prone to corrosion.2,3 Here, we present a method that can be used to protect complex hybrid 3D nanocolloids against corrosion.

The method uses a nanoscale shadow growth technique, which we term ‘nano-glancing angle deposition (nanoGLAD)’.4 It can be used to grow three dimensional (3D) nanocolloids with some flexibility in the size, shape, and material composition of the nanoparticles. However, this scheme alone does not offer a means to prevent corrosion. Here, we show how the method can be adapted to grow 3D core-shell nanocolloids that are stable in various physiological environments.5

We report a refined nanoGLAD scheme which, in conjunction with atomic layer deposition (ALD), can be used to protect multifunctional nanocolloids even in corrosive environments. The challenge is to ensure the complete encapsulation of the nanomaterial (core) by a defect-free shell layer. We discuss a promising metallic oxide shell layer that is chemically inert and that does not affect the colloidal stability. We demonstrate magnetic nanocolloids that without the protective layer corrode within hours in an acidic environment, but that are stable for weeks and in some cases even months when grown by the advanced nanoGLAD process. Entirely new applications are possible,6,7 including ones with Mg nanoparticles in aqueous solutions8 and for biomedical applications at low pH.9

1. Y. Xia, Y. Xiong, B. Lim and S. E. Skrabalak, *Angew Chem Int Ed*, 2009, **48**, 60-103.
2. A.-H. Lu, E. L. Salabas and F. Schüth, *Angew Chem Int Ed*, 2007, **46**, 1222-1244.
3. A. M. Goodman, Y. Cao, C. Urban, O. Neumann, C. Ayala-Orozco, M. W. Knight, A. Joshi, P. Nordlander and N. J. Halas, *ACS Nano*, 2014, **8**, 3222-3231.
4. A. G. Mark, J. G. Gibbs, T.-C. Lee and P. Fischer, *Nat Mater*, 2013, **12**, 802-807.
5. H.-H. Jeong, M. Alarcón-Correa, A.G. Mark, K. Son, T.-C. Lee, and P. Fischer, Corrosion protection of nanoparticles (In preparation).
6. H.-H. Jeong, A. G. Mark, M. Alarcon-Correa, I. Kim, P. Oswald, T.-C. Lee and P. Fischer, *Nat Commun*, 2016, **7**, 11331.
7. H.-H. Jeong, A. G. Mark, T.-C. Lee, M. Alarcón-Correa, S. Eslami, T. Qiu, J. G. Gibbs and P. Fischer, *Nano Lett*, 2016, **16**, 4887-4894.
8. H.-H. Jeong, A. G. Mark and P. Fischer, *Chem Commun*, 2016, **52**, 12179-12182.
9. D. Walker, B. T. Käsdorf, H.-H. Jeong, O. Lieleg and P. Fischer, *Sci Adv*, 2015, **1**, e1500501.